



Singapore Examinations and Assessment Board



Singapore–Cambridge Secondary Education Certificate (2027)

G3 Science Syllabus codes

- K326 Science: Physics, Chemistry**
- K327 Science: Physics, Biology**
- K328 Science: Chemistry, Biology**

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AIMS

The syllabus aims 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 science in the real world
 - 2.2 deepen their interest in science 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 and use the disciplinary ideas to approach, analyse and solve problems in biological, chemical and physical systems.
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* represents 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.

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: The ASE Companion to 16–19 Science (2000)*' and the recommendations on terms, units and symbols in '*Biological Nomenclature 4th Edition (2009)*' published by the Institute of Biology, in conjunction with the Association for Science Education);
3. scientific instruments and apparatus, including techniques of operation and aspects of safety;
4. scientific quantities and their determination;
5. scientific and technological applications with their social, economic and environmental implications.

The subject content defines the factual knowledge that candidates may be required to recall and explain. Questions testing these objectives will often begin with one of the following words: *define, state, 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 subject content because questions testing such skills may be based on information which is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a novel situation. Questions testing these objectives will often begin with one of the following words: *predict, 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, 2, 3 and 4)

- A** Knowledge with Understanding, approximately 50% of the marks with approximately 20% allocated to recall.
- B** Handling Information and Solving Problems, approximately 50% of the marks.

Practical Assessment (Paper 5)

Paper 5 is designed to test appropriate skills in C, Experimental Skills and Investigations.

In one or more of the questions in Paper 5, candidates will be expected to suggest a modification or an extension, which does not need to be executed. Depending on the context in which the modification / extension element is set, the number of marks associated with this element will be in the range of 10% to 20% of the total marks available for the practical test.

SCHEME OF ASSESSMENT

Candidates are required to enter for Paper 1, Paper 5 and two of Papers 2, 3 and 4.

Paper	Type of Paper	Duration	Marks	Weighting
1	Multiple Choice	1 h	40	20.0%
2	Structured and Free Response (Physics)	1 h 15 min	65	32.5%
3	Structured and Free Response (Chemistry)	1 h 15 min	65	32.5%
4	Structured and Free Response (Biology)	1 h 15 min	65	32.5%
5	Practical Test	1 h 30 min	30	15.0%

Science (Physics, Chemistry), Syllabus K326

Paper 1 will be based on the Physics and Chemistry sections of the syllabus.

Paper 2 will be based on the Physics section of the syllabus.

Paper 3 will be based on the Chemistry section of the syllabus.

Paper 5 will be based on the Physics and Chemistry sections of the syllabus.

Science (Physics, Biology), Syllabus K327

Paper 1 will be based on the Physics and Biology sections of the syllabus.

Paper 2 will be based on the Physics section of the syllabus.

Paper 4 will be based on the Biology section of the syllabus.

Paper 5 will be based on the Physics and Biology sections of the syllabus.

Science (Chemistry, Biology), Syllabus K328

Paper 1 will be based on the Chemistry and Biology sections of the syllabus.

Paper 3 will be based on the Chemistry section of the syllabus.

Paper 4 will be based on the Biology section of the syllabus.

Paper 5 will be based on the Chemistry and Biology sections of the syllabus.

Theory papers

Paper 1 (1 h, 40 marks)

This paper consists of 40 compulsory multiple choice questions providing approximately equal coverage of the two appropriate sections of the syllabus.

This paper will be set at the same time for all three syllabuses, K326, K327, K328.

A copy of the *Data Sheet ‘Colours of Some Common Metal Hydroxides’* and *‘The Periodic Table of Elements’* will be printed as part of Paper 1 for syllabus K326 and K328.

Paper 2 (1 h 15 min, 65 marks)

This paper consists of two sections.

Section A will carry 55 marks and will contain a number of compulsory structured questions. The last question will carry 10 marks.

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

The questions will be based on the Physics section of the syllabus.

Paper 3 (1 h 15 min, 65 marks)

This paper consists of two sections.

Section A will carry 55 marks and will contain a number of compulsory structured questions. The last question will carry 10 marks.

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

The questions will be based on the Chemistry section of the syllabus.

A copy of the *Data Sheet ‘Colours of Some Common Metal Hydroxides’* and *‘The Periodic Table of Elements’* will be printed as part of this Paper.

Paper 4 (1 h 15 min, 65 marks)

This paper consists of two sections.

Section A will carry 55 marks and will contain a number of compulsory structured questions. The last question will carry 10 marks.

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

The questions will be based on the Biology section of the syllabus.

Practical assessment

Paper 5 (1 h 30 min, 30 marks) consisting of *one or two* compulsory questions on each of the two Sciences. The Physics question(s) will be identical in K326 and K327. The Chemistry and the Biology question(s) will, likewise, be common to the respective papers.

This Paper will be set at the same time for all *three* syllabuses, K326, K327, and K328.

The use of reference material, other than the Chemistry Practical Notes is not permitted.

In one or both questions, candidates will be expected to suggest a modification or extension, which does not need to be executed.

Physics section

INTRODUCTION

The Secondary Education Certificate G3 Science (Physics) Syllabus provides students with a coherent understanding of energy, matter, and their interrelationships. It focuses on investigating natural phenomena and then applying patterns, models (including mathematical ones), principles, theories and laws to explain the physical behaviour of the universe. The theories and concepts presented in this syllabus belong to a branch of physics commonly referred to as classical physics. Modern physics, developed to explain the quantum properties at the atomic and sub-atomic level, is built on knowledge of these classical theories and concepts.

Students should think of physics in terms of scales. Whereas the classical theories such as Newton's laws of motion apply to common physical systems that are larger than the size of atoms, a more comprehensive theory, quantum theory, is needed to describe systems that are very small, at the atomic and sub-atomic scales. It is at this atomic and sub-atomic scale that physicists are currently making new discoveries and inventing new applications.

It is envisaged that teaching and learning programmes based on this syllabus would 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 to effectively engage and challenge their students. It is expected that students will apply investigative and problem-solving skills, effectively communicate the theoretical concepts covered in this course and appreciate the contribution physics makes to our understanding of the physical world.

DISCIPLINARY IDEAS OF PHYSICS

The disciplinary ideas of Physics represent the overarching ideas essential for the understanding of Physics. An understanding of these ideas helps students see the interconnectedness of ideas within and across the sub-disciplines of Physics. 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.

Disciplinary ideas are introduced at the upper secondary levels when students begin to specialise in the sub-disciplines of science.

1. Matter and energy make up the Universe
2. Matter interacts through forces and fields
3. Forces help us understand motion
4. Waves can transfer energy without transferring matter
5. Conservation laws constrain the changes in systems
6. Microscopic models can explain macroscopic phenomena

CONTENT STRUCTURE

Section	Topics
I. Measurement	1. Physical Quantities, Units and Measurement
II. Newtonian Mechanics	2. Kinematics 3. Force and Pressure 4. Dynamics 5. Turning Effect of Forces 6. Energy
III. Thermal Physics	7. Kinetic Particle Model of Matter 8. Thermal Processes
IV. Waves	9. General Wave Properties 10. Electromagnetic Spectrum 11. Light
V. Electricity and Magnetism	12. Electric Charges and Current of Electricity 13. D.C. Circuits 14. Practical Electricity 15. Magnetism and Electromagnetism
VI. Radioactivity	16. Radioactivity

SUBJECT CONTENT

SECTION 1: MEASUREMENT

Overview

Physics is an experimental science and precise measurements enable the collection of useful experimental data which can be tested against hypothesis for the development of physical theories. With the development of better measurement tools and techniques, the data available is improved and scientific knowledge continue to evolve in light of new information.

There is a variety of instruments available and our choice of instrument should take into consideration the precision, and feasibility of the choice of instrument when making measurements. We need to be cognisant of the limitations associated with the measurement process which can arise from the precision of the instrument chosen, the mechanics of the measuring instrument and the design of the experiment.

Apart from the need of accurate measurements, interactions between objects in systems should also be described with precisely defined quantities and units and as these interactions could range from celestial objects to sub-atomic particles, prefixes in order-of-ten are necessary to depict such diversity in range of magnitude.

1 Physical Quantities, Units and Measurement

Content

- Physical quantities and SI units
- Measurement
- Scalars and vectors

Learning Outcomes

Candidates should be able to:

- (a) show an understanding that physical quantities typically consist of a numerical magnitude and a unit
- (b) recall the following base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)
- (c) use the following prefixes and their symbols to indicate decimal sub-multiples and multiples of the SI units: nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T)
- (d) show an understanding of the orders of magnitude of the sizes of common objects ranging from a typical atom to the Earth
- (e) select and explain the use of appropriate measuring instruments to measure or determine physical quantities listed in "Summary of key quantities, symbols and units" taking into consideration the range and precision of the instrument
- (f) state what is meant by *scalar* and *vector* quantities and give common examples of each

SECTION II: NEWTONIAN MECHANICS**Overview**

Mechanics is the branch of physics that deals with the study of motion and its causes. Through a careful process of observation and experimentation, Galileo Galilei used experiments to overturn Aristotle's ideas of the motion of objects, for example the flawed idea that heavy objects fall faster than lighter ones, which dominated physics for about 2,000 years.

The greatest contribution to the development of mechanics is by one of the greatest physicists of all time, Isaac Newton. By extending Galileo's methods and understanding of motion and gravitation, Newton developed the three laws of motion and his law of universal gravitation, and successfully applied them to both terrestrial and celestial systems to predict and explain phenomena. He showed that nature is governed by a few special rules or laws that can be expressed in mathematical formulae. Newton's combination of logical experimentation and mathematical analysis shaped the way science has been done ever since.

2 Kinematics**Content**

- Speed, velocity and acceleration
- Graphical analysis of motion
- Free-fall

Learning Outcomes

Candidates should be able to:

- (a) state what is meant by speed and velocity
- (b) calculate $\text{average speed} = \text{distance travelled} / \text{time taken}$
- (c) state what is meant by uniform acceleration and calculate the value of acceleration using $\text{change in velocity} / \text{time taken}$
- (d) interpret given examples of non-uniform acceleration
- (e) plot and interpret a distance-time graph and a speed-time graph for motion in one direction.
- (f) deduce from the shape of a distance-time graph when a body travelling in one direction is:
 - (i) at rest
 - (ii) moving with uniform speed
 - (iii) moving with non-uniform speed
- (g) deduce from the shape of a speed-time graph when a body travelling in one direction is:
 - (i) at rest
 - (ii) moving with uniform speed
 - (iii) moving with uniform acceleration
 - (iv) moving with non-uniform acceleration
- (h) calculate the area under a speed-time graph to determine the distance travelled for motion in one direction with uniform speed or uniform acceleration
- (i) state that the acceleration of free fall for a body near to the Earth is constant and is approximately 10 m/s^2

3 Force and Pressure

Content

- Types of forces
- Mass, weight and gravitational field
- Density
- Pressure

Learning Outcomes

Candidates should be able to:

- (a) identify and distinguish between contact forces (e.g. friction, air resistance, tension and normal force) and non-contact forces (e.g. gravitational, electrostatic and magnetic forces)
- (b) state that mass is a measure of the amount of matter in a body
- (c) state that a gravitational field is a region in which a mass experiences a force due to gravitational attraction
- (d) define gravitational field strength, g , as *gravitational force per unit mass placed at that point*
- (e) recall and apply the relationship $\text{weight} = \text{mass} \times \text{gravitational field strength}$ to new situations or to solve related problems
- (f) distinguish between mass and weight
- (g) recall and apply the relationship $\text{density} = \text{mass} / \text{volume}$ to new situations or to solve related problems
- (h) define pressure in terms of force and area
- (i) recall and apply the relationship $\text{pressure} = \text{force} / \text{area}$ to new situations or to solve related problems

4 Dynamics

Content

- Newton's laws of motion
- Effects of resistive forces on motion

Learning Outcomes

Candidates should be able to:

- (a) apply Newton's Laws to:
 - (i) describe the effect of balanced and unbalanced forces on a body
 - (ii) describe the ways in which a force may change the motion of a body
 - (iii) identify action-reaction pairs acting on two interacting bodies
(stating of Newton's Laws is not required)
- (b) identify forces acting on a body and draw free body diagram(s) representing the forces acting on the body (for cases involving forces acting in at most two dimensions)

- (c) recall and apply the relationship $\text{resultant force} = \text{mass} \times \text{acceleration}$ to new situations or to solve related problems
- (d) explain the effects of friction on the motion of a body

5 Turning Effects of Forces

Content

- Moments
- Equilibrium
- Centre of gravity

Learning Outcomes

Candidates should be able to:

- (a) describe the moment of a force about a pivot in terms of its turning effect and relate this to everyday examples
- (b) recall and apply the relationship $\text{moment of a force (or torque)} = \text{force} \times \text{perpendicular distance from the pivot}$ to new situations or to solve related problems
- (c) state the principle of moments for a body in equilibrium
- (d) apply the principle of moments to new situations or to solve related problems
- (e) show an understanding that the weight of a body may be taken as acting at a single point known as its centre of gravity

6 Energy

Content

- Energy stores and transfers
- Work
- Power

Learning Outcomes

Candidates should be able to:

- (a) show an understanding that there are energy stores, e.g. kinetic, potential (gravitational, chemical, elastic), nuclear and internal, and that energy can be transferred from one store to another:
 - (i) Mechanically (by a force acting over a distance),
 - (ii) Electrically (by an electric current),
 - (iii) By heating (due to a temperature difference),
 - (iv) By propagation of waves (both electromagnetic and mechanical)
- (b) recall and apply the relationships for kinetic energy ($E_k = \frac{1}{2}mv^2$) and gravitational potential energy near the Earth's surface ($E_p = mgh$) to new situations or to solve related problems
- (c) state the principle of the conservation of energy and apply the principle to new situations or to solve related problems

- (d) recall and apply the relationship $\text{work done} = \text{force} \times \text{distance moved in the direction of the force}$ to new situations or to solve related problems
- (e) recall and apply the relationship $\text{power} = \text{energy transfer} / \text{time taken}$ to new situations or to solve related problems

SECTION III: THERMAL PHYSICS**Overview**

When asked what was the most valuable scientific information in a single sentence, Richard Feynman response was, 'All things are made of atoms – little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence ... there is an enormous amount of information about the world.' (Six Easy Pieces, p.4)

Understanding thermal physics requires us to approach the concepts from both the macroscopic and microscopic lenses. The *Kinetic Particle Model of Matter* is a cornerstone theory that is used extensively to explain how different types of matter exhibit certain physical properties by relating them to behaviour of atoms and molecules.

By nature, energy exchange takes place between bodies of different temperatures until thermal equilibrium is reached. Energy may be transferred between bodies by heating through processes like conduction, convection and radiation. These processes could cause changes in the molecular structure of matter and result in macroscopic observations, e.g. monsoon winds and ocean currents observed are convectional currents produced in the process of regulating differences in temperature.

7 Kinetic Particle Model of Matter**Content**

- States of matter
- Kinetic Particle Model
- Internal energy

Learning Outcomes

Candidates should be able to:

- (a) compare the physical properties of solids, liquids and gases
- (b) use the kinetic particle model to describe the different states of matter (solids, liquids and gases), relating their physical properties to the arrangement and motion of the particles (e.g. molecules, atoms) and the forces and distances between particles
- (c) relate the rise in temperature of a body to the increase in average kinetic energy of all the particles in the body
- (d) describe internal energy as an energy store that is made up of the total kinetic energy associated with the random motion of the particles and the total potential energy between the particles in the system
- (e) describe melting/solidification and boiling/condensation as processes of energy transfer without a change in temperature

8 Thermal Processes

Content

- Thermal equilibrium
- Conduction
- Convection
- Radiation

Learning Outcomes

Candidates should be able to:

- (a) show an understanding that energy is transferred (by heating) from a region of higher temperature to a region of lower temperature until thermal equilibrium is achieved between the two regions
- (b) describe, in microscopic terms, how conduction occurs in solids (via vibration of atoms/molecules and movement of electrons)
- (c) describe, in terms of density changes, how convection occurs in fluids
- (d) explain that energy transfer by electromagnetic radiation does not require a material medium and that this rate of energy transfer to/from a body is affected by its:
 - (i) surface colour and texture
 - (ii) surface temperature
 - (iii) surface area
- (e) apply the concepts of conduction, convection and radiation in everyday examples.

SECTION IV: WAVES**Overview**

All waves have properties in common and a wave model can be used to explain many phenomena, both natural (like water waves and sound) and artificial (like many forms of electromagnetic waves). The ability of waves to transfer energy at great speed provides valuable propositions.

Much of our current understanding of wave motion has come from the study of acoustics, which is the science of sound. Many of the ancient Greek philosophers were interested in music. They had hypothesized that there was a connection between waves and sound, and that vibrations must be responsible for sounds. Pythagoras observed in 550 BC that vibrating strings produced sound, and worked to determine the mathematical relationships between the lengths of strings that made harmonious tones.

Scientific theories of wave propagation became more prominent in the 17th Century, when Galileo Galilei published a clear statement that connected vibrating bodies to the sounds they produce. In 1640 Robert Boyle's classic experiment on the sound produced by a ticking watch in a partially evacuated glass vessel provided evidence that air is necessary, either for the production or transmission of sound.

The mathematical theory of sound propagation began with Isaac Newton, whose *Principia* (1686) included a mechanical interpretation of sound as being 'pressure' pulses transmitted through neighbouring fluid particles. In the 18th Century, French mathematician and scientist Jean Le Rond d'Alembert derived the wave equation, a thorough and general mathematical description of waves, which laid the foundation for generations of scientists to study and describe wave phenomena.

9 General Properties of Waves**Content**

- Describing wave motion
- Wave properties
- Sound

Learning Outcomes

Candidates should be able to:

- (a) describe what is meant by wave motion as illustrated by vibrations in ropes and springs and by waves in a ripple tank (including use of the term wavefront)
- (b) show an understanding that waves transfer energy without transferring matter
- (c) define and use the terms *speed*, *frequency*, *wavelength*, *period* and *amplitude* including graphical representations
- (d) recall and apply the relationship $\text{speed of wave} = \text{frequency} \times \text{wavelength}$ to new situations or to solve related problems
- (e) compare transverse and longitudinal waves and give suitable examples of each
- (f) show an understanding that sound can be produced by vibrating sources and a medium is required for the transmission of sound.
- (g) describe the longitudinal nature of sound waves in terms of the processes of compression and rarefaction

- (h) relate loudness of a sound wave to its amplitude and pitch to its frequency
- (i) describe how the reflection of sound may produce an echo, and how this may be used for measuring distances

10 Electromagnetic Spectrum

Content

- Properties of electromagnetic waves
- Applications of electromagnetic waves
- Effects of electromagnetic waves on cells and tissues

Learning Outcomes

Candidates should be able to:

- (a) state that all electromagnetic waves are transverse waves that travel with the same speed in vacuum
- (b) describe the main regions of the electromagnetic spectrum in order of wavelength and frequency
- (c) state examples of typical uses of the following regions of the electromagnetic spectrum:
 - (i) radio waves (e.g. radio and television communication, astronomy and RFID tags)
 - (ii) microwaves (e.g. mobile (cell) phones, microwave oven and satellite television)
 - (iii) infrared (e.g. infra-red remote controllers, intruder alarms and thermal imaging)
 - (iv) visible light (e.g. photography, optical fibres in medicine and telecommunications)
 - (v) ultraviolet (e.g. sunbeds, bank note authentication and disinfecting water)
 - (vi) X-rays (e.g. medical radiology, security screening and industrial defect detection)
 - (vii) gamma (γ) rays (e.g. sterilising food, detection of cancer and its treatment)
- (d) describe how over-exposure to electromagnetic waves can have hazardous effects (e.g. heating and ionising effects of radiation) on living cells and tissue

11 Light

Content

- Reflection of light
- Refraction of light
- Thin converging lenses

Learning Outcomes

Candidates should be able to:

- (a) recall and use the terms *normal*, *angle of incidence* and *angle of reflection* to describe the reflection of light
- (b) state that, for reflection, the angle of incidence is equal to the angle of reflection and use this principle in constructions, measurements and calculations
- (c) recall and use the terms *normal*, *angle of incidence* and *angle of refraction* to describe the refraction of light

- (d) recall and apply the relationship $\sin i / \sin r = \text{constant}$ to new situations or to solve related problems
- (e) define *refractive index* of a medium in terms of the ratio of speed of light in vacuum and in the medium
- (f) describe the action of a thin converging lens on a beam of light
- (g) define the *focal length* for a converging lens
- (h) describe the characteristics of images (e.g. real / virtual, magnified / diminished, and upright / inverted) formed by a thin converging lens (recall of the characteristics of images formed for specific object distances is not required).

SECTION V: ELECTRICITY AND MAGNETISM**Overview**

Electricity and magnetism were seen as separate and independent phenomena in the past. It only was when Danish physicist Hans Christian Ørsted discovered, accidentally, in 1820 that a magnetic needle is deflected when the current in a nearby wire varies – a phenomenon establishing a relationship between electricity and magnetism.

Inspired by Ørsted's discovery, André-Marie Ampère conducted a series of experiments in the same year designed to elucidate the exact nature of the relationship between electric current-flow and magnetism. Further works by Michael Faraday reinforced the magnetic effect of a current and introduced the idea of a 'field' of action to explain why electricity and magnetism had an 'area of activity'.

However, it was the work of James Clerk Maxwell, a mathematical physicist, who provided mathematical tools and equations to describe Faraday's ideas of the field. His works went on to prove that electromagnetic fields have wave-like properties which was a very important discovery in physics.

12 Electric Charge and Current of Electricity**Content**

- Electric charge
- Conventional current and electron flow
- Electromotive force and potential difference
- Resistance

Learning Outcomes

Candidates should be able to:

- (a) state that there are positive and negative charges and that charge is measured in coulombs
- (b) state that unlike charges attract and like charges repel
- (c) state that current is the rate of flow of charge and that it is measured in amperes
- (d) distinguish between conventional current and electron flow
- (e) recall and apply the relationship $charge = current \times time$ to new situations or to solve related problems
- (f) state that the electromotive force (e.m.f.) of an electrical source of energy is measured in volts
- (g) state that the potential difference (p.d.) across a component in a circuit is the work done per unit charge in driving charges through the component and that it is measured in volts
- (h) state that $resistance = p.d. / current$
- (i) apply the relationship $R = V/I$ to new situations or to solve related problems
- (j) recall and apply the relationship of the proportionality between resistance and the length and cross-sectional area of a wire to new situations or to solve related problems

13 D.C. Circuits

Content

- Circuit diagrams
- Series and parallel circuits

Learning Outcomes

Candidates should be able to:

- (a) draw circuit diagrams with power sources (cell or battery), switches, lamps, light-emitting diodes (LEDs), resistors (fixed and variable), fuses, ammeters and voltmeters
- (b) state that the current at every point in a series circuit is the same and apply the principle to new situations or to solve related problems
- (c) state that the sum of the potential differences in a series circuit is equal to the potential difference across the whole circuit and apply the principle to new situations or to solve related problems
- (d) state that the sum of the currents in the separate branches of a parallel circuit is equal to the current from the source and apply the principle to new situations or to solve related problems
- (e) state that the potential difference across the separate branches of a parallel circuit is the same and apply the principle to new situations or to solve related problems
- (f) recall and apply the formulae for the effective resistance of a number of resistors in series and in parallel to new situations or to solve related problems
- (g) recall and apply the relevant relationships, including $R = V/I$ and those for current, potential differences and resistors in series and in parallel circuits, in calculations involving a whole circuit.

14 Practical Electricity

Content

- Electrical working, power and energy
- Dangers of electricity
- Safe use of electricity in the home

Learning Outcomes

Candidates should be able to:

- (a) describe the use of the heating effect of electricity in appliances such as electric kettles, ovens and heaters
- (b) recall and apply the relationships $P = VI$ and $E = VI t$ to new situations or to solve related problems
- (c) calculate the cost of using electrical appliances where the energy unit is the kW h
- (d) state the hazards of using electricity in the following situations:
 - (i) damaged insulation
 - (ii) overheating of cables
 - (iii) damp conditions

- (e) explain the use of fuses and circuit breakers in electrical circuits and of fuse ratings
- (f) explain the need for earthing metal casings and for double insulation
- (g) state the meaning of the terms *live*, *neutral* and *earth*
- (h) describe the wiring in a mains plug
- (i) explain why switches, fuses, and circuit breakers are fitted to the live wire.

15 Magnetism and Electromagnetism

Content

- Laws of magnetism
- Magnetic properties of matter
- Magnetic field
- Magnetic effect of a current
- Force on a current-carrying conductor

Learning Outcomes

Candidates should be able to:

- (a) state the properties of magnets
- (b) describe induced magnetism caused by placing magnetic material close to a strong magnet or within a current-carrying solenoid
- (c) distinguish between temporary magnets (e.g. iron) and permanent magnets (e.g. steel) in terms of their properties and uses
- (d) describe how a bar magnet (e.g. a compass) can be used to determine the direction of a magnetic field
- (e) draw the magnetic field pattern around a bar magnet and between the poles of two bar magnets.
- (f) draw the pattern of the magnetic field due to currents in straight wires and in solenoids and state the effect on the magnetic field due to change in the magnitude and/or direction of the current
- (g) describe experiments to show the force on a current-carrying conductor in a magnetic field, including the effect of reversing
 - (i) the current
 - (ii) the direction of the field
- (h) deduce the relative directions of force, field and current when any two of these quantities are at right angles to each other using Fleming's left-hand rule
- (i) explain how a current-carrying coil in a magnetic field (e.g. in a motor) experiences a turning effect (recall of structure of an electric motor is not required)

SECTION VI: RADIOACTIVITY**Overview**

Radioactivity was first discovered through the handling of radioactive uranium by physicists Pierre and Marie Curie during which they suffered radioactive burns due to inadequate handling of the substance.

Radioactivity is the study of the nature of the radiation emitted by radioactive materials. It was later understood that there are three types of emissions: the alpha particles (helium atoms with no electrons), beta particles (fast moving electrons) and the gamma rays (electromagnetic radiation similar to X-rays). These emissions are the result of the decay or disintegration of an unstable atomic nucleus.

Radioactivity have important medical uses, which include the killing of cancer cells. However excessive exposure to radioactivity can cause cancer if the dose is too high. Many early scientists working with radioactive materials died early from the harmful effects of high radiation before proper safety guidelines were drawn. ‘Radiometric dating’ makes use of a radioactive element’s half-life to help determine the age of rocks or carbon.

Large amounts of energy are also involved in radioactive emissions and physicists quickly recognized the power of this. Many scientists working on this from 1930 to 1940 in Europe were forced to leave their home countries, fleeing to the United States due to the development of the war. This led to a ‘brain drain’ which benefited the United States and allowed them to develop the two atomic bombs which ended the war. This highlights the impact on science on society and human interactions. Since the development of the atomic bomb, much has been learnt about how to control the release of energy and nuclear power can generate electricity with only a fraction of the greenhouse gases released by burning coal and other fossil fuels.

Because radiation cannot be easily seen, it is commonly feared and shunned. Coupled with news about the dangers of nuclear radiation and the potential detriments to health, the general public is apprehensive about the use and application of any form of radiation. This topic aims to provide an objective evaluation of the risks and benefits of the use of radiation through the development of a good understanding of the many practical uses of radioactive materials.

16 Radioactivity**Content**

- The composition of the atom
- Radioactive decay
- Dangers and uses of radioactivity

Learning Outcomes

Candidates should be able to:

- (a) describe the composition of an atom in terms of a positively charged nucleus (with protons and neutrons) and negatively charged electrons
- (b) use the terms proton (atomic) number Z, nucleon (mass) number A and isotope
- (c) use and interpret the term nuclide and use the nuclide notation ${}^A_Z X$
- (d) show an understanding that nuclear decay is a random and spontaneous process whereby an unstable nucleus loses energy by emitting radiation
- (e) show an understanding of the nature of alpha (α), beta (β), and gamma (γ) radiation (including ionising effect and penetrating power) [β -particles are assumed to be β^- particles only]

- (f) show an understanding of background radiation
- (g) use the term half-life in simple calculations, which might involve information in tables or decay curves
- (h) state the applications (e.g. medical and industrial uses) and hazards of radioactivity.

SUMMARY OF KEY QUANTITIES, SYMBOLS AND UNITS

Students should be able to state the symbols for the following physical quantities and, where indicated, state the units in which they are measured. Students should be able to define those items indicated by an asterisk (*).

Quantity	Symbol	Unit
length	$l, h \dots$	km, m, cm, mm
area	A	m^2, cm^2
volume	V	m^3, cm^3
weight*	W	N
mass	m, M	kg, g, mg
time	t	h, min, s, ms
period*	T	s
density*	ρ	$\text{g/cm}^3, \text{kg/m}^3$
speed*	u, v	km/h, m/s, cm/s
acceleration*	a	m/s^2
acceleration of free fall	g	$\text{m/s}^2, \text{N/kg}$
force*	F, f	N
moment of force*		N m
work done*	W, E	J
energy	E	J, kWh
power*	P	W
pressure*	p, P	Pa, N/m ²
temperature	θ, T	°C, K
frequency*	f	Hz
wavelength*	λ	m, cm
focal length	f	m, cm
angle of incidence	i	degree (°)
angles of reflection, refraction	r	degree (°)
potential difference*/voltage	V	V, mV
current*	I	A, mA
charge	q, Q	C, As
e.m.f.*	E	V
resistance	R	Ω
proton number	Z	
nucleon number	A	
half-life	$t_{1/2}$	s
activity of a radioactive source	A	Bq

Chemistry section

INTRODUCTION

The Secondary Education Certificate G3 Science (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 materials, 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.

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.

CONTENT STRUCTURE

Section	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 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) distillation and fractional distillation (see also 11.1(b))
 - (iii) 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)
- (c) interpret paper chromatograms including comparison with ‘known’ samples
(the use of R_f values is **not** required)
- (d) deduce from given melting point and boiling point data the identities of substances and their purity.

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.

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 the examination)
- (c) define *proton (atomic) number* and *nucleon (mass) number*
- (d) interpret and use nuclide notations such as $^{12}_6\text{C}$
- (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 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. $\text{NaCl}; \text{MgCl}_2$
- (c) relate the physical properties (including electrical property) of ionic compounds to their lattice structure.

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. H₂; O₂; H₂O; CH₄; CO₂
- (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.

3.3 Structure and Properties of Materials

- (a) describe the differences between elements, compounds and mixtures
- (b) describe the general physical properties of metals as solids having high melting and boiling points, malleable and good conductors of heat and electricity
- (c) describe an alloy as a mixture of a metal with another element, e.g. brass; stainless steel
- (d) identify representations of metals and alloys from diagrams of structures.

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 stoichiometric reacting masses and volumes of gases (one mole of gas occupies 24 dm³ 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)
- (e) apply the concept of solution concentration (in mol/dm³ or g/dm³) to process the results of volumetric experiments (e.g. titration) and to solve simple problems.
(appropriate guidance will be provided where unfamiliar reactions such as redox are involved. Calculations on % yield and % purity are **not** required.)

5 Acid-Base Chemistry

Learning Outcomes

Candidates should be able to:

- (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 the characteristic properties of acids as in reactions with metals, bases and carbonates to form salts
(description of the preparation of pure salts is **not** required)
- (d) describe the reaction between hydrogen ions and hydroxide ions to produce water,
 $H^+ + OH^- \rightarrow H_2O$, as neutralisation
- (e) describe the importance of controlling the pH in soils and how excess acidity can be treated using calcium hydroxide
- (f) describe the characteristic properties of bases in reactions with acids and with ammonium salts
- (g) classify oxides as acidic, basic, amphoteric or neutral based on metallic/non-metallic character.

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); 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

Learning Outcomes

Candidates should be able to:

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

8 Patterns in the Periodic Table

Content

- 8.1 Periodic Trends
- 8.2 Group Properties
- 8.3 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) explain the similarities between the elements in the same group of the Periodic Table in terms of their electronic configuration
- (d) describe the change from metallic to non-metallic character from left to right across a period of the Periodic Table
- (e) describe the relationship between number of outer (valence) electrons and metallic/non-metallic character
- (f) 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 lack of reactivity of the elements in Group 18 (the noble gases) in terms of their electronic configurations.

8.3 Reactivity Series

- (a) place in order of reactivity calcium, copper, (hydrogen), iron, lead, magnesium, potassium, silver, sodium and zinc by reference to the reactions, if any, of the metals with water, steam and dilute hydrochloric acid
- (b) deduce the order of reactivity from a given set of experimental results
- (c) describe the ease of obtaining metals from their ores by relating the elements to their positions in the reactivity series
- (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.

9 Chemical Energetics

Learning Outcomes

Candidates should be able to:

- (a) describe the term *exothermic* as a process or chemical reaction which transfers energy, often in the form of heat, to the surroundings and may be detected by an increase in temperature, e.g. the reaction between sodium hydroxide and hydrochloric acid
- (b) describe the term *endothermic* as a process or chemical reaction which takes in energy, often in the form of heat, from the surroundings and may be detected by a decrease in temperature, e.g. the dissolving of ammonium nitrate in water.

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) 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 and Carboxylic Acids
- 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, is more environmentally sustainable in terms of the offset in carbon dioxide emission during burning by that taken in during plant growth (see also **12(e)**).

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 unbranched alkanes, C_1 to C_3 , and name the unbranched alkanes methane to propane
- (d) describe alkanes (exemplified by methane) as being generally unreactive except in terms of combustion and substitution by chlorine
- (e) describe the alkenes as a homologous series of unsaturated hydrocarbons with the general formula C_nH_{2n}
- (f) draw the structures of unbranched alkenes, C_2 and C_3 , and name the unbranched alkenes ethene and propene
- (g) 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
- (h) describe the difference between saturated and unsaturated hydrocarbons from their molecular structures and by using aqueous bromine
- (i) describe the reactions of alkenes (exemplified by ethene) in terms of combustion, polymerisation (see also 11.4(b)) and the addition with bromine and hydrogen
- (j) state the meaning of *polyunsaturated* when applied to food products
- (k) describe the manufacture of margarine by the addition of hydrogen to unsaturated vegetable oils to form a solid product.

11.3 Alcohols and Carboxylic Acids

- (a) describe the alcohols as a homologous series containing the $-OH$ group
- (b) draw the structures of unbranched alcohols, C_1 to C_3 , and name the unbranched alcohols methanol to propanol
- (c) describe the reactions of alcohols in terms of combustion and oxidation to carboxylic acids
- (d) describe the formation of ethanol by fermentation of glucose
- (e) describe the carboxylic acids as a homologous series containing the $-CO_2H$ group
- (f) describe the formation of ethanoic acid by the oxidation of ethanol by atmospheric oxygen or acidified potassium manganate(VII).

11.4 Polymers

- (a) describe polymers as large molecules built up from small units (monomers), different polymers having different units
- (b) describe the formation of poly(ethene) as an example of addition polymerisation of ethene as the monomer (see also 11.2(i))
- (c) state some uses of poly(ethene) as a typical plastic, e.g. plastic bags; clingfilm
- (d) deduce the structure of the addition polymer product from a given monomer and vice versa
- (e) describe the pollution problems caused by the disposal of non-biodegradable plastics
- (f) 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 cracking of plastic waste into fuel)
- (g) 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 NO₂); 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) 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
- (e) 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))
- (f) 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 } 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	—

CHEMISTRY PRACTICAL NOTES

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.
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

Colours of Some Common Metal Hydroxides

aluminium hydroxide	white
calcium hydroxide	white
copper(II) hydroxide	light blue
iron(II) hydroxide	green
iron(III) hydroxide	red-brown
zinc hydroxide	white

The Periodic Table of Elements

		Group																					
1	2																						
																		13	14	15	16	17	18
3 Li lithium 7	4 Be beryllium 9																						
11 Na sodium 23	12 Mg magnesium 24																						
19 K potassium 39	20 Ca calcium 40																						
37 Rb rubidium 85	38 Sr strontium 88																						
55 Cs caesium 133	56 Ba barium 137																						
87 Fr francium —	88 Ra radium —																						
Key																							
proton (atomic) number																							
atomic symbol																							
name																							
relative atomic mass																							
5 B boron 11	6 C carbon 12																						
13 Al aluminium 27	14 Si silicon 28																						
5 B boron 11	7 N nitrogen 14																						
13 Al aluminium 27	8 O oxygen 16																						
5 B boron 11	9 F fluorine 19																						
2 He helium 4	10 Ne neon 20																						
5 B boron 11	11 Ar argon 40																						
13 Al aluminium 27	12 Cl chlorine 35.5																						
5 B boron 11	13 Br bromine 80																						
13 Al aluminium 27	14 Kr krypton 84																						
5 B boron 11	15 Te tellurium 127																						
13 Al aluminium 27	16 Po polonium —																						
5 B boron 11	17 At astatine —																						
13 Al aluminium 27	18 Rn radon —																						
57 La lanthanum 139	58 Ce cerium 140																						
89 Ac actinium —	59 Pr praseodymium 141																						
57 La lanthanum 139	60 Nd neodymium 144																						
89 Ac actinium —	61 Pm promethium —																						
57 La lanthanum 139	62 Sm samarium 150																						
89 Ac actinium —	63 Eu europium 152																						
57 La lanthanum 139	64 Gd gadolinium 157																						
89 Ac actinium —	65 Tb terbium 159																						
57 La lanthanum 139	66 Dy dysprosium 163																						
89 Ac actinium —	67 Ho holmium 165																						
57 La lanthanum 139	68 Er erbium 167																						
89 Ac actinium —	69 Tm thulium 169																						
57 La lanthanum 139	70 Yb ytterbium 173																						
89 Ac actinium —	71 Lu lutetium 175																						
89 Ac actinium —	72 Es einsteinium —																						
89 Ac actinium —	73 Md mendelevium —																						
89 Ac actinium —	74 No nobelium —																						
89 Ac actinium —	75 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, $L = 6.02 \times 10^{23} \text{ mol}^{-1}$.

Biology section

INTRODUCTION

The Secondary Education Certificate G3 Science (Biology) Syllabus is designed to have less emphasis on factual materials, but a much 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 in teaching topics in this syllabus. The assessment will be specifically intended to test skills, comprehension and insight in familiar and unfamiliar contexts.

DISCIPLINARY IDEAS OF BIOLOGY

The disciplinary ideas of Biology 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 question of how living organisms work to sustain life. The purpose of equipping students with an understanding of these ideas is to develop in them a coherent view and conceptual framework of scientific knowledge to facilitate the application and transfer of learning. These ideas can be revisited throughout the syllabus, deepened at higher levels of learning and beyond the schooling years.

- 1 **The Cell** – Diverse life forms are similar in that their basic unit are cells.
- 2 **Structure and Function** – Structure and function of organisms from the molecular to the organ system levels are related to each other.
- 3 **Systems** – Biological systems interact among themselves and with the environment resulting in the flow of energy and nutrients.
- 4 **Energy** – To ensure survival, living organisms obtain, transform and utilise energy from the external world.
- 5 **Homeostasis, Co-ordination and Response** – Living organisms detect changes both from the surrounding environment and within themselves so that they are able to respond to these changes to maintain a constant internal environment needed for sustaining life.
- 6 **Heredity** – Genetic information is passed down from parents to offspring during reproduction to ensure the continuity of life.
- 7 **Evolution** – The diversity of living organisms is achieved through a process of evolution, driven by mechanisms such as natural selection.

CONTENT STRUCTURE

Section	Topics
I. CELLS AND THE CHEMISTRY OF LIFE	1. Cell Structure and Organisation 2. Movement of Substances 3. Biological Molecules
II. THE HUMAN BODY – MAINTAINING LIFE	4. Nutrition in Humans 5. Transport in Humans 6. Respiration in Humans 7. Infectious Diseases in Humans
III. LIVING TOGETHER – PLANTS, ANIMALS AND ECOSYSTEMS	8. Nutrition and Transport in Flowering Plants 9. Organisms and their Environment
IV. CONTINUITY OF LIFE	10. Molecular Genetics 11. Reproduction in Humans 12. Inheritance

SUBJECT CONTENT

SECTION I: CELLS AND THE CHEMISTRY OF LIFE

Overview

Living things are different from non-living things in their ability to grow, reproduce, move, and respond to change. Understanding what makes these characteristics of life possible requires an appreciation of the hierarchical organisation of life (from cells → tissues → organs → systems → organism) and the processes needed to sustain life at each level.

In this section, we begin by exploring life at the smallest level. Amidst the great diversity of living organisms on earth, all living organisms are fundamentally similar at the smallest level; they are all made of cells and a common set of carbon-based molecules. Physiological processes in living organisms can be explained through activities happening at the cellular level. For instance, the transport of oxygen around the body is made possible by red blood cells that bind oxygen to haemoglobin.

In order to sustain life, all living things require three macromolecules – carbohydrates, proteins and fats. They make life possible by providing energy, building cellular structures, and for growth and repair.

The overarching ideas of this section are cells as the basic unit of life, correlation between structure and function and how living organisms obtain, transform and utilise energy from the external world at the cellular level to sustain life. Knowing how life works at the cellular and molecular level will provide students with a foundation to understand processes needed to sustain life at the tissue, organ and system levels, which are covered in subsequent sections of this syllabus.

1 Cell Structure and Organisation

Content

- Plant and Animal Cells
- Cell Specialisation

Learning Outcomes

Candidates should be able to:

- (a) identify and state the functions of the following cell structures (including organelles) of typical plant and animal cells from diagrams, light micrographs and as seen under the light microscope using prepared slides and fresh material treated with an appropriate temporary staining technique:
 - cell wall
 - cell membrane
 - cytoplasm
 - nucleus
 - cell vacuoles (large, sap-filled in plant cells, small, temporary in animal cells)
 - chloroplasts
- (b) identify and state the functions of the following organelles from diagrams and electron micrographs:
 - mitochondria
 - ribosomes

- (c) compare the structure of typical animal and plant cells
- (d) explain how the structures of specialised cells are adapted to their functions (e.g. muscle cell – many mitochondria to supply more energy, root hair cell – large surface area of cell membrane for greater absorption, red blood cell – lack of nucleus allowing it to transport more oxygen)

2 Movement of Substances

Content

- Diffusion
- Osmosis

Learning Outcomes

Candidates should be able to:

- (a) define *diffusion* and describe its role in nutrient uptake and gaseous exchange in plants and humans
- (b) define *osmosis*, investigate and describe the effects of osmosis on plant and animal tissues

3 Biological Molecules

Content

- Carbohydrates, Fats and Proteins
- Enzymes

Learning Outcomes

Candidates should be able to:

- (a) state the main roles of carbohydrates, fats and proteins in living organisms:
 - carbohydrates as an immediate source of energy
 - fats for insulation and long-term storage of energy
 - proteins for growth and repair of cells
- (b) describe and carry out tests for:
 - starch (using iodine in potassium iodide solution)
 - reducing sugars (using Benedict's solution)
 - protein (using biuret solution)
 - fats (using ethanol)
- (c) state that large molecules are synthesised from smaller basic units:
 - cellulose, glycogen and starch from glucose
 - polypeptides and proteins from amino acids
 - lipids such as fats from glycerol and fatty acids

- (d) explain the mode of action of enzymes in terms of an active site, enzyme-substrate complex and enzyme specificity using the 'lock and key' hypothesis
- (e) investigate and explain the effects of temperature and pH on the rate of enzyme catalysed reactions

SECTION II: THE HUMAN BODY – MAINTAINING LIFE**Overview**

Life is sustained through the integrated organisation of the whole organism. In humans, the maintenance and regulation of life processes include nutrition, transport and respiration.

Living systems utilise energy and macromolecules to maintain life processes such as growth, reproduction and homeostasis. Interactions also exist between living systems within organisms, which are often accompanied by the transfer of energy between matter and transfer or exchange of matter. Each system has their component parts, characterised by the division of labour. This division of labour enables an organism to function efficiently and allows for the various systems to work together as a co-ordinated whole.

The threat of diseases disrupts the maintenance of important life processes and the functioning of human body systems. In ancient times, the concept of ‘catching’ a disease was unheard of, and diseases were even thought to be caused by the imbalance of ‘humours’ (internal fluids) within the body. However, with the invention of the microscope, we have found out that infectious diseases are often caused by pathogens, e.g. viruses and bacteria.

The overarching ideas in the study of this section are the co-ordination of the human body system as a whole and the correlation between structure and function.

4 Nutrition in Humans**Content**

- Human Digestive System
- Physical and Chemical Digestion
- Absorption and Assimilation

Learning Outcomes

Candidates should be able to:

- (a) describe the functions of the various parts of the digestive system: mouth, salivary glands, oesophagus, stomach, duodenum, pancreas, gall bladder, liver, ileum, colon, rectum, anus, in relation to ingestion, digestion, absorption, assimilation and egestion of food, as appropriate
- (b) describe the functions of enzymes (e.g. amylase, maltase, protease, lipase) in digestion, listing the substrates and end-products
- (c) state the function of the hepatic portal vein as the transport of blood rich in absorbed nutrients from the small intestine to the liver
- (d) state the role of the liver in:
 - conversion of glucose to glycogen and vice versa
 - fat digestion
 - metabolism of amino acids and formation of urea
 - breakdown of alcohol
 - breakdown of hormones
- (e) define a *hormone* as a chemical substance, produced by a gland, carried by the blood, which alters the activity of one or more specific target organs

- (f) outline how blood glucose concentration is regulated by insulin and glucagon
- (g) describe type 2 *diabetes mellitus* in terms of a persistently higher than normal blood glucose concentration due to the body's resistance to insulin or insufficient production of insulin
- (h) identify the risk factors of (e.g. unhealthy diet and sedentary lifestyle) and ways to manage type 2 *diabetes mellitus*

5 Transport in Humans

Content

- Parts and Functions of the Circulatory System
- Blood
- Coronary Heart Disease

Learning Outcomes

Candidates should be able to:

- (a) identify the main blood vessels to and from the heart, lungs, liver and kidney
- (b) relate the structures of arteries, veins and capillaries to their functions (specific names of muscle layers in arteries and veins are **not** required)
- (c) state the components of blood and their roles in transport and defence:
 - red blood cells – haemoglobin for oxygen transport
 - plasma – transport of blood cells, ions, soluble food substances, hormones, carbon dioxide, urea, vitamins, plasma proteins
 - white blood cells – phagocytosis, antibody formation and tissue rejection
 - platelets – fibrinogen to fibrin, causing clotting
- (d) describe the structure and function of the heart in terms of muscular contraction and the working of valves (histology of the heart muscle, names of nerves and transmitter substances are **not** required)
- (e) describe coronary heart disease in terms of the occlusion of coronary arteries and list the possible causes, such as unhealthy diet, sedentary lifestyle, and smoking, stating the possible preventative measures

6 Respiration in Humans

Content

- Human Gas Exchange
- Cellular Respiration

Learning Outcomes

Candidates should be able to:

- (a) identify the larynx, trachea, bronchi, bronchioles, alveoli and associated capillaries and state their functions in human gaseous exchange
- (b) explain how the structure of an alveolus is suited for its function of gaseous exchange
- (c) state the major toxic components of tobacco smoke – nicotine, tar and carbon monoxide, and describe their effects on health
- (d) define *aerobic respiration* in human cells as the release of energy by the breakdown of glucose in the presence of oxygen and state the word equation
- (e) define *anaerobic respiration* in human cells as the release of energy by the breakdown of glucose in the absence of oxygen and state the word equation
- (f) explain why cells respire anaerobically during vigorous exercise resulting in an oxygen debt that is removed by rapid, deep breathing after exercise

7 Infectious Diseases in Humans

Content

- Organisms affecting Human Health
- Influenza and Pneumococcal Disease
- Prevention and Treatment of Infectious Diseases

Learning Outcomes

Candidates should be able to:

- (a) state that infectious diseases can be spread from person to person whereas non-infectious diseases cannot and identify examples of each
- (b) explain that infectious diseases are caused by pathogens such as bacteria and viruses and can be spread from person to person through body fluids, food and water (knowledge of the structure of bacteria and viruses is **not** required)
- (c) state the signs and symptoms of:
 - influenza – caused by the influenza virus
 - pneumococcal disease – caused by the bacteria, pneumococcus
- (d) describe the transmission and methods to reduce the transmission of:
 - influenza virus
 - pneumococcus

- (e) state that vaccines contain an agent that resembles a pathogen and prevent infectious diseases by stimulating white blood cells to quickly produce antibodies when the pathogen invades
- (f) state that antibiotics kill bacteria and are ineffective against viruses
- (g) explain that the misuse and overuse of antibiotics may accelerate the emergence of antibiotic-resistant bacteria

SECTION III: LIVING TOGETHER – PLANTS, ANIMALS AND ECOSYSTEMS**Overview**

The sun is the principal source of energy for almost all living organisms on earth, without which, life will not exist as it is today. Green plants are able to capture and convert light energy to useful chemical forms through the unique process of photosynthesis. Other organisms depend on this energy captured by plants through direct or indirect feeding relationships to sustain life.

The study of ecology will further explain how all organisms are interdependent on the transfer of energy and matter in this intricate web of life. Humans are by far the singular most influential species in ensuring the conservation of the fragile ecosystem and thus, there are important lessons to be learnt from this highly interdependent relationship among organisms. In the face of global warming as one of the major challenges confronting the world now, examining how human actions can reduce the effects of global warming takes on a pressing urgency to ensure the sustainability of the environment and life on Earth.

The overarching idea of this section is the interaction between organisms in the ecosystem for the sustainability of life through the transfer of energy and matter.

8 Nutrition and Transport in Flowering Plants**Content**

- Plant Structure
- Photosynthesis
- Transpiration
- Translocation

Learning Outcomes

Candidates should be able to:

- (a) identify the cellular and tissue structure of a dicotyledonous leaf, as seen in transverse section using the light microscope and describe the significance of these features in terms of their functions, such as the
 - distribution of chloroplasts for photosynthesis
 - stomata and mesophyll cells for gaseous exchange
 - vascular bundles for transport
- (b) identify the positions of and state the functions of xylem vessels and phloem in sections of a herbaceous dicotyledonous leaf and stem, under the light microscope
- (c) explain how the structure of a root hair cell is suited for its function of water and ion uptake
- (d) state that chlorophyll absorbs light energy and converts it into chemical energy for the formation of carbohydrates and their subsequent uses
- (e) briefly explain why most forms of life are completely dependent on photosynthesis
- (f) state the word equation for photosynthesis (details of light-dependent and light-independent stages are **not required**)
- (g) describe how carbon dioxide reaches mesophyll cells in a leaf

- (h) investigate and describe the effects of varying light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis (e.g. in submerged aquatic plants)
- (i) state that *transpiration* is the loss of water vapour from the stomata
- (j) briefly explain the movement of water through the stem in terms of transpiration pull
- (k) investigate and explain:
 - the effects of variation of air movement, temperature, humidity and light intensity on transpiration rate
 - how wilting occurs
- (l) define the term *translocation* as the transport of food (mainly sucrose) in the phloem tissue

9 Organisms and their Environment

Content

- Energy Flow
- Food Chains and Food Webs
- Carbon Cycle and Global Warming
- Effects of Man on the Ecosystem

Learning Outcomes

Candidates should be able to:

- (a) describe the non-cyclical nature of energy flow
- (b) describe the roles of producers, consumers and decomposers in food chains and food webs
- (c) explain how energy losses occur along food chains, and discuss the efficiency of energy transfer between trophic levels
- (d) interpret pyramids of numbers and biomass
- (e) describe how carbon is cycled within an ecosystem and outline the role of forests and oceans as carbon sinks
- (f) describe how human activities, such as deforestation and use of fossil fuels, cause an increase in atmospheric carbon dioxide concentration, leading to global warming
- (g) discuss how human actions can reduce the effects of global warming

SECTION IV: CONTINUITY OF LIFE

Overview

The many aspects of structure and function that we have examined in this syllabus can be viewed in the widest context as various adaptations aimed at ensuring reproductive success. Reproduction is vital for the survival of species across generations.

In this section, we examine the processes that contribute to the continuity of life. These processes include how genes interact to produce hereditary characteristics in the offspring and how genetic information is passed from one generation to the next.

Some important scientists who contributed to findings in this section include Gregor Mendel – who published his observations from breeding experiments on pea plants and James Watson and Francis Crick – who developed the model for deoxyribonucleic acid (DNA), a molecule that was deduced as the hereditary material that is passed down through generations. Models aid in the visualisation of science and led to the breakthrough in the discovery of the double-helix molecule – DNA.

The overarching ideas of this section are the storage of genetic information in the DNA and the passing down of genetic information through generations to ensure the continuity of life.

10 Molecular Genetics

Content

- The Structure of DNA
- From DNA to Proteins

Learning Outcomes

Candidates should be able to:

- (a) outline the relationships among DNA, genes and chromosomes
- (b) state that DNA is a double helix comprising two strands of nucleotides, each nucleotide formed of a sugar, a phosphate group and one of four different bases
- (c) state the rule of complementary base pairing
- (d) state that each gene:
 - is a sequence of nucleotides, as part of a DNA molecule
 - codes for one polypeptide
 - is a unit of inheritance
- (e) state that DNA is used to carry the genetic code, which is used to synthesise specific polypeptides (details of transcription and translation are **not** required)

11 Reproduction in Humans

Content

- Sexual Reproduction in Humans
- Sexually Transmitted Diseases

Learning Outcomes

Candidates should be able to:

- (a) define *sexual reproduction* as the process involving the fusion of nuclei of male and female gametes to form a zygote and the production of genetically dissimilar offspring
- (b) identify the male reproductive system and state the functions of: testes, scrotum, sperm ducts, prostate gland, urethra and penis
- (c) identify the female reproductive system and state the functions of: ovaries, oviducts, uterus, cervix and vagina
- (d) outline the menstrual cycle with reference to the alternation of menstruation and ovulation, the natural variation in its length, and the fertile and infertile phases of the cycle with reference to the effects of progesterone and oestrogen only
- (e) describe fertilisation and early development of the zygote simply in terms of the formation of a ball of cells which becomes implanted in the wall of the uterus
- (f) discuss the transmission of human immunodeficiency virus (HIV) and methods to reduce transmission

12 Inheritance

Content

- The Passage of Genetic Information from Parent to Offspring
- Monohybrid Crosses
- Variation

Learning Outcomes

Candidates should be able to:

- (a) distinguish between the terms *gene* and *allele*
- (b) distinguish between continuous and discontinuous variation and give examples of each
- (c) explain the terms *dominant*, *recessive*, *homozygous*, *heterozygous*, *phenotype* and *genotype*
- (d) predict the results of simple crosses with expected ratios of 3:1 and 1:1, using the terms homozygous, heterozygous, F₁ generation and F₂ generation
- (e) explain why observed ratios often differ from expected ratios, especially when there are small numbers of progeny
- (f) use genetic diagrams to solve problems involving monohybrid inheritance

- (g) describe the determination of sex in humans – XX and XY chromosomes
- (h) describe mutation as a change in the sequence of a gene such as in sickle cell anaemia, or in the chromosome number, such as the 47 chromosomes in the condition known as Down syndrome
- (i) name ionising radiation (e.g. X-ray) and chemical mutagens as factors which may increase the rate of mutation

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 learning. This list is not exhaustive.

Quantity	Symbol	Unit
length	l	mm, cm, m
area	A	cm^2, m^2
volume	V	$\text{cm}^3, \text{dm}^3, \text{m}^3$
mass	m	mg, g, kg
concentration	c	g/dm^3
time	t	ms, s, min
pH	pH	—
temperature	T	$^\circ\text{C}$
energy	E	J

PRACTICAL ASSESSMENT

Scientific subjects are, by 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 5, as a formal practical test, and is outlined in the **Scheme of Assessment**.

Paper 5 Practical Test

Physics Practical Test

Candidates may be asked to carry out exercises based on:

- (a) measurements of
 - (i) length by using tapes, rules, digital calipers and digital micrometers
 - (ii) time interval (including period of a simple pendulum) by using digital stopwatches
 - (iii) volume of solids/liquids by using measuring cylinders
 - (iv) mass and weight by using electronic balances and spring balances
 - (v) temperature by using laboratory thermometers
 - (vi) current and voltage by using ammeters and voltmeters
- (b) determination of the density of a liquid, or a regularly or irregularly shaped solid, that sinks in water
- (c) determination of the value of acceleration of free fall
- (d) investigation of the effects of balanced and unbalanced forces
- (e) the principle of moments
- (f) determination of the position of the centre of gravity of a plane lamina
- (g) investigation of the factors affecting transfer of energy by thermal processes
- (h) the law of reflection
- (i) determination of the position and characteristics of an optical image formed by a plane mirror or a thin converging lens

- (j) the refraction of light through glass blocks
- (k) determination of the resistance of a circuit component

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.

Apparatus List

This list below gives guidance to Centres concerning the apparatus and items that are expected to be generally available for examination purposes. The list is not intended to be exhaustive.

The apparatus and materials requirement for Paper 5 will vary from year to year. Centres will be notified in advance of the details of the apparatus and materials required for each practical examination.

Spare sets of apparatus must be available to allow for breakages and malfunctions.

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

Electrical	Mechanics and General Items
Ammeter (analogue): f.s.d 1 A	Pendulum bob
Voltmeter (analogue): f.s.d 3 V, f.s.d. 5V	Stand, boss and clamp: × 2 (Rod length: 60 cm)
Cells: 2 x 1.5 V with holder	
Lamp and holder: 2.5 V, 0.3 A	Pivot
Rheostat: Max resistance: 22 Ω, Rating: at least 3.3 A	Pulley
Resistors, various	Newton-meter: 1 N, 2.5 N
Switch	Rule with millimetre scale (1 × 1 m, 1 × 0.5 m, 1 × 300 mm)
Jockey	
Leads and crocodile clips	Digital calipers to 0.01 mm(1 per 4–6 candidates)
Wire: constantan 28 s.w.g. or metric equivalents	Digital micrometer screw gauge to 0.001 mm
Wire: nichrome 28, 32 s.w.g. or metric equivalents	(1 per 4–6 candidates)
Magnets: 2 × bar magnets	Stopwatch (reading to 0.1 s or better)
Compass: 1 × small	Balance to 0.01 g (1 per 8–12 candidates)
	Plasticine
	Blu-Tack
Heat	Springs
Long stem thermometer: –10° C to 110° C at 1° C	Optical pin
Beaker: 500 cm ³ , 2 × 250 cm ³	Slotted masses: 1 × 5 g; 1 × 10 g; 2 × 20 g;
Boiling tube, 150 mm × 25 mm	4 × 50 g; 1 × 50 g hanger
Measuring cylinder: 50 cm ³ , 100 cm ³	Slotted masses: 4 × 100 g; 1 × 100 g hanger
Plastic or polystyrene cup 200 cm ³	Burette
Means to heat water safely to boiling	Rubber tubing
Heating mat	Cork
Stirrer	Dropper
	String/thread/twine
Light	Scissors
Glass block (120 mm × 60 mm × 20 mm)	Adhesive tape
Microscope slides	Card (assorted sizes)
Mirror, plane (100 mm × 50 mm)	Wood (assorted sizes, for various uses, e.g. support)
Lens, converging f = 15 cm	
Lens holder	Wooden board
Screen (10 cm wide, 15 cm high)	Sand and tray
Torchlight	Bricks: 2 × (approx. 22 cm × 10 cm × 7 cm)
Protractor	
Pin board (23 cm × 30 cm)	
Pins	
Tracing paper	

Chemistry Practical Test

Candidates may be asked to carry out exercises based on:

- (a) quantitative experiments involving the use of a pipette, burette and an indicator such as methyl orange or screened methyl orange; if titrations other than acid / alkali are set, full instructions and other necessary information will be given. Candidates are expected to be familiar with the use of burettes with taps.
- (b) speeds of reaction that may involve measuring of quantities, e.g. volume, length, mass or time measurement
- (c) measurements of temperature based on thermometers with 1°C graduations
- (d) problems of an investigatory nature, possibly including suitable organic compounds
- (e) paper chromatography
- (f) filtration
- (g) qualitative inorganic analysis involving an element, a compound or a mixture, including precipitation reactions, and tests for oxidising and reducing agents (as specified in the syllabus)

Candidates should be familiar with the identification of ions and gases as specified in the syllabus.

Candidates would **not** be required to carry out tests involving sulfur dioxide gas or describe methods to prepare salts.

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

This is not intended to be an exhaustive list.

Responsibility for safety matters rests with Centres. Candidates should also be aware of the need for safe handling of chemicals and apparatus.

Candidates are not allowed to refer to notebooks, textbooks or any other information in the practical examination. *Chemistry Practical Notes* will be included in the question paper for the use of candidates in the examination.

Candidates may also be required to perform 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 cm³ and they should ensure that they have carried out a sufficient number of titrations, e.g. in an experiment with a good end-point, two titres within 0.20 cm³.
- (b) In qualitative analysis, candidates should use approximately 1 cm depth of a solution (1–2 cm³) 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 cm³
- one pipette, 25 cm³
- a supply of dropping pipettes
- one pipette filler
- two conical flasks within the range 150 cm³ to 250 cm³
- measuring cylinders, 10 cm³, 25 cm³ and 50 cm³
- one filter funnel
- beakers, squat form with lip: 100 cm³ and 250 cm³
- thermometer: -10° C to +110° C at 1° C graduations
- a polystyrene or other plastic beaker of approximate capacity 150 cm³
- test-tubes (Pyrex or hard glass), approximately 125 mm × 15 mm
- boiling tubes, approximately 150 mm × 25 mm
- 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
- wash bottle
- glass rod
- one white tile

The apparatus and material requirements for Paper 5 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/dm³)
- nitric acid (approximately 1.0 mol/dm³)
- sulfuric acid (approximately 0.5 mol/dm³)
- aqueous ammonia (approximately 1.0 mol/dm³)
- aqueous sodium hydroxide (approximately 1.0 mol/dm³)
- aqueous barium nitrate (approximately 0.2 mol/dm³)
- aqueous silver nitrate (approximately 0.05 mol/dm³)
- limewater (a saturated solution of calcium hydroxide)
- aqueous potassium manganate(VII) (approximately 0.02 mol/dm³)
- aqueous potassium iodide (approximately 0.1 mol/dm³)
- aluminium foil
- red and blue litmus paper and Universal Indicator paper

Biology Practical Test

- 1 The practical examination is designed to test candidates' abilities to:
 - (a) follow carefully a sequence of instructions within a set time allowance
 - (b) use familiar and unfamiliar techniques to record their observations and make deductions from them
 - (c) employ manipulative skills in assembling apparatus, in using chemical reagents and in using such instruments as mounted needles, scalpels and razor blades, forceps and scissors
 - (d) observe reactions, read simple measuring instruments and perform simple arithmetical calculations
 - (e) recognise and observe features of familiar and unfamiliar biological specimens, record their observations and make deductions about functions of whole specimens or their parts
 - (f) make clear line drawings of the specimens provided, indicate magnification and to label familiar structures
 - (g) interpret unfamiliar data and draw conclusions from their interpretations
 - (h) measure to an accuracy of 1 mm, using a ruler.
 - (i) comment on a procedure used in an experiment and suggest an improvement
 - (j) design / plan an investigation to solve a problem
- 2 Candidates may be asked to carry out simple physiological experiments, involving tests for food substances (specifically reducing sugars with Benedict's solution, starch using iodine solution, protein using the biuret test and fats using the ethanol emulsion test), enzyme reactions, hydrogen carbonate indicator solution, cobalt(II) chloride paper etc. It is expected that glassware and instruments normally found in a laboratory (e.g. beakers, test-tube racks, funnels, thermometers, droppers and so on) should be available for these experiments.
- 3 Candidates may be asked to carry out simple physiological experiments, involving the use of the above mentioned instruments 1(c) on plant or animal materials. Accurate observations of these specimens will need a hand lens of not less than $\times 6$ magnification for each candidate.
- 4 The material set will be closely related to the subject matter of the syllabus, but will not necessarily be limited to the particular types mentioned therein. In order to assist their own practical work, and to supply possible examination specimens, schools are asked to build up a reference collection of material.
- 5 When planning practical work, teachers should make sure that they do not contravene any school, education authority, or government regulations which restrict the sampling, in educational establishments, of urine, saliva, blood or other bodily secretions and tissues.

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 and practical examinations may require additional apparatus and materials. General laboratory glassware and items that are commonly regarded as standard equipment in a Biology laboratory (e.g. Bunsen burner, tripod and gauze, safety goggles, paper towels and so on) are not included in this list.

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

Light microscope, with high-, medium- and low-power objective lens (2 candidates to 1)

Microscope slides and coverslips

Mounted needle

Hand lens (not less than $\times 6$)

Half metre rule or metre rule

30 cm plastic ruler with a mm scale

Syringes (e.g. 1 cm³, 5 cm³, 10 cm³)

Dropper/Pasteur pipettes

Measuring cylinders

Beakers

Petri dishes

Test-tubes (some of which should be heat-resistant)

Test-tube rack and holder

Boiling tubes

Boiling tube rack

Glass rod

Rubber bungs to fit test-tubes and boiling tubes

Knife or scalpel

Forceps

Capillary tubes

Visking tubings

Rubber tubings

Thermometer: -10°C to $+110^{\circ}\text{C}$

Stopwatch

White tile

Filter funnel and paper

Pestle and mortar

Spatulas

Glass marker pen

Cotton wool

Black paper

Aluminium foil

Balance, single pan, direct reading, 0.01 g or better (1 per 8–12 candidates)

Retort stand and clamp

Bench lamp with 60W bulb

Distilled/deionised water in a wash bottle

Cutting mat

The apparatus and material requirements for Paper 5 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 would be notified in advance of the full list of all the reagents that are required for each practical examination.

Iodine solution, in a container with a dropping pipette
Benedict's solution, in a container with a dropping pipette
Ethanol (denatured), flammable – in a stoppered bottle with a dropping pipette
Biuret reagent, in a container with a dropping pipette
Glucose solution
Starch solution
Sodium chloride
Dilute hydrochloric acid
Hydrogencarbonate indicator
Sodium bicarbonate/sodium hydrogencarbonate
Limewater
Universal Indicator paper and chart
Litmus paper
Cobalt chloride paper
Methylene blue
Vaseline/petroleum jelly (or similar)

GLOSSARY OF TERMS USED IN SCIENCE 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) and the recommendations on terms, units and symbols in 'Biological Nomenclature 4th Edition (2009)' published by the Institute of Biology, in conjunction with the ASE, 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 dm³ 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, –CONH₂ and –CO₂H 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.

Geometrical Instruments

Candidates should have geometrical instruments with them for Paper 1 and Paper 2 for syllabus K326 and K327.