

# CHEMISTRY

## Higher 2 (2017)

### (Syllabus 9647)

## CONTENTS

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	<i>Page</i>
INTRODUCTION	2
AIMS	2
ASSESSMENT OBJECTIVES	3
SCHEME OF ASSESSMENT	4
ADDITIONAL INFORMATION	6
SUBJECT CONTENT	7
PRACTICAL ASSESSMENT	26
QUALITATIVE ANALYSIS NOTES	28
SUMMARY OF KEY QUANTITIES AND UNITS	30
MATHEMATICAL REQUIREMENTS	31
GLOSSARY OF TERMS	32
SPECIAL NOTE	33
TEXTBOOKS	34
DATA BOOKLET	35
PERIODIC TABLE	45

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## INTRODUCTION

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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

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

The 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 importance
  - 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 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

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

### **A Knowledge with understanding**

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

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

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.)

### **C Experimental skills and investigations**

Students should be able to:

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

## **SCHEME OF ASSESSMENT**

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All school candidates are required to enter for Papers 1, 2, 3 and 4.

Paper	Type of Paper	Duration	Weighting (%)	Marks
1	Multiple Choice	1 h	20.0	40
2	Structured Questions Planning	2 h	25.0 5.0	60 12
3	Free Response Questions	2 h	35.0	80
4	School-based Science Practical Assessment (SPA)	-	15.0	40

### **Paper 1** (1 h)(40 marks)

Forty multiple choice questions, all compulsory. Thirty items will be of the direct choice type and ten of the multiple completion type.

All questions will include 4 responses.

**Paper 2** (2 h)(72 marks)

A variable number of structured questions including one or two data-based questions and a question on Planning. All questions are compulsory and answered on the question paper. The data-based question(s) constitute(s) 15–20 marks for this paper whilst the Planning question constitutes 12 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. The Planning Question will assess appropriate aspects of objectives C1 to C5. Some questions, including the Planning question, will also require candidates to integrate knowledge and understanding from different areas and topics of the chemistry syllabus.

**Paper 3** (2 h)(80 marks)

Candidates will be required to answer a total of four out of five 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.

**Paper 4** (40 marks)

The School-Based Science Practical Assessment (SPA) will take place over an appropriate period that the candidates are offering the subject. There are two compulsory assessments which will assess appropriate aspects of objectives C1 to C5 in the following skill areas:

- Manipulation, measurement and observation (MMO)
- Presentation of data and observations (PDO)
- Analysis, conclusions and evaluation (ACE)

Each assessment assesses these three skill areas MMO, PDO and ACE, which may not be necessarily equally weighted, to a total of 20 marks. The range of marks for the three skill areas are as follows: MMO, 4–8 marks; PDO, 4–8; ACE, 8–10 marks.

The assessment of PDO and ACE may also include questions on data-analysis which do not require practical equipment and apparatus. Candidates will not be permitted to refer to books and laboratory notebooks during the assessment.

Refer to the SPA Handbook for more detailed information on the conduct of SPA.

**Marks allocated to assessment objectives and syllabus areas**

Assessment Objectives		Weighting	Assessment Components
A	Knowledge with understanding	32%	Papers 1, 2, 3
B	Handling, applying and evaluating information	48%	Papers 1, 2, 3
C	Experimental skills and investigations	20%	Papers 2, 4

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

## ADDITIONAL INFORMATION

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### ***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 the nomenclature used in the syllabus. The proposals in '*Signs, Symbols and Systematics*' (*The Association for Science Education Companion to 16–19 Science*, 2000) will generally be adopted although the traditional names sulfate, sulfite, nitrate, nitrite, sulfurous and nitrous acids will be used in question papers. Sulfur (and all compounds of sulfur) will be spelt with f (not with ph) in question papers, however students can use either spelling in their answers.

### ***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.

# SUBJECT CONTENT

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## 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 mass*, based on the  $^{12}\text{C}$  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 formula*
- 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

[when performing calculations, candidates' answers should reflect the number of significant figures given or asked for in the question]

- deduce stoichiometric relationships from calculations such as those in (g)

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

**3. CHEMICAL BONDING****Content**

- 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; ethene
  - (ii) co-ordinate (dative covalent) bonding, as in 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  $\sigma$  and  $\pi$  bonds (see also Section 10.1)
- (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

#### 4. THE GASEOUS STATE

##### Content

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

##### Learning Outcomes

Candidates should be able to:

- state the basic assumptions of the kinetic theory as applied to an ideal gas
- explain qualitatively in terms of intermolecular forces and molecular size:
  - the conditions necessary for a gas to approach ideal behaviour
  - the limitations of ideality at very high pressures and very low temperatures
- state and use the general gas equation  $pV = nRT$  in calculations, including the determination of  $M_r$

#### 5. CHEMICAL ENERGETICS

##### Content

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

##### Learning Outcomes

Candidates should be able to:

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

- (e) apply Hess' Law to construct simple energy cycles, e.g. Born-Haber cycle, and carry out calculations involving such cycles and relevant energy terms (including ionisation energy and electron affinity), 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
  - the formation of a simple ionic solid and of its aqueous solution
  - average bond energies
- (f) construct and interpret a reaction pathway diagram, in terms of the enthalpy change of the reaction and of the activation energy
- (g) explain and use the term *entropy*
- (h) discuss the effects on the entropy of a chemical system by the following:
- change in temperature
  - change in phase
  - change in the number of particles (especially for gaseous systems)
  - mixing of particles
- [quantitative treatment is **not** required]
- (i) predict whether the entropy change for a given process or reaction is positive or negative
- (j) define *standard Gibbs free energy change of reaction* by means of the equation  $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$
- (k) calculate  $\Delta G^{\ominus}$  for a reaction using the equation  $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$   
[the calculation of standard entropy change,  $\Delta S^{\ominus}$ , for a reaction using standard entropies,  $S^{\ominus}$ , is **not** required]
- (l) state whether a reaction or process will be spontaneous by using the sign of  $\Delta G^{\ominus}$
- (m) predict the effect of temperature change on the spontaneity of a reaction, given standard enthalpy and entropy changes

## 6. ELECTROCHEMISTRY

### Content

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

**Learning Outcomes**

Candidates should be able to:

- (a) describe and explain redox processes in terms of electron transfer and/or of changes in oxidation number (oxidation state)
- (b) define the terms:
  - (i) *standard electrode (redox) potential*
  - (ii) *standard cell potential*
- (c) describe the standard hydrogen electrode
- (d) describe methods used to measure the standard electrode potentials of:
  - (i) metals or non-metals in contact with their ions in aqueous solution
  - (ii) ions of the same element in different oxidation states
- (e) calculate a standard cell potential by combining two standard electrode potentials
- (f) use standard cell potentials to:
  - (i) explain/deduce the direction of electron flow from a simple cell
  - (ii) predict the feasibility of a reaction
- (g) understand the limitations in the use of standard cell potentials to predict the feasibility of a reaction
- (h) construct redox equations using the relevant half-equations (see also Section 9.4)
- (i) predict qualitatively how the value of an electrode potential varies with the concentration of the aqueous ion
- (j) state the possible advantages of developing other types of cell, e.g. the H<sub>2</sub>/O<sub>2</sub> fuel cell and improved batteries (as in electric vehicles) in terms of smaller size, lower mass and higher voltage
- (k) state the relationship,  $F = Le$ , between the Faraday constant, the Avogadro constant and the charge on the electron
- (l) predict the identity of the substance liberated during electrolysis from the state of electrolyte (molten or aqueous), position in the redox series (electrode potential) and concentration
- (m) calculate:
  - (i) the quantity of charge passed during electrolysis
  - (ii) the mass and/or volume of substance liberated during electrolysis, including those in the electrolysis of H<sub>2</sub>SO<sub>4</sub>(aq); Na<sub>2</sub>SO<sub>4</sub>(aq)
- (n) explain, in terms of the electrode reactions, the industrial processes of:
  - (i) the anodising of aluminium
  - (ii) the electrolytic purification of copper

[technical details are **not** required]

## 7. EQUILIBRIA

### Content

- Chemical equilibria: reversible reactions; dynamic equilibrium
  - (i) Factors affecting chemical equilibria
  - (ii) Equilibrium constants
  - (iii) The Haber process
- Ionic equilibria
  - (i) Brønsted-Lowry theory of acids and bases
  - (ii) Acid dissociation constants,  $K_a$  and the use of  $pK_a$
  - (iii) Base dissociation constants,  $K_b$  and the use of  $pK_b$
  - (iv) The ionic product of water,  $K_w$
  - (v) pH: choice of pH indicators
  - (vi) Buffer solutions
  - (vii) Solubility product; the common ion effect

### Learning Outcomes

Candidates should be able to:

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

- (m) describe the changes in pH during acid-base titrations and explain these changes in terms of the strengths of the acids and bases
- (n)
  - (i) explain how buffer solutions control pH
  - (ii) describe and explain their uses, including the role of  $\text{H}_2\text{CO}_3/\text{HCO}_3^-$  in controlling pH in blood
- (o) calculate the pH of buffer solutions, given appropriate data
- (p) show understanding of, and apply, the concept of solubility product,  $K_{\text{sp}}$
- (q) calculate  $K_{\text{sp}}$  from concentrations and *vice versa*
- (r) show understanding of the common ion effect

## 8. REACTION KINETICS

### Content

- Simple rate equations; orders of reaction; rate constants
- Concept of activation energy
- Effect of concentration, temperature, and catalysts on reaction rate
- Homogeneous and heterogeneous catalysis
- 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; rate-determining step; activation energy; catalysis
- (b) construct and use rate equations of the form  $\text{rate} = k[\text{A}]^m[\text{B}]^n$  (limited to simple cases of single-step reactions and of multi-step processes with a rate-determining step, for which  $m$  and  $n$  are 0, 1 or 2), including:
  - (i) deducing the order of a reaction by the initial rates method
  - (ii) justifying, for zero- and first-order reactions, the order of reaction from concentration-time graphs
  - (iii) verifying that a suggested reaction mechanism is consistent with the observed kinetics
  - (iv) predicting the order that would result from a given reaction mechanism
  - (v) calculating an initial rate using concentration data
 [integrated forms of rate equations are **not** required]
- (c)
  - (i) show understanding that the half-life of a first-order reaction is independent of concentration
  - (ii) use the half-life of a first-order reaction in calculations
- (d) calculate a rate constant using the initial rates method
- (e) devise a suitable experimental technique for studying the rate of a reaction, from given information
- (f) explain qualitatively, in terms of collisions, the effect of concentration changes on the rate of a reaction
- (g) show understanding, including reference to the Boltzmann distribution, of what is meant by the term *activation energy*

- (h) explain qualitatively, in terms both of the Boltzmann distribution and of collision frequency, the effect of temperature change on a rate constant (and hence, on the rate) of a reaction
- (i) (i) explain that, in the presence of a catalyst, a reaction has a different mechanism, i.e. one of lower activation energy, giving a larger rate constant  
 (ii) interpret this catalytic effect on a rate constant in terms of the Boltzmann distribution
- (j) outline the different modes of action of homogeneous and heterogeneous catalysis, including:  
 (i) the Haber process  
 (ii) the catalytic removal of oxides of nitrogen in the exhaust gases from car engines (see also Section 10.2)  
 (iii) the catalytic role of atmospheric oxides of nitrogen in the oxidation of atmospheric sulfur dioxide  
 (iv) catalytic role of  $\text{Fe}^{2+}$  in the  $\text{I}^-/\text{S}_2\text{O}_8^{2-}$  reaction
- (k) describe enzymes as biological catalysts which may have specific activity
- (l) explain the relationship between substrate concentration and the rate of an enzyme-catalysed reaction in biochemical systems

## 9. INORGANIC CHEMISTRY

### Preamble

It is intended that the study should:

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

be based on a study of the patterns:

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

introduce, with examples, the transition elements and their compounds

apply unifying themes to inorganic chemistry, such as atomic structure (Section 2), chemical bonding (Section 3), redox (Section 6), the reactions of ions, acid-base behaviour, precipitation (Section 7) and complexing behaviour (Section 9.4), where appropriate;

include

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

## 9.1 THE PERIODIC TABLE: CHEMICAL PERIODICITY

### Content

- 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 sulfur only) and of the chlorides (sodium to phosphorus only)
  - (iii) Reactions of these oxides and chlorides with water
  - (iv) Acid/base behaviour of these oxides and the corresponding hydroxides

### Learning Outcomes

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

- (a) describe qualitatively (and indicate the periodicity in) the variations in atomic radius, ionic radius, melting point and electrical conductivity of the elements (see the *Data Booklet*)
- (b) explain qualitatively the variation in atomic radius and ionic radius
- (c) interpret the variation in melting point and in electrical conductivity in terms of the presence of simple molecular, giant molecular or metallic bonding in the elements
- (d) explain the variation in first ionisation energy
- (e) describe the reactions, if any, of the elements with oxygen (to give  $\text{Na}_2\text{O}$ ;  $\text{MgO}$ ;  $\text{Al}_2\text{O}_3$ ;  $\text{P}_4\text{O}_6$ ;  $\text{P}_4\text{O}_{10}$ ;  $\text{SO}_2$ ;  $\text{SO}_3$ ), and chlorine (to give  $\text{NaCl}$ ;  $\text{MgCl}_2$ ;  $\text{AlCl}_3$ ;  $\text{SiCl}_4$ ;  $\text{PCl}_3$ ;  $\text{PCl}_5$ )
- (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



**9.2 GROUP II****Content**

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

**Learning Outcomes**

Candidates should be able to:

- describe the reactions of the elements with oxygen and water
- describe the behaviour of the oxides with water
- interpret and explain qualitatively the trend in the thermal stability of the nitrates in terms of the charge density of the cation and the polarisability of the large anion
- interpret, and make predictions from, the trends in physical and chemical properties of the elements and their compounds

**9.3 GROUP VII****Content**

- The similarities and trends in the physical and chemical properties of chlorine, bromine and iodine
  - Characteristic physical properties
  - The relative reactivity of the elements as oxidising agents
  - Some reactions of the halide ions
  - The reactions of chlorine with aqueous sodium hydroxide

**Learning Outcomes**

Candidates should be able to:

- describe the trends in volatility and colour of chlorine, bromine and iodine
- analyse the volatility of the elements in terms of van der Waals' forces
- describe and deduce from  $E^\ominus$  values the relative reactivity of the elements as oxidising agents
- describe and explain the reactions of the elements with hydrogen
- describe and explain the relative thermal stabilities of the hydrides,
  - interpret these relative stabilities in terms of bond energies
- describe and explain the reactions of halide ions with:
  - aqueous silver ions followed by aqueous ammonia,
  - concentrated sulfuric acid
- describe and analyse in terms of changes of oxidation number the reaction of chlorine with cold, and with hot, aqueous sodium hydroxide

## 9.4 AN INTRODUCTION TO THE CHEMISTRY OF TRANSITION ELEMENTS

### Content

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

### Learning Outcomes

Candidates should be able to:

- explain what is meant by a transition element, in terms of d-block elements forming one or more stable ions with incomplete d orbitals
- state the electronic configuration of a first row transition element and of its ions
- state that the atomic radii, ionic radii and first ionisation energies of the transition elements are relatively invariant
- contrast, qualitatively, the melting point; density; atomic radius; ionic radius; first ionisation energy and conductivity of the transition elements with those of calcium as a typical s-block element
- describe the tendency of transition elements to have variable oxidation states
- predict from a given electronic configuration, the likely oxidation states of a transition element
- describe and explain the use of  $\text{Fe}^{3+}/\text{Fe}^{2+}$ ,  $\text{MnO}_4^-/\text{Mn}^{2+}$  and  $\text{Cr}_2\text{O}_7^{2-}/\text{Cr}^{3+}$  as examples of redox systems (see also Section 6)
- explain the reactions of transition elements with ligands to form complexes, including the complexes of copper(II) ions with water and ammonia
  - describe the formation, and state the colour of, these complexes
- predict, using  $E^\ominus$  values, the likelihood of redox reactions
- explain qualitatively that ligand exchange may occur, including  $\text{CO}/\text{O}_2$  in haemoglobin
- explain how some transition elements and/or their compounds can act as catalysts (see also 8(j))
- explain, in terms of d orbital splitting, why transition element complexes are usually coloured

## 10. ORGANIC CHEMISTRY

### Preamble

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

In their study of organic chemistry, candidates may wish to group the organic reactions in terms of the mechanisms in the syllabus where possible. Candidates may wish to compare and contrast the different mechanisms.

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

## 10.1 INTRODUCTORY TOPICS

In each of the sections below, 10.1 to 10.7, 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

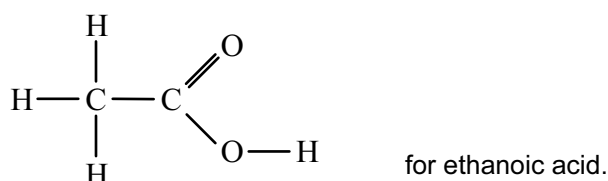
- Molecular, structural and empirical formulae
- Functional groups and the naming of organic compounds
- Characteristic organic reactions
- Shapes of organic molecules;  $\sigma$  and  $\pi$  bonds
- Isomerism: *structural*; *geometrical*; *optical*

### Structural formulae

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

### Displayed formulae

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

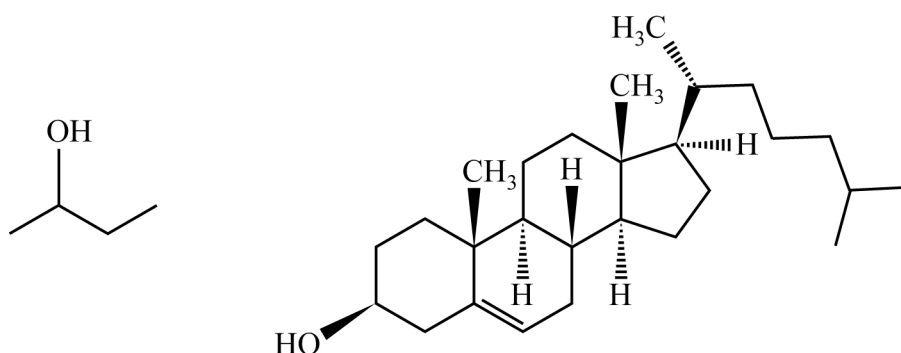



### Skeletal formulae

A skeletal formula is a simplified representation of an organic formula. It is derived from the structural formula by removing hydrogen atoms (and their associated bonds) and carbon atoms from alkyl chains, leaving just the carbon-carbon bonds in the carbon skeleton and the associated functional groups.

Skeletal or partial-skeletal representations may be used in question papers and are acceptable in candidates' answers where they are unambiguous.

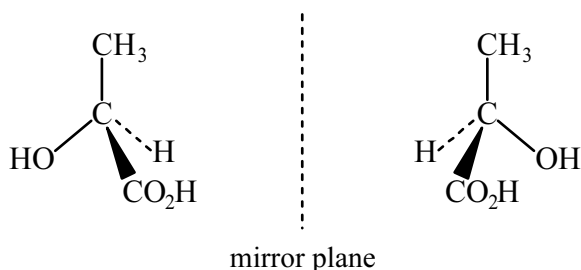
The skeletal formula for butan-2-ol and a partial-skeletal formula for cholesterol are shown below.



The  convention for representing the aromatic ring is preferred.

## Optical Isomers

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



## Learning Outcomes

Candidates should be able to:

- (a) interpret, and use the nomenclature, general formulae and displayed formulae of the following classes of compound:
  - (i) alkanes, alkenes and arenes
  - (ii) halogenoalkanes and halogenoarenes
  - (iii) alcohols (including primary, secondary and tertiary) and phenols
  - (iv) aldehydes and ketones
  - (v) carboxylic acids, acyl chlorides and esters
  - (vi) amines, amides, amino acids and nitriles
- (b) interpret, and use the following terminology associated with organic reactions:
  - (i) functional group
  - (ii) homolytic and heterolytic fission
  - (iii) free radical, initiation, propagation, termination
  - (iv) nucleophile, electrophile
  - (v) addition, substitution, elimination, hydrolysis
  - (vi) oxidation and reduction

[in equations for organic redox reactions, the symbols [O] and [H] are acceptable]
- (c) describe  $sp^3$  hybridisation, as in ethane molecule,  $sp^2$  hybridisation, as in ethene and benzene molecules, and  $sp$  hybridisation, as in ethyne molecule
- (d) explain the shapes of, and bond angles in, the ethane, ethene, benzene, and ethyne molecules in relation to  $\sigma$  and  $\pi$  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  $\pi$  bonds  
[use of E, Z nomenclature is **not** required]
- (h) explain what is meant by a chiral centre
- (i) deduce whether a given molecule is optically active based on the presence or absence of chiral centres and/or a plane of symmetry

- (j) recognise that optical isomers have identical physical properties except in the direction in which they rotate plane-polarised light
- (k) recognise that optical isomers have identical chemical properties except in their interactions with another chiral molecule
- (l) recognise that different stereoisomers exhibit different biological properties, for example in drug action
- (m) deduce the possible isomers for an organic molecule of known molecular formula
- (n) identify chiral centres and/or geometrical isomerism in a molecule of given structural formula

## 10.2 HYDROCARBONS

### Content

- Alkanes (exemplified by ethane)
  - (i) Free-radical reactions
- Alkenes (exemplified by ethene)
  - (i) Addition and oxidation reactions
- Arenes (exemplified by benzene and methylbenzene)
  - (i) Influence of delocalised  $\pi$  electrons on structure and properties
  - (ii) Substitution reactions with electrophiles
  - (iii) Oxidation of side-chain
- 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 mechanism of free-radical substitution at methyl groups with particular reference to the initiation, propagation and termination reactions
- (d) describe the chemistry of alkenes as exemplified, where relevant, by the following reactions of ethene:
  - (i) addition of hydrogen, steam, hydrogen halides and halogens
  - (ii) oxidation by cold, dilute manganate(VII) ions to form the diol
  - (iii) oxidation by hot, concentrated manganate(VII) ions leading to the rupture of the carbon-to-carbon double bond in order to determine the position of alkene linkages in larger molecules
- (e) describe the mechanism of electrophilic addition in alkenes, using bromine/ethene as an example
- (f) describe the chemistry of arenes as exemplified by the following reactions of benzene and methylbenzene:
  - (i) substitution reactions with chlorine and with bromine
  - (ii) nitration
  - (iii) oxidation of the side-chain to give a carboxylic acid

- (g) (i) describe the mechanism of electrophilic substitution in arenes, using the mono-nitration of benzene as an example  
 (ii) describe the effect of the delocalisation of electrons in arenes in such reactions
- (h) predict whether halogenation will occur in the side-chain or aromatic nucleus in arenes depending on reaction conditions
- (i) apply the knowledge of positions of substitution in the electrophilic substitution reactions of mono-substituted arenes
- (j) recognise the environmental consequences of:  
 (i) carbon monoxide, oxides of nitrogen and unburnt hydrocarbons arising from the internal combustion engine and of their catalytic removal  
 (ii) gases that contribute to the enhanced greenhouse effect

### 10.3 HALOGEN DERIVATIVES

#### Content

- Halogenoalkanes and halogenoarenes
  - (i) Nucleophilic 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 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 substitutions (by both  $S_N1$  and  $S_N2$  mechanisms) in halogenoalkanes
- (c) interpret the different reactivities of halogenoalkanes and chlorobenzene with particular reference to hydrolysis and to the relative strengths of the C-Hal bonds
- (d) explain the uses of fluoroalkanes and fluorohalogenoalkanes in terms of their relative chemical inertness
- (e) 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]

**10.4 HYDROXY COMPOUNDS****Content**

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

**Learning Outcomes**

Candidates should be able to:

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

**10.5 CARBONYL COMPOUNDS****Content**

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

**Learning Outcomes**

Candidates should be able to:

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

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

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

**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
  - (iii) acyl chlorides, using ethanoyl chloride as an example
- (c) explain the acidity of carboxylic acids and of chlorine-substituted ethanoic acids in terms of their structures
- (d) describe the hydrolysis of acyl chlorides
- (e) describe the reactions of acyl chlorides with alcohols, phenols and primary amines
- (f) explain the relative ease of hydrolysis of acyl chlorides, alkyl chlorides and aryl chlorides
- (g) describe the formation of esters from acyl chlorides, using phenyl benzoate as an example
- (h) describe the acid and base hydrolyses of esters



## 10.7 NITROGEN COMPOUNDS

### Content

- Amines (exemplified by ethylamine and phenylamine)
  - (i) Their formation
  - (ii) Salt formation
  - (iii) Other reactions of phenylamine
- Amides (exemplified by ethanamide)
  - (i) Their formation from acyl chlorides
  - (ii) Their hydrolysis
- Amino acids (exemplified by aminoethanoic acid)
  - (i) Their acid and base properties
  - (ii) Zwitterion formation
- Proteins
  - (i) Protein structure: primary; secondary; tertiary; quaternary structures
  - (ii) The hydrolysis of proteins
  - (iii) Denaturation of proteins

### Learning Outcomes

Candidates should be able to:

- (a) describe the formation of ethylamine (by nitrile reduction see also Section 10.3) and of phenylamine (by the reduction of nitrobenzene)
- (b) explain the basicity of amines
- (c) explain the relative basicities of ammonia, ethylamine and phenylamine in terms of their structures
- (d) describe the reaction of phenylamine with aqueous bromine
- (e) describe the formation of amides from the reaction between  $\text{RNH}_2$  and  $\text{R}'\text{COCl}$
- (f) 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) describe the formation of peptide (amide) bonds between amino acids and, hence, explain protein formation
- (i) list the major functions of proteins in the body
- (j) describe the hydrolysis of proteins
- (k) explain the term *primary structure* of proteins
- (l) recognise that the twenty amino acids that make up all the proteins in the body are  $\alpha$ -amino acids with the general formula  $\text{RCH}(\text{NH}_2)\text{CO}_2\text{H}$ , and be able to interpret the properties of  $\alpha$ -amino acids in terms of the nature of the R group
- (m) describe the secondary structure of proteins:  $\alpha$ -helix and  $\beta$ -pleated sheet and the stabilisation of these structures by hydrogen bonding

- (n) 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, disulfide bridges, hydrogen bonds and van der Waals' forces)
- (o) describe
  - (i) the quaternary structure of proteins
  - (ii) the protein components of haemoglobin
- (p) explain denaturation of proteins by heavy metal ions, extremes of temperature and pH changes
- (q) apply the knowledge of the loss and formation of secondary and tertiary structures to interpret common everyday phenomena

## **PRACTICAL ASSESSMENT**

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Scientific subjects are, by their nature, experimental. It is therefore important that, wherever possible, the candidates carry out appropriate practical work to illustrate the theoretical principles to facilitate the learning of this subject.

The guidance material for practical work, which is published separately, will provide examples of appropriate practical activities. These exemplars will provide a guide to the type and complexity of the exercises for practical assessment.

Candidates will be assessed in the following skill areas:

(a) Planning (P)

Candidates should be able to:

- define question/problem using appropriate knowledge and understanding
- give a clear logical account of the experimental procedure to be followed
- describe how the data should be used in order to reach a conclusion
- assess the risks of the experiment and describe precautions that should be taken to keep risks to a minimum

(b) Manipulation, measurement and observation (MMO)

Candidates should be able to:

- demonstrate high level of manipulative skills in all aspects of practical activity
- make and record accurately, in a suitable manner, all observations with good details and/or all measurements to appropriate degree of precision
- recognise anomalous observations and/or measurements (where appropriate) with reasons indicated and suggest possible causes

## (c) Presentation of data and observations (PDO)

Candidates should be able to:

- present all information in an appropriate form
- manipulate observations and/or measurements effectively in order to identify trends/patterns
- present all quantitative data to an appropriate number of significant figures

## (d) Analysis, conclusions and evaluation (ACE)

Candidates should be able to:

- analyse and interpret data appropriately in relation to the task
- draw comprehensive conclusions based on underlying principles
- identify significant sources of errors, limitations of measurements and/or experimental procedures used, and explain how they affect the final result(s)
- state and explain how significant errors/limitations (including experimental procedures) may be overcome/improved as appropriate

Skill P will be assessed in Paper 2. Candidates will be required to answer a question constituting 12 marks among the compulsory questions in Paper 2. The assessment of Skill P will be set in the context of the content syllabus, requiring candidates to apply and integrate knowledge and understanding from different sections of the syllabus. It may also require treatment of given experimental data in drawing relevant conclusion and analysis of proposed plan.

For school candidates, skills MMO, PDO and ACE will be assessed by two school-based assessments (SPA). The school-based practical assessments will be set in the context of the syllabus.

Centres will be notified in advance of the details of the apparatus and materials required for these assessments. The assessment of PDO and ACE may also include questions on data analysis, which do not require practical equipment and apparatus.

Within the Schemes of Assessment, school-based practical assessment (for school candidates) constitutes 15% of the Higher 2 examination. The planning component in Paper 2 constitutes 5% of the Higher 2 examination. It is therefore recommended that the schemes of work include learning opportunities that apportion a commensurate amount of time for the development and acquisition of practical skills.

## QUALITATIVE ANALYSIS NOTES

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

### 1 Reactions of aqueous cations

cation	reaction with	
	NaOH(aq)	NH <sub>3</sub> (aq)
aluminium, Al <sup>3+</sup> (aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH <sub>4</sub> <sup>+</sup> (aq)	ammonia produced on heating	
barium, Ba <sup>2+</sup> (aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca <sup>2+</sup> (aq)	white. ppt. with high [Ca <sup>2+</sup> (aq)]	no ppt.
chromium(III), Cr <sup>3+</sup> (aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu <sup>2+</sup> (aq),	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II), Fe <sup>2+</sup> (aq)	green ppt. insoluble in excess	green ppt. insoluble in excess
iron(III), Fe <sup>3+</sup> (aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
lead(II), Pb <sup>2+</sup> (aq)	white ppt. soluble in excess	white ppt. insoluble in excess
magnesium, Mg <sup>2+</sup> (aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn <sup>2+</sup> (aq)	off-white ppt. insoluble in excess	off-white ppt. insoluble in excess
zinc, Zn <sup>2+</sup> (aq)	white ppt. soluble in excess	white ppt. soluble in excess

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

## 2 Reactions of anions

ion	reaction
carbonate, $\text{CO}_3^{2-}$	$\text{CO}_2$ liberated by dilute acids
chloride, $\text{Cl}^-(\text{aq})$	gives white ppt. with $\text{Ag}^+(\text{aq})$ (soluble in $\text{NH}_3(\text{aq})$ ); gives white ppt. with $\text{Pb}^{2+}(\text{aq})$
bromide, $\text{Br}^-(\text{aq})$	gives pale cream ppt. with $\text{Ag}^+(\text{aq})$ (partially soluble in $\text{NH}_3(\text{aq})$ ); gives white ppt. with $\text{Pb}^{2+}(\text{aq})$
iodide, $\text{I}^-(\text{aq})$	gives yellow ppt. with $\text{Ag}^+(\text{aq})$ (insoluble in $\text{NH}_3(\text{aq})$ ); gives yellow ppt. with $\text{Pb}^{2+}(\text{aq})$
nitrate, $\text{NO}_3^-(\text{aq})$	$\text{NH}_3$ liberated on heating with $\text{OH}^-(\text{aq})$ and <i>Al</i> foil
nitrite, $\text{NO}_2^-(\text{aq})$	$\text{NH}_3$ liberated on heating with $\text{OH}^-(\text{aq})$ and <i>Al</i> foil; $\text{NO}$ liberated by dilute acids (colourless $\text{NO} \rightarrow$ (pale) brown $\text{NO}_2$ in air)
sulfate, $\text{SO}_4^{2-}(\text{aq})$	gives white ppt. with $\text{Ba}^{2+}(\text{aq})$ or with $\text{Pb}^{2+}(\text{aq})$ (insoluble in excess dilute strong acids)
sulfite, $\text{SO}_3^{2-}(\text{aq})$	$\text{SO}_2$ liberated with dilute acids; gives white ppt. with $\text{Ba}^{2+}(\text{aq})$ (soluble in dilute strong acids)

## 3 Tests for gases

gas	test and test result
ammonia, $\text{NH}_3$	turns damp red litmus paper blue;
carbon dioxide, $\text{CO}_2$	gives a white ppt. with limewater (ppt. dissolves with excess $\text{CO}_2$ )
chlorine, $\text{Cl}_2$	bleaches damp litmus paper
hydrogen, $\text{H}_2$	“pops” with a lighted splint
oxygen, $\text{O}_2$	relights a glowing splint
sulfur dioxide, $\text{SO}_2$	turns aqueous acidified potassium manganate(VII) from purple to colourless

## SUMMARY OF KEY QUANTITIES AND UNITS

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

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

## MATHEMATICAL REQUIREMENTS

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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 calculators to evaluate logarithms (for pH calculations), squares, square roots, and reciprocals.

Change the subject of an equation. (Most such equations involve only the simpler operations but may include positive and negative indices and square roots.)

Substitute physical quantities into an equation using consistent units so as to calculate one quantity. Check the dimensional consistency of such calculations, e.g. the units of a rate constant  $k$ .

Solve simple algebraic equations.

Comprehend and use the symbols/notations  $<$ ,  $>$ ,  $\approx$ ,  $/$ ,  $\Delta$ ,  $\equiv$ ,  $\times$  (or  $<x>$ ).

Test tabulated pairs of values for direct proportionality by a graphical method or by constancy of ratio.

Select appropriate variables and scales for plotting a graph, especially to obtain a linear graph of the form  $y = mx + c$ .

Determine and interpret the slope and intercept of a linear graph.

Choose by inspection a straight line that will serve as the 'least bad' linear model for a set of data presented graphically.

Understand (i) the slope of a tangent to a curve as a measure of rate of change, (ii) the 'area' below a curve where the area has physical significance, e.g. Boltzmann distribution curves.

Comprehend how to handle numerical work so that significant figures are neither lost unnecessarily nor used beyond what is justified.

Estimate orders of magnitude.

Formulate simple algebraic equations as mathematical models, e.g. construct a rate equation, and identify failures of such models.

### Calculators

Any calculator used must be on the Singapore Examinations and Assessment Board list of approved calculators.

## GLOSSARY OF TERMS

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

1. *Define (the term(s)...) is intended literally, only a formal statement or equivalent paraphrase being required.*
2. *What do you understand by/What is meant by (the term(s)...) normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in the light of the indicated mark value.*
3. *State implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained 'by inspection'.*
4. *List requires a number of points, generally each of one word, with no elaboration. Where a given number of points is specified, this should not be exceeded.*
5. *Explain may imply reasoning or some reference to theory, depending on the context.*
6. *Describe requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena.*  
*In other contexts, describe and give an account of should be interpreted more generally, i.e. the candidate has greater discretion about the nature and the organisation of the material to be included in the answer. Describe and explain may be coupled in a similar way to state and explain.*
7. *Discuss requires candidates to give a critical account of the points involved in the topic.*
8. *Outline implies brevity, i.e. restricting the answer to giving essentials.*
9. *Predict 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

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**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

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Teachers may find reference to the following books helpful.

Chemistry for Advanced Level by P Cann and 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 and 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 and Holman, published by Nelson Thornes

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

Experiments and Exercises in Basic Chemistry (5th Edition) by S Murov and 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

## 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<sup>-1</sup>**

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

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

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

**(b) Polyatomic molecules**

<b>Bond</b>	<b>Energy/kJ mol<sup>-1</sup></b>
C—C	350
C=C	610
C≡C	840
C $\cdots$ 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
$[\text{Ni}(\text{NH}_3)_6]^{2+} + 2\text{e}^-$	$\rightleftharpoons$	$\text{Ni} + 6\text{NH}_3$	-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
$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$	$\rightleftharpoons$	$4\text{OH}^-$	+0.40
$\text{O}_2 + 2\text{H}^+ + 2\text{e}^-$	$\rightleftharpoons$	$\text{H}_2\text{O}_2$	+0.68
$2\text{H}_2\text{O} + 2\text{e}^-$	$\rightleftharpoons$	$\text{H}_2 + 2\text{OH}^-$	-0.83
$\text{Pb}^{2+} + 2\text{e}^-$	$\rightleftharpoons$	$\text{Pb}$	-0.13
$\text{Pb}^{4+} + 2\text{e}^-$	$\rightleftharpoons$	$\text{Pb}^{2+}$	+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
$\text{S}_2\text{O}_8^{2-} + 2\text{e}^-$	$\rightleftharpoons$	$2\text{SO}_4^{2-}$	+2.01
$\text{S}_4\text{O}_6^{2-} + 2\text{e}^-$	$\rightleftharpoons$	$2\text{S}_2\text{O}_3^{2-}$	+0.09
$\text{Sn}^{2+} + 2\text{e}^-$	$\rightleftharpoons$	$\text{Sn}$	-0.14
$\text{Sn}^{4+} + 2\text{e}^-$	$\rightleftharpoons$	$\text{Sn}^{2+}$	+0.15
$\text{V}^{2+} + 2\text{e}^-$	$\rightleftharpoons$	$\text{V}$	-1.20
$\text{V}^{3+} + \text{e}^-$	$\rightleftharpoons$	$\text{V}^{2+}$	-0.26
$\text{VO}^{2+} + 2\text{H}^+ + \text{e}^-$	$\rightleftharpoons$	$\text{V}^{3+} + \text{H}_2\text{O}$	+0.34
$\text{VO}_2^+ + 2\text{H}^+ + \text{e}^-$	$\rightleftharpoons$	$\text{VO}^{2+} + \text{H}_2\text{O}$	+1.00
$\text{VO}_3^- + 4\text{H}^+ + \text{e}^-$	$\rightleftharpoons$	$\text{VO}^{2+} + 2\text{H}_2\text{O}$	+1.00
$\text{Zn}^{2+} + 2\text{e}^-$	$\rightleftharpoons$	$\text{Zn}$	-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	$E^\ominus / \text{V}$
$\text{F}_2 + 2\text{e}^- \rightleftharpoons 2\text{F}^-$	+2.87
$\text{S}_2\text{O}_8^{2-} + 2\text{e}^- \rightleftharpoons 2\text{SO}_4^{2-}$	+2.01
$\text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}$	+1.77
$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 4\text{H}_2\text{O}$	+1.52
$\text{PbO}_2 + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Pb}^{2+} + 2\text{H}_2\text{O}$	+1.47
$\text{Cl}_2 + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-$	+1.36
$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightleftharpoons 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$	+1.33
$\text{Br}_2 + 2\text{e}^- \rightleftharpoons 2\text{Br}^-$	+1.07
$\text{NO}_3^- + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{NO}_2 + \text{H}_2\text{O}$	+0.81
$\text{Ag}^+ + \text{e}^- \rightleftharpoons \text{Ag}$	+0.80
$\text{Fe}^{3+} + \text{e}^- \rightleftharpoons \text{Fe}^{2+}$	+0.77
$\text{I}_2 + 2\text{e}^- \rightleftharpoons 2\text{I}^-$	+0.54
$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightleftharpoons 4\text{OH}^-$	+0.40
$\text{Cu}^{2+} + 2\text{e}^- \rightleftharpoons \text{Cu}$	+0.34
$\text{SO}_4^{2-} + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{SO}_2 + 2\text{H}_2\text{O}$	+0.17
$\text{Sn}^{4+} + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+}$	+0.15
$\text{S}_4\text{O}_6^{2-} + 2\text{e}^- \rightleftharpoons 2\text{S}_2\text{O}_3^{2-}$	+0.09
$2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2$	0.00
$\text{Pb}^{2+} + 2\text{e}^- \rightleftharpoons \text{Pb}$	-0.13
$\text{Sn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Sn}$	-0.14
$\text{Fe}^{2+} + 2\text{e}^- \rightleftharpoons \text{Fe}$	-0.44
$\text{Zn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Zn}$	-0.76
$\text{Mg}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mg}$	-2.38
$\text{Ca}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ca}$	-2.87
$\text{K}^+ + \text{e}^- \rightleftharpoons \text{K}$	-2.92

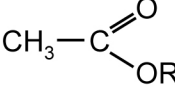
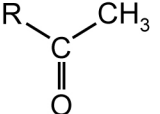
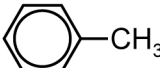
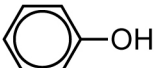
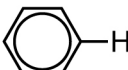
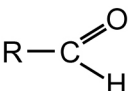
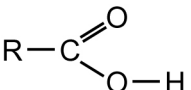
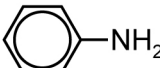
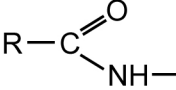
## Atomic and ionic radii

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

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

Bond		Characteristic ranges Wavenumber (reciprocal wavelength) /cm <sup>-1</sup>
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 value ( $\delta$ ) relative to T.M.S.=0**

<i>Type of proton</i>	<i>Chemical shift (ppm)</i>
$R-CH_3$	0.9
$R-CH_2-R$	1.3
$R_3CH$	1.4–1.7
	2.0
	2.1
	2.3
$R-C\equiv C-H$	1.8–3.1
$R-CH_2-Hal$	3.2–3.7
$R-O-CH_3$	3.3–4.0
$R-O-H$	0.5–6.0*
$R_2C=CH-$	4.5–6.0
	4.5–7.0*
	6.0–9.0
	9.0–10.0
	9.0–13.0*
$R-NH_2$	1.0–5.0*
	3.0–6.0*
	5.0–12.0*

\*Sensitive to solvent, concentration

# The Periodic Table of Elements

Group																															
I	II											III	IV	V	VI	VII	0														
		<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: auto;"> <b>Key</b>                      relative atomic mass                      atomic symbol                      name                      atomic number                 </div>										<div style="border: 1px solid black; padding: 2px; width: fit-content; margin: auto;">                     1.0                      H                      hydrogen                      1                 </div>								<div style="border: 1px solid black; padding: 2px; width: fit-content; margin: auto;">                     4.0                      He                      helium                      2                 </div>											
6.9 Li lithium 3	9.0 Be beryllium 4											10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18	39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	95.9 Mo molybdenum 42	– Tc technetium 43	101 Ru ruthenium 44	103 Rh rhodium 45	106 Pd palladium 46	108 Ag silver 47	112 Cd cadmium 48	115 In indium 49	119 Sn tin 50	122 Sb antimony 51	128 Te tellurium 52	127 I iodine 53	131 Xe xenon 54														
133 Cs caesium 55	137 Ba barium 56	139 La lanthanum 57	178 Hf hafnium 72	181 Ta tantalum 73	184 W tungsten 74	186 Re rhenium 75	190 Os osmium 76	192 Ir iridium 77	195 Pt platinum 78	197 Au gold 79	201 Hg mercury 80	204 Tl thallium 81	207 Pb lead 82	209 Bi bismuth 83	– Po polonium 84	– At astatine 85	– Rn radon 86														
– Fr francium 87	– Ra radium 88	– Ac actinium 89	– Rf rutherfordium 104	– Db dubnium 105	– Sg seaborgium 106	– Bh bohrium 107	– Hs hassium 108	– Mt meitnerium 109	– Uun ununillium 110	– Uuu unununium 111	– Uub ununbium 112	– Uuq ununquadium 114	– Uuh ununhexium 116	–	–	–	– Uuo ununoctium 118														

45

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