# Biology

## Singapore-Cambridge General Certificate of Education Advanced Level Higher 2 (2019)

## (Syllabus 9744)

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# PREAMBLE

This preamble sets out the approach, objectives, directions and philosophy of the H2 Biology syllabus.

In Singapore, Biology education from Primary to A-Level has been organised as a continuum in the following manner:

(a) from Primary 3 to Primary 6, students learn about how life works at the systems level

(b) from Lower Secondary Science to O-Level Biology, students learn about how life works at the physiological level

(c) at A-Level, students learn about how life works at the cellular and molecular levels while understanding the implications of these at the macro level.

The Biology syllabus is developed as a seamless continuum from O-Level to A-Level, without the need for topics to be revisited at A-Level. The O-Level syllabus is foundational and thus should provide the necessary background for study at A-Level. Students who intend to offer H2 Biology will therefore be assumed to have knowledge and understanding of O-Level Biology, either as a single subject or as part of a balanced science course.

Many new and important fields of biology have emerged through recent advancements in life sciences. Vast amounts of knowledge have been generated, as evident from the sprouting of scientific journals catering to niche areas of research. As such, this syllabus refines and updates the content knowledge of the previous syllabus (9648) so that students can keep up to date with knowledge that is relevant for their participation in a technology-driven economy.

# INTRODUCTION

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

The syllabus has been arranged in the form of Core and Extension content to be studied by all candidates. The syllabus places emphasis on the applications of biology and the impact of recent developments on the needs of contemporary society.

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

The value of learning H2 Biology ultimately hinges on the development of a scientific mind and disposition while addressing the broader questions of what life is and how life is sustained. The Science Curriculum Framework developed by the Ministry of Education elaborates on the development of the scientific mind and disposition. Through the study of the H2 Biology course, students will be prepared for life science-related courses at university and, consequently, careers that are related to this field.

# AIMS

The syllabus aims to:

1. provide students with an experience that develops their interest in biology and builds the knowledge, skills and attitudes necessary for further studies in related fields

2. enable students to become scientifically literate citizens who are well-prepared for the challenges of the 21st century

3. develop in students the understanding, skills, ethics and attitudes relevant to the *Practices of Science,* including the following:

   3.1 understanding the nature of scientific knowledge

   3.2 demonstrating science inquiry skills

   3.3 relating science and society

4. address the broader questions of what life is and how life is sustained, including:

   4.1 understanding life at the cellular and molecular levels, and making connections to how these micro-systems interact at the physiological and organismal levels

   4.2 recognising the evolving nature of biological knowledge

   4.3 stimulating interest in and demonstrating care for the local and global environment.

# PRACTICES OF SCIENCE

Science as a discipline is more than the acquisition of a *body of knowledge* (e.g. scientific facts, concepts, laws and theories); it is a way of knowing and doing. It includes an understanding of the nature of scientific knowledge and how this knowledge is generated, established and communicated. Scientists rely on a set of established procedures and practices associated with scientific inquiry to gather evidence and test their ideas on how the natural world works. However, there is no single method and the real process of science is often complex and iterative, following many different paths. While science is powerful, generating knowledge that forms the basis for many technological feats and innovations, it has limitations.

The *Practices of Science* are explicitly articulated in the syllabus to allow teachers to embed them as learning objectives in their lessons. Students' understanding of the nature and limitations of science and scientific inquiry are developed effectively when the practices are taught in the context of relevant science content. Attitudes relevant to science such as *inquisitiveness*, *concern for accuracy* and *precision*, *objectivity*, *integrity* and *perseverance* should be emphasised in the teaching of these practices where appropriate. For example, students learning science should be introduced to the use of technology as an aid in practical work or as a tool for the interpretation of experimental and theoretical results.

The *Practices of Science* comprise three components:

**1. Understanding the Nature of Scientific Knowledge**

1.1 Understand that science is an evidence-based, model-building enterprise concerned with the natural world

1.2 Understand that the use of both logic and creativity is required in the generation of scientific knowledge

1.3 Recognise that scientific knowledge is generated from consensus within the community of scientists through a process of critical debate and peer review

1.4 Understand that scientific knowledge is reliable and durable, yet subject to revision in the light of new evidence

**2. Demonstrating Science Inquiry Skills**

2.1 Identify scientific problems, observe phenomena and pose scientific questions/hypotheses

2.2 Plan and conduct investigations by selecting the appropriate experimental procedures, apparatus and materials, with due regard for accuracy, precision and safety

2.3 Obtain, organise and represent data in an appropriate manner

2.4 Analyse and interpret data

2.5 Construct explanations based on evidence and justify these explanations through sound reasoning and logical argument

2.6 Use appropriate models[1] to explain concepts, solve problems and make predictions

2.7 Make decisions based on evaluation of evidence, processes, claims and conclusions

2.8 Communicate scientific findings and information using appropriate language and terminology

[1] A model is a representation of an idea, an object, a process or a system that is used to describe and explain phenomena that cannot be experienced directly. Models exist in different forms, from the concrete, such as physical scale models, to the abstract, such as diagrams or mathematical expressions. The use of models involves the understanding that all models contain approximations and assumptions limiting their validity and predictive power.

**3. Relating Science and Society**

3.1 Recognise that the application of scientific knowledge to problem solving could be influenced by other considerations such as economic, social, environmental and ethical factors

3.2 Demonstrate an understanding of the benefits and risks associated with the application of science to society

3.3 Use scientific principles and reasoning to understand, analyse and evaluate real-world systems, as well as to generate solutions for problem solving

# CURRICULUM FRAMEWORK

The rapid progress in the field of life sciences poses a challenge for Biology education, especially in terms of designing a framework that integrates fundamental knowledge, skills and attitudes. With this in mind, this syllabus has adopted a framework that will chart a new direction for Biology education. An overview of this framework is depicted in Fig. 1: H2 Biology Curriculum Framework.

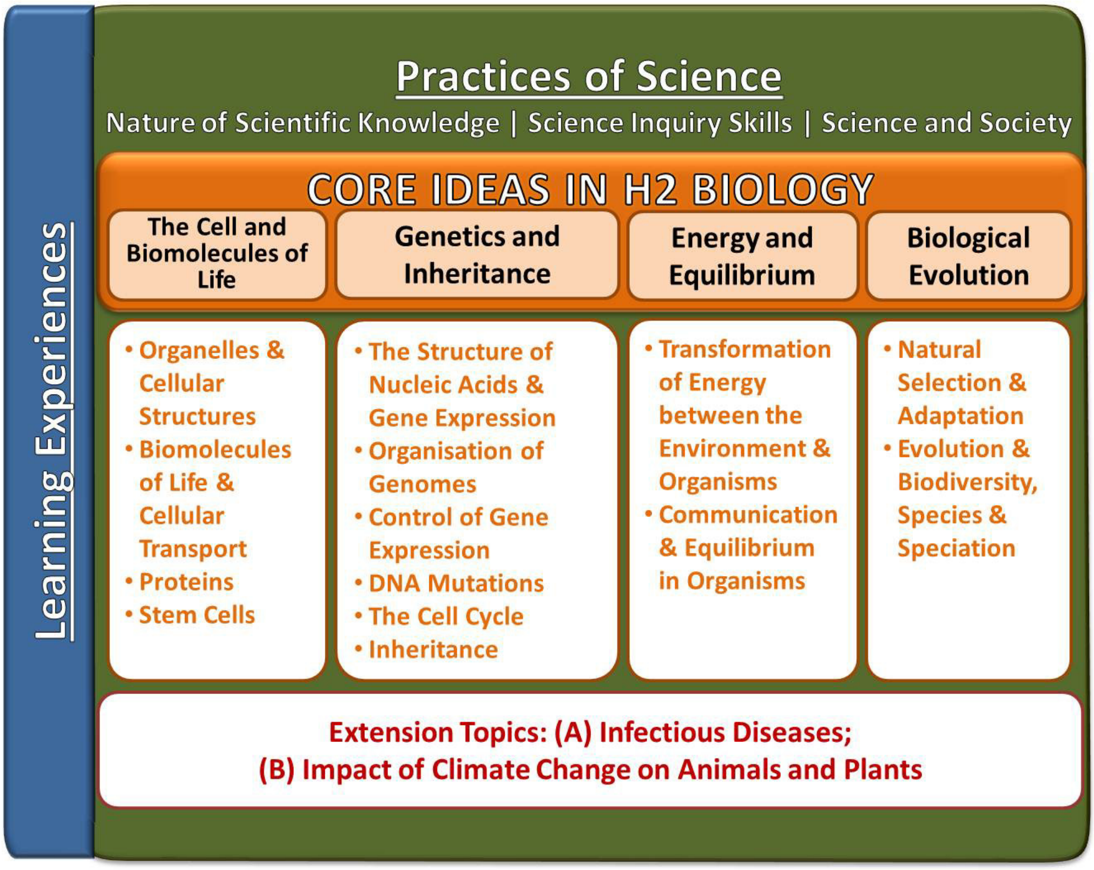


**Fig. 1:** H2 Biology Curriculum Framework

The *Practices of Science* are common to the natural sciences of Physics, Chemistry and Biology. These practices highlight the ways of thinking and doing that are inherent in the scientific approach, with the aim of equipping students with the understanding, skills, and attitudes shared by the scientific disciplines, including an appropriate approach to ethical issues.

The content in this H2 Biology syllabus is organised around four *Core Ideas* of Biology and two *Extension Topics*. The *Learning Experiences*[2] refer to a range of learning opportunities selected by teachers to link the biology content of the *Core Ideas* and *Extension Topics* with the *Practices of Science*, to enhance students' learning of the concepts. Rather than being mandatory, teachers are encouraged to incorporate *Learning Experiences* that match the interests and abilities of their students and provide opportunities to illustrate and exemplify the *Practices of Science*, where appropriate. Real-world contexts can help illustrate the biology concepts and their applications. Experimental activities and ICT tools can also be used to build students' understanding.

The two *Extension Topics* are based on important emerging biological issues impacting both the local and global contexts. They require students to demonstrate assimilation of the *Core Ideas* and extend their knowledge and understanding to real-world challenges. Furthermore, *Extension Topics* will equip students with the necessary knowledge and process skills to make informed decisions about scientific issues. In line with this, the two *Extension Topics* chosen are (A) Infectious Diseases and (B) Impact of Climate Change on Animals and Plants. Both *Extension Topics* take up about 10% of the total H2 Biology curriculum.

Students are expected to study all four *Core Ideas* and both *Extension Topics*.

[2] *Learning Experiences* can be found in the Teaching and Learning Syllabus.

# 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 with understanding in relation to:

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

The syllabus content defines the factual materials that candidates need to recall and explain. Questions testing the objectives above will often begin with one of the following words: *define, state, name, describe, explain or outline* (see the *Glossary of Terms*).

### B Handling, applying and evaluating information

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

1. locate, select, organise, interpret and present information from a variety of sources
2. handle information, distinguishing the relevant from the extraneous
3. manipulate numerical and other data and translate information from one form to another
4. present reasoned explanations for phenomena, patterns, trends and relationships
5. make comparisons that may include the identification of similarities and differences
6. analyse and evaluate information to identify patterns, report trends, draw inferences, report conclusions and construct arguments
7. justify decisions, make predictions and propose hypotheses
8. apply knowledge, including principles, to novel situations
9. use skills, knowledge and understanding from different areas of Biology to solve problems
10. organise and present information, ideas and arguments clearly and coherently, using appropriate language.

These *Assessment Objectives* above cannot be precisely specified in the syllabus content because questions testing such skills are often 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 may begin with one of the following words: *discuss, predict, suggest, calculate* or *determine* (see the *Glossary of Terms*).

**C Experimental skills and investigations**

Candidates should be able to:

1. follow a detailed sequence of instructions or apply standard techniques
2. devise and plan investigations which may include constructing and/or testing a hypothesis and select techniques, apparatus and materials
3. use techniques, apparatus and materials safely and effectively
4. make and record observations, measurements and estimates
5. interpret and evaluate observations and experimental data
6. evaluate methods and techniques, and suggest possible improvements.

# SCHEME OF ASSESSMENT

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

| Paper | Type of Paper | Duration | Weighting (%) | Marks |
|---|---|---|---|---|
| 1 | **Multiple Choice** | 1 h | 15 | 30 |
| 2 | **Structured Questions** | 2 h | 30 | 100 |
| 3 | **Long Structured and Free-response Questions** | 2 h | 35 | 75 |
| 4 | **Practical** | 2 h 30 min | 20 | 55 |

***Paper 1*** (1 h, 30 marks)
This paper will consist of 30 compulsory multiple choice questions. All questions will be of the direct choice type with 4 options.

***Paper 2*** (2 h, 100 marks)
This paper will consist of a variable number of structured questions, all compulsory, including data-based or comprehension-type questions. These include questions which require candidates to integrate knowledge and understanding from different areas of the syllabus.

***Paper 3*** (2 h, 75 marks)
This paper will consist of a variable number of long structured questions, all compulsory, including data-based or comprehension-type questions and one free-response question of 25 marks. These include questions that assess the higher-order skills of analysing, making conclusions and evaluating information and require candidates to integrate knowledge and understanding from different areas of the syllabus.

*Section A* (50 marks) will comprise two or more compulsory long structured questions. There will be one or more stimulus materials which may be taken or adapted from a source such as a scientific journal or book which may not necessarily relate directly to the content of the syllabus. Questions may require candidates to explain terms used in the passage, analyse data, justify decisions, perform calculations and draw conclusions based on information in the stimulus material.

*Section B* (25 marks) will comprise two free-response questions, from which candidates will choose **one**. The quality of scientific argumentation and written communication will be given a percentage of the marks available.

***Paper 4*** (2 h 30 min, 55 marks)
This paper will assess appropriate aspects of objectives C1 to C6 in the following skill areas:

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

The assessment of skill area P will have a weighting of 5%, and the skill areas MMO, PDO and ACE will have a weighting of 15%. Candidates will require access to apparatus, as stated in the Confidential Instructions. For some questions, candidates may be allocated a specific time for access to the apparatus. Paper 4 may also include data handling/interpretation questions that do not require apparatus, in order to test the skill areas of PDO and ACE.

Candidates are **NOT** allowed to refer to notebooks, textbooks or any other information in the Practical Examination.

**Weighting of Assessment Objectives**

| Assessment Objective | | Weighting (%) | Assessment Components |
|---|---|---|---|
| **A** | Knowledge with understanding | 32 | Papers 1, 2, 3 |
| **B** | Handling, applying and evaluating information | 48 | Papers 1, 2, 3 |
| **C** | Experimental skills and investigations | 20 | Paper 4 |

# ADDITIONAL INFORMATION

Modern biological sciences draw extensively on concepts from the physical sciences. It is desirable therefore that, by the end of the course, students should have knowledge of the following topics, sufficient to aid understanding of biological systems. No questions will be set directly on them except where relevant to the assessment of a Learning Outcome.

- The electromagnetic spectrum
- Energy changes (potential energy, activation energy, chemical bond energy)
- Molecules, atoms, ions, electrons
- Acids, bases, pH, buffers
- Isotopes, including radioactive isotopes
- Oxidation and reduction
- Hydrolysis, condensation

**Nomenclature**

Candidates will be expected to be familiar with the nomenclature used in the syllabus. The proposals in "*Signs, Symbols and Systematics*" (The Association for Science Education Companion to 16–19 Science, 2000) and the recommendations on terms, units and symbols in "*Biological Nomenclature*" (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 acid and nitrous acid will be used in question papers. Sulfur (and all compounds of sulfur) will be spelt with f (not with ph) in question papers. However, candidates can use either spelling in their answers.

**Disallowed Subject Combinations**

Candidates may not simultaneously offer Biology at H1 and H2 Levels.

**Units and Significant Figures**

Candidates should be aware that misuse of units and/or significant figures, e.g. 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.

# STRUCTURE OF SYLLABUS

The syllabus is divided into two parts: *Core Ideas* and *Extension Topics*, to be studied by all candidates.

I. Core Ideas. There are **4 Core Ideas**:

   1. The Cell and Biomolecules of Life
   2. Genetics and Inheritance
   3. Energy and Equilibrium
   4. Biological Evolution.

II. Extension Topics. There are **2 Extension Topics**:

   A. Infectious Diseases

   B. Impact of Climate Change on Animals and Plants.

# I. CORE IDEAS

## 1 The Cell and Biomolecules of Life

**Content**

- The cell theory
- Outline functions of membrane systems and organelles in cells
- The structure of a typical bacterial cell
- The structures of biomolecules and their functions
- The structural components of viruses
- The fluid mosaic model of membrane structure
- Mode of action of enzymes
- Stem cells

**Learning Outcomes**

Candidates should be able to:

(a) outline the cell theory with the understanding that cells are the smallest unit of life, all cells come from pre-existing cells, and living organisms are composed of cells

(b) interpret and recognise drawings, photomicrographs and electronmicrographs of the following membrane systems and organelles: rough and smooth endoplasmic reticulum, Golgi body, mitochondria, ribosomes, lysosomes, chloroplasts, cell surface membrane, nuclear envelope, centrioles, nucleus and nucleolus (for practical assessment, candidates may be required to operate a light microscope, mount slides and use a graticule)

(c) outline the functions of the membrane systems and organelles listed in (b)

(d) describe the structure of a typical bacterial cell (small and unicellular, peptidoglycan cell wall, circular DNA, 70S ribosomes and lack of membrane-bound organelles)

(e) describe the structural components of viruses, including enveloped viruses and bacteriophages, and interpret drawings and photographs of them

(f) discuss how viruses challenge the cell theory and concepts of what is considered living

(g) describe the structure and properties of the following monomers:

i. $\alpha$-glucose and $\beta$-glucose (in carbohydrates)

ii. glycerol and fatty acids (in lipids)

iii. amino acids (in proteins) (knowledge of chemical formulae of specific R-groups of different amino acids is not required)

(h) describe the formation and breakage of the following bonds:

i. glycosidic bond

ii. ester bond

iii. peptide bond

(i) describe the structures and properties of the following biomolecules and explain how these are related to their roles in living organisms:

i. starch (including amylose and amylopectin)

ii. cellulose

iii. glycogen

iv. triglyceride

v. phospholipid

(j) explain the fluid mosaic model and the roles of the constituent biomolecules (including phospholipids, proteins, glycolipids, glycoproteins and cholesterol) in cell membranes

(k) outline the functions of membranes at the surface of cells and membranes within the cell

(l) explain how and why different substances move across membranes through simple diffusion, osmosis, facilitated diffusion, active transport, endocytosis and exocytosis

(m) explain primary structure, secondary structure, tertiary structure and quaternary structure of proteins, and describe the types of bonds that hold the molecule in shape (hydrogen, ionic and disulfide bonds, and hydrophobic interactions)

(n) explain the effects of temperature and pH on protein structure

(o) describe the molecular structure of the following proteins and explain how the structure of each protein relates to the function it plays:

i. haemoglobin (transport)

ii. collagen (structural)

iii. G-protein linked receptor (signalling)

(knowledge of details of the number of amino acids and types of secondary structures present is not required)

(p) explain the mode of action of enzymes in terms of an active site, enzyme-substrate complex, lowering of activation energy and enzyme specificity using the lock-and-key and induced-fit hypotheses

(q) investigate and explain the effects of temperature, pH, enzyme concentration and substrate concentration of an enzyme-catalysed reaction by measuring rates of formation of products (e.g. measuring gas produced using catalase) or rate of disappearance of substrate (e.g. using amylase, starch and iodine)

(r) describe the structure of competitive and non-competitive inhibitors with reference to the binding sites of the inhibitor

(s) explain the effects of competitive and non-competitive inhibitors (including allosteric inhibitors) on the rate of enzyme activity

(t) describe the unique features of zygotic stem cells, embryonic stem cells and blood stem cells, correctly using the terms totipotency (zygotic stem cells which have the ability to differentiate into any cell type to form whole organisms and so are also pluripotent and multipotent), pluripotency (embryonic stem cells which have the ability to differentiate into almost any cell type to form any organ and so are not totipotent but are multipotent) and multipotency (blood stem cells which have the ability to differentiate into a limited range of cell types and so are not pluripotent or totipotent)

(u) explain the normal functions of stem cells in a living organism, including embryonic stem cells and blood stem cells

(v) discuss the ethical implications of the application of stem cells in research and medical applications and how human induced pluripotent stem cells (iPSCs) overcome some of these issues (procedural details of how iPSCs are formed are not required).

Use the knowledge gained in this section in new situations or to solve related problems.

## 2 Genetics and Inheritance

### Content

- DNA – structure and function
- Central Dogma – DNA to RNA, RNA to protein
- The structure of eukaryotic chromatin
- The genetics of viruses
- The genetics of bacteria
- Genome organisation at the DNA level
- Control of gene expression
- DNA analysis and genomics
- Mutations
- Replication and division of nuclei and cells
- Understanding of chromosome number and variation
- Effect of meiosis on chromosome number and variation
- The molecular biology of cancer
- The passage of information from parents to offspring
- Genotypes and phenotypes
- Dihybrid crosses
- Linkage and crossing-over
- Interaction between loci
- The effect of genotype and environment on the phenotype

### Learning Outcomes

Candidates should be able to:

(a) describe the structure and roles of DNA and RNA (tRNA, rRNA and mRNA) (knowledge of mitochondrial DNA is not required)

(b) describe the process of DNA replication and how the end replication problem arises

(c) describe how the information on DNA is used to synthesise polypeptides in prokaryotes and eukaryotes (description of the processes of transcription, formation of mRNA from pre-mRNA and translation is required)

(d) describe the structure and organisation of viral, prokaryotic and eukaryotic genomes (including DNA/RNA, single-/double-stranded, number of nucleotides, packing of DNA, linearity/circularity and presence/absence of introns)

(e) describe how the genomes of viruses are inherited through outlining the reproductive cycles of:

   i. bacteriophages that reproduce via a lytic cycle only, including T4 phage
   ii. bacteriophages that reproduce via lytic and lysogenic cycles, including lambda phage
   iii. enveloped viruses, including influenza
   iv. retroviruses, including HIV

(f) describe how variation in viral genomes arises, including antigenic shift and antigenic drift

(g) outline the mechanism of asexual reproduction by binary fission in a typical prokaryote and describe how transformation, transduction and conjugation (including the role of F plasmids but not Hfr) give rise to variation in prokaryotic genomes

(h) describe the structure and function of non-coding DNA in eukaryotes (i.e. portions that do not encode protein or RNA, including introns, centromeres, telomeres, promoters, enhancers and silencers) (knowledge of transposons, satellite DNA, pseudo-genes and duplication of segments is not required)

(i) explain how gene expression in prokaryotes can be regulated, through the concept of simple operons (including *lac* and *trp* operons), including the role of regulatory genes, and distinguish between inducible and repressible systems (knowledge of attenuation of the *trp* operon is not required)

(j) explain how differential (i.e. spatial and temporal) gene expression in eukaryotes can be regulated at different levels:

i. chromatin level (histone modification and DNA methylation)

ii. transcriptional level (control elements, such as promoters, silencers and enhancers, and proteins, such as transcription factors and repressors)

iii. post-transcriptional level (processing of pre-mRNA in terms of splicing, polyadenylation and 5' capping)

iv. translational level (half-life of RNA and initiation of translation)

v. post-translational level (biochemical modification and protein degradation)

(k) describe the principles and procedures of these molecular techniques:

i. polymerase chain reaction (including its advantages and limitations)

ii. gel electrophoresis

iii. Southern blotting and nucleic acid hybridisation

(l) explain what is meant by the terms *gene mutation* and *chromosomal aberration*. For gene mutation, knowledge of how substitution, addition and deletion could change the amino acid sequence (including frameshift) is required. For chromosomal aberration, knowledge of numerical aberration (including aneuploidy, as in the case of trisomy 21, i.e. Down syndrome) and structural aberration (including translocation, duplication, inversion and deletion) is required

(m) explain how gene mutations can result in diseases (including sickle cell anaemia)

(n) describe the events that occur during the mitotic cell cycle and the main stages of mitosis (including the behaviour of chromosomes, nuclear envelope, cell membrane and centrioles)

(o) explain the significance of the mitotic cell cycle (including growth, repair and asexual reproduction) and the need to regulate it tightly (knowledge that dysregulation of checkpoints of cell division can result in uncontrolled cell division and cancer is required, but detail of the mechanism is not required)

(p) identify the causative factors, including genetic, chemical carcinogens, ionising radiation and loss of immunity, which may increase the chances of cancerous growth

(q) explain how the loss of function mutation of tumour suppressor genes, including *p53*, and gain in function mutation of proto-oncogenes, including *ras*, results in uncontrolled cell division

(r) describe the development of cancer as a multi-step process that includes accumulation of mutations, angiogenesis and metastasis

(s) describe the events that occur during the meiotic cell cycle and the main stages of meiosis (including the behaviour of chromosomes, nuclear envelope, cell membrane and centrioles) (names of the main stages are expected, but not the sub-divisions of prophase)

(t) explain the significance of the meiotic cell cycle (including how meiosis and random fertilisation can lead to variation)

(u) explain the terms: *locus*, *allele*, *dominant*, *recessive*, *codominant*, *incomplete dominance*, *homozygous*, *heterozygous*, *phenotype*, *genotype* and *linkage*

(v) explain how genes are inherited from one generation to the next via the germ cells or gametes

(w) explain how genotype is linked to phenotype

(x) use genetic diagrams to solve problems in dihybrid crosses, including those involving codominance, incomplete dominance, multiple alleles, sex linkage, autosomal linkage and epistasis

(y) use genetic diagrams to solve problems involving test crosses

(z) explain the meaning of the terms linkage and crossing-over and explain the effect of linkage and crossing-over on the phenotypic ratios from dihybrid crosses

(aa) describe the interaction between loci (epistasis) and predict phenotypic ratios in problems involving epistasis (knowledge of the expected ratio for various types of epistasis is not required; focus of this section is on problem solving)

(bb) explain how the environment may affect the phenotype (including how diet affects the differentiation of honey bees and how temperature affects fur colour of Himalayan rabbits)

(cc) explain the difference between genetic variation that is continuous (many, additive genes control a characteristic) and genetic variation that is discontinuous (one or a few genes control a characteristic)

(dd) use the chi-squared test to test the significance of differences between observed and expected results.

Use the knowledge gained in this section in new situations or to solve related problems.

## 3 Energy and Equilibrium

**Content**

- The need for energy in living organisms
- Photosynthesis as an energy-trapping process
- Respiration as an energy-releasing process
- Aerobic respiration
- Anaerobic respiration
- An overview of cell signalling and communication
  - signal reception and the initiation of transduction
  - signal transduction pathways
  - cellular responses to signals

**Learning Outcomes**

Candidates should be able to:

(a) identify components of chloroplasts and mitochondria in drawings, photomicrographs and electronmicrographs

(b) explain the absorption and action spectra of photosynthetic pigments

(c) with reference to the chloroplast structure, describe and explain how light energy is harnessed and converted into chemical energy during the light-dependent reactions of photosynthesis

(d) outline the three phases of the Calvin cycle in C3 plants: (i) $CO_2$ fixation, (ii) PGA reduction and (iii) ribulose bisphosphate (RuBP) regeneration, indicating the roles of rubisco, ATP and reduced NADP in these processes that ultimately allow synthesis of sugars

(e) discuss limiting factors in photosynthesis and carry out investigations on the effect of limiting factors such as temperature, light intensity and carbon dioxide concentration on the rate of photosynthesis

(f) outline the process of glycolysis, highlighting the location, raw materials used and products formed (knowledge of details of the intermediate compounds and isomerisation is not required)

(g) outline the processes of the link reaction and Krebs cycle, highlighting the location, raw materials used and products formed (in terms of dehydrogenation and decarboxylation)

(h) outline the process of oxidative phosphorylation including the role of oxygen and the electron transport chain in aerobic respiration (names of complexes in the ETC are not required)

(i) explain the production of a small yield of ATP from respiration in anaerobic conditions in yeast and in mammalian muscle tissue

(j) explain the significance of the formation of ethanol in yeast and lactate in mammals in the regeneration of NAD

(k) investigate the effect of factors such as substrate concentration, type of substrate and temperature on the rate of respiration

(l) outline chemiosmosis in photosynthesis and respiration (names of complexes in the ETC are not required)

(m) outline the main stages of cell signalling:

   i. ligand-receptor interaction
   ii. signal transduction (phosphorylation cascade and signal amplification)
   iii. cellular response (change in gene expression)

   (knowledge of intracellular receptors is not required)

(n) explain the roles and nature of second messengers (including cyclic AMP)

(o) explain the role of kinases and phosphatases in signal amplification

(p) outline how insulin and glucagon regulate the concentration of blood glucose through the respective tyrosine kinase receptor and G-protein linked receptor. (The outline should be limited to describing how the ligand induces a conformational change in a membrane-bound receptor to trigger downstream signalling pathways that elicit physiological changes in blood glucose concentration. Details of different second messengers and specific kinases activated in the pathway are not required.)

Use the knowledge gained in this section in new situations or to solve related problems.

## 4 Biological Evolution

**Content**

- The concept of the species
- The neo-Darwinian revolution
- Variation, natural selection and evolution
- Evidence of evolution
- Classification

**Learning Outcomes**

Candidates should be able to:

(a) explain why variation (as a result of mutation, meiosis and sexual reproduction) is important in natural selection

(b) explain, with examples, how environmental factors act as forces of natural selection

(c) explain the role of natural selection in evolution

(d) explain why the population is the smallest unit that can evolve

(e) explain how genetic variation (including recessive alleles) may be preserved in a natural population

(f) define biological evolution as descent with modification and explain the link between micro-evolution and macro-evolution

(g) explain how evidence based on homologies identified in biochemical data (molecular homologies) and the fossil record (anatomical homologies), together with biogeography, supports Darwin's theory of evolution

(h) explain the various concepts of the species (biological, ecological, morphological, genetic and phylogenetic concepts)

(i) define biological classification as the organisation of species according to shared characteristics and describe how evolutionary relationship is established

(j) explain how new species are formed with respect to geographical isolation (allopatric speciation) and behavioural or physiological isolation within the same geographical location (sympatric speciation)

(k) define phylogeny as the organisation of species to show their evolutionary relationships

(l) explain the importance of the use of genome sequences in reconstructing phylogenetic relationships and state the advantages of molecular methods, including multiple sequence alignment (nucleotide and amino acid), in classifying organisms.

Use the knowledge gained in this section in new situations or to solve related problems.

## II. EXTENSION TOPICS

### A Infectious Diseases

**Content**

- The immune system – adaptive and innate
- Genetic recombination
- Mode of viral and bacterial infections
- Vaccination and modes of action of antibiotics

**Learning Outcomes**

Candidates should be able to:

(a) describe the specific (adaptive) and non-specific (innate) immune systems including active and passive, natural and acquired immunity

(b) outline the roles of B lymphocytes, T lymphocytes, antigen-presenting cells and memory cells in specific primary and secondary immune responses

(c) explain the relationship of the molecular structure of antibodies to their functions, using IgG as an example

(d) explain how genetic recombination during development results in millions of different antibody molecules (including somatic recombination, hyper-mutation and class switching)

(e) discuss how vaccination can control disease (including the eradication of small pox), limited to vaccination stimulates immunity without causing the disease and vaccination of a high enough proportion of the population can break the disease transmission cycle

(f) discuss the benefits and risks of vaccination

(g) explain how viruses, including influenza and HIV, cause diseases in humans through the disruption of host tissue and functions (including HIV and T helper cells, influenza and epithelial cells of the respiratory tract)

(h) explain the mode of transmission and infection of bacterial pathogens, using *Mycobacterium tuberculosis* as an example

(i) describe the modes of action of antibiotics, including penicillin, on bacteria.

Use the knowledge gained in this section in new situations or to solve related problems.

## B Impact of Climate Change on Animals and Plants

**Content**

- Human activities that contribute to climate change
- Effects of climate change on the environment, plants and animals
- Impact on biodiversity, biomedicines and the global food supply
- Viral dengue disease in humans and how global warming affects its spread

**Learning Outcomes**

Candidates should be able to:

(a) identify and explain the human activities over the last few centuries that have contributed to climate change through increased emission of greenhouse gases (limited to $CO_2$ and methane) including burning of fossil fuels linked to increasing energy usage, clearing of forests and food choices (increasing consumption of meat)

(b) explain the effects of climate change as a result of greenhouse gas emissions including the melting of polar ice caps, rising sea levels, stress on fresh water supplies, heat waves, heavy rains, death of coral reefs, migration of fishes and insects, and release of greenhouse gases in frozen organic matter

(c) explain how climate change affects plant distribution (vertical and latitude) and plant adaptations, including morphology and physiology

(d) discuss the consequences to the global food supply of increased environmental stress resulting from climate change, including the effects on plants and animals of increased temperature and more extreme weather conditions

(e) explain how temperature changes impact insects, including increased temperature leading to increased metabolism and the narrow temperature tolerance of insects

(f) outline the life-cycle of *Aedes aegypti* as an example of a typical mosquito vector

(g) outline the development of viral dengue disease in humans, including host-pathogen interactions, human susceptibility to the virus, pathogen virulence, transmission and drug resistance

(h) explain how global warming affects the spread of mosquito-borne infectious diseases, including malaria and dengue, beyond the tropics

(i) discuss the effects of increased environmental stress (including increased temperatures and more extreme weather conditions) as a result of global climate change, on habitats, organisms, food chains and niche occupation

(j) discuss how climate change affects the rich biodiversity of the tropics including the potential loss of this rich reservoir for biomedicines and genetic diversity for food.

Use the knowledge gained in this section in new situations or to solve related problems.

# PRACTICAL ASSESSMENT

Scientific subjects are, by their nature, experimental. It is therefore important that, wherever possible, the candidates carry out appropriate practical work to support the learning of this subject and to develop the expected practical skills.

**Paper 4 Practical**

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

Candidates will be assessed in the following skill areas:

(a) Planning (P)

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

(b) Manipulation, measurement and observation (MMO)

Candidates should be able to:
- demonstrate a high level of manipulative skills in all aspects of practical activity
- make and record accurate observations with good details and measurements to an appropriate degree of precision
- make appropriate decisions about measurements or observations
- recognise anomalous observations and/or measurements (where appropriate) with reasons indicated.

(c) Presentation of data and observations (PDO)

Candidates should be able to:
- present all information in an appropriate form
- manipulate measurements effectively in order to identify trends/patterns
- present all quantitative data to an appropriate number of decimal places/significant figures.

(d) Analysis, conclusions and evaluation (ACE)

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

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

The assessment of skills MMO, PDO and ACE will also be set mainly in the context of the syllabus content and will require access to apparatus, as stated in the Confidential Instructions. For some questions, candidates may be allocated a specific time for access to the apparatus. The assessment of PDO and ACE may also include questions on data-analysis which do not require practical equipment and apparatus.

Within the Scheme of Assessment, Paper 4 is weighted to 20% of the Higher 2 assessment. It is therefore recommended that the schemes of work include learning opportunities that apportion a commensurate amount of time for the development and acquisition of practical skills. The guidance for practical work, which is published separately, will provide examples of practical activities.

Candidates are **NOT** allowed to refer to notebooks, textbooks or any other information in the Practical examination.

**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 that will be specified in the Confidential Instructions, e.g. enzymes, indicators, plastic straws, etc. Furthermore, general laboratory glassware and items that are commonly regarded as standard equipment in a Biology laboratory (e.g. Bunsen burners, tripods and gauze, thermostatic water-baths, safety goggles, disposable gloves, paper towels, etc.) are not included in this list.

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

Light microscope, with high- and low-power objective lens and fitted eyepiece graticule (2 candidates to 1)
Stage micrometer (2 candidates to 1)
Microscope slides and coverslips
Mounted needles
Hand lens (not less than ×6) (2 candidates to 1)
Half-metre rule or metre rule
Ruler in mm
Syringes (e.g. $1\,cm^3$, $5\,cm^3$, $10\,cm^3$)
Droppers or 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
Small containers
Glass rod
Corks or rubber bungs to fit test-tubes and boiling tubes
Knife or scalpel
Forceps
Cork borer (2 candidates to 1)
Capillary tubes
Vaseline/petroleum jelly (or similar)
Specimen tubes
Visking tubing
Silicone tubing
Thermometer: –10 °C to +110 °C
Stopwatch
White tile
Filter paper and funnel
Mortar and pestle (2 candidates to 1)
Spatulas
Glass marker pen
Cotton wool
Black paper
Aluminium foil
Balance to 0.01 g (to be made accessible to candidates)
Retort stand and clamp
Bench lamp
Distilled or deionised water
Microfuge tubes and rack
Micropipettes (e.g. 20 μl, 1000 μl, etc.)(2 candidates to 1) and disposable tips
Inoculating loops

Agarose gel electrophoresis cell (including tank, lid, cables, gel tray, comb) and power supply (to be made accessible to candidates)
TAE/TBE buffer
Agarose powder
Nutrient medium

The apparatus and material requirements for Paper 4 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 the reagents required for each practical examination.

iodine in potassium iodide solution
Benedict's solution
biuret reagent
sucrose (use AR for non-reducing sugar test)
glucose
starch
potassium hydroxide
sodium chloride
dilute hydrochloric acid
hydrogencarbonate indicator (bicarbonate indicator)
sodium hydrogencarbonate (sodium bicarbonate)
limewater
Universal Indicator paper and chart
litmus paper
methylene blue
DCPIP (2,6-dichlorophenolindophenol)

# MATHEMATICAL REQUIREMENTS

Questions set in the examination may involve the basic processes of mathematics for the calculation and use of decimals, means, ratios and percentages.

Candidates may be required to (i) construct graphs or present data in other suitable graphical forms, and (ii) calculate rates of processes.

Candidates should be aware of the problems of drawing conclusions from limited data and should appreciate levels of significance, standard deviation and probability, and the use of *t*- and chi-squared tests.

**Notes on the Use of Statistics in Biology**

Candidates should know how to apply a *t*-test and a chi-squared test. *t*-tests are of value in much of Biology, while the chi-squared test allows the evaluation of the results of breeding experiments and ecological sampling. Each of these tests is dealt with fully in many books on statistics for Biology.

Candidates are not expected to remember the following equations or what the symbols stand for. They are expected to be able to use the equations to calculate standard deviations, to test for significant differences between the means of two small unpaired samples and to perform a chi-squared test on suitable data from genetics or ecology. Candidates will be given access to the equations, the meaning of the symbols, a *t*-table and a chi-squared table.

standard deviation $$s = \sqrt{\frac{\sum\left(x - \bar{x}\right)^2}{n - 1}}$$

*t*-test $$t = \frac{\left|\bar{x}_1 - \bar{x}_2\right|}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}} \qquad v = n_1 + n_2 - 2$$

$\chi^2$ test $$\chi^2 = \sum\frac{\left(\mathrm{O} - \mathrm{E}\right)^2}{\mathrm{E}} \qquad v = \mathrm{c} - 1$$

*Key to symbols*

| | | |
|---|---|---|
| $s$* = standard deviation | $\sum$ = 'sum of' | $\bar{x}$ = mean |
| $n$ = sample size (number of observations) | $x$ = observation | |
| $v$ = degrees of freedom | O = observed 'value' | |
| E = expected 'value' | c = number of classes | |

*Candidates should note that on some calculators the symbol $\sigma$ may appear instead of the symbol $s$.

Candidates are not expected to be familiar with the term *standard error*, nor to appreciate the difference between $s_n$ ($\sigma_n$) and $s_{n-1}$ ($\sigma_{n-1}$). $\chi^2$ tests will only be expected on one row of data. Candidates should have a brief understanding of what is meant by the term *normal distribution* and appreciate levels of significance. (Tables will be provided.) Questions involving the use of a *t*-test or $\chi^2$ test may be set on Papers 1, 2 and 3. Questions involving an understanding of the use of the tests may be set on Paper 4 but detailed computation will not be required.

**Calculators**

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

# TEXTBOOKS AND REFERENCES

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Plopper, G, Sikorski, E and Sharp, D (2014) *Lewin's Cells* (Revised Third Edition) (Jones and Bartlett) ISBN 1284029395

Pomerville, J C (2013) *Fundamentals of Microbiology* (Tenth Edition) (Jones and Bartlett) ISBN 1284039684

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**Evolution**

Dobzhansky, T (March 1973) Nothing in Biology Makes Sense Except in the Light of Evolution, *American Biology Teacher* vol. 35 (3)

**Climate Change**

Alley, R B (2000) *The Two-mile Time Machine* (First Edition) (Princeton Science Library) ISBN 9780691160832

Bickford, D, Howard, S D, Ng, D J J and Sheridan, J A (2010) Impacts of climate change on the amphibians and reptiles of Southeast Asia*. Biodiversity and Conservation*.

Sheridan, J A and Bickford, D P (2011) Shrinking body size as an ecological response to climate change. *Nature Climate Change* 1:401–406

# GLOSSARY OF TERMS

It is hoped that the glossary (which is relevant only to science subjects) will prove helpful to candidates as a guide; 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. *Analyse* is a context-specific term involving the identification of the constituent parts of a complex situation or result, an assessment of their individual implications and a consideration of how these relate to one another and to scientific knowledge and understanding. Analysis may require further processing of mathematical data to reveal underlying trends and patterns.

2. *Calculate* is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved.

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

4. *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.

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

6. *Deduce* is used in a similar way as predict except that some supporting statement is required, e.g. reference to a law/principle, or the necessary reasoning is to be included in the answer.

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

8. *Describe* requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena.

   In other contexts, describe and give an account of should be interpreted more generally, i.e. the candidate has greater discretion about the nature and the organisation of the material to be included in the answer. Describe and explain may be coupled in a similar way to state and explain.

9. *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula, e.g. relative molecular mass.

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

11. *Draw* is often used in the context of drawing biological specimens. This is an instruction to make a freehand diagram to show the structures observed, as accurately as possible with respect to shape and proportion. Lines delimiting distinct regions should be continuous.

    In other contexts, this will require an accurate representation of the required subject according to the applicable conventions and criteria. E.g. Draw the structure of a molecule of glucose.

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

13. *Evaluate* is a context-specific term requiring a critical use of information to make a judgement or determination of a particular value or quality (e.g. accuracy). Evaluation of the validity of an experimental procedure, a set of results or a conclusion involves an assessment of the extent to which the procedures, results or conclusions are likely to obtain or represent a ‘true’ outcome. This will require consideration of the advantages and disadvantages, strengths and weaknesses, and limitations of the underlying approach, as well as other relevant criteria as applicable, and their relative importance.

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

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

16. *Justify* requires candidates to give reasoning in support of an answer (for example, a decision, conclusion, explanation or claim), based on a consideration of available evidence, including experimental data, together with relevant scientific knowledge and understanding.

17. *Label* requires candidates to use an appropriate label (and labelling line, where necessary) to accurately show the position of a structure, region or point within a diagram or graph, according to the requirements of the assessment.

18. *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.

19. *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.

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

21. *Predict* implies that the candidate is not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted in an early part of the question.

22. *Recognise* is often used to identify facts, characteristics or concepts that are critical (relevant/ appropriate) to the understanding of a situation, event, process or phenomenon.

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

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

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

25. *Suggest* is used in two main contexts, i.e. either to imply that there is no unique answer (e.g. in chemistry, two or more substances may satisfy the given conditions describing an ‘unknown’), or to imply that candidates are expected to apply their general knowledge to a ‘novel’ situation, one that may be formally ‘not in the syllabus’.

26. *What is meant by (the term(s)...)* normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in the light of the indicated mark value.