AS Level subject content

1 Cell structure

All organisms are composed of cells. Knowledge of the structure and function of cells underpins much of biology. The fundamental differences between eukaryotic and prokaryotic cells are explored and provide useful biological background for the topic on Infectious diseases (Topic 10). Viruses are introduced as non-cellular structures, which gives candidates the opportunity to consider whether cells are the basic unit of life.

The use of light microscopes is a fundamental skill that is developed in this topic and applied throughout several other topics of the syllabus.

1.1 The microscope in cell studies

Learning outcomes
Candidates should be able to:

1 make temporary preparations of cellular material suitable for viewing with a light microscope

2 draw cells from microscope slides and photomicrographs

3 calculate magnifications of images and actual sizes of specimens from drawings, photomicrographs and electron micrographs (scanning and transmission)

4 use an eyepiece graticule and stage micrometer scale to make measurements and use the appropriate units, millimetre (mm), micrometre (μm) and nanometre (nm)

5 define resolution and magnification and explain the differences between these terms, with reference to light microscopy and electron microscopy

1.2 Cells as the basic units of living organisms

Learning outcomes
Candidates should be able to:

1 recognise organelles and other cell structures found in eukaryotic cells and outline their structures and functions, limited to:

- cell surface membrane
- nucleus, nuclear envelope and nucleolus
- rough endoplasmic reticulum
- smooth endoplasmic reticulum
- Golgi body (Golgi apparatus or Golgi complex)
- mitochondria (including the presence of small circular DNA)
- ribosomes (80S in the cytoplasm and 70S in chloroplasts and mitochondria)
- lysosomes
- centrioles and microtubules
- cilia
- microvilli
- chloroplasts (including the presence of small circular DNA)
- cell wall
- plasmodesmata
- large permanent vacuole and tonoplast of plant cells

continued

1.2 Cells as the basic units of living organisms (continued)

Learning outcomes

Candidates should be able to:

2 describe and interpret photomicrographs, electron micrographs and drawings of typical plant and animal cells

3 compare the structure of typical plant and animal cells

4 state that cells use ATP from respiration for energy-requiring processes

5 outline key structural features of a prokaryotic cell as found in a typical bacterium, including:

- unicellular
- generally 1–5 μm diameter
- peptidoglycan cell walls
- circular DNA
- 70S ribosomes
- absence of organelles surrounded by double membranes

6 compare the structure of a prokaryotic cell as found in a typical bacterium with the structures of typical eukaryotic cells in plants and animals

7 state that all viruses are non-cellular structures with a nucleic acid core (either DNA or RNA) and a capsid made of protein, and that some viruses have an outer envelope made of phospholipids

2 Biological molecules

This topic introduces carbohydrates, lipids and proteins: organic molecules that are important in cells. Nucleic acids, another class of biological molecule, are covered in Topic 6. All of these molecules are based on the versatile element carbon. This topic explains how carbohydrates, lipids and proteins, which have a great diversity of function in organisms, are assembled from smaller organic molecules such as glucose, amino acids, glycerol and fatty acids.

The emphasis in this topic is on the relationship between molecular structures and their functions. Some of these ideas are continued in other topics, for example, the functions of haemoglobin in gas transport in Transport in mammals (Topic 8), phospholipids in membranes in Cell membranes and transport (Topic 4) and antibodies in Immunity (Topic 11).

Life as we know it would not be possible without water. Understanding the properties of this extraordinary molecule is an essential part of any study of biological molecules. Some of the roles of water are in this topic, others are in Topics 4, 7, 8, 12, 13 and 14.

2.1 Testing for biological molecules

Learning outcomes
Candidates should be able to:

1 describe and carry out the Benedict's test for reducing sugars, the iodine test for starch, the emulsion test for lipids and the biuret test for proteins

2 describe and carry out a semi-quantitative Benedict's test on a reducing sugar solution by standardising the test and using the results (time to first colour change or comparison to colour standards) to estimate the concentration

3 describe and carry out a test to identify the presence of non-reducing sugars, using acid hydrolysis and Benedict's solution

2.2 Carbohydrates and lipids

Learning outcomes
Candidates should be able to:

1 describe and draw the ring forms of α-glucose and β-glucose

2 define the terms monomer, polymer, macromolecule, monosaccharide, disaccharide and polysaccharide

3 state the role of covalent bonds in joining smaller molecules together to form polymers

4 state that glucose, fructose and maltose are reducing sugars and that sucrose is a non-reducing sugar

5 describe the formation of a glycosidic bond by condensation, with reference to disaccharides, including sucrose, and polysaccharides

continued

2.2 Carbohydrates and lipids continued	**Learning outcomes** Candidates should be able to: 6 describe the breakage of a glycosidic bond in polysaccharides and disaccharides by hydrolysis, with reference to the non-reducing sugar test 7 describe the molecular structure of the polysaccharides starch (amylose and amylopectin) and glycogen and relate their structures to their functions in living organisms 8 describe the molecular structure of the polysaccharide cellulose and outline how the arrangement of cellulose molecules contributes to the function of plant cell walls 9 state that triglycerides are non-polar hydrophobic molecules and describe the molecular structure of triglycerides with reference to fatty acids (saturated and unsaturated), glycerol and the formation of ester bonds 10 relate the molecular structure of triglycerides to their functions in living organisms 11 describe the molecular structure of phospholipids with reference to their hydrophilic (polar) phosphate heads and hydrophobic (non-polar) fatty acid tails
2.3 Proteins	**Learning outcomes** Candidates should be able to: 1 describe and draw the general structure of an amino acid and the formation and breakage of a peptide bond 2 explain the meaning of the terms primary structure, secondary structure, tertiary structure and quaternary structure of proteins 3 describe the types of interaction that hold protein molecules in shape: • hydrophobic interactions • hydrogen bonding • ionic bonding • covalent bonding, including disulfide bonds 4 state that globular proteins are generally soluble and have physiological roles and fibrous proteins are generally insoluble and have structural roles 5 describe the structure of a molecule of haemoglobin as an example of a globular protein, including the formation of its quaternary structure from two alpha (α) chains (α–globin), two beta (β) chains (β–globin) and a haem group 6 relate the structure of haemoglobin to its function, including the importance of iron in the haem group 7 describe the structure of a molecule of collagen as an example of a fibrous protein, and the arrangement of collagen molecules to form collagen fibres 8 relate the structures of collagen molecules and collagen fibres to their function

2.4 Water	**Learning outcomes** Candidates should be able to: 1 explain how hydrogen bonding occurs between water molecules and relate the properties of water to its roles in living organisms, limited to solvent action, high specific heat capacity and latent heat of vaporisation

3 Enzymes

Enzymes are essential for life to exist. The mode of action of enzymes and the factors that affect their activity are explored in this topic. Prior knowledge for this topic is an understanding that an enzyme is a biological catalyst that increases the rate of a reaction and remains unchanged when the reaction is complete.

There are many opportunities in this topic for candidates to gain experience of carrying out practical investigations and analysing, interpreting and evaluating their results.

3.1 Mode of action of enzymes

Learning outcomes
Candidates should be able to:

1 state that enzymes are globular proteins that catalyse reactions inside cells (intracellular enzymes) or are secreted to catalyse reactions outside cells (extracellular enzymes)

2 explain the mode of action of enzymes in terms of an active site, enzyme–substrate complex, lowering of activation energy and enzyme specificity, including the lock-and-key hypothesis and the induced-fit hypothesis

3 investigate the progress of enzyme-catalysed reactions by measuring rates of formation of products using catalase and rates of disappearance of substrate using amylase

4 outline the use of a colorimeter for measuring the progress of enzyme-catalysed reactions that involve colour changes

3.2 Factors that affect enzyme action

Learning outcomes
Candidates should be able to:

1 investigate and explain the effects of the following factors on the rate of enzyme-catalysed reactions:
- temperature
- pH (using buffer solutions)
- enzyme concentration
- substrate concentration
- inhibitor concentration

2 explain that the maximum rate of reaction (V_{max}) is used to derive the Michaelis–Menten constant (K_m), which is used to compare the affinity of different enzymes for their substrates

3 explain the effects of reversible inhibitors, both competitive and non-competitive, on enzyme activity

4 investigate the difference in activity between an enzyme immobilised in alginate and the same enzyme free in solution, and state the advantages of using immobilised enzymes

4 Cell membranes and transport

The fluid mosaic model, introduced in 1972, describes the way in which biological molecules are arranged to form cell membranes. The model continues to be modified as understanding improves of the ways in which substances cross membranes, how cells interact and how cells respond to signals. The model also provides the basis for our understanding of passive and active movement of molecules and ions between cells and their surroundings, cell-to-cell interactions and long-distance cell signalling.

Investigating the effects of different factors on diffusion, osmosis and membrane permeability involves an understanding of the properties of phospholipids and proteins covered in Biological molecules (Topic 2).

4.1 Fluid mosaic membranes

Learning outcomes
Candidates should be able to:

1 describe the fluid mosaic model of membrane structure with reference to the hydrophobic and hydrophilic interactions that account for the formation of the phospholipid bilayer and the arrangement of proteins

2 describe the arrangement of cholesterol, glycolipids and glycoproteins in cell surface membranes

3 describe the roles of phospholipids, cholesterol, glycolipids, proteins and glycoproteins in cell surface membranes, with reference to stability, fluidity, permeability, transport (carrier proteins and channel proteins), cell signalling (cell surface receptors) and cell recognition (cell surface antigens – see 11.1.2)

4 outline the main stages in the process of cell signalling leading to specific responses:
- secretion of specific chemicals (ligands) from cells
- transport of ligands to target cells
- binding of ligands to cell surface receptors on target cells

4.2 Movement into and out of cells

Learning outcomes
Candidates should be able to:

1 describe and explain the processes of simple diffusion, facilitated diffusion, osmosis, active transport, endocytosis and exocytosis

2 investigate simple diffusion and osmosis using plant tissue and non-living materials, including dialysis (Visking) tubing and agar

3 illustrate the principle that surface area to volume ratios decrease with increasing size by calculating surface areas and volumes of simple 3-D shapes (as shown in the Mathematical requirements)

4 investigate the effect of changing surface area to volume ratio on diffusion using agar blocks of different sizes

continued

4.2 Movement into and out of cells continued	**Learning outcomes** Candidates should be able to: 5 investigate the effects of immersing plant tissues in solutions of different water potentials, using the results to estimate the water potential of the tissues 6 explain the movement of water between cells and solutions in terms of water potential and explain the different effects of the movement of water on plant cells and animal cells (knowledge of solute potential and pressure potential is not expected)

5 The mitotic cell cycle

When body cells reach a certain size they divide into two cells. Nuclear division occurs first, followed by division of the cytoplasm. The mitotic cell cycle of eukaryotes involves DNA replication followed by nuclear division. This ensures the genetic uniformity of all daughter cells.

5.1 Replication and division of nuclei and cells

Learning outcomes
Candidates should be able to:

1 describe the structure of a chromosome, limited to:
- DNA
- histone proteins
- sister chromatids
- centromere
- telomeres

2 explain the importance of mitosis in the production of genetically identical daughter cells during:
- growth of multicellular organisms
- replacement of damaged or dead cells
- repair of tissues by cell replacement
- asexual reproduction

3 outline the mitotic cell cycle, including:
- interphase (growth in G_1 and G_2 phases and DNA replication in S phase)
- mitosis
- cytokinesis

4 outline the role of telomeres in preventing the loss of genes from the ends of chromosomes during DNA replication

5 outline the role of stem cells in cell replacement and tissue repair by mitosis

6 explain how uncontrolled cell division can result in the formation of a tumour

5.2 Chromosome behaviour in mitosis

Learning outcomes
Candidates should be able to:

1 describe the behaviour of chromosomes in plant and animal cells during the mitotic cell cycle and the associated behaviour of the nuclear envelope, the cell surface membrane and the spindle (names of the main stages of mitosis are expected: prophase, metaphase, anaphase and telophase)

2 interpret photomicrographs, diagrams and microscope slides of cells in different stages of the mitotic cell cycle and identify the main stages of mitosis

6 Nucleic acids and protein synthesis

Nucleic acids have roles in the storage and retrieval of genetic information and in the use of this information to synthesise polypeptides. DNA is the molecule of heredity and is an extremely stable molecule that cells replicate with great accuracy. The genetic code explains how the sequence of nucleotides in DNA and messenger RNA (mRNA) determines the sequence of amino acids that make up a polypeptide. In eukaryotes this involves the processes of transcription in the nucleus to produce mRNA, followed by translation in the cytoplasm to produce polypeptides.

6.1 Structure of nucleic acids and replication of DNA

Learning outcomes
Candidates should be able to:

1 describe the structure of nucleotides, including the phosphorylated nucleotide ATP (structural formulae are not expected)

2 state that the bases adenine and guanine are purines with a double ring structure, and that the bases cytosine, thymine and uracil are pyrimidines with a single ring structure (structural formulae for bases are not expected)

3 describe the structure of a DNA molecule as a double helix, including:

- the importance of complementary base pairing between the 5′ to 3′ strand and the 3′ to 5′ strand (antiparallel strands)
- differences in hydrogen bonding between C–G and A–T base pairs
- linking of nucleotides by phosphodiester bonds

4 describe the semi-conservative replication of DNA during the S phase of the cell cycle, including:

- the roles of DNA polymerase and DNA ligase (knowledge of other enzymes in DNA replication in cells and different types of DNA polymerase is not expected)
- the differences between leading strand and lagging strand replication as a consequence of DNA polymerase adding nucleotides only in a 5′ to 3′ direction

5 describe the structure of an RNA molecule, using the example of messenger RNA (mRNA)

6.2 Protein synthesis

Learning outcomes
Candidates should be able to:

1 state that a polypeptide is coded for by a gene and that a gene is a sequence of nucleotides that forms part of a DNA molecule

2 describe the principle of the universal genetic code in which different triplets of DNA bases either code for specific amino acids or correspond to start and stop codons

continued

6.2 Protein synthesis continued

Learning outcomes

Candidates should be able to:

3 describe how the information in DNA is used during transcription and translation to construct polypeptides, including the roles of:
- RNA polymerase
- messenger RNA (mRNA)
- codons
- transfer RNA (tRNA)
- anticodons
- ribosomes

4 state that the strand of a DNA molecule that is used in transcription is called the transcribed or template strand and that the other strand is called the non-transcribed strand

5 explain that, in eukaryotes, the RNA molecule formed following transcription (primary transcript) is modified by the removal of non-coding sequences (introns) and the joining together of coding sequences (exons) to form mRNA

6 state that a gene mutation is a change in the sequence of base pairs in a DNA molecule that may result in an altered polypeptide

7 explain that a gene mutation is a result of substitution or deletion or insertion of nucleotides in DNA and outline how each of these types of mutation may affect the polypeptide produced

7 Transport in plants

Flowering plants do not have compact bodies like those of many animals. Leaves and extensive root systems spread out to obtain the light energy, carbon dioxide, mineral ions and water that plants gain from their environment to make organic molecules, such as sugars and amino acids. Transport systems in plants move substances from where they are absorbed or produced to where they are stored or used.

7.1 Structure of transport tissues

Learning outcomes
Candidates should be able to:

1 draw plan diagrams of transverse sections of stems, roots and leaves of herbaceous dicotyledonous plants from microscope slides and photomicrographs

2 describe the distribution of xylem and phloem in transverse sections of stems, roots and leaves of herbaceous dicotyledonous plants

3 draw and label xylem vessel elements, phloem sieve tube elements and companion cells from microscope slides, photomicrographs and electron micrographs

4 relate the structure of xylem vessel elements, phloem sieve tube elements and companion cells to their functions

7.2 Transport mechanisms

Learning outcomes
Candidates should be able to:

1 state that some mineral ions and organic compounds can be transported within plants dissolved in water

2 describe the transport of water from the soil to the xylem through the:
- apoplast pathway, including reference to lignin and cellulose
- symplast pathway, including reference to the endodermis, Casparian strip and suberin

3 explain that transpiration involves the evaporation of water from the internal surfaces of leaves followed by diffusion of water vapour to the atmosphere

4 explain how hydrogen bonding of water molecules is involved with movement of water in the xylem by cohesion-tension in transpiration pull and by adhesion to cellulose in cell walls

5 make annotated drawings of transverse sections of leaves from xerophytic plants to explain how they are adapted to reduce water loss by transpiration

6 state that assimilates dissolved in water, such as sucrose and amino acids, move from sources to sinks in phloem sieve tubes

7 explain how companion cells transfer assimilates to phloem sieve tubes, with reference to proton pumps and cotransporter proteins

8 explain mass flow in phloem sieve tubes down a hydrostatic pressure gradient from source to sink

8 Transport in mammals

As animals become larger, more complex and more active, transport systems become essential to supply nutrients to, and remove waste from, individual cells. Mammals are far more active than plants and require much greater supplies of oxygen. This is transported by haemoglobin inside red blood cells.

8.1 The circulatory system

Learning outcomes

Candidates should be able to:

1 state that the mammalian circulatory system is a closed double circulation consisting of a heart, blood and blood vessels including arteries, arterioles, capillaries, venules and veins

2 describe the functions of the main blood vessels of the pulmonary and systemic circulations, limited to pulmonary artery, pulmonary vein, aorta and vena cava

3 recognise arteries, veins and capillaries from microscope slides, photomicrographs and electron micrographs and make plan diagrams showing the structure of arteries and veins in transverse section (TS) and longitudinal section (LS)

4 explain how the structure of muscular arteries, elastic arteries, veins and capillaries are each related to their functions

5 recognise and draw red blood cells, monocytes, neutrophils and lymphocytes from microscope slides, photomicrographs and electron micrographs

6 state that water is the main component of blood and tissue fluid and relate the properties of water to its role in transport in mammals, limited to solvent action and high specific heat capacity

7 state the functions of tissue fluid and describe the formation of tissue fluid in a capillary network

8.2 Transport of oxygen and carbon dioxide	**Learning outcomes** Candidates should be able to: 1 describe the role of red blood cells in transporting oxygen and carbon dioxide with reference to the roles of: • haemoglobin • carbonic anhydrase • the formation of haemoglobinic acid • the formation of carbaminohaemoglobin 2 describe the chloride shift and explain the importance of the chloride shift 3 describe the role of plasma in the transport of carbon dioxide 4 describe and explain the oxygen dissociation curve of adult haemoglobin 5 explain the importance of the oxygen dissociation curve at partial pressures of oxygen in the lungs and in respiring tissues 6 describe the Bohr shift and explain the importance of the Bohr shift
8.3 The heart	**Learning outcomes** Candidates should be able to: 1 describe the external and internal structure of the mammalian heart 2 explain the differences in the thickness of the walls of the: • atria and ventricles • left ventricle and right ventricle 3 describe the cardiac cycle, with reference to the relationship between blood pressure changes during systole and diastole and the opening and closing of valves 4 explain the roles of the sinoatrial node, the atrioventricular node and the Purkyne tissue in the cardiac cycle (knowledge of nervous and hormonal control is not expected)

9 Gas exchange

The gas exchange system is responsible for the uptake of oxygen into the blood and the excretion of carbon dioxide. An understanding of this system shows how cells, tissues and organs function together to exchange these gases between the blood and the environment.

9.1 The gas exchange system

Learning outcomes

Candidates should be able to:

1 describe the structure of the human gas exchange system, limited to:
- lungs
- trachea
- bronchi
- bronchioles
- alveoli
- capillary network

2 describe the distribution in the gas exchange system of cartilage, ciliated epithelium, goblet cells, squamous epithelium of alveoli, smooth muscle and capillaries

3 recognise cartilage, ciliated epithelium, goblet cells, squamous epithelium of alveoli, smooth muscle and capillaries in microscope slides, photomicrographs and electron micrographs

4 recognise trachea, bronchi, bronchioles and alveoli in microscope slides, photomicrographs and electron micrographs and make plan diagrams of transverse sections of the walls of the trachea and bronchus

5 describe the functions of ciliated epithelial cells, goblet cells and mucous glands in maintaining the health of the gas exchange system

6 describe the functions in the gas exchange system of cartilage, smooth muscle, elastic fibres and squamous epithelium

7 describe gas exchange between air in the alveoli and blood in the capillaries

10 Infectious diseases

The infectious diseases studied in this topic are caused by pathogens that are transmitted from one human host to another. Some, like *Plasmodium* that causes malaria, are transmitted by vectors, but there are many other methods of transmission, such as through water and food or during sexual activity. An understanding of the biology of the pathogen and its mode of transmission is essential if the disease is to be controlled and ultimately prevented.

10.1 Infectious diseases

Learning outcomes
Candidates should be able to:

1 state that infectious diseases are caused by pathogens and are transmissible

2 state the name and type of pathogen that causes each of the following diseases:

- cholera – caused by the bacterium *Vibrio cholerae*
- malaria – caused by the protoctists *Plasmodium falciparum*, *Plasmodium malariae*, *Plasmodium ovale* and *Plasmodium vivax*
- tuberculosis (TB) – caused by the bacteria *Mycobacterium tuberculosis* and *Mycobacterium bovis*
- HIV/AIDS – caused by the human immunodeficiency virus (HIV)

3 explain how cholera, malaria, TB and HIV are transmitted

4 discuss the biological, social and economic factors that need to be considered in the prevention and control of cholera, malaria, TB and HIV (details of the life cycle of the malarial parasite are not expected)

10.2 Antibiotics

Learning outcomes
Candidates should be able to:

1 outline how penicillin acts on bacteria and why antibiotics do not affect viruses

2 discuss the consequences of antibiotic resistance and the steps that can be taken to reduce its impact

11 Immunity

An understanding of the immune system shows how cells and molecules function together to protect the body against infectious diseases and how, after an initial infection, the body is protected from subsequent infections by the same pathogen. Phagocytosis is an immediate non-specific part of the immune system, while the actions of lymphocytes provide effective defence against specific pathogens.

11.1 The immune system

Learning outcomes
Candidates should be able to:

1 describe the mode of action of phagocytes (macrophages and neutrophils)

2 explain what is meant by an antigen (see 4.1.3) and state the difference between self antigens and non-self antigens

3 describe the sequence of events that occurs during a primary immune response with reference to the roles of:

- macrophages
- B-lymphocytes, including plasma cells
- T-lymphocytes, limited to T-helper cells and T-killer cells

4 explain the role of memory cells in the secondary immune response and in long-term immunity

11.2 Antibodies and vaccination

Learning outcomes
Candidates should be able to:

1 relate the molecular structure of antibodies to their functions

2 outline the hybridoma method for the production of monoclonal antibodies

3 outline the principles of using monoclonal antibodies in the diagnosis of disease and in the treatment of disease

4 describe the differences between active immunity and passive immunity and between natural immunity and artificial immunity

5 explain that vaccines contain antigens that stimulate immune responses to provide long-term immunity

6 explain how vaccination programmes can help to control the spread of infectious diseases

A Level subject content

12 Energy and respiration

Energy is a fundamental concept in biology. All living organisms require a source of cellular energy to drive their various activities. All organisms respire by using enzyme-catalysed reactions to release energy from energy-rich molecules such as glucose and fatty acids and transfer that energy to ATP. ATP is the universal energy currency of cells. In eukaryotes, aerobic respiration occurs in mitochondria.

The practical activities in this topic give opportunities for candidates to plan investigations, analyse and interpret data and evaluate experimental procedures and the quality of the data collected.

12.1 Energy

Learning outcomes

Candidates should be able to:

1 outline the need for energy in living organisms, as illustrated by active transport, movement and anabolic reactions, such as those occurring in DNA replication and protein synthesis

2 describe the features of ATP that make it suitable as the universal energy currency

3 state that ATP is synthesised by:
- transfer of phosphate in substrate-linked reactions
- chemiosmosis in membranes of mitochondria and chloroplasts

4 explain the relative energy values of carbohydrates, lipids and proteins as respiratory substrates

5 state that the respiratory quotient (RQ) is the ratio of the number of molecules of carbon dioxide produced to the number of molecules of oxygen taken in, as a result of respiration

6 calculate RQ values of different respiratory substrates from equations for respiration

7 describe and carry out investigations, using simple respirometers, to determine the RQ of germinating seeds or small invertebrates (e.g. blowfly larvae)

12.2 Respiration

Learning outcomes

Candidates should be able to:

1 State where each of the four stages in aerobic respiration occurs in eukaryotic cells:
   - glycolysis in the cytoplasm
   - link reaction in the mitochondrial matrix
   - Krebs cycle in the mitochondrial matrix
   - oxidative phosphorylation on the inner membrane of mitochondria

2 outline glycolysis as phosphorylation of glucose and the subsequent splitting of fructose 1,6-bisphosphate (6C) into two triose phosphate molecules (3C), which are then further oxidised to pyruvate (3C), with the production of ATP and reduced NAD

3 explain that, when oxygen is available, pyruvate enters mitochondria to take part in the link reaction

4 describe the link reaction, including the role of coenzyme A in the transfer of acetyl (2C) groups

5 outline the Krebs cycle, explaining that oxaloacetate (4C) acts as an acceptor of the 2C fragment from acetyl coenzyme A to form citrate (6C), which is converted back to oxaloacetate in a series of small steps

6 explain that reactions in the Krebs cycle involve decarboxylation and dehydrogenation and the reduction of the coenzymes NAD and FAD

7 describe the role of NAD and FAD in transferring hydrogen to carriers in the inner mitochondrial membrane

8 explain that during oxidative phosphorylation:
   - hydrogen atoms split into protons and energetic electrons
   - energetic electrons release energy as they pass through the electron transport chain (details of carriers are not expected)
   - the released energy is used to transfer protons across the inner mitochondrial membrane
   - protons return to the mitochondrial matrix by facilitated diffusion through ATP synthase, providing energy for ATP synthesis (details of ATP synthase are not expected)
   - oxygen acts as the final electron acceptor to form water

9 describe the relationship between the structure and function of mitochondria using diagrams and electron micrographs

10 outline respiration in anaerobic conditions in mammals (lactate fermentation) and in yeast cells (ethanol fermentation)

continued

12.2 Respiration continued

Learning outcomes

Candidates should be able to:

11 explain why the energy yield from respiration in aerobic conditions is much greater than the energy yield from respiration in anaerobic conditions (a detailed account of the total yield of ATP from the aerobic respiration of glucose is not expected)

12 explain how rice is adapted to grow with its roots submerged in water, limited to the development of aerenchyma in roots, ethanol fermentation in roots and faster growth of stems

13 describe and carry out investigations using redox indicators, including DCPIP and methylene blue, to determine the effects of temperature and substrate concentration on the rate of respiration of yeast

14 describe and carry out investigations using simple respirometers to determine the effect of temperature on the rate of respiration

13 Photosynthesis

Photosynthesis is the energy transfer process that is the basis of nearly all life on Earth. It provides energy directly or indirectly to all the organisms in most food chains. In eukaryotes, the process occurs within chloroplasts. Candidates should apply their knowledge of plant cells from Cell structure (Topic 1) and leaf structure from Transport in plants (Topic 7) while studying photosynthesis. Various environmental factors influence the rate at which photosynthesis occurs.

The practical activities in this topic give opportunities for candidates to plan investigations, analyse and interpret data and evaluate experimental procedures and the quality of the data that they collect.

13.1 Photosynthesis as an energy transfer process

Learning outcomes

Candidates should be able to:

1 describe the relationship between the structure of chloroplasts, as shown in diagrams and electron micrographs, and their function

2 explain that energy transferred as ATP and reduced NADP from the light-dependent stage is used during the light-independent stage (Calvin cycle) of photosynthesis to produce complex organic molecules

3 state that within a chloroplast, the thylakoids (thylakoid membranes and thylakoid spaces), which occur in stacks called grana, are the site of the light-dependent stage and the stroma is the site of the light-independent stage

4 describe the role of chloroplast pigments (chlorophyll *a*, chlorophyll *b*, carotene and xanthophyll) in light absorption in thylakoids

5 interpret absorption spectra of chloroplast pigments and action spectra for photosynthesis

6 describe and use chromatography to separate and identify chloroplast pigments (reference should be made to R_f values in identification of chloroplast pigments)

7 state that cyclic photophosphorylation and non-cyclic photophosphorylation occur during the light-dependent stage of photosynthesis

8 explain that in cyclic photophosphorylation:
- only photosystem I (PSI) is involved
- photoactivation of chlorophyll occurs
- ATP is synthesised

9 explain that in non-cyclic photophosphorylation:
- photosystem I (PSI) and photosystem II (PSII) are both involved
- photoactivation of chlorophyll occurs
- the oxygen-evolving complex catalyses the photolysis of water
- ATP and reduced NADP are synthesised

continued

13.1 Photosynthesis as an energy transfer process continued	**Learning outcomes** Candidates should be able to: 10 explain that during photophosphorylation: • energetic electrons release energy as they pass through the electron transport chain (details of carriers are not expected) • the released energy is used to transfer protons across the thylakoid membrane • protons return to the stroma from the thylakoid space by facilitated diffusion through ATP synthase, providing energy for ATP synthesis (details of ATP synthase are not expected) 11 outline the three main stages of the Calvin cycle: • rubisco catalyses the fixation of carbon dioxide by combination with a molecule of ribulose bisphosphate (RuBP), a 5C compound, to yield two molecules of glycerate 3-phosphate (GP), a 3C compound • GP is reduced to triose phosphate (TP) in reactions involving reduced NADP and ATP • RuBP is regenerated from TP in reactions that use ATP 12 state that Calvin cycle intermediates are used to produce other molecules, limited to GP to produce some amino acids and TP to produce carbohydrates, lipids and amino acids
13.2 Investigation of limiting factors	**Learning outcomes** Candidates should be able to: 1 state that light intensity, carbon dioxide concentration and temperature are examples of limiting factors of photosynthesis 2 explain the effects of changes in light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis 3 describe and carry out investigations using redox indicators, including DCPIP and methylene blue, and a suspension of chloroplasts to determine the effects of light intensity and light wavelength on the rate of photosynthesis 4 describe and carry out investigations using whole plants, including aquatic plants, to determine the effects of light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis

14 Homeostasis

Cells function most efficiently if they are kept in near optimum conditions. Cells in multicellular animals are surrounded by tissue fluid. The composition of tissue fluid is kept constant by exchanges with the blood as discussed in the topic on Transport in mammals (Topic 8). In mammals, core temperature, blood glucose concentration and blood water potential are maintained within narrow limits to ensure the efficient operation of cells. Prior knowledge for this topic includes an understanding that waste products are excreted from the body and an outline of the structure and function of the nervous and endocrine systems. In plants, guard cells respond to fluctuations in environmental conditions and open and close stomata as appropriate for photosynthesis and conserving water.

14.1 Homeostasis in mammals

Learning outcomes
Candidates should be able to:

1 explain what is meant by homeostasis and the importance of homeostasis in mammals

2 explain the principles of homeostasis in terms of internal and external stimuli, receptors, coordination systems (nervous system and endocrine system), effectors (muscles and glands) and negative feedback

3 state that urea is produced in the liver from the deamination of excess amino acids

4 describe the structure of the human kidney, limited to:
- fibrous capsule
- cortex
- medulla
- renal pelvis
- ureter
- branches of the renal artery and renal vein

5 Identify, in diagrams, photomicrographs and electron micrographs, the parts of a nephron and its associated blood vessels and structures, limited to:
- glomerulus
- Bowman's capsule
- proximal convoluted tubule
- loop of Henle
- distal convoluted tubule
- collecting duct

6 describe and explain the formation of urine in the nephron, limited to:
- the formation of glomerular filtrate by ultrafiltration in the Bowman's capsule
- selective reabsorption in the proximal convoluted tubule

7 relate the detailed structure of the Bowman's capsule and proximal convoluted tubule to their functions in the formation of urine

8 describe the roles of the hypothalamus, posterior pituitary gland, antidiuretic hormone (ADH), aquaporins and collecting ducts in osmoregulation

continued

14.1 Homeostasis in mammals continued

Learning outcomes
Candidates should be able to:

9 describe the principles of cell signalling using the example of the control of blood glucose concentration by glucagon, limited to:
- binding of hormone to cell surface receptor causing conformational change
- activation of G-protein leading to stimulation of adenylyl cyclase
- formation of the second messenger, cyclic AMP (cAMP)
- activation of protein kinase A by cAMP leading to initiation of an enzyme cascade
- amplification of the signal through the enzyme cascade as a result of activation of more and more enzymes by phosphorylation
- cellular response in which the final enzyme in the pathway is activated, catalysing the breakdown of glycogen

10 explain how negative feedback control mechanisms regulate blood glucose concentration, with reference to the effects of insulin on muscle cells and liver cells and the effect of glucagon on liver cells

11 explain the principles of operation of test strips and biosensors for measuring the concentration of glucose in blood and urine, with reference to glucose oxidase and peroxidase enzymes

14.2 Homeostasis in plants

Learning outcomes
Candidates should be able to:

1 explain that stomata respond to changes in environmental conditions by opening and closing and that regulation of stomatal aperture balances the need for carbon dioxide uptake by diffusion with the need to minimise water loss by transpiration

2 explain that stomata have daily rhythms of opening and closing

3 describe the structure and function of guard cells and explain the mechanism by which they open and close stomata

4 describe the role of abscisic acid in the closure of stomata during times of water stress, including the role of calcium ions as a second messenger

15 Control and coordination

All the activities of multicellular organisms require coordinating, some very rapidly and some more slowly. The nervous system and the endocrine system provide coordination in mammals. Coordination systems also exist in plants.

15.1 Control and coordination in mammals

Learning outcomes

Candidates should be able to:

1 describe the features of the endocrine system with reference to the hormones ADH, glucagon and insulin (see 14.1.8, 14.1.9 and 14.1.10)

2 compare the features of the nervous system and the endocrine system

3 describe the structure and function of a sensory neurone and a motor neurone and state that intermediate neurones connect sensory neurones and motor neurones

4 outline the role of sensory receptor cells in detecting stimuli and stimulating the transmission of impulses in sensory neurones

5 describe the sequence of events that results in an action potential in a sensory neurone, using a chemoreceptor cell in a human taste bud as an example

6 describe and explain changes to the membrane potential of neurones, including:

- how the resting potential is maintained
- the events that occur during an action potential
- how the resting potential is restored during the refractory period

7 describe and explain the rapid transmission of an impulse in a myelinated neurone with reference to saltatory conduction

8 explain the importance of the refractory period in determining the frequency of impulses

9 describe the structure of a cholinergic synapse and explain how it functions, including the role of calcium ions

10 describe the roles of neuromuscular junctions, the T-tubule system and sarcoplasmic reticulum in stimulating contraction in striated muscle

11 describe the ultrastructure of striated muscle with reference to sarcomere structure using electron micrographs and diagrams

12 explain the sliding filament model of muscular contraction including the roles of troponin, tropomyosin, calcium ions and ATP

15.2	**Control and coordination in plants**	**Learning outcomes** Candidates should be able to: 1 describe the rapid response of the Venus fly trap to stimulation of hairs on the lobes of modified leaves and explain how the closure of the trap is achieved 2 explain the role of auxin in elongation growth by stimulating proton pumping to acidify cell walls 3 describe the role of gibberellin in the germination of barley (see 16.3.4)

16 Inheritance

Genetic information is transmitted from generation to generation to maintain the continuity of life. In sexual reproduction, meiosis introduces genetic variation so that offspring resemble their parents but are not identical to them. Genetic crosses reveal how some features are inherited. The phenotype of organisms is determined partly by the genes that they have inherited and partly by the effect of the environment. Genes determine how organisms develop; gene control in bacteria gives us a glimpse of this process in action.

16.1 Passage of information from parents to offspring

Learning outcomes
Candidates should be able to:

1 explain the meanings of the terms haploid (n) and diploid (2n)

2 explain what is meant by homologous pairs of chromosomes

3 explain the need for a reduction division during meiosis in the production of gametes

4 describe the behaviour of chromosomes in plant and animal cells during meiosis and the associated behaviour of the nuclear envelope, the cell surface membrane and the spindle (names of the main stages of meiosis, but not the sub-divisions of prophase I, are expected: prophase I, metaphase I, anaphase I, telophase I, prophase II, metaphase II, anaphase II and telophase II)

5 interpret photomicrographs and diagrams of cells in different stages of meiosis and identify the main stages of meiosis

6 explain that crossing over and random orientation (independent assortment) of pairs of homologous chromosomes and sister chromatids during meiosis produces genetically different gametes

7 explain that the random fusion of gametes at fertilisation produces genetically different individuals

16.2 The roles of genes in determining the phenotype

Learning outcomes
Candidates should be able to:

1 explain the terms gene, locus, allele, dominant, recessive, codominant, linkage, test cross, F1, F2, phenotype, genotype, homozygous and heterozygous

2 interpret and construct genetic diagrams, including Punnett squares, to explain and predict the results of monohybrid crosses and dihybrid crosses that involve dominance, codominance, multiple alleles and sex linkage

3 interpret and construct genetic diagrams, including Punnett squares, to explain and predict the results of dihybrid crosses that involve autosomal linkage and epistasis (knowledge of the expected ratios for different types of epistasis is not expected)

4 interpret and construct genetic diagrams, including Punnett squares, to explain and predict the results of test crosses

5 use the chi-squared test to test the significance of differences between observed and expected results (the formula for the chi-squared test will be provided, as shown in the Mathematical requirements)

continued

16.2 The roles of genes in determining the phenotype continued	**Learning outcomes** Candidates should be able to: 6 explain the relationship between genes, proteins and phenotype with respect to the: • *TYR* gene, tyrosinase and albinism • *HBB* gene, haemoglobin and sickle cell anaemia • *F8* gene, factor VIII and haemophilia • *HTT* gene, huntingtin and Huntington's disease 7 explain the role of gibberellin in stem elongation including the role of the dominant allele, *Le*, that codes for a functional enzyme in the gibberellin synthesis pathway, and the recessive allele, *le*, that codes for a non-functional enzyme
16.3 Gene control	**Learning outcomes** Candidates should be able to: 1 describe the differences between structural genes and regulatory genes and the differences between repressible enzymes and inducible enzymes 2 explain genetic control of protein production in a prokaryote using the *lac* operon (knowledge of the role of cAMP is not expected) 3 state that transcription factors are proteins that bind to DNA and are involved in the control of gene expression in eukaryotes by decreasing or increasing the rate of transcription 4 explain how gibberellin activates genes by causing the breakdown of DELLA protein repressors, which normally inhibit factors that promote transcription

17 Selection and evolution

In 1858, Charles Darwin and Alfred Russel Wallace proposed a theory of natural selection to account for the evolution of species. A year later, Darwin published *On the Origin of Species*, providing evidence for the way in which aspects of the environment act as agents of selection and determine which phenotypic forms survive and which do not. The individuals best adapted to the prevailing conditions are most likely to succeed in the 'struggle for existence'.

17.1 Variation

Learning outcomes
Candidates should be able to:

1 explain, with examples, that phenotypic variation is due to genetic factors or environmental factors or a combination of genetic and environmental factors

2 explain what is meant by discontinuous variation and continuous variation

3 explain the genetic basis of discontinuous variation and continuous variation

4 use the *t*-test to compare the means of two different samples (the formula for the *t*-test will be provided, as shown in the Mathematical requirements)

17.2 Natural and artificial selection

Learning outcomes
Candidates should be able to:

1 explain that natural selection occurs because populations have the capacity to produce many offspring that compete for resources; in the 'struggle for existence', individuals that are best adapted are most likely to survive to reproduce and pass on their alleles to the next generation

2 explain how environmental factors can act as stabilising, disruptive and directional forces of natural selection

3 explain how selection, the founder effect and genetic drift, including the bottleneck effect, may affect allele frequencies in populations

4 outline how bacteria become resistant to antibiotics as an example of natural selection

5 use the Hardy–Weinberg principle to calculate allele and genotype frequencies in populations and state the conditions when this principle can be applied (the two equations for the Hardy–Weinberg principle will be provided, as shown in the Mathematical requirements)

6 describe the principles of selective breeding (artificial selection)

7 outline the following examples of selective breeding:

- the introduction of disease resistance to varieties of wheat and rice
- inbreeding and hybridisation to produce vigorous, uniform varieties of maize
- improving the milk yield of dairy cattle

17.3 Evolution

Learning outcomes

Candidates should be able to:

1 outline the theory of evolution as a process leading to the formation of new species from pre-existing species over time, as a result of changes to gene pools from generation to generation

2 discuss how DNA sequence data can show evolutionary relationships between species

3 explain how speciation may occur as a result of genetic isolation by:

- geographical separation (allopatric speciation)
- ecological and behavioural separation (sympatric speciation)

18 Classification, biodiversity and conservation

Classification systems attempt to order all the organisms that exist on Earth according to their characteristics and evolutionary relationships with one another. There are opportunities in this topic for candidates to observe different species in their locality and assess species distribution and abundance. Fieldwork is an important part of a biological education because it provides opportunities to appreciate and analyse biodiversity, and to study the interactions between organisms and their environment. The biodiversity of the Earth is threatened by human activities and climate change. Conserving biodiversity is a difficult task; individuals, local groups, national and international organisations can all make significant contributions. Candidates should appreciate the threats to biodiversity and consider some of the steps taken in conservation, both locally and globally.

18.1 Classification

Learning outcomes
Candidates should be able to:

1 discuss the meaning of the term species, limited to the biological species concept, morphological species concept and ecological species concept

2 describe the classification of organisms into three domains: Archaea, Bacteria and Eukarya

3 state that Archaea and Bacteria are prokaryotes and that there are differences between them, limited to differences in membrane lipids, ribosomal RNA and composition of cell walls

4 describe the classification of organisms in the Eukarya domain into the taxonomic hierarchy of kingdom, phylum, class, order, family, genus and species

5 outline the characteristic features of the kingdoms Protoctista, Fungi, Plantae and Animalia

6 outline how viruses are classified, limited to the type of nucleic acid (RNA or DNA) and whether this is single stranded or double stranded

18.2 Biodiversity

Learning outcomes
Candidates should be able to:

1 define the terms ecosystem and niche

2 explain that biodiversity can be assessed at different levels, including:
- the number and range of different ecosystems and habitats
- the number of species and their relative abundance
- the genetic variation within each species

3 explain the importance of random sampling in determining the biodiversity of an area

4 describe and use suitable methods to assess the distribution and abundance of organisms in an area, limited to frame quadrats, line transects, belt transects and mark-release-recapture using the Lincoln index (the formula for the Lincoln index will be provided, as shown in the Mathematical requirements)

continued

18.2 Biodiversity continued	**Learning outcomes** Candidates should be able to: 5 use Spearman's rank correlation and Pearson's linear correlation to analyse the relationships between two variables, including how biotic and abiotic factors affect the distribution and abundance of species (the formulae for these correlations will be provided, as shown in the Mathematical requirements) 6 use Simpson's index of diversity (*D*) to calculate the biodiversity of an area, and state the significance of different values of *D* (the formula for Simpson's index of diversity will be provided, as shown in the Mathematical requirements)
18.3 Conservation	**Learning outcomes** Candidates should be able to: 1 explain why populations and species can become extinct as a result of: • climate change • competition • hunting by humans • degradation and loss of habitats 2 outline reasons for the need to maintain biodiversity 3 outline the roles of zoos, botanic gardens, conserved areas (including national parks and marine parks), 'frozen zoos' and seed banks, in the conservation of endangered species 4 describe methods of assisted reproduction used in the conservation of endangered mammals, limited to IVF, embryo transfer and surrogacy 5 explain reasons for controlling invasive alien species 6 outline the role in conservation of the International Union for Conservation of Nature (IUCN) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

19 Genetic technology

The discovery in the early 1950s of the structure of DNA by Watson and Crick, supported by the work of Franklin, Wilkins and Chargaff, and discoveries since, have led to many applications of genetic technology in areas of medicine, agriculture and forensic science. This topic relies heavily on prior knowledge of DNA and RNA structure and protein synthesis from the topic on Nucleic acids and protein synthesis (Topic 6).

Candidates will benefit from carrying out practical work using electrophoresis, either with DNA or specially prepared dyes used to represent DNA.

19.1 Principles of genetic technology

Learning outcomes
Candidates should be able to:

1 define the term recombinant DNA

2 explain that genetic engineering is the deliberate manipulation of genetic material to modify specific characteristics of an organism and that this may involve transferring a gene into an organism so that the gene is expressed

3 explain that genes to be transferred into an organism may be:
- extracted from the DNA of a donor organism
- synthesised from the mRNA of a donor organism
- synthesised chemically from nucleotides

4 explain the roles of restriction endonucleases, DNA ligase, plasmids, DNA polymerase and reverse transcriptase in the transfer of a gene into an organism

5 explain why a promoter may have to be transferred into an organism as well as the desired gene

6 explain how gene expression may be confirmed by the use of marker genes coding for fluorescent products

7 explain that gene editing is a form of genetic engineering involving the insertion, deletion or replacement of DNA at specific sites in the genome

8 describe and explain the steps involved in the polymerase chain reaction (PCR) to clone and amplify DNA, including the role of *Taq* polymerase

9 describe and explain how gel electrophoresis is used to separate DNA fragments of different lengths

10 outline how microarrays are used in the analysis of genomes and in detecting mRNA in studies of gene expression

11 outline the benefits of using databases that provide information about nucleotide sequences of genes and genomes, and amino acid sequences of proteins and protein structures

19.2 Genetic technology applied to medicine	**Learning outcomes** Candidates should be able to: 1 explain the advantages of using recombinant human proteins to treat disease, using the examples insulin, factor VIII and adenosine deaminase 2 outline the advantages of genetic screening, using the examples of breast cancer (*BRCA1* and *BRCA2*), Huntington's disease and cystic fibrosis 3 outline how genetic diseases can be treated with gene therapy, using the examples severe combined immunodeficiency (SCID) and inherited eye diseases 4 discuss the social and ethical considerations of using genetic screening and gene therapy in medicine
19.3 Genetically modified organisms in agriculture	**Learning outcomes** Candidates should be able to: 1 explain that genetic engineering may help to solve the global demand for food by improving the quality and productivity of farmed animals and crop plants, using the examples of GM salmon, herbicide resistance in soybean and insect resistance in cotton 2 discuss the ethical and social implications of using genetically modified organisms (GMOs) in food production

4 Details of the assessment

Paper 1 Multiple Choice

Written paper, 1 hour 15 minutes, 40 marks

Forty multiple-choice questions of the four-choice type, testing assessment objectives AO1 and AO2.

Questions are based on the AS Level syllabus content.

Paper 2 AS Level Structured Questions

Written paper, 1 hour 15 minutes, 60 marks

Structured questions testing assessment objectives AO1 and AO2.

Questions are based on the AS Level syllabus content.

Paper 3 Advanced Practical Skills

Practical test, 2 hours, 40 marks

This paper tests assessment objective AO3 in a practical context.

Questions are based on the practical skills (including the use of a light microscope) in the Practical assessment section of the syllabus for Paper 3. The context of the questions may be outside the syllabus content.

Paper 4 A Level Structured Questions

Written paper, 2 hours, 100 marks

Structured questions testing assessment objectives AO1 and AO2.

Questions are based on the A Level syllabus content; knowledge of material from the AS Level syllabus content will be required.

Paper 5 Planning, Analysis and Evaluation

Written paper, 1 hour 15 minutes, 30 marks

Structured questions testing assessment objective AO3.

Questions are based on the practical skills of planning, analysis and evaluation in the Practical assessment section of the syllabus for Paper 5. The context of the questions may be outside the syllabus content.