Chemistry

Singapore-Cambridge General Certificate of Education Ordinary Level (2018)

(Syllabus 5073)

CONTENTS

Singapore Examinations and Assessment Board

CAMBRIDGE International Examinations

INTRODUCTION

This syllabus is designed to place less emphasis on factual materials and greater emphasis on the understanding and application of scientific concepts and principles. This approach has been adapted 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 materials, which may have only short term relevance.

It is important that, throughout the course, attention should be drawn to:

(i) the finite life of the world's resources and hence the need for recycling and conservation

(ii) economic considerations in the chemical industry, such as the availability and cost of raw materials and energy

(iii) the social, environmental, health and safety issues relating to the chemical industry

(iv) the importance of chemicals in industry and in everyday life.

It is envisaged that teaching and learning programmes based on this syllabus will feature a wide variety of learning experiences designed to promote acquisition of expertise and understanding. Teachers are encouraged to use a combination of appropriate strategies including developing appropriate practical works for their students to facilitate a greater understanding of the subject.

AIMS

These are not listed in order of priority.

The aims are to:

1. provide, through well-designed studies of experimental and practical chemistry, a worthwhile educational experience for all students, whether or not they go on to study science beyond this level and, in particular, to enable them to acquire sufficient understanding and knowledge to

    1.1 become confident citizens in a technological world, able to take or develop an informed interest in matters of scientific importance

    1.2 recognise the usefulness, and limitations, of scientific methods and models and to appreciate their applicability in other disciplines and in everyday life

    1.3 be suitably prepared for studies beyond Ordinary Level in chemistry, in applied sciences or in science-related courses.

2. develop abilities and skills that

    2.1 are relevant to the study and practice of science

    2.2 are useful in everyday life

    2.3 encourage efficient and safe practice

    2.4 encourage effective communication.

3. develop attitudes relevant to science such as
   - 3.1 accuracy and precision
   - 3.2 objectivity
   - 3.3 integrity
   - 3.4 inquiry
   - 3.5 initiative
   - 3.6 inventiveness.
4. stimulate interest in and care for the local and global 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 communications, as an aid to experiments and as a tool for interpretation of experimental and theoretical results.

ASSESSMENT OBJECTIVES

A Knowledge with Understanding

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

1. scientific phenomena, facts, laws, definitions, concepts, theories
2. scientific vocabulary, terminology, conventions (including symbols, quantities and units contained in '*Signs, Symbols and Systematics 16–19*', Association for Science Education, 2000)
3. scientific instruments and apparatus, including techniques of operation and aspects of safety
4. scientific quantities and their determination
5. scientific and technological applications with their social, economic and environmental implications.

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

B Handling Information and Solving Problems

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. translate information from one form to another
3. manipulate numerical and other data
4. use information to identify patterns, report trends and draw inferences
5. present reasoned explanations for phenomena, patterns and relationships
6. make predictions and propose hypotheses
7. solve problems.

These assessment objectives cannot be precisely specified in the subject content because questions testing these objectives may be based on information which is unfamiliar to the candidates. 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*, *deduce*, *suggest*, *calculate* or *determine*. (See the *Glossary of Terms*).

C Experimental Skills and Investigations

Students should be able to:

1. follow a sequence of instructions
2. use techniques, apparatus and materials
3. make and record observations, measurements and estimates
4. interpret and evaluate observations and experimental results
5. plan investigations, select techniques, apparatus and materials
6. evaluate methods and suggest possible improvements.

Weighting of Assessment Objectives

Theory Papers (Papers 1 and 2)

A Knowledge with Understanding, approximately 45% of the marks with approximately 15% allocated to recall.

B Handling Information and Solving Problems, approximately 55% of the marks.

School-based Science Practical Assessment (SPA) (Paper 3)

C Experimental Skills and Investigations, 100% of the marks.

SCHEME OF ASSESSMENT

Candidates are required to enter for Papers 1, 2 and 3.

Paper	Type of Paper	Duration	Marks	Weighting
1	Multiple Choice	1 h	40	30%
2	Structured and Free Response	1 h 45 min	80	50%
3	School-based Science Practical Assessment (SPA)	–	96	20%

Theory Papers

Paper 1 (1 h, 40 marks), consisting of 40 compulsory multiple choice items of the direct choice type.

A copy of the Periodic Table of Elements will be printed as part of this Paper.

Paper 2 (1 h 45 min, 80 marks), consisting of two sections.

Section A will carry 50 marks and will consist of a variable number of compulsory structured questions.

Section B will carry 30 marks and will consist of three questions.

The first two questions are compulsory questions, one of which will be a data-based question requiring candidates to interpret, evaluate or solve problems using a stem of information. This question will carry 8–12 marks.

The last question will be presented in an either/or form and will carry 10 marks.

A copy of the Periodic Table of Elements will be printed as part of this Paper.

School-based Science Practical Assessment (SPA)

Paper 3 (96 marks)

The School-based Science Practical Assessment (SPA) will be conducted to assess appropriate aspects of objectives C1 to C6. SPA will take place over an appropriate period that the candidates are offering the subject. The assessment of science practical skills is grouped into 3 skill sets:

Skill set 1 – Performing and Observing

Skill set 2 – Analysing

Skill set 3 – Planning

Each candidate is to be assessed only **twice** for each of skill sets 1 and 2 and only **once** for skill set 3.

Weighting and Marks Computation of the 3 Skill Sets

The overall level of performance of each skill set (skill sets 1, 2 and 3) is the sum total of the level of performance of each strand within the skill set.

The weighting and marks computation of the skill sets are as follows:

Skill Set	No. of Assessments (a)	Max Marks per Assessment (b)	Weight (c)	Sub-total ($a \times b \times c$)	Weighting
1	2	6	4	$2 \times 6 \times 4 = 48$	50%
2	2	4	3	$2 \times 4 \times 3 = 24$	25%
3	1	4	6	$1 \times 4 \times 6 = 24$	25%
Total Marks for SPA				96	

Please refer to the *SPA Information Booklet* for more detailed information on the conduct of SPA.

CONTENT STRUCTURE

Section		Topic	
I.	**EXPERIMENTAL CHEMISTRY**	1.	Experimental Chemistry
II.	**ATOMIC STRUCTURE AND STOICHIOMETRY**	2. 3.	The Particulate Nature of Matter Formulae, Stoichiometry and the Mole Concept
III.	**CHEMISTRY OF REACTIONS**	4. 5. 6. 7.	Electrolysis Energy from Chemicals Chemical Reactions Acids, Bases and Salts
IV.	**PERIODICITY**	8. 9.	The Periodic Table Metals
V.	**ATMOSPHERE**	10.	Air
VI.	**ORGANIC CHEMISTRY**	11.	Organic Chemistry

SUBJECT CONTENT

SECTION I: EXPERIMENTAL CHEMISTRY

Overview
Chemistry is typically an experimental science and relies primarily on practical work. It is important for students to learn the techniques of handling laboratory apparatus and to pay special attention to safety while working in the laboratory. Accidents happened even to German chemist, Robert Bunsen, while working in the laboratory. Robert Bunsen spent most of his time doing experiments in the laboratory and at the age of 25, he lost an eye in a laboratory explosion due to the lack of proper eye protection.

In this section, students examine the appropriate use of simple apparatus and chemicals, and the experimental techniques. Students need to be aware of the importance of purity in the electronic, pharmaceutical, food and beverage industries, and be allowed to try out different methods of purification and analysis in school science laboratories. Students should be able to appreciate the need for precision and accuracy in making readings and also value the need for safe handling and disposing of chemicals.

1 Experimental Chemistry

Content

1.1 Experimental design

1.2 Methods of purification and analysis

1.3 Identification of ions and gases

Learning Outcomes

Candidates should be able to:

1.1 Experimental design

(a) name appropriate apparatus for the measurement of time, temperature, mass and volume, including burettes, pipettes, measuring cylinders and gas syringes

(b) suggest suitable apparatus, given relevant information, for a variety of simple experiments, including collection of gases and measurement of rates of reaction.

1.2 Methods of purification and analysis

(a) describe methods of separation and purification for the components of mixtures, to include:
- (i) use of a suitable solvent, filtration and crystallisation or evaporation
- (ii) sublimation
- (iii) distillation and fractional distillation (see also **11.1**(b))
- (iv) use of a separating funnel
- (v) paper chromatography

(b) suggest suitable separation and purification methods, given information about the substances involved in the following types of mixtures:
- (i) solid-solid
- (ii) solid-liquid
- (iii) liquid-liquid (miscible and immiscible)

(c) interpret paper chromatograms including comparison with 'known' samples and the use of R_f values

(d) explain the need to use locating agents in the chromatography of colourless compounds (knowledge of specific locating agents is **not** required)

(e) deduce from the given melting point and boiling point the identities of substances and their purity

(f) explain that the measurement of purity in substances used in everyday life, e.g. foodstuffs and drugs, is important.

1.3 Identification of ions and gases

(a) describe the use of aqueous sodium hydroxide and aqueous ammonia to identify the following aqueous cations: aluminium, ammonium, calcium, copper(II), iron(II), iron(III), lead(II) and zinc (formulae of complex ions are **not** required)

(b) describe tests to identify the following anions: carbonate (by the addition of dilute acid and subsequent use of limewater); chloride (by reaction of an aqueous solution with nitric acid and aqueous silver nitrate); iodide (by reaction of an aqueous solution with nitric acid and aqueous silver nitrate); nitrate (by reduction with aluminium in aqueous sodium hydroxide to ammonia and subsequent use of litmus paper) and sulfate (by reaction of an aqueous solution with nitric acid and aqueous barium nitrate)

(c) describe tests to identify the following gases: ammonia (using damp red litmus paper); carbon dioxide (using limewater); chlorine (using damp litmus paper); hydrogen (using a burning splint); oxygen (using a glowing splint) and sulfur dioxide (using acidified potassium manganate(VII)).

SECTION II: ATOMIC STRUCTURE AND STOICHIOMETRY

Overview
For over 2000 years, people have wondered about the fundamental building blocks of matter. As far back as 440 BC, the Greek Leucippus and his pupil Democritus coined the term atomos to describe the smallest particle of matter. It translates to mean something that is indivisible. In the eighteenth century, chemist, John Dalton, revived the term when he suggested that each element was made up of unique atoms and the atoms of an element are all the same. At that time, there were about 35 known elements. This simple model could explain the millions of different materials around us.

Differences between atoms give elements their different chemical properties. Atoms of one or more substances (reactants) undergo some ‘rearrangements’ during a chemical change (reaction). These rearrangements form new and different substances (products). After the chemical reaction, all the atoms of the reactants are still present in the products. Balanced chemical equations can be written because of the law of conservation of mass. These equations make it possible to predict the masses of reactants and products involved in chemical reactions.

In this section, the idea of atoms and chemical bonding being the most important fundamental concept in Chemistry is introduced. The knowledge of atomic structure opens the door for students to understand the world of chemical reactions. Students are also introduced to the use of models and theories in the study of the structures of atoms, molecules and ions, and the bonding in elements and compounds. Calculations for chemical reactions involving chemical formulae, reacting masses and volumes, and concentrations introduce students to the fundamentals of stoichiometry.

2 The Particulate Nature of Matter

Content

2.1 Kinetic particle theory

2.2 Atomic structure

2.3 Structure and properties of materials

2.4 Ionic bonding

2.5 Covalent bonding

2.6 Metallic bonding

Learning Outcomes

Candidates should be able to:

2.1 Kinetic particle theory

(a) describe the solid, liquid and gaseous states of matter and explain their interconversion in terms of the kinetic particle theory and of the energy changes involved

(b) describe and explain evidence for the movement of particles in liquids and gases (the treatment of Brownian motion is **not** required)

(c) explain everyday effects of diffusion in terms of particles, e.g. the spread of perfumes and cooking aromas; tea and coffee grains in water

(d) state qualitatively the effect of molecular mass on the rate of diffusion and explain the dependence of rate of diffusion on temperature.

2.2 Atomic structure

(a) state the relative charges and approximate relative masses of a proton, a neutron and an electron

(b) describe, with the aid of diagrams, the structure of an atom as containing protons and neutrons (nucleons) in the nucleus and electrons arranged in shells (energy levels)

(knowledge of s, p, d and f classification is **not** required; a copy of the Periodic Table will be available in Papers 1 and 2)

(c) define *proton (atomic) number* and *nucleon (mass) number*

(d) interpret and use symbols such as $^{12}_{6}C$

(e) define the term *isotopes*

(f) deduce the numbers of protons, neutrons and electrons in atoms and ions given proton and nucleon numbers.

2.3 Structure and properties of materials

(a) describe the differences between elements, compounds and mixtures

(b) compare the structure of simple molecular substances, e.g. methane; iodine, with those of giant molecular substances, e.g. poly(ethene); sand (silicon dioxide); diamond; graphite in order to deduce their properties

(c) compare the bonding and structures of diamond and graphite in order to deduce their properties such as electrical conductivity, lubricating or cutting action (candidates will **not** be required to draw the structures)

(d) deduce the physical and chemical properties of substances from their structures and bonding and vice versa.

2.4 Ionic bonding

(a) describe the formation of ions by electron loss/gain in order to obtain the electronic configuration of a noble gas

(b) describe the formation of ionic bonds between metals and non-metals, e.g. $NaCl$; $MgCl_2$

(c) state that ionic materials contain a giant lattice in which the ions are held by electrostatic attraction, e.g. $NaCl$ (candidates will **not** be required to draw diagrams of ionic lattices)

(d) deduce the formulae of other ionic compounds from diagrams of their lattice structures, limited to binary compounds

(e) relate the physical properties (including electrical property) of ionic compounds to their lattice structure.

2.5 Covalent bonding

(a) describe the formation of a covalent bond by the sharing of a pair of electrons in order to gain the electronic configuration of a noble gas

(b) describe, using ‘dot-and-cross’ diagrams, the formation of covalent bonds between non-metallic elements, e.g. H_2; O_2; H_2O; CH_4; CO_2

(c) deduce the arrangement of electrons in other covalent molecules

(d) relate the physical properties (including electrical property) of covalent substances to their structure and bonding.

2.6 Metallic bondin g

(a) describe metals as a lattice of positive ions in a ‘sea of electrons’

(b) relate the electrical conductivity of metals to the mobility of the electrons in the structure (see also **9.1**(a)).

3 Formulae, Stoichiometry and the Mole Concept

Learning Outcomes

Candidates should be able to:

(a) state the symbols of the elements and formulae of the compounds mentioned in the syllabus

(b) deduce the formulae of simple compounds from the relative numbers of atoms present and vice versa

(c) deduce the formulae of ionic compounds from the charges on the ions present and vice versa

(d) interpret chemical equations with state symbols

(e) construct chemical equations, with state symbols, including ionic equations

(f) define relative atomic mass, A_r

(g) define relative molecular mass, M_r, and calculate relative molecular mass (and relative formula mass) as the sum of relative atomic masses

(h) calculate the percentage mass of an element in a compound when given appropriate information

(i) calculate empirical and molecular formulae from relevant data

(j) calculate stoichiometric reacting masses and volumes of gases (one mole of gas occupies 24 dm^3 at room temperature and pressure); calculations involving the idea of limiting reactants may be set

(knowledge of the gas laws and the calculations of gaseous volumes at different temperatures and pressures are **not** required)

(k) apply the concept of solution concentration (in mol / dm^3 or g / dm^3) to process the results of volumetric experiments and to solve simple problems

(Appropriate guidance will be provided where unfamiliar reactions are involved.)

(l) calculate % yield and % purity.

SECTION III: CHEMISTRY OF REACTIONS

Overview
Chemists like Humphry Davy and Svante Arrhenius played important roles in providing a comprehensive understanding of what happens in chemical reactions. A new era of electrochemistry started when Humphry Davy (1778–1829), a British chemist, built a powerful battery to pass electricity through molten salts. He discovered elements, such as potassium, sodium, calcium and magnesium, by liberating them from their molten compounds. Swedish chemist, Svante Arrhenius, in 1887, proposed the theory that acids, bases, and salts in water are composed of ions. He also proposed a simple yet beautiful model of neutralisation – the combination of hydrogen and hydroxyl ions to form water.

In this section, students examine the chemical decomposition of substances by electrolysis, characteristic properties of acids, bases and salts, and also their reactions with substances, the factors affecting the rate of reaction and also the energy changes during a reaction. Students should be able to appreciate the importance of proper laboratory techniques and precise calculations for accurate results, and the importance of controlling variables in making comparisons. They should also value the knowledge of the hazardous nature of acids/alkalis and the safe handling, storing and disposing of chemicals.

4 Electrolysis

Learning Outcomes

Candidates should be able to:

(a) describe electrolysis as the conduction of electricity by an ionic compound (an electrolyte), when molten or dissolved in water, leading to the decomposition of the electrolyte

(b) describe electrolysis as evidence for the existence of ions which are held in a lattice when solid but which are free to move when molten or in solution

(c) describe, in terms of the mobility of ions present and the electrode products, the electrolysis of molten sodium chloride, using inert electrodes

(d) predict the likely products of the electrolysis of a molten binary compound

(e) apply the idea of selective discharge based on

- (i) cations: linked to the reactivity series (see also **9.2**)
- (ii) anions: halides, hydroxides and sulfates (e.g. aqueous copper(II) sulfate and dilute sodium chloride solution (as essentially the electrolysis of water))
- (iii) concentration effects (as in the electrolysis of concentrated and dilute aqueous sodium chloride)

(In all cases above, **inert** electrodes are used.)

(f) predict the likely products of the electrolysis of an aqueous electrolyte, given relevant information

(g) construct ionic equations for the reactions occurring at the electrodes during the electrolysis, given relevant information

(h) describe the electrolysis of aqueous copper(II) sulfate with copper electrodes as a means of purifying copper (**no** technical details are required)

(i) describe the electroplating of metals, e.g. copper plating, and state one use of electroplating

(j) describe the production of electrical energy from simple cells (i.e. two electrodes in an electrolyte) linked to the reactivity series (see also **9.2**) and redox reactions (in terms of electron transfer).

5 Energy from Chemicals

Learning Outcomes

Candidates should be able to:

(a) describe the meaning of enthalpy change in terms of exothermic (ΔH negative) and endothermic (ΔH positive) reactions

(b) represent energy changes by energy profile diagrams, including reaction enthalpy changes and activation energies (see also **6.1**(c),**6.1**(d))

(c) describe bond breaking as an endothermic process and bond making as an exothermic process

(d) explain overall enthalpy changes in terms of the energy changes associated with the breaking and making of covalent bonds

(e) describe hydrogen, derived from water or hydrocarbons, as a potential fuel, reacting with oxygen to generate electricity directly in a fuel cell (details of the construction and operation of a fuel cell are **not** required).

6 Chemical Reactions

Content

6.1 Speed of reaction

6.2 Redox

Learning Outcomes

Candidates should be able to:

6.1 Speed of reaction

(a) describe the effect of concentration, pressure, particle size and temperature on the speeds of reactions and explain these effects in terms of collisions between reacting particles

(b) define the term *catalyst* and describe the effect of catalysts (including enzymes) on the speeds of reactions

(c) explain how pathways with lower activation energies account for the increase in speeds of reactions (see also **5**(b))

(d) state that some compounds act as catalysts in a range of industrial processes and that enzymes are biological catalysts (see also **5**(b), **6.1**(c), **8.3**(b) and **10**(d))

(e) suggest a suitable method for investigating the effect of a given variable on the speed of a reaction

(f) interpret data obtained from experiments concerned with speed of reaction.

6.2 Redox

(a) define *oxidation* and *reduction* (redox) in terms of oxygen/hydrogen gain/loss

(b) define *redox* in terms of electron transfer and changes in oxidation state

(c) identify redox reactions in terms of oxygen/hydrogen gain/loss, electron gain/loss and changes in oxidation state

(d) describe the use of aqueous potassium iodide and acidified potassium manganate(VII) in testing for oxidising and reducing agents from the resulting colour changes.

7 Acids, Bases and Salts

Content

7.1 Acids and bases

7.2 Salts

7.3 Ammonia

Learning Outcomes

Candidates should be able to:

7.1 Acids and bases

(a) describe the meanings of the terms acid and alkali in terms of the ions they produce in aqueous solution and their effects on Universal Indicator

(b) describe how to test hydrogen ion concentration and hence relative acidity using Universal Indicator and the pH scale

(c) describe qualitatively the difference between strong and weak acids in terms of the extent of ionisation

(d) describe the characteristic properties of acids as in reactions with metals, bases and carbonates

(e) state the uses of sulfuric acid in the manufacture of detergents and fertilisers; and as a battery acid

(f) describe the reaction between hydrogen ions and hydroxide ions to produce water, $H^+ + OH^- \rightarrow H_2O$, as neutralisation

(g) describe the importance of controlling the pH in soils and how excess acidity can be treated using calcium hydroxide

(h) describe the characteristic properties of bases in reactions with acids and with ammonium salts

(i) classify oxides as acidic, basic, amphoteric or neutral based on metallic/non-metallic character.

7.2 Salts

(a) describe the techniques used in the preparation, separation and purification of salts as examples of some of the techniques specified in Section **1.2**(a) (methods for preparation should include precipitation and titration together with reactions of acids with metals, insoluble bases and insoluble carbonates)

(b) describe the general rules of solubility for common salts to include nitrates, chlorides (including silver and lead), sulfates (including barium, calcium and lead), carbonates, hydroxides, Group I cations and ammonium salts

(c) suggest a method of preparing a given salt from suitable starting materials, given appropriate information.

7.3 Ammonia

(a) describe the use of nitrogen, from air, and hydrogen, from the cracking of crude oil, in the manufacture of ammonia

(b) state that some chemical reactions are reversible, e.g. manufacture of ammonia

(c) describe the essential conditions for the manufacture of ammonia by the Haber process

(d) describe the displacement of ammonia from its salts.

SECTION IV: PERIODICITY

Overview
The development of the Periodic Table started in the 1800s as chemists began to recognise similarities in the properties of various elements and place them in families. The most famous and successful classification, widely accepted by chemists, was published in 1869 by Dmitri Mendeleev, a Russian chemist. His Periodic Table arranged the elements known at that time, in order of increasing atomic masses.

The International Union of Pure and Applied Chemistry (IUPAC) is the gatekeeper of elements and it oversees the Periodic Table of elements. Until 2007, the Periodic Table consisted of 111 officially named elements. However, in 2009 it was reported that Element 112, with an atomic number of 112 and about 277 times heavier than hydrogen, was discovered by Sigurd Hoffmann and his team of 21 scientists from Germany, Finland, Russia and Slovakia. It is currently the heaviest element in the Periodic Table.

In this section, students examine the periodic trends and group properties of elements, occurrence of metals, their properties, reactivity and uses. Students should be able to appreciate the development of the Periodic Table and hence to envisage that scientific knowledge changes and accumulates over time, and also the need for conserving some of the finite resources.

8 The Periodic Table

Content

8.1 Periodic trends

8.2 Group properties

8.3 Transition elements

Learning Outcomes

Candidates should be able to:

8.1 Periodic trends

(a) describe the Periodic Table as an arrangement of the elements in the order of increasing proton (atomic) number

(b) describe how the position of an element in the Periodic Table is related to proton number and electronic structure

(c) describe the relationship between group number and the ionic charge of an element

(d) explain the similarities between the elements in the same group of the Periodic Table in terms of their electronic structure

(e) describe the change from metallic to non-metallic character from left to right across a period of the Period Table

(f) describe the relationship between group number, number of valency electrons and metallic/non-metallic character

(g) predict the properties of elements in Group I and Group VII using the Periodic Table.

8.2 Group properties

(a) describe lithium, sodium and potassium in Group **I** (the alkali metals) as a collection of relatively soft, low density metals showing a trend in melting point and in their reaction with water

(b) describe chlorine, bromine and iodine in Group V**II** (the halogens) as a collection of diatomic non-metals showing a trend in colour, state and their displacement reactions with solutions of other halide ions

(c) describe the elements in Group 0 (the noble gases) as a collection of monatomic elements that are chemically unreactive and hence important in providing an inert atmosphere, e.g. argon and neon in light bulbs; helium in balloons; argon in the manufacture of steel

(d) describe the lack of reactivity of the noble gases in terms of their electronic structures.

8.3 Transition elements

(a) describe the transition elements as metals having high melting points, high density, variable oxidation state and forming coloured compounds

(b) state that the elements and/or their compounds are often able to act as catalysts (see also **6.1**(d)).

9 Metals

Content

9.1 Properties of metals

9.2 Reactivity series

9.3 Extraction of metals

9.4 Recycling of metals

9.5 Iron

Learning Outcomes

Candidates should be able to:

9.1 Properties of metals

(a) describe the general physical properties of metals as solids having high melting and boiling points, malleable, good conductors of heat and electricity in terms of their structure (see also **2.6**(b))

(b) describe *alloys* as a mixture of a metal with another element, e.g. brass; stainless steel

(c) identify representations of metals and alloys from diagrams of structures

(d) explain why alloys have different physical properties to their constituent elements.

9.2 Reactivity series

(a) place in order of reactivity calcium, copper, (hydrogen), iron, lead, magnesium, potassium, silver, sodium and zinc by reference to

  (i) the reactions, if any, of the metals with water, steam and dilute hydrochloric acid,

  (ii) the reduction, if any, of their oxides by carbon and/or by hydrogen

(b) describe the reactivity series as related to the tendency of a metal to form its positive ion, illustrated by its reaction with

  (i) the aqueous ions of the other listed metals

  (ii) the oxides of the other listed metals

(c) deduce the order of reactivity from a given set of experimental results

(d) describe the action of heat on the carbonates of the listed metals and relate thermal stability to the reactivity series.

9.3 Extraction of metals

(a) describe the ease of obtaining metals from their ores by relating the elements to their positions in the reactivity series.

9.4 Recycling of metals

(a) describe metal ores as a finite resource and hence the need to recycle metals, e.g. recycling of iron

(b) discuss the social, economic and environmental issues of recycling metals.

9.5 Iron

(a) describe and explain the essential reactions in the extraction of iron using haematite, limestone and coke in the blast furnace

(b) describe steels as alloys which are a mixture of iron with carbon or other metals and how controlled use of these additives changes the properties of the iron, e.g. high carbon steels are strong but brittle whereas low carbon steels are softer and more easily shaped

(c) state the uses of mild steel, e.g. car bodies; machinery, and stainless steel, e.g. chemical plants; cutlery; surgical instruments

(d) describe the essential conditions for the corrosion (rusting) of iron as the presence of oxygen and water; prevention of rusting can be achieved by placing a barrier around the metal, e.g. painting; greasing; plastic coating; galvanising

(e) describe the sacrificial protection of iron by a more reactive metal in terms of the reactivity series where the more reactive metal corrodes preferentially, e.g. underwater pipes have a piece of magnesium attached to them.

SECTION V: ATMOSPHERE

Overview
Our atmosphere has been taken for granted in the past. In the last few decades, scientists and the general public began to realise the adverse effects of pollutants on the air we breathe. It is recognised that pollutants such as sulfur dioxide, oxides of nitrogen, carbon monoxide and particulates released into the atmosphere as a result of energy generation and increased use of motor vehicles, have serious health and environmental consequences.

Increase in levels of carbon dioxide gas leading to global warming has been a worldwide concern. Many nations have taken steps to discuss the reasons behind environmental changes and rise in Earth's temperature which has given grounds to global warming. There was discussion on reducing greenhouse gas emissions during the 2009 United Nations Climate Change Conference. With the control of carbon emissions, the world is likely to face less severe consequences of extreme weather conditions such as floods and tsunamis.

In this section, the sources of air pollutants and their effects are examined. Students should be able to value the knowledge of the hazardous nature of pollutants and the environmental issues related to air pollution.

10. Air

Learning Outcomes

Candidates should be able to:

(a) describe the volume composition of gases present in dry air as being approximately 78% nitrogen, 21% oxygen and the remainder being noble gases (with argon as the main constituent) and carbon dioxide

(b) name some common atmospheric pollutants, e.g. carbon monoxide; methane; nitrogen oxides (NO and NO_2); ozone; sulfur dioxide; unburned hydrocarbons

(c) state the sources of these pollutants as
- (i) carbon monoxide from incomplete combustion of carbon-containing substances
- (ii) nitrogen oxides from lightning activity and internal combustion engines
- (iii) sulfur dioxide from volcanoes and combustion of fossil fuels

(d) describe the reactions used in possible solutions to the problems arising from some of the pollutants named in (b)
- (i) the redox reactions in catalytic converters to remove combustion pollutants (see also **6.1**(d))
- (ii) the use of calcium carbonate to reduce the effect of 'acid rain' and in flue gas desulfurisation

(e) discuss some of the effects of these pollutants on health and on the environment
- (i) the poisonous nature of carbon monoxide
- (ii) the role of nitrogen dioxide and sulfur dioxide in the formation of 'acid rain' and its effects on respiration and buildings

(f) discuss the importance of the ozone layer and the problems involved with the depletion of ozone by reaction with chlorine-containing compounds, chlorofluorocarbons (CFCs)

(g) describe the carbon cycle in simple terms, to include
- (i) the processes of combustion, respiration and photosynthesis
- (ii) how the carbon cycle regulates the amount of carbon dioxide in the atmosphere

(h) state that carbon dioxide and methane are greenhouse gases and may contribute to global warming, give the sources of these gases and discuss the possible consequences of an increase in global warming.

SECTION VI: ORGANIC CHEMISTRY

Overview
In the nineteenth century, chemists believed that all organic chemicals originated in tissues of living organisms. Friedrich Wohler, in 1828, challenged this belief and synthesised the organic compound urea, a compound found in urine, under laboratory conditions. His work led other chemists to attempt the synthesis of other organic compounds.

In this section, students examine the sources of fuels, some basic concepts of organic chemistry such as homologous series, functional group, general formula and structural formula, and polymers. Students should be able to identify and name unbranched alkanes, alkenes, alcohols and carboxylic acids. They should recognise that materials such as plastics, detergents and medicines, and even the food that we eat are examples of organic compounds. Students should be able to value the need for assessing the impacts of the use of synthetic materials and the environmental issues related to the use of plastics.

11 Organic Chemistry

Content

11.1 Fuels and crude oil

11.2 Alkanes

11.3 Alkenes

11.4 Alcohols

11.5 Carboxylic acids

11.6 Macromolecules

Learning Outcomes

Candidates should be able to:

11.1 Fuels and crude oil

(a) name natural gas, mainly methane, and petroleum as sources of energy

(b) describe petroleum as a mixture of hydrocarbons and its separation into useful fractions by fractional distillation (see also **1.2**(a))

(c) name the following fractions and state their uses
- (i) petrol (gasoline) as a fuel in cars
- (ii) naphtha as the feedstock and main source of hydrocarbons used for the production of a wide range of organic compounds in the petrochemical industry (see also **11.1**(d))
- (iii) paraffin (kerosene) as a fuel for heating and cooking and for aircraft engines
- (iv) diesel as a fuel for diesel engines
- (v) lubricating oils as lubricants and as a source of polishes and waxes
- (vi) bitumen for making road surfaces

(d) describe the issues relating to the competing uses of oil as an energy source and as a chemical feedstock (see also **11.1**(c)(ii)).

11.2 Alkanes

(a) describe an homologous series as a group of compounds with a general formula, similar chemical properties and showing a gradation in physical properties as a result of increase in the size and mass of the molecules, e.g. melting and boiling points; viscosity; flammability

(b) describe the alkanes as an homologous series of saturated hydrocarbons with the general formula C_nH_{2n+2}

(c) draw the structures of branched and unbranched alkanes, C_1 to C_4, and name the unbranched alkanes methane to butane

(d) define *isomerism* and identify isomers

(e) describe the properties of alkanes (exemplified by methane) as being generally unreactive except in terms of combustion and substitution by chlorine.

11.3 Alkenes

(a) describe the alkenes as an homologous series of unsaturated hydrocarbons with the general formula C_nH_{2n}

(b) draw the structures of branched and unbranched alkenes, C_2 to C_4, and name the unbranched alkenes ethene to butene

(c) describe the manufacture of alkenes and hydrogen by cracking hydrocarbons and recognise that cracking is essential to match the demand for fractions containing smaller molecules from the refinery process

(d) describe the difference between saturated and unsaturated hydrocarbons from their molecular structures and by using aqueous bromine

(e) describe the properties of alkenes (exemplified by ethene) in terms of combustion, polymerisation and the addition reactions with bromine, steam and hydrogen

(f) state the meaning of *polyunsaturated* when applied to food products

(g) describe the manufacture of margarine by the addition of hydrogen to unsaturated vegetable oils to form a solid product.

11.4 Alcohols

(a) describe the alcohols as an homologous series containing the –OH group

(b) draw the structures of alcohols, C_1 to C_4, and name the unbranched alcohols methanol to butanol

(c) describe the properties of alcohols in terms of combustion and oxidation to carboxylic acids

(d) describe the formation of ethanol by the catalysed addition of steam to ethene and by fermentation of glucose

(e) state some uses of ethanol, e.g. as a solvent; as a fuel; as a constituent of alcoholic beverages.

11.5 Carboxylic acids

(a) describe the carboxylic acids as an homologous series containing the $–CO_2H$ group

(b) draw the structures of carboxylic acids methanoic acid to butanoic acid and name the unbranched acids, methanoic acid to butanoic acid

(c) describe the carboxylic acids as weak acids, reacting with carbonates, bases and some metals

(d) describe the formation of ethanoic acid by the oxidation of ethanol by atmospheric oxygen or acidified potassium manganate(VII)

(e) describe the reaction of a carboxylic acid with an alcohol to form an ester, e.g. ethyl ethanoate

(f) state some commercial uses of esters, e.g. perfumes; flavourings; solvents.

11.6 Macromolecules

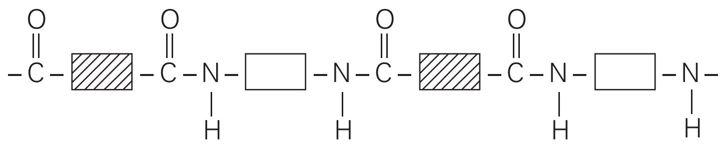
(a) describe macromolecules as large molecules built up from small units, different macromolecules having different units and/or different linkages

(b) describe the formation of poly(ethene) as an example of addition polymerisation of ethene as the monomer

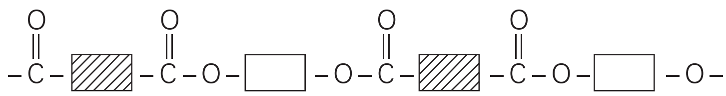
(c) state some uses of poly(ethene) as a typical plastic, e.g. plastic bags; clingfilm

(d) deduce the structure of the polymer product from a given monomer and vice versa

(e) describe nylon, a polyamide, and *Terylene*, a polyester, as condensation polymers, the partial structure of nylon being represented as



and the partial structure of *Terylene* as



(Details of manufacture and mechanisms of these polymerisations are **not** required)

(f) state some typical uses of man-made fibres such as nylon and *Terylene*, e.g. clothing; curtain materials; fishing line; parachutes; sleeping bags

(g) describe the pollution problems caused by the disposal of non-biodegradable plastics.

SUMMARY OF KEY QUANTITIES, SYMBOLS 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	Symbol	Unit
Base quantities		
mass	m	g, kg, tonne
length	l	cm, m
time	t	s, min
amount of substance	n	mol
Other quantities		
temperature	θ, t	°C
volume	V, v	cm^3, m^3, dm^3
density	ρ	g/cm^3, kg/m^3
atomic mass	m_a	g
relative { atomic / isotopic } mass	A_r	–
molecular mass	m	g
relative molecular mass	M_r	–
molar mass	M	g/mol
nucleon number	A	–
proton number	Z	–
neutron number	N	–
enthalpy change of reaction	ΔH	J, kJ
bond energy	-	kJ/mol
concentration	c	mol/dm^3, g/dm^3
pH	pH	–

PRACTICAL GUIDELINES

Scientific subjects are, by their nature, experimental. It is therefore important that the candidates carry out appropriate practical work to facilitate the learning of this subject. A list of suggested practical work is provided.

1. Separation techniques including filtration, simple paper chromatography and distillation

2. Measurements of temperature based on thermometers with 1 °C graduation

3. Determination of melting point and boiling point

4. Experiments involving the preparation of salts

5. Experiments involving the solubility of salts

6. Titration involving the use of a pipette, burette and an indicator such as methyl orange or screened methyl orange; full instructions and other necessary information will be given for titration other than acid/alkali and the use of other indicators

7. Identification of ions and gases as specified in the syllabus
   Candidates would not be required to carry out tests involving Pb^{2+} ions or sulfur dioxide gas.

8. Experiments involving displacement reactions

9. Tests for oxidising and reducing agents as specified in the syllabus

10. Experiments involving speed of reactions

11. Experiments involving organic substances such as polymerisation and test for saturation

This is not intended to be an exhaustive list. Reference may be made to the techniques used in these experiments in the theory papers but no detailed description of the experimental procedures will be required.

NOTES FOR QUALITATIVE ANALYSIS

Test for anions

anion	test	test result
carbonate (CO_3^{2-})	add dilute acid	effervescence, carbon dioxide produced
chloride (Cl^-) [in solution]	acidify with dilute nitric acid, then add aqueous silver nitrate	white ppt.
iodide (I^-) [in solution]	acidify with dilute nitric acid, then add aqueous silver nitrate	yellow ppt.
nitrate (NO_3^-) [in solution]	add aqueous sodium hydroxide, then aluminium foil; warm carefully	ammonia produced
sulfate (SO_4^{2-}) [in solution]	acidify with dilute nitric acid, then add aqueous barium nitrate	white ppt.

Test for aqueous cations

cation	effect of aqueous sodium hydroxide	effect of aqueous ammonia
aluminium (Al^{3+})	white ppt., soluble in excess giving a colourless solution	white ppt., insoluble in excess
ammonium (NH_4^+)	ammonia produced on warming	–
calcium (Ca^{2+})	white ppt., insoluble in excess	no ppt.
copper(II) (Cu^{2+})	light blue ppt., insoluble in excess	light blue ppt., soluble in excess giving a dark blue solution
iron(II) (Fe^{2+})	green ppt., insoluble in excess	green ppt., insoluble in excess
iron(III) (Fe^{3+})	red-brown ppt., insoluble in excess	red-brown ppt., insoluble in excess
lead(II) (Pb^{2+})	white ppt., soluble in excess giving a colourless solution	white ppt., insoluble in excess
zinc (Zn^{2+})	white ppt., soluble in excess giving a colourless solution	white ppt., soluble in excess giving a colourless solution

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

Test for gases

gas	**test and test result**
ammonia (NH_3)	turns damp red litmus paper blue
carbon dioxide (CO_2)	gives white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine (Cl_2)	bleaches damp litmus paper
hydrogen (H_2)	'pops' with a lighted splint
oxygen (O_2)	relights a glowing splint
sulfur dioxide (SO_2)	turns aqueous acidified potassium manganate(VII) from purple to colourless

The Periodic Table of Elements

Group																	
I	II											III	IV	V	VI	VII	0
							1 **H** Hydrogen 1										4 **He** Helium 2
7 **Li** Lithium 3	9 **Be** Beryllium 4											11 **B** Boron 5	12 **C** Carbon 6	14 **N** Nitrogen 7	16 **O** Oxygen 8	19 **F** Fluorine 9	20 **Ne** Neon 10
23 **Na** Sodium 11	24 **Mg** Magnesium 12											27 **Al** Aluminium 13	28 **Si** Silicon 14	31 **P** Phosphorus 15	32 **S** Sulfur 16	35.5 **Cl** Chlorine 17	40 **Ar** Argon 18
39 **K** Potassium 19	40 **Ca** Calcium 20	45 **Sc** Scandium 21	48 **Ti** Titanium 22	51 **V** Vanadium 23	52 **Cr** Chromium 24	55 **Mn** Manganese 25	56 **Fe** Iron 26	59 **Co** Cobalt 27	59 **Ni** Nickel 28	64 **Cu** Copper 29	65 **Zn** Zinc 30	70 **Ga** Gallium 31	73 **Ge** Germanium 32	75 **As** Arsenic 33	79 **Se** Selenium 34	80 **Br** Bromine 35	84 **Kr** Krypton 36
85 **Rb** Rubidium 37	88 **Sr** Strontium 38	89 **Y** Yttrium 39	91 **Zr** Zirconium 40	93 **Nb** Niobium 41	96 **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	209 **Po** Polonium 84	210 **At** Astatine 85	222 **Rn** Radon 86
223 **Fr** Francium 87	226 **Ra** Radium 88	227 **Ac** Actinium 89 †															

* 58–71 Lanthanoid series
† 90–103 Actinoid series

140 **Ce** Cerium 58	141 **Pr** Praseodymium 59	144 **Nd** Neodymium 60	147 **Pm** Promethium 61	150 **Sm** Samarium 62	152 **Eu** Europium 63	157 **Gd** Gadolinium 64	159 **Tb** Terbium 65	162 **Dy** Dysprosium 66	165 **Ho** Holmium 67	167 **Er** Erbium 68	169 **Tm** Thulium 69	173 **Yb** Ytterbium 70	175 **Lu** Lutetium 71
232 **Th** Thorium 90	231 **Pa** Protactinium 91	238 **U** Uranium 92	237 **Np** Neptunium 93	244 **Pu** Plutonium 94	243 **Am** Americium 95	247 **Cm** Curium 96	247 **Bk** Berkelium 97	251 **Cf** Californium 98	252 **Es** Einsteinium 99	257 **Fm** Fermium 100	258 **Md** Mendelevium 101	259 **No** Nobelium 102	260 **Lr** Lawrencium 103

Key

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

The volume of one mole of any gas is 24 dm^3 at room temperature and pressure (r.t.p.).

MATHEMATICAL REQUIREMENTS

Candidates should be able to:

1. add, subtract, multiply and divide
2. use averages, decimals, fractions, percentages, ratios and reciprocals
3. recognise and use standard notation
4. use direct and inverse proportion
5. use positive, whole number indices
6. draw charts and graphs from given data
7. interpret charts and graphs
8. select suitable scales and axes for graphs
9. make approximate evaluations of numerical expressions
10. recognise and use the relationship between length, surface area and volume, and their units on metric scales
11. recognise and convert between appropriate units
12. solve equations of the form $x = yz$ for any one term when the other two are known
13. comprehend and use the symbols/notations $<$, $>$, $\approx$, /, $\propto$
14. comprehend how to handle numerical work so that significant figures are neither lost unnecessarily nor used beyond what is justified.

GLOSSARY OF TERMS USED IN CHEMISTRY PAPERS

It is hoped that the glossary (which is relevant only to science papers) 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. *Calculate* is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved.

2. *Classify* requires candidates to group things based on common characteristics.

3. *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.

4. *Compare* requires candidates to provide both similarities and differences between things or concepts.

5. *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.

6. *Define (the term(s)…)* is intended literally. Only a formal statement or equivalent paraphrase being required.

7. *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 the latter instance the answer may often follow a standard pattern, e.g. Apparatus, Method, Measurement, Results and Precautions.

   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.*

8. *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.

9. *Discuss* requires candidates to give a critical account of the points involved in the topic.

10. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned, making such simplifying assumptions as may be necessary about the points of principle and about values of quantities not otherwise included in the question.

11. *Explain* may imply reasoning or some reference to theory, depending on the context.

12. *Find* is a general term that may be variously interpreted as calculate, measure, determine etc.

13. *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.

14. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or angle, using a protractor.

15. *Outline* implies brevity, i.e. restricting the answer to giving essentials.

16. *Predict* or *deduce* implies that the candidate is not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted from an earlier part of the question. *Predict* also implies a concise answer with no supporting statement required.

17. *Sketch*, when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct, but candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having the intercept, asymptote or discontinuity at a particular value.

    In diagrams, *sketch* implies that a simple, freehand drawing is acceptable; nevertheless, care should be taken over proportions and the clear exposition of important details.

18. *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained 'by inspection'.

19. *Suggest* is used in two main contexts, i.e. either to imply that there is no unique answer, 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'.

20. *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 light of the indicated mark value.

SPECIAL NOTE

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.

It is intended that, in order to avoid difficulties arising out of the use of l as the symbol for litre, use of dm^3 in place of l or litre will be made.

In chemistry, full *structural formulae (displayed formulae)* in answers should show in detail both the relative placing of atoms and the number of bonds between atoms. Hence, $–CONH_2$ and $–CO_2H$ are not satisfactory as full structural formulae, although either of the usual symbols for the benzene ring is acceptable.

Units and 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.

Calculators
An approved calculator may be used in all papers.