Singapore Examinations and Assessment Board

CAMBRIDGE International Education

Singapore–Cambridge Secondary Education Certificate (2027)

G3 Chemistry (Syllabus K324)

CONTENTS

INTRODUCTION

The Secondary Education Certificate G3 Chemistry Syllabus is designed to place less emphasis on factual materials while having a 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 complex and globalised world, rather than focusing on large quantities of factual material, which may have only short-term relevance.

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 scientific expertise and understanding, and to develop values and attitudes relevant to science. Teachers are encouraged to use a combination of appropriate strategies including developing practical work for their students to facilitate a greater understanding of the subject. It is expected that students will apply investigative and problem-solving skills and effectively communicate the theoretical concepts covered in this course.

AIMS

The aims of a course based on this syllabus should be to:

1. provide a worthwhile educational experience for all students, whether or not they go on to study science beyond this level.

2. develop in students the understanding and skills relevant to the practices of science, and enable them to

   2.1 appreciate practical applications of Chemistry in the real world

   2.2 deepen their interest in Chemistry for future learning and work

   2.3 become scientifically literate citizens who can innovate and seize opportunities in the 21st century

   2.4 develop a way of thinking to approach, analyse and solve problems by explaining macroscopic characteristics and changes in chemical systems through the use of sub-microscopic and symbolic representations.

3. develop in students the values, ethics and attitudes relevant to science such as

   3.1 curiosity – desiring to explore the environment and question what is found

   3.2 creativity – seeking innovative and relevant ways to solve problems

   3.3 integrity – handling and communicating data and information with complete honesty

   3.4 objectivity – seeking data and information to validate observations and explanations without bias

   3.5 open-mindedness – accepting all knowledge as tentative and suspending judgement, tolerance for ambiguity, willingness to change views if the evidence is convincing

   3.6 resilience – not giving up on the pursuit of answers/solutions, willingness to take risks and embrace failure as part of the learning process

   3.7 responsibility – showing care and concern for living things and awareness of our responsibility for the quality of the environment

   3.8 healthy scepticism – questioning the observations, methods, processes and data, as well as trying to review one's own ideas.

PRACTICES OF SCIENCE

The *Practices of Science* represent the set of established procedures and practices associated with scientific inquiry, what scientific knowledge is and how it is generated and established, and how Science is applied in society respectively. It consists of three components:

1. Demonstrating Ways of Thinking and Doing in Science (WoTD)

1.1 Posing questions and defining problems

1.2 Designing investigations

1.3 Conducting experiments and testing solutions

1.4 Analysing and interpreting data

1.5 Communicating, evaluating and defending ideas with evidence

1.6 Making informed decisions and taking responsible actions

1.7 Using and developing models

1.8 Constructing explanations and designing solutions

2. Understanding the Nature of Scientific Knowledge (NOS)

2.1 Science is an evidence-based, model-building enterprise concerned with understanding the natural world

2.2 Science assumes there are natural causes for physical phenomena and an order and consistency in natural systems

2.3 Scientific knowledge is generated using a set of established procedures and practices, and through a process of critical debate within the scientific community

2.4 Scientific knowledge is reliable and durable, yet open to change in the light of new evidence

3. Relating Science, Technology, Society and Environment (STSE)

3.1 There are risks and benefits associated with the applications of science in society. Science and its applications have the potential to bring about both benefits and harm to society

3.2 Applications of science often have ethical, social, economic and environmental implications

3.3 Applications of new scientific discoveries often inspire technological advancements while advances in technology motivate scientists to ask new questions and/or empower scientists in their inquiry (e.g. collecting more precise data or carrying out more complex data analysis)

The *Practices of Science* serve to highlight that the discipline of Science is more than the acquisition of a *body of knowledge* (e.g. scientific facts, concepts, laws, and theories); it is also a way of *thinking and doing*. In particular, it is important to appreciate that the cognitive, epistemic and social aspects of the *Practices of Science* are intricately related. For example, observation of events can lead to the generation of scientific knowledge which is, simultaneously, shaped by the beliefs of scientific knowledge. In addition, scientists develop models to construct theories, based on the assumption that there is order and consistency in natural systems. The practice of theory-making, in turn, reinforces the explanatory power of scientific knowledge. The scientific endeavour is embedded in the wider ethical, social, economic and environmental contexts.

DISCIPLINARY IDEAS OF CHEMISTRY

The disciplinary ideas of Chemistry described below represent the overarching ideas which can be applied to explain, analyse and solve a variety of problems that seek to address the broader questions of what matter is and how particles interact with one another. Equipping students with a coherent view and conceptual framework facilitates the application and transfer of learning. These disciplinary ideas can be revisited and deepened at higher levels of learning and beyond the schooling years.

1. Matter is made up of a variety of chemical elements, each with characteristic properties, and the smallest particle that characterises a chemical element is an atom.

2. The structure of matter and its chemical and physical properties are determined by the arrangement of particles and electrostatic interactions between them.

3. Energy changes across and within systems usually occur during physical and chemical changes, when there is rearrangement of particles.

4. Energy plays a key role in influencing the rate and extent of physical and chemical changes.

5. Matter and energy are conserved in all physical and chemical changes.

ASSESSMENT OBJECTIVES

The *Assessment Objectives* listed below reflect those parts of the *Aims* and *Practices of Science* that will be assessed.

A Knowledge with Understanding

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

1. scientific phenomena, facts, laws, definitions, concepts and theories

2. scientific vocabulary, terminology and 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 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, name, describe, explain or outline* (see the *Glossary of Terms*).

B Handling Information and Solving Problems

Candidates 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 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, deduce, suggest, calculate* or *determine* (see the *Glossary of Terms*).

C Experimental Skills and Investigations

Candidates 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.

Practical Assessment (Paper 3)

Paper 3 will assess appropriate aspects of assessment objectives C1 to C6 in the following skill areas:

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

The assessment of Planning (P) will have a weighting of 15%. The assessment of skill areas MMO, PDO and ACE will have a weighting of 85%.

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	Practical	1 h 50 min	40	20%

Theory Papers

Paper 1 (1 h, 40 marks)

This paper consists of 40 compulsory multiple choice items.

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

Paper 2 (1 h 45 min, 80 marks)

This paper consists of two sections.

Section A will carry 70 marks and will consist of a variable number of compulsory structured questions. The last two questions will carry 20 marks, one of which is a data-based question requiring candidates to interpret, evaluate or solve problems using a stem of information. The data-based question will carry 8–12 marks.

Section B will carry 10 marks and will consist of two questions. Candidates must answer only one out of these two questions.

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

Practical Assessment

Paper 3 (1h 50 min, 40 marks)

This paper consists of a variable number of compulsory practical questions.

One, or more, of the questions may incorporate assessment of Planning (P) and require candidates to apply and integrate knowledge and understanding from different sections of the syllabus. The assessment of PDO and ACE may include questions on data-analysis which do not require practical equipment and apparatus.

Candidates are not allowed to refer to notebooks, textbooks or any other information during the assessment.

A copy of the *Notes for Qualitative Analysis* will be printed as part of this Paper.

CONTENT STRUCTURE

Sections	Topics
I. Matter – Structures and Properties	1. Experimental Chemistry 2. The Particulate Nature of Matter 3. Chemical Bonding and Structure
II. Chemical Reactions	4. Chemical Calculations 5. Acid-Base Chemistry 6. Qualitative Analysis 7. Redox Chemistry 8. Patterns in the Periodic Table 9. Chemical Energetics 10. Rate of Reactions
III. Chemistry in a Sustainable World	11. Organic Chemistry 12. Maintaining Air Quality

SUBJECT CONTENT

SECTION I: MATTER – STRUCTURES AND PROPERTIES

Overview

Matter is understood in terms of particles, the way particles are arranged and the forces that hold them together. Evidence of the particulate nature of matter come from daily observable phenomena such as diffusion and crystal growth. The simplest particle is known as an atom, which consists of sub-atomic particles like protons, neutrons and electrons. A myriad of molecules with different properties are formed from the atoms of hundreds of elements discovered to date. The physical properties of a substance are determined by how its particles are arranged (i.e. structure) and the strength of the electrostatic forces between them.

Chemistry is typically an experimental science and relies primarily on practical work. This section also examines the appropriate use of simple apparatus and chemicals, and experimental techniques.

1. Experimental Chemistry

Content

1.1 Experimental Design

1.2 Methods of Purification and Analysis

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 drying and collection of gases and measurement of rates of reaction

(drying agents will be limited to calcium oxide, concentrated sulfuric acid and fused calcium chloride).

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 given melting point and boiling point data the identities of substances and their purity

(f) explain the importance of measuring the purity in substances used in everyday life, e.g. foodstuffs and drugs.

2. The Particulate Nature of Matter

Content

2.1 Kinetic Particle Theory

2.2 Atomic Structure

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 consisting of 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 nuclide notations 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.

3. Chemical Bonding and Structure

Content

3.1 Ionic Bonding

3.2 Covalent Bonding

3.3 Metallic Bonding

3.4 Structure and Properties of Materials

Learning Outcomes

Candidates should be able to:

3.1 Ionic Bonding

(a) describe the formation of ions by electron loss/gain and that these ions usually have the electronic configuration of a noble gas

(b) describe, including the use of ‘dot-and-cross’ diagrams, 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) relate the physical properties (including electrical property) of ionic compounds to their lattice structure (see also **3.4**(g)).

3.2 Covalent Bonding

(a) describe the formation of a covalent bond by the sharing of a pair of electrons and that the atoms in the molecules usually have 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 (see also **3.4**(g)).

3.3 Metallic Bonding

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

(b) 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 **3.4**(g)).

3.4 Structure and Properties of Materials

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

(b) describe an alloy 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

(e) compare the structures of the following substances in order to deduce their properties:

(i) simple molecular substances, e.g. methane, iodine

(ii) macromolecules, e.g. poly(ethene)

(iii) giant covalent substances, e.g. sand (silicon dioxide), diamond, graphite

(see also **3.4**(g))

(f) 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)

(g) deduce the physical and chemical properties of substances from their structures and bonding and vice versa (see also **3.1**(d), **3.2**(d), **3.3**(b) and **3.4**(e)).

SECTION II: CHEMICAL REACTIONS

Overview

This section provides an understanding of the changes at the sub-microscopic level during chemical reactions. Different types of chemical reactions (acid-base, precipitation and redox reactions) are delved into and lay the foundation for understanding what happens to energy and rate of reactions during a chemical change. The study of reactions also reveals patterns in the chemical properties of substances, leading to the organisation of elements in the Periodic Table.

In all chemical reactions, matter is conserved and this is illustrated by balanced chemical equations. Chemists use symbols and formulae to construct these chemical equations, from which the molar ratios are used to quantify the amount of reactants and products in a reaction.

4. Chemical Calculations

Content

4.1 Formulae and Equation Writing

4.2 The Mole Concept and Stoichiometry

Learning Outcomes

Candidates should be able to:

4.1 Formulae and Equation Writing

(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.

4.2 The Mole Concept and Stoichiometry

(a) define relative atomic mass, A_r

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

(c) define the term *mole* in terms of the Avogadro constant

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

(e) calculate empirical and molecular formulae from relevant data

(f) 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)

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

(appropriate guidance will be provided where unfamiliar reactions are involved)

(h) calculate % yield and % purity.

5. Acid-Base Chemistry

Content

5.1 Acids and Bases

5.2 Salts

5.3 Ammonia

Learning Outcomes

Candidates should be able to:

5.1 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 neutrality and relative acidity and alkalinity, in terms of
- (i) relative H^+ and OH^- ion concentrations,
- (ii) colour in Universal Indicator, and
- (iii) the pH scale

(calculation of pH from hydrogen ion concentration is **not** required)

(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 to form salts

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

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

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

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

5.2 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 those of silver and lead), sulfates (including those of barium, calcium and lead), carbonates, hydroxides, salts of Group 1 cations and ammonium salts

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

5.3 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) interpret data relating to the conditions used in industry for processes involving reversible reactions, e.g. manufacture of ammonia by the Haber Process

(knowledge of Le Chatelier's Principle is **not** required).

6. Qualitative Analysis

Learning Outcomes

Candidates should be able to:

(a) describe the use of aqueous sodium hydroxide and/or aqueous ammonia to identify the following aqueous cations through the formation of precipitates (if any) and their subsequent solubility: aluminium, ammonium (together with evolution of ammonia gas upon warming), calcium, copper(II), iron(II), iron(III) 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 damp red 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)).

7. Redox Chemistry

Content

7.1 Oxidation and Reduction

7.2 Electrochemistry

Learning Outcomes

Candidates should be able to:

7.1 Oxidation and Reduction

(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.

7.2 Electrochemistry

(a) describe electrolysis as the conduction of electricity through an ionic compound (an electrolyte), when molten or dissolved in water, leading to chemical changes (including decomposition) at the electrodes

(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 ionic compound using inert electrodes

(e) apply the idea of selective discharge based on

- (i) cations: linked to the reactivity series (see also **8.4**)
- (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 **8.4**) and redox reactions (in terms of electron transfer)

(k) describe hydrogen, derived from water or hydrocarbons, as a potential fuel, reacting with oxygen to generate electricity directly in a hydrogen fuel cell

(details of the construction and operation of a fuel cell are **not** required).

8. Patterns in the Periodic Table

Content

8.1 Periodic Trends

8.2 Group Properties

8.3 Transition Elements

8.4 Reactivity Series

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 configuration

(c) describe the relationship between number of outer (valence) electrons and the ionic charge of an ion for the first twenty elements

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

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

(f) describe the relationship between number of outer (valence) electrons and metallic/non-metallic character

(g) predict the properties of elements in Group 1 and Group 17 using the Periodic Table.

8.2 Group Properties

(a) describe lithium, sodium and potassium in Group 1 (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 17 (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 18 (the noble gases) as a collection of monoatomic elements that are chemically unreactive and hence important in providing an inert environment, 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 configurations.

8.3 Transition Elements

(a) describe typical transition elements as metals having high melting point, 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 **10**(d)).

8.4 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

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

(f) 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

(g) 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.

9. Chemical Energetics

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 **10**(c), **10**(d))

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

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

10. Rate of Reactions

Learning Outcomes

Candidates should be able to:

(a) describe the effect of concentration, pressure, particle size and temperature on the rates 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 rates of reactions

(c) explain how pathways with lower activation energies account for the increase in rates of reactions (see also **9**(b))

(d) state that some compounds act as catalysts in a range of industrial processes and that enzymes are biological catalysts (see also **8.3**(b), **9**(b), **10**(c) and **12**(d))

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

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

SECTION III: CHEMISTRY IN A SUSTAINABLE WORLD

Overview

Ubiquitous in modern life, organic compounds range from the fuels we burn, the materials we use such as plastics to the food we eat. Urbanisation, industrialisation, increasing population and economic development especially in developing countries also create a huge demand for consumption of material goods and energy, accelerating the rate of waste output and emissions of pollutants. The excessive use of crude oil and its products results in detrimental effects on the environment and sustainability. Chemists have made significant contributions towards reducing these effects and improving sustainability through innovative use of chemical knowledge.

In this section, knowledge and concepts from other topics within the syllabus are applied to assess the impacts of the consumption of organic compounds like fuels and plastics, the environmental issues related to their use and the solutions afforded by chemistry.

11. Organic Chemistry

Content

11.1 Fuels and Crude Oil

11.2 Hydrocarbons

11.3 Alcohols, Carboxylic Acids and Esters

11.4 Polymers

In describing reactions, candidates will be expected to quote the reagents, e.g. aqueous bromine, and the essential conditions, e.g. high temperature and pressure. Detailed conditions involving specific temperature and pressure values are not required.

Learning Outcomes

Candidates should be able to:

11.1 Fuels and Crude Oil

(a) name natural gas, mainly methane, and crude oil as non-renewable sources of energy

(b) describe crude oil as a mixture of hydrocarbons and its separation by fractional distillation to yield fractions which have competing uses as fuels and as a source of chemicals (see also **1.2**(a))

(c) describe biofuel (exemplified by bioethanol from sugarcane) as a renewable alternative to natural gas and crude oil

(d) describe how biofuel, when compared to fossil fuels, can be more environmentally sustainable in terms of carbon dioxide emission (see also **12**(g)).

11.2 Hydrocarbons

(a) describe a 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

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

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

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

(h) 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

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

(j) describe the reactions of alkenes (exemplified by ethene) in terms of combustion, polymerisation (see also **11.4**(b)), and the addition with bromine, steam and hydrogen

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

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

11.3 Alcohols, Carboxylic Acids and Esters

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

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

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

(f) draw the structures of carboxylic acids, C_1 to C_4, and name the unbranched acids methanoic acid to butanoic acid

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

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

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

(j) deduce the name and formula of an ester from the unbranched carboxylic acid, C_1 to C_4, and alcohol, C_1 to C_4, and vice versa.

11.4 Polymers

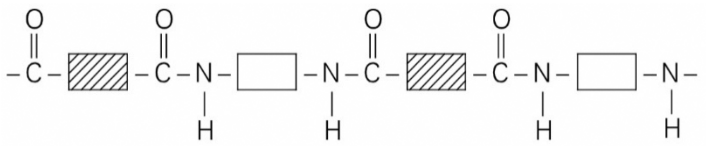
(a) describe polymers as large molecules built up from small units (monomers), different polymers having different units and/or different linkages

(b) describe the formation of poly(ethene) as an example of addition polymerisation of ethene as the monomer (see also **11.2**(j))

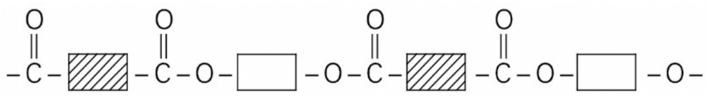
(c) state some uses of poly(ethene) as a typical plastic, e.g. plastic bags; clingfilm

(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



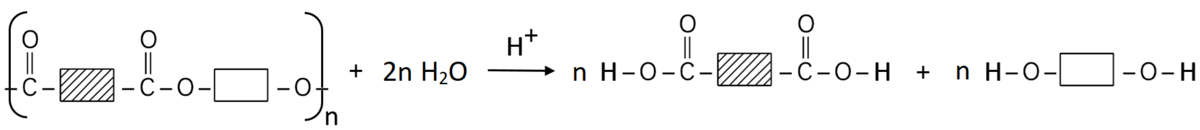
(details of manufacture and mechanisms of these polymerisations are **not** required)

(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

(h) describe two methods of recycling plastics as
   (i) physical method (exemplified by melting small pieces of poly(ethene) waste into pellets)
   (ii) chemical method (exemplified by depolymerisation and cracking of plastic waste into chemical feedstock and fuel respectively)

(i) describe depolymerisation as a process in which polymers are broken down into their monomers, exemplified by hydrolysis of polyesters using acid as a catalyst



(details of mechanisms are **not** required)

(j) discuss the social, economic and environmental issues of recycling plastics.

12. Maintaining Air Quality

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 **10**(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 toxic 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

(see also **11.1**(d))

(h) state that carbon dioxide and methane are greenhouse gases and may contribute to global warming; give the sources of these gases and describe the potential effects of increased levels of these greenhouse gases, including more extreme weather events and melting of polar ice.

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	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, J/mol, kJ/mol
bond energy	–	kJ/mol
concentration	c	mol/dm^3, g/dm^3
pH	pH	–

PRACTICAL ASSESSMENT

Scientific subjects are, by their nature, experimental. It is therefore important that an assessment of a candidate's knowledge and understanding of science should include a component relating to practical work and experimental skills.

This assessment is provided in Paper 3 as a formal practical test and is outlined in the *Scheme of Assessment*.

Paper 3 Practical

This paper is designed to assess a candidate's competence in those practical skills which can realistically be assessed within the context of a formal practical assessment.

Candidates will be assessed in the following skill areas:

(a) Planning (P)

Candidates should be able to:

- identify key variables for a given question/problem
- outline an experimental procedure to investigate the question/problem
- describe how the data should be used in order to reach a conclusion
- identify the risks of the experiment and state precautions that should be taken to keep risks to a minimum

(b) Manipulation, measurement and observation (MMO)

Candidates should be able to:

- set up apparatus correctly by following written instructions or diagrams
- use common laboratory apparatus and techniques to collect data and make observations
- describe and explain how apparatus and techniques are used correctly
- make and record accurate observations with good details and measurements to an appropriate degree of precision
- make appropriate decisions about measurements or observations

(c) Presentation of data and observations (PDO)

Candidates should be able to:

- present all information in an appropriate form
- manipulate measurements effectively for analysis
- present all quantitative data to an appropriate number of decimal places/significant figures

(d) Analysis, conclusions and evaluation (ACE)

Candidates should be able to:

- analyse and interpret data or observations appropriately in relation to the task
- draw conclusion(s) from the interpretation of experimental data or observations and underlying principles
- make predictions based on their data and conclusions
- identify significant sources of errors and explain how they affect the results
- state and explain how significant errors may be overcome or reduced, as appropriate, including how experimental procedures may be improved

One, or more, of the questions may incorporate some assessment of skill area P, set in the context of the syllabus content, requiring candidates to apply and integrate knowledge and understanding from different sections of the syllabus. It may also require the treatment of given experimental data in drawing relevant conclusion and analysis of proposed plan.

The assessment of skills MMO, PDO and ACE will be set mainly in the context of the syllabus content. The assessment of PDO and ACE may also include questions on data-analysis which do not require practical equipment and apparatus.

Within the *Scheme of Assessment*, the practical paper constitutes 20% of the Secondary Education Certificate G3 Chemistry 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.

Candidates should be able to use appropriate apparatus/equipment to record a range of measurements such as mass, length, time, volume and temperature. In addition, candidates are expected to have been exposed to a range of experimental techniques in the following areas:

1. Titration, e.g. acid-base titration (with suitable indicators such as methyl orange, screened methyl orange, and thymolphthalein). Other types of titrations may also be required, and where appropriate, sufficient working details will be given.

2. Speeds of reaction that may involve measuring of quantities, e.g. temperature, volume, length, mass or time measurements

3. Experiments involving separation techniques such as paper chromatography, filtration and distillation

4. Salt preparation

5. Gas collection
   Candidates would not be required to carry out drying of gases during practical examination.

6. Qualitative inorganic analysis involving an element, a compound or a mixture, including displacement reactions and tests for oxidising and reducing agents. Candidates should be familiar with the reactions of cations, reactions of anions and tests for gases as detailed in the *Notes for Qualitative Analysis*.

   Candidates would not be required to carry out tests involving sulfur dioxide gas.

   Reactions involving ions not included in the *Notes for Qualitative Analysis* may be tested: in such cases, candidates will **not** be expected to identify the ions but only to draw conclusions of a general nature.

   Candidates should **not** attempt tests, other than those specified, on substances, except when it is appropriate to test for a gas.

7. Qualitative organic analysis requiring a knowledge of simple organic reactions as outlined in Topic 11 Organic Chemistry, e.g. test-tube reactions indicating the presence of unsaturation (C=C) may be set, but this would be for the testing of observation skills and drawing general conclusions only.

This is not intended to be an exhaustive list. Candidates are expected to be familiar with the use of data-loggers. Assessment of Skill P may include the appropriate use of data-loggers.

Responsibility for safety matters rests with Centres.

Candidates are **not** allowed to refer to notebooks, textbooks or any other information in the practical examination. *Notes for Qualitative Analysis* will be included in the question paper for the use of candidates in the examination. Candidates may be required to carry out simple calculations.

Practical Techniques

The following notes are intended to give schools and candidates an indication of the accuracy that is expected in titration and general instructions for qualitative analysis.

(a) Candidates should normally record burette readings to the nearest 0.05 cm^3 and they should ensure that they have carried out a sufficient number of titrations, e.g. in an experiment with a good end-point, two titres within 0.20 cm^3.

(b) In qualitative analysis, candidates should use approximately 1 cm depth of a solution (1–2 cm^3) for each test and add reagents slowly, ensuring good mixing, until no further change is seen. Candidates should indicate at what stage a change occurs. Answers should include details of colour changes and precipitates formed, and the name and test for any gases evolved.

Apparatus List

This list given below has been drawn up in order to give guidance to Centres concerning the apparatus that is expected to be generally available for examination purposes. The list is not intended to be exhaustive, in particular, items (such as Bunsen burners, tripods, test-tube holders) that are commonly regarded as standard equipment in a chemical laboratory are not included.

Unless otherwise stated, the rate of allocation is ‘per candidate’.

one burette, 50 cm^3
one pipette, 25 cm^3
a supply of dropping pipettes
one pipette filler
two conical flasks within the range 150 cm^3 to 250 cm^3
measuring cylinders, 10 cm^3, 25 cm^3, 50 cm^3 and 100 cm^3
one filter funnel
beakers, squat form with lip: 100 cm^3 and 250 cm^3
thermometer: –10° C to +110° C at 1° C graduations
a polystyrene or other plastic beaker of approximate capacity 150 cm^3
test-tubes (Pyrex or hard glass), approximately 125 mm × 15 mm
boiling tubes, approximately 150 mm × 25 mm
one-hole bung, which fits a boiling tube, connected to rubber or plastic tubing
a tub of at least 1 dm^3 capacity
a pair of tongs
a ceramic crucible (15 cm^3 to 30 cm^3) with lid and means of support for heating, such as triangle clay pipe or wire gauze
stopwatch to measure to an accuracy of about 1 s
balance, single-pan, direct reading, 0.01 g or better (1 per 8–12 candidates)
stand and clamp suitable for a burette and measuring cylinders
wash bottle
glass rod
one white tile

The apparatus and material requirements for Paper 3 will vary year on year. Centres will be notified in advance of the details of the apparatus and materials required for each practical examination.

Reagents

This list given below has been drawn up in order to give guidance to Centres concerning the standard reagents that are expected to be generally available for examination purposes. The list is not intended to be exhaustive and Centres will be notified in advance of the full list of all reagents that are required for each practical examination.

hydrochloric acid (approximately 1.0 mol/dm^3)
nitric acid (approximately 1.0 mol/dm^3)
sulfuric acid (approximately 0.5 mol/dm^3)
aqueous ammonia (approximately 1.0 mol/dm^3)
aqueous sodium hydroxide (approximately 1.0 mol/dm^3)
aqueous barium nitrate (approximately 0.2 mol/dm^3)
aqueous silver nitrate (approximately 0.05 mol/dm^3)
limewater (a saturated solution of calcium hydroxide)
aqueous potassium manganate(VII) (approximately 0.02 mol/dm^3)
aqueous potassium iodide (approximately 0.1 mol/dm^3)
aluminium foil
red and blue litmus paper and Universal Indicator paper

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
zinc (Zn^{2+})	white ppt., soluble in excess giving a colourless solution	white ppt., soluble in excess giving a colourless solution

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

Key

proton (atomic) number atomic symbol name relative atomic mass

Group																	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
							1 H hydrogen 1										2 He helium 4
3 Li lithium 7	4 Be beryllium 9											5 B boron 11	6 C carbon 12	7 N nitrogen 14	8 O oxygen 16	9 F fluorine 19	10 Ne neon 20
11 Na sodium 23	12 Mg magnesium 24											13 Al aluminium 27	14 Si silicon 28	15 P phosphorus 31	16 S sulfur 32	17 Cl chlorine 35.5	18 Ar argon 40
19 K potassium 39	20 Ca calcium 40	21 Sc scandium 45	22 Ti titanium 48	23 V vanadium 51	24 Cr chromium 52	25 Mn manganese 55	26 Fe iron 56	27 Co cobalt 59	28 Ni nickel 59	29 Cu copper 64	30 Zn zinc 65	31 Ga gallium 70	32 Ge germanium 73	33 As arsenic 75	34 Se selenium 79	35 Br bromine 80	36 Kr krypton 84
37 Rb rubidium 85	38 Sr strontium 88	39 Y yttrium 89	40 Zr zirconium 91	41 Nb niobium 93	42 Mo molybdenum 96	43 Tc technetium –	44 Ru ruthenium 101	45 Rh rhodium 103	46 Pd palladium 106	47 Ag silver 108	48 Cd cadmium 112	49 In indium 115	50 Sn tin 119	51 Sb antimony 122	52 Te tellurium 128	53 I iodine 127	54 Xe xenon 131
55 Cs caesium 133	56 Ba barium 137	57–71 lanthanoids	72 Hf hafnium 178	73 Ta tantalum 181	74 W tungsten 184	75 Re rhenium 186	76 Os osmium 190	77 Ir iridium 192	78 Pt platinum 195	79 Au gold 197	80 Hg mercury 201	81 Tl thallium 204	82 Pb lead 207	83 Bi bismuth 209	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

lanthanoids	57 La lanthanum 139	58 Ce cerium 140	59 Pr praseodymium 141	60 Nd neodymium 144	61 Pm promethium –	62 Sm samarium 150	63 Eu europium 152	64 Gd gadolinium 157	65 Tb terbium 159	66 Dy dysprosium 163	67 Ho holmium 165	68 Er erbium 167	69 Tm thulium 169	70 Yb ytterbium 173	71 Lu lutetium 175
actinoids	89 Ac actinium –	90 Th thorium 232	91 Pa protactinium 231	92 U uranium 238	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –

The volume of one mole of any gas is 24 dm^3 at room temperature and pressure (r.t.p.).
The Avogadro constant, $L = 6.02 \times 10^{23}\ mol^{-1}$.

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

Candidates 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 candidates 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 the 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.