Practice exam-style questions

When answering a question, look at the number of marks the question has as this correlates to the number of points your answer needs to cover. For example, a 5-mark question may require 5 points. Answers given here may provide more points than the number of marks for a question, but this is to give you options on what can be included in your answer. Separate marking points are indicated with a semi-colon.

Theme A Unity and diversity

A1.1 Water

Paper 1

1 C

2 D

3 B

4 B

5 a i Uncovered: 50 °C

ii Covered with wet tissue paper: 55 °C

Both needed

Acceptable range 49–51 °C and 54–56 °C, respectively

Units required

Accept negative numbers (−50 °C and −55 °C)

Working on its own without an answer is insufficient for the mark (e.g. 80 − 30)

b

- volume/mass of water they contain
- temperature of water
- placed in similar environment/on similar surface *OWTTE [or words to that effect]*
- container must be the same shape/size/volume/surface area

Do not award 'ambient room temperature' or 'material of cups'

Do not accept 'type of water'

c 18 °C *OR* room temperature

If the answer is given as a numerical value then units are required

(Questions 6–8 HL only)

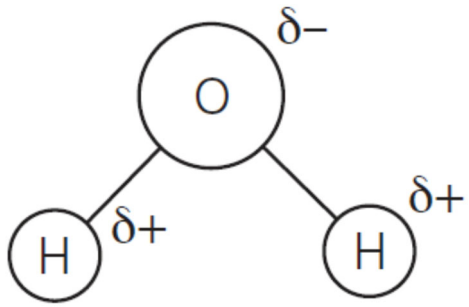
6 D

7 A

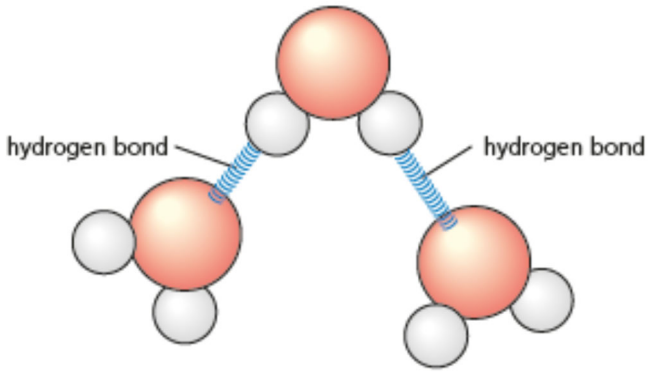
8 C

Paper 2

1 The oxygen nucleus draws electrons (negatively charged) away from the hydrogen nucleus (positively charged); the water molecule carries an unequal distribution of electrical charge, even though it is electrically neutral overall.



There is electrostatic attraction between the positively charged region of one water molecule and the negatively charged region of a neighbouring one, giving rise to weak bonds or intermolecular forces called hydrogen bonds.



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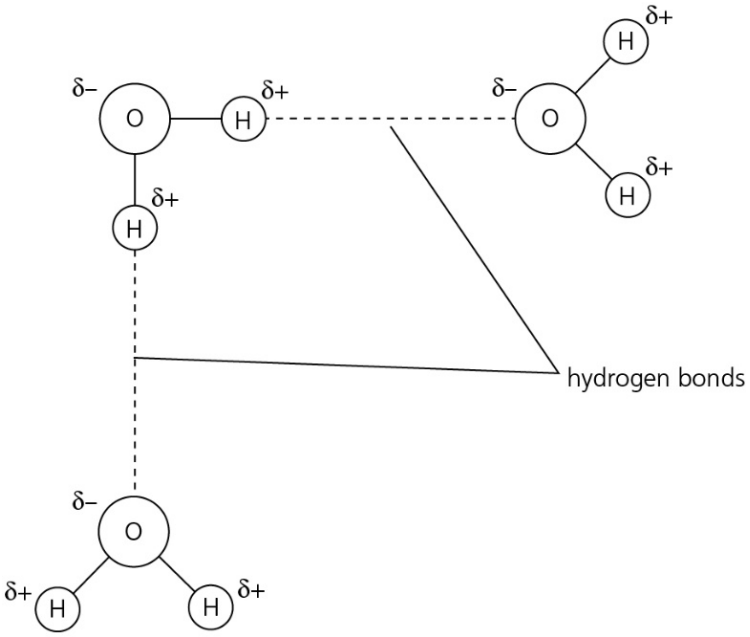


3 Water molecule is polar *OR* water has weak positive and negative charges; water forms hydrogen bonds with polar substances; positive/hydrogen side/pole of water attracted to negative ions *OR* negative/oxygen side/pole attracted to positive ions; glucose/other example dissolves because it is polar *OR* sodium chloride/other example dissolves because ions are attracted to water.
[Max 3 marks]

4 Water molecules are attracted to each other/stick together because of hydrogen bonding; these cohesive forces allow water molecules to be drawn up xylem vessels in plants by the evaporative loss of water from the leaves.

5 Water is cohesive so can be pulled up/moved under tension in xylem;

cohesion in water/water molecules stick together (due to hydrogen bonds);

cohesion helps transport under tension of water/sap in xylem/transpiration stream;

adhesion between water and cell walls/cellulose/polar molecules;

adhesion/capillary action helps water to rise in plants/stems/xylem/helps keep leaf walls moist;

water is an excellent/universal solvent/dissolves many different substances;

solvent properties (due to hydrogen bonds) with polar/hydrophilic molecules;

solvent properties exemplified by glucose/other example of a polar solute;

medium for transport in blood/xylem/phloem;

high latent heat of evaporation/(much) energy required for evaporation so water useful as coolant/for sweating;

medium for metabolic reactions/(metabolic) reactions happen dissolved in water;

used in chemical reactions/photosynthesis/hydrolysis in organisms;

high (specific) heat capacity, so much energy required to change its temperature/water temperature changes less;

high heat capacity so stable habitat/temperature of water changes slowly;

important for habitats because water is liquid due to high boiling point/due to water freezing on the surface/ice floats so lakes/oceans do not freeze allowing life under the ice;

surface tension due to cohesion allows organisms to live on water surface.
[Max 5 marks]

6 Water is a polar molecule; oxygen has a partial negative charge/hydrogen has a partial positive charge; hydrogen bonds form between adjacent water molecules; water remains liquid over wide range of temperatures/0–100 °C; moderates temperature fluctuation/stable environment; accurate reference to specific heat; sweating/evaporation cools organisms; polarity makes water a good/universal solvent for polar/ionic substances; (all) metabolic reactions of cells take place in (aqueous) solutions; blood/xylem/phloem transport solutes in water; cohesive properties allow capillary action/transpiration stream/water column in xylem.
[Max 8 marks]

(Question 7 HL only)

7 a $0.1 \times 0.7 = 0.07$
$0.1 \times 1.5 = 0.15$

b D and E

c The mass of the planet (and hence its gravitational field strength).

d Water has a high specific heat capacity because hydrogen bonding means more thermal energy is required to increase the temperature; the surface of water has ‘surface tension’ as a result of

hydrogen bonds attracting water molecules strongly; water is an excellent solvent because hydrogen bonding allows it to form bonds with ions (positive and negative) and small polar and non-polar molecules; water has extremely strong cohesive properties because of hydrogen bonding.
[Max 3 marks]

A1.2 Nucleic acids

Paper 1

1 B

2 C

3 D

4 B

5 C

6 B

7 D

(Questions 8–10 HL only)

8 A

9 A

10 B

Paper 2

1

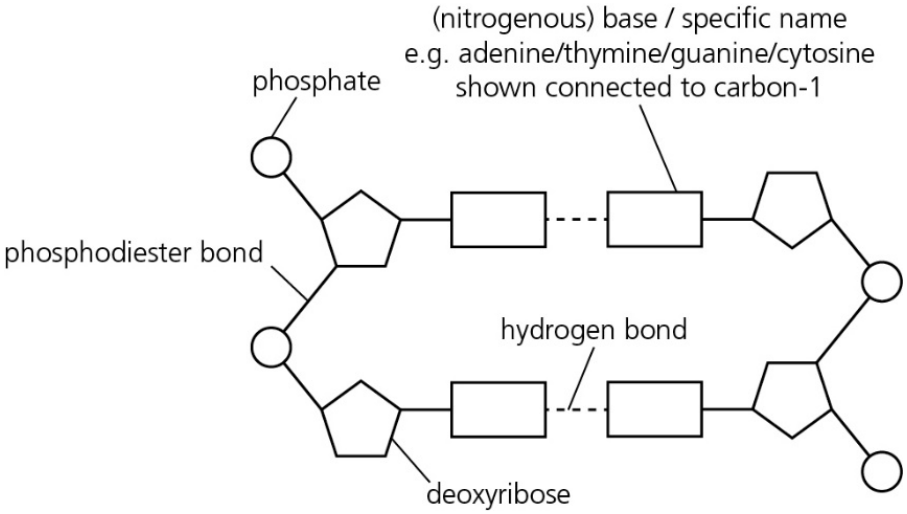


Diagram to include labels indicating a phosphate, a deoxyribose, a (nitrogenous) base/specific base, e.g. adenine/thymine/guanine/cytosine, shown connected to carbon-1, a hydrogen bond, covalent bond/phosphodiester bond; nucleotides to include phosphate, sugar and base by (shape or label); diagram to show complementary base pairing or A bonded to T, C with G.
[Max 3 marks if nucleotides shown in a single strand. Max 4 marks if antiparallel structure not shown.]

2

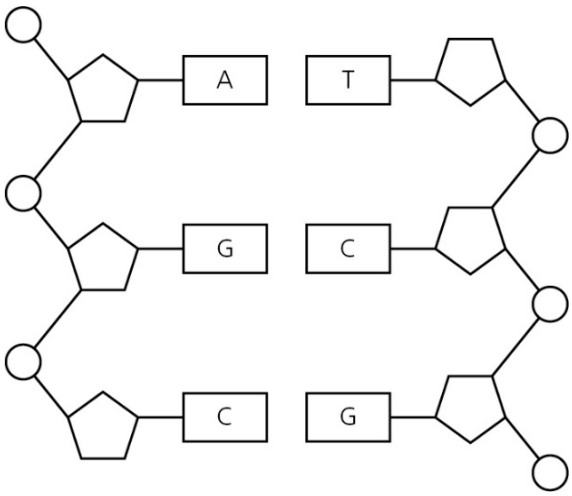


Diagram to include correct base sequence: T, C, G; strand drawn antiparallel; correct shapes used. [Max 2 marks if bonds are not from the correct carbon or if the nucleotides are not joined.]

3 Nitrogenous bases; phosphate group; pentose sugar; polymers of nucleotides/polynucleotides. *[Any two]*

4 a = phosphate group; b = deoxyribose; c = phosphodiester bond/covalent bond; d = nitrogenous base

5 Cohesion in water/water molecules stick together (due to hydrogen bonds);

cohesion helps transport under tension of water/sap in xylem/transpiration stream;

adhesion between water and cell walls/cellulose/polar molecules;

adhesion/capillary action helps water to rise in plants/stems/xylem/helps keep leaf walls moist;

solvent properties (due to hydrogen bonds) with polar/hydrophilic molecules;

solvent properties exemplified by glucose/other example of a polar solute;

high latent heat of evaporation/(much) energy required for evaporation, so water useful as coolant/for sweating;

high (specific) heat capacity, so water temperature changes less;

base pairing between bases/nucleotides/strands in DNA by hydrogen bonding;

base pairing between bases in RNA and DNA for transcription/between codon and anticodon for translation;

proteins have hydrogen bonding in secondary structure/α-helix/β-pleated sheet;

proteins have hydrogen bonding between R-groups/in tertiary structure/to maintain conformation;

habitats because water is liquid due to high boiling point/due to water freezing on the surface;

habitats on water surface due to surface tension.

[Max 7 marks]

(Questions 6–7 HL only)

6 Negatively charged DNA associates with positively charged amino acids on the surface of the histone protein; for attraction between the negatively charged DNA backbone and the histone proteins, the proteins must be positively charged; attraction between DNA and histone proteins allows sequences of DNA to be tightly wound around eight histone protein cores.

7 The evidence for the unique importance of DNA was proved by an experiment carried out by Martha Chase and Alfred Hershey, with a bacteriophage virus; two identical *E. coli* cultures were infected, one with a ^{32}P-labelled virus and one with a ^{35}S-labelled virus: subsequently, radioactively labelled viruses were obtained only from the bacteria infected with virus labelled with ^{32}P/the ^{35}S label did not enter the host cell at all; Chase and Hershey's experiment demonstrated that the DNA part of the virus enters the host cell and carries the genetic information for the production of new viruses; this experiment shows how technological developments open up new possibilities for experiments: when radioisotopes were made available to scientists as research tools, the Hershey–Chase experiment became possible.

Erwin Chargaff analysed the composition of DNA from a range of organisms and found similar patterns: the number of purine bases (adenine and guanine) always was equal to the number of pyrimidine bases (cytosine and thymine); the number of adenine bases was equal to the number of thymine bases, and the number of guanine bases equalled the number of cytosine bases; this demonstrates that organic bases found in DNA are of two distinct types with contrasting shapes: cytosine and thymine are pyrimidines or single-ring bases, adenine and guanine are purines or double-ring bases; only a purine will fit with a pyrimidine between the sugar–phosphate backbones, when base pairing occurs: therefore, in DNA adenine must pair with thymine, and cytosine must pair with guanine; Chargaff's data falsified the tetranucleotide hypothesis that there was a repeating sequence of the four bases in DNA.

Scientists (Watson and Crick) used models to test their ideas on the possible structure of DNA; other scientists (e.g. Rosalind Franklin and Maurice Wilkins) used experimental methods/X-ray diffraction to understand the physical structure of the DNA molecule/discovered that DNA is a double helix.
[Max 8 marks]

A2.1 Origins of cells (HL only)

Paper 1 (HL only)

1 A

2 B

3 B

4

a Both (histidine and glycine) show catalytic activity; histidine more effective/greater % yield than glycine (after 4/7 cycles); glycine more effective (than histidine) after 1 cycle; effectiveness of glycine decreases after 4 cycles whereas that of histidine remains high. [Max 3 marks]

b Salt used to mimic conditions in the oceans; evaporation cycles reflect conditions in shallow lagoons/pools/intertidal zones; high temperature expected on pre-biotic earth; atmosphere in chamber is anoxic/lacks oxygen; biomolecule concentrations can increase (since oxygen/life forms are absent).
[Max 3 marks]

c Abiotic synthesis of organic molecules in atmosphere; at hydrothermal/deep sea vents in ocean floor *(do not accept volcanoes)*; extra-terrestrial origin of organic molecules/comets contain a variety of organic compounds; evidence for water elsewhere in solar system; clay particles act as replication platform/catalyst for formation of biomolecules; hot springs.
[Max 2 marks]
Do not accept 'primordial soup' as that is what is described in the question.

Paper 2 (HL only)

1 a Protocells

b Reducing atmosphere/no free oxygen; a lot of hydrogen and ammonia; water vapour present; (carbon present as) methane; solar/high-energy radiation; lightning; high temperatures; intense volcanic activity; radioactive elements present.

c Carries genetic information; RNA molecules have catalytic properties (ribozymes).

2 a i Lightning/electrical discharge

ii *Award [1] for any two of the following:* N_2, CO_2, water, ammonia, methane, hydrogen

iii Organic acids/amino acids

b RNA was the first replicating material/genetic material and the first catalyst/enzyme (with clay minerals).

3 Miller and Urey investigated how simple organic molecules might have arisen from the chemicals present on early Earth, using a reaction vessel in which specific environmental conditions could be reproduced; strong electric sparks (simulating lightning) were passed through mixtures of methane, ammonia, hydrogen and water vapour; the experiment was successful: they discovered that amino acids were formed naturally, as well as other compounds; this approach confirmed that organic molecules can be synthesized outside cells, in the absence of oxygen; the conditions of the Miller–Urey experiment were believed at the time (1953) to simulate the atmosphere of early Earth, which was assumed to be reducing (hydrogen rich) and rich in methane; however, current research suggests that methane was in low abundance in the early atmosphere, with carbon largely in the form of carbon dioxide (oxygen rich); the Miller–Urey experiment used electrical discharges rather than UV light to simulate high-energy input into the early Earth system; however, organic molecules such as amino acids and bases are generated when carbon dioxide, nitrogen and water are subjected to ionizing (nuclear) radiation and UV light, as well as electrical discharges; the Miller–Urey experiment did not produce nucleotides; experiments to reproduce the conditions of pre-biotic chemistry only recently succeeded in generating nucleotides; nucleotides have now been chemically synthesized via a new approach involving four simple organic molecules – cyanamide, cyanoacetylene, glycolaldehyde and glyceraldehyde – that are readily produced under reasonable pre-biotic conditions.
[Max 4 marks]

A2.2 Cell structure

Paper 1

1 B

2 B

3 A

4 A

5 C

6

Feature	Measurement on scale bar	Actual size
diameter of the nucleus	56 mm	**5.83 µm**
length of a mitochondrion	16 mm	**1.67 µm**
width of the cell	14 cm	**14.58 µm**
diameter of a lysosome	4 mm	**0.42 µm / 416.67 nm**
pore in the nuclear envelope	3 mm	**0.31 µm / 312.5 nm**
length of the cell	25.5 cm	**26.56 µm**

[Max 3 marks for all correct; 2 marks for 5 correct; 1 mark for 3–4 correct; no marks for 0–2 correct]

(Questions 7–10 HL only)

7 C

8 C

9 D

10 A

Paper 2

1 Cell wall; pili/flagella; 70S ribosomes; nucleoid/circular DNA *OR* naked DNA; plasmids.
[Max 3 marks]

As students do not need to know the structure of Mycobacterium tuberculosis, all prokaryotic structures are accepted.

Ignore references to membrane-bound organelles.

2 Nucleus/nuclear membrane; membrane-bound organelles; mitochondria; rough ER/smooth ER/Golgi apparatus; lysosomes/centrioles; large/80S ribosomes/ribosomes attached to a membrane; linear chromosomes/histones.
[Max 4 marks]

3 Nutrition: process by which organisms take in and make use of food/nutrients (*OWTTE*);
metabolism: conversion of organic molecules/chemical reactions in an organism;
growth: increase in size/mass/number of cells within an organism;
response/irritability/sensitivity: reactions/responsiveness to stimuli/factors;
homeostasis: regulating/maintaining constant/stable interior environment;
reproduction: production of similar cells/organisms from existing ones/offspring;
excretion: elimination of (metabolic) wastes.
[Max 4 marks]

4 a (A loop of) DNA; 70S ribosomes; double membrane; electron transport chains/enzyme complexes in (internal) membranes; enzymes in a region of fluid/in stroma and matrix; large area of (internal) membrane/cristae and thylakoids.
[Max 2 marks]

No marks awarded for functions rather than structures, for example ATP production.

b **Similarities**: Both chloroplasts and mitochondria function to generate metabolic energy in the cell; both synthesize ATP (on the thylakoid membrane and mitochondrial inner membrane); both contain circular DNA; both contain 70S ribosomes; both organelles have a double membrane; both are similar size/relatively large organelles, typically 0.5–1.5 μm wide and 3.0–10.0 μm long.

Differences: Chloroplasts synthesize glucose from CO_2, water and sunlight energy, producing oxygen as a waste product, whereas mitochondria break down glucose to release energy, producing water and carbon dioxide as waste products; chloroplasts carry out anabolic reactions/photosynthesis whereas mitochondria carry out catabolic reactions/respiration; mitochondria have inner folds called cristae, chloroplast contains pigments in thylakoids, which form grana; chloroplasts contain photosynthetic pigments whereas mitochondria do not; chloroplasts are only found in plant cells whereas mitochondria are found in all eukaryotic cells.
[Max 4 marks; if no similarities given, max 3 marks]

c Section through cell shows mitochondria in different cross-sections; mitochondria will appear circular if they are cut in transverse section/across (the long axis); some mitochondria may have just divided (by binary fission).
[Max 2 marks]

5 **Similarities**: both contain 70S ribosomes; both contain naked/circular DNA; both are a similar/same size.

Differences: chloroplasts are cell organelles, present in eukaryotic plant cells, and contain chlorophyll/photosynthetic pigments, whereas prokaryotic cells are cells and not organelles; some, not all, prokaryotic cells contain photosynthetic pigments/chlorophyll; chloroplasts have a double membrane, where the internal membrane is highly folded whereas prokaryotic cells only have one outer membrane; prokaryotic cells may have pili/flagella whereas chloroplasts do not; prokaryotic cells have a cell wall whereas a chloroplasts do not.
[Max 4 marks]

6 **a** I: cell wall; II: nucleus/chromatin

Both needed.

b III: chloroplast; necessary for photosynthesis/converts light energy into chemical energy; contains chlorophyll to absorb light; (contains enzymes) for production of carbohydrate/glucose/starch.
[Max 2 marks]

7 **a**

Organelle	Name	Principal role
I	rough endoplasmic reticulum/RER *OR* ribosome	protein synthesis/production for export from cell
II	mitochondrion/mitochondria	aerobic (cell) respiration *OR* ATP/energy release

b **Similarities**: both are cell organelles/the result of compartmentalization within the cell; both are made from membrane/are membrane-bound structures.

Differences: mitochondria carry out aerobic respiration and are responsible for ATP production, whereas RER is involved in protein synthesis and the export of proteins from the cell; mitochondria have an internal folded membrane whereas RER is made from a single membrane folded into cisternae/flattened membrane discs; RER membrane is connected to the nuclear membrane/endoplasmic reticulum is contiguous with (connected to) the membrane of the nuclear envelope, whereas mitochondria are not/are discrete organelles within the cytoplasm; RER produces vesicles whereas mitochondria do not.
[Max 4 marks; if no similarities given, max 3 marks]

8 **Cell theory**:

- cell theory is the accepted explanation of life;
- organisms are composed of (one or more) cells;
- cells are the basic/fundamental/smallest units of life;
- cells can only come from pre-existing cells;
- spontaneous generation of life has been disproven.

Limitations:

- striated muscle cells contain many nuclei (while most eukaryotic cells have one nucleus);
- red blood cells have no nucleus (while most eukaryotic cells have one nucleus);
- aseptate fungal hyphae are tube-like structures that contain no cell membranes between the many nuclei;
- phloem tissue consists of sieve tubes and companion cells: the mature sieve tube elements are an example of an atypical cell structure because they do not contain a nucleus or many other organelles;
- viruses have some characteristics of living organisms but are not cells;
- if all cells come from pre-existing cells, where did the first one come from?

[Max 7 marks; if no limitations, max 5 marks]

(Questions 9–11 HL only)

9 Mitochondria/chloroplasts show features in common with prokaryotes: they are a similar size; they multiply by binary fission/in same manner; they have a naked loop of DNA/circular DNA/own DNA; they are surrounded by a double membrane.
[Max 3 marks]

10 Endocytosis/engulfing of prokaryote by a larger/another/anaerobic prokaryote/cell; double membrane of the mitochondrion is the result of endocytosis

OR

inner membrane of mitochondrion from engulfed cell and outer from food vacuole; (engulfed prokaryotic cell) was aerobic/respired aerobically/consumed oxygen

OR

(engulfed prokaryotic cell) provided energy/ATP; (engulfed prokaryotic cell) not destroyed/not digested

OR

(endo)symbiotic/mutualistic relationship developed; (engulfed prokaryotic cell) had its own DNA/own (70S) ribosomes

No marks awarded for 'mitochondria make ATP'.

[Max 2 marks]

11 The proteome is all the proteins produced by a cell; all cells of a multicellular organism have the same set of genes, but the set of proteins produced in different tissues is different; the set of proteins produced is dependent on gene expression; the genome is constant, but the proteome varies and is dynamic within an organism; changes in gene expression can be triggered by changes in the environment of the cell; specific genes are expressed in different cells, according to a required function; the proteome varies with the function, location or environmental conditions of the cell through the process of cell differentiation; cell differentiation allows division of labour, where specialized cells are efficient at carrying out their particular function, such as transport, support or protection.
[Max 7 marks]

A2.3 Viruses (HL only)

Paper 1 (HL only)

1 B

2 C

3 C

4 C

Paper 2 (HL only)

1 a 20 000 cases; number of deaths = 7800 to 8400
percentage of reported cases who had died = (7800 / 20 000) × 100 = 39%. *Accept range 37–41%*

b In the period July to August 2014, there are approximately 900 deaths; growth in number of deaths is rising rapidly/exponential; from December 2014 to January 2015, there are 1000 deaths, but the rate of increase is beginning to slow; although the number of deaths in the two periods is similar, the curve may be starting to plateau; suggesting that measures taken to control the spread of Ebola have been effective; although too early to predict.
[Max 2 marks]

c Number of deaths as a proportion of reported cases:
Guinea = 66.7%, Liberia = 45.0%, Sierra Leone = 30.9%
Different measures taken to control the spread of Ebola in each region, with measures in Sierra Leone more successful than in Liberia and Guinea; healthcare system may be more effective in regions with lower proportion of deaths; regions with higher number of deaths may have a higher proportion of vulnerable groups; urban populations may have better access to health services and lower mortality than rural populations; differences in accuracy of reporting of reported cases/deaths in each region; different strains of Ebola in each region, with strain in Guinea the most virulent; number of deaths greater in areas with new/virulent strain as local population has no/limited immunity; strains that are different genetically have implications for prevention and therapy because vaccines or therapeutic options developed may only work for one strain/Sierra Leone.
[Max 2 marks]

2 Extremely small/size range of 20–400 nm in diameter; have nucleic acid (DNA or RNA) as genetic material; a capsid made of protein surrounds the nucleic acid; no cytoplasm; the genome consists of DNA or RNA/linear or circular molecule of nucleic acid/single-stranded or double-stranded/one or more than one copy of the genome; the capsid is a sheath/coat built from protein subunits/capsomeres, enclosing the viral genome; the capsid protects the viral genome/(a bacteriophage has a tail shaft with fibres that is used to attach the virus to a bacterial cell wall); envelopes comprised of phospholipids derived from cell surface membrane of host cell; the envelope surrounds the capsid and is embedded with glycoproteins; the envelope protects the virion (mature virus particle) from enzymes and other chemicals (giving them an adaptive advantage over capsid-only virions).
[Max 6 marks]

3 In the lytic cycle, a phage attaches itself to a host bacterium and injects its DNA, which undergoes replication to form new virions that then lyse the cell. In the lysogenic life cycle, a phage attaches to a bacterium and injects its genome, but it does not undergo a full replication cycle. Instead it becomes resident within the bacterial host where it is maintained in a dormant state. In the lysogenic life cycle, viral DNA is incorporated into the host cell's DNA to form a prophage. In the lysogenic life cycle, the bacteriophage's viral DNA replicates together with the DNA of the host cell. Under stressful conditions, the phage DNA is removed from the bacterial chromosome and enters the lytic cycle.

	Lytic cycle	Lysogenic cycle
integration of the viral DNA	viral DNA does not integrate into the host cell's DNA	viral DNA integrates into the host cell's DNA
host DNA hydrolysis	host DNA is hydrolysed in this phage	host DNA is not hydrolysed in this phage
viral DNA replication	viral DNA replication occurs independently	viral DNA replication occurs depending upon the host cell replication
virulence	this cycle is virulent	this cycle is non-virulent
lysis of host cell	the virions are released from the host cell by lysis	host cell is not lysed in the cycle
time	short period	long term

[Max 5 marks]

4 The phage attaches to the surface of the bacterium (the host)/the tail fibre of the λ phage binds to specific receptors on the surface of *E. coli* (attachment); the protein capsid is left outside;

the phage is adsorbed on to the bacterium and injects its DNA/genome (double-stranded DNA) into the host cell; the viral DNA enters the bacterium; entry of the viral DNA into the bacterium is known as penetration; phage DNA is replicated; bacterial DNA is broken down/DNA hydrolysis takes place;

viral DNA is replicated and used to form new virus particles (biosynthesis); viral genes are expressed using host enzymes to produce viral proteins, which self-assemble to form mature bacteriophage lambda virions (maturation process); the bacterial cell lyses (bursts) and hundreds of the newly made phage particles are released;

in the lytic life cycle, the viral DNA remains as a separate molecule within the bacterial cell, rather than becoming incorporated with the host DNA, and replicates separately from the host bacterial DNA. The release of bacteriophage lambda from its host *E. coli* cell involves the lysis of the bacterial cell wall, resulting in the death of the cell.
[Max 5 marks]

5 Rapid life cycles/reproduction of viruses allows mutations to alter genome/undergoes genetic changes; genetic alterations alter proteins/antigens on the surface of the virus; after vaccination, the body responds to infection by producing antibodies; mutations in viral genome mean that the immune system can no longer recognize viral particles/antigens and so the vaccine is ineffective; antibodies no longer attach to viral antigens; repeated vaccinations are needed to track mutations in the viral genome.
[Max 2 marks]

6 The virus is able to survive conditions when host cells are incapable of reproducing; allows virus to remain dormant when conditions are unfavourable for lytic cycle; healthy bacteria grown in rich medium contain high levels of proteases: these enzymes catalyse the splitting of specific bonds in viral precursor proteins or in cellular proteins, which is essential for the completion of the viral infectious cycle; poorly growing bacteria have low levels of proteases and so will encourage establishment of a lysogenic cycle; the phage persists for generations in the bacterial chromosome; the genome of the phage is replicated much faster.
[Max 3 marks]

A3.1 Diversity of organisms

Paper 1

1 D

2 A

3 B

4 B

(Questions 5–6 HL only)

5 C

6 A

Paper 2

1 a Organisms can potentially interbreed; to produce fertile offspring; same sequence of genes (on chromosomes)/same types of chromosomes; similar traits/phenotype/*OWTTE*; same chromosome number/karyotype.
[Max 3 marks]

b A gene pool is all the genes/alleles in an (interbreeding) population; the gene pool splits/divides/separates during speciation; due to reproductive isolation (of groups within a species); temporal/behavioural/geographic isolation (can cause reproductive isolation); divergence of gene pools; allele frequencies change; natural selection different (in the isolated groups so there is divergence); different (random) mutations occur (in the isolated populations so there is divergence); speciation has occurred when differences between populations prevent interbreeding.
[Max 5 marks]
Marks not awarded for the same idea (e.g. reproductive isolation separating populations vs speciation due to interbreeding not being possible).

2 The binomial system of names for species is universal among biologists
OR named according to a globally recognized scheme;

it allows us to classify organisms into groups based on similar characteristics/common ancestry/DNA; every species is given a binomial name; members of the same species can mate and produce fertile offspring; genus is written first, followed by species; genus is capitalized, (followed by) species is lower case
OR an underlined correct example/stated that it must be underlined or italicized.
[Max 4 marks]

(Questions 3–4 HL only)

3 A barcode has lines and spaces of varying thicknesses and printed in different combinations; the DNA profile produced by gel electrophoresis is unique to an individual, and is made from bars and gaps, forming specific patterns; although individuals may have slightly different genetic profiles, overall 'barcodes' can be developed that represent the genetic makeup of the species; DNA barcoding is a method of species identification using a short section of DNA from a specific gene or genes; the genes chosen have less intraspecific (within species) variation than interspecific (between species) variation; for most animal groups, biologists use the sequence obtained from the mitochondrial cytochrome c oxidase gene; small samples of DNA can be amplified using the polymerase chain reaction (PCR) to produce a barcode; once barcodes for a sufficient number of species have been established, environments can be sampled to obtain DNA from a variety of organisms, which allows the biodiversity of habitats to be investigated rapidly.
[Max 7 marks]

4 a A dichotomous key is organised in steps, with two options given at each step; the two options identify contrasting features of the species; dichotomous keys progressively divide the specimens into smaller groups; diagnostic features of the specimen are identified (e.g. number of legs, shape); at each division point of the key, the best option of the two is chosen; the process is repeated until the key indicates the name of the species.
[Max 4 marks]

b An organism might not be in the key; terminology used in the key can be difficult for non-experts; there might not be a key available for the organisms under investigation; some features cannot be easily established in the field, e.g. whether an animal has a placenta or not, or whether an animal is endothermic or ectothermic; some organisms significantly change their body shape during their lifetime (e.g. frogs have an aquatic tadpole juvenile form, which is very different from the adult), which keys must take into account; many organisms show differences between male and females of the species/sexual dimorphism which can cause difficulties when identifying species, e.g. insects.
[Max 2 marks]

A3.2 Classification and cladistics (HL only)

Paper 1 (HL only)

1 D

2 C

3 B

4 B

5 B

Paper 2 (HL only)

1 a The clade containing the lemurs and lorises are the most distantly related to humans.

b Lemurs and lorises are in a separate clade to the other primate groups; lemurs and lorises share a recent common ancestor; the two different clades arose from different ancestral stocks and display their own distinctive character.
[Max 2 marks]

c The New World monkeys are only distantly related to Old World monkeys; Old World monkeys are more closely related to apes and humans than to New World monkeys; Old World monkeys and apes (catarrhines) are found in Africa and Asia, while New World monkeys (platyrrhines) live in Central and South America; geographical separation of the two groups led to independent evolution on different continents, leading to divergence of the clades.
[Max 3 marks]

2 a Binomial system of naming uses two names, the genus and species names; the system is used internationally so that species can be identified accurately.

b i Both turtles are the same class.

ii Both belong to the same genus (*Kinosternon*).

iii They are different species/have different species names.

c *Sophora flavescens* is a different genus and species; based only on the scientific names there is not enough evidence to decide the evolutionary relationship with the yellow mud turtle; the species name does not determine the evolutionary relationship.
[Max 2 marks]

d In different languages organisms are called different common names; scientific names allow scientists to use one unique name for a species so organisms can be identified whichever language is used for communication; any valid example similar to the one used at the start of the question.
[Max 2 marks]

3 **Analogous**: different evolutionary origin/do not share (recent) common ancestor (despite similarities of function); arise by convergent evolution; classification based on analogous traits brings together dissimilar species/is artificial.;

Homologous: similar (internal) structures/pentadactyl limb/other example of homologous structures due to common ancestry; different uses/functions; arise by adaptive radiation/divergent evolution; (natural) classification is based on homologous traits (not analogous); classification based on homologous traits has predictive values/matches evolutionary history.
[Max 4 marks]

4 Similarities/differences between organisms/species/clades; (probable) evolutionary relationships/closeness/common ancestry/phylogeny; divergence/splits/speciation/branches/nodes; relative similarity/differences between base sequence/amino acid sequence.
[Max 3 marks]

5 Biochemical information, e.g. provided by DNA and proteins; base sequences of genes or amino acid sequences of proteins; morphological traits can be used to assign organisms to clades, although care must be taken to ensure that these characteristics are homologous and not analogous; differences in DNA and protein sequences provide a system that accurately maps the relationship between species, whereas morphological differences, while being the only options for many organisms (e.g. those with only fossil remains), can lead to problems where convergent evolution has taken place; parsimony analysis is used to select the most probable cladogram in which observed sequence variation between clades is accounted for with the smallest number of sequence changes.
[Max 3 marks]

6

Eukaryote	Archaea
linear chromosomes	circular genome
cell wall sometimes present, made from chitin (fungi) or cellulose (plants); never made of peptidoglycan	cell walls present but lack peptidoglycan/glycoprotein
introns frequent	introns typically absent
lipids different/cell membrane with glycerol-esters	lipids different/cell membrane with glycerol-ether
not found in extreme environments	found in extreme environments

[Max 3 marks]

7 **a** **i** Tuatara

ii Some (taxa) are extinct *OR* convergence (of body form) could have occurred (confusing interpretation of the data).

b **i** Base sequences of a gene/DNA/mitochondrial DNA *OR* amino acid sequences of a protein; species with the most similarities (in base sequence/amino acid sequence/genome) have recently diverged/have a common ancestor/are closely related *OR* members of a clade accumulate the fewest mutations on same base sequences/vice versa/*OWTTE*.
[Max 2 marks]

ii Fossils/comparative anatomy/homologous structures/vestigial structures.

c (Because) it allows easier identification of a species; (because) it can help identify common ancestors/evolutionary paths/close relationships (showing degree of biodiversity)/*OWTTE*; (because) it is universal/cross-cultural language that avoids problems of local names of organisms *OR* (because) it promotes international collaboration *OR* (because) it facilitates access to the history/background of the species/indexing for retrieval of relevant (taxonomic) information/*OWTTE*; (because) it allows (biodiversity) research of larger taxa (e.g. examination of a family of large cats rather than one species).
[Max 2 marks]

8 a Sharks

b Four limbs

c Bony skeleton

d Sharks have a cartilaginous skeleton while bony fish have a skeleton made of bone (collagen and calcium phosphate).

e Hair, and eggs with shells.

f Crocodiles

9 Cladistics is a classification system used to construct evolutionary trees; organisms are categorized based on shared derived characteristics that can be traced to a group's most recent common ancestor and are not present in more distant ancestors; characteristics can be anatomical, physiological, behavioural, or genetic and protein sequences; a clade is a group of organisms that has evolved from a common ancestor; cladograms are diagrams used in cladistics to show evolutionary relationships between organisms; branch points in the tree represent the time at which a division between two taxa occurred; the degree of divergence between branches represents the differences that have developed between the two taxa since they diverged; the most objective evidence for placing organisms in the same clade comes from base sequences of genes or amino acid sequences of proteins; cladistics is an example of phylogenetic systematics; monophyletic taxa are natural; organisms are related through evolutionary descent; evolutionary modifications uniquely shared by organisms are evidence of their unique phylogenetic history; cladistics can be used to reassess taxonomic groupings/for reclassification, e.g. some members of the figwort family been reclassified into a new family due to DNA analysis, which showed that the similarities in flower shape were a product of convergent evolution.
[Max 7 marks]

A4.1 Evolution and speciation

Paper 1

1 C

2 B

3 A

4 (Homologous structures have evolved) from a common ancestor; divergent evolution/adaptive radiation; similarities in forelimb bones (in birds, bats and humans)/description of the similarities in bones; different uses/functions.
[Max 2 marks]

5 a Selective breeding involves identifying the largest, the best or the most useful of the progeny for human needs, and using them as the next generation of parents: continuous removal of progeny showing less-desired features, generation by generation, leads to deliberate genetic change; variation between different domesticated animal breeds and varieties of crop plant, and between them and the original wild species, shows how rapidly evolutionary changes can occur; the genetic constitution of the population may change rapidly.
[Max 3 marks]

b **Similarities**: both use variation to select phenotypes for the next generation; variation is created by random mutation, resulting in different alleles.
[Max 1 mark]

Differences: involve different selection mechanisms: one by nature (natural selection) and one by humans (artificial selection); natural selection results in the development of populations with phenotypes that are better adapted to their environment and which increase survival, whereas selective breeding results in populations with phenotypes that are useful to humans but which do not increase survival/adaptation to the environment; natural selection results in the evolution of new species whereas selective breeding generates new varieties of the same species.
[Max 3 marks]

(Questions 6–9 HL only)

6 B

7 D

8 B

9 a **Mutation**: spontaneous mutation or inherited variation in the genotype of these organisms provided genetic variation of each organism.
Natural selection: difference in selection pressure (e.g. food type) due to the different habitats that these forms are found in; there would be one phenotype that would be at a selective advantage (perhaps due to differences in the beak and skull) in the environment as it is better adapted to the living conditions; these will survive, reproduce and pass on their genes to offspring.
Isolation: as these different forms are found on the different islands/habitats, they are geographically isolated. Interbreeding is prevented and, hence, prevention of gene flow.
[Max 3 marks]

b Similarities in morphological structures could be due to convergent evolution.

Paper 2

1 **Similarities**: both use variation generated by random mutation to select organisms that are adapted to their environment; traits develop in an environment that help a species survive and reproduce.
[Max 1 mark]

Differences: convergent evolution occurs when different species evolve similar biological adaptations in response to similar selective pressures: this happens when species occupy similar ecological niches; traits that arise through convergent evolution are analogous structures; divergent evolution occurs when an ancestral species splits into two reproductively isolated groups, causing each group to develop different traits under their respective selective pressures and natural selection; traits that arise through divergent evolution are homologous structures; divergent evolution is evolution from a common ancestor, whereas convergent evolution is evolution from unrelated species due to similar selection pressures; convergent evolution occurs when two species with different ancestral origins develop similar traits, whereas divergent evolution occurs when two species diverge from a common ancestor and develop different traits.
[Max 4 marks]

2 Evolution is the cumulative change in the heritable characteristics of a population; evolution is the development of new types of living organism from pre-existing types by the accumulation of genetic differences over many generations through the process of natural selection of chance variations; adaptations that give a survival advantage are selected; for speciation to occur/development of new species, populations of an ancestral species must become separated so that different environmental factors can act on them; isolation mechanisms can be physical, behavioural or ecological; environmental change provides new niches and opportunities for evolution.

An example of speciation driven by geographical isolation is speciation in the great apes in western and central Africa. Chimpanzees (*Pan troglodytes*) are found north of the Congo River, and a closely related species, the bonobos (*Pan paniscus*), are located south of the river, with the Congo River forming a barrier between the two species so that there is geographical isolation; chimpanzees and bonobos diverged from a common ancestor between one million and two million years ago; the Congo River separated the ancestor of the chimpanzee and bonobo populations so interbreeding could not take place/Congo River acts as a geographical barrier; different environmental conditions on either side of the river led to them evolving into two species.
[Max 7 marks]

3 A population can be divided into two isolated populations by the appearance of a barrier: before separation, individuals shared a common gene pool, but after isolation, disturbing processes such as natural selection, mutation and random genetic drift may occur independently in both populations, causing them to diverge in their features and characteristics; reproductive isolation occurs, where different species cannot interbreed and have fertile offspring/gene flow is prevented between them: when members of related populations have evolved to this point and have become fully reproductively isolated, they are recognized as members of different species; e.g. speciation in the great apes in western and central Africa: chimpanzees (*Pan troglodytes*) are found north of the Congo River, and a closely related species, the bonobos (*Pan paniscus*), are located south of the river, the Congo River forms a barrier to the two species, so that there is geographical isolation between the two different species.

HL only (you may have included these points if you are studying HL Biology):

Reproductive isolation can also occur via temporal isolation, which occurs when organisms produce gametes at different times or seasons; e.g. the rainbow trout (spring) and brown trout (autumn).

Behavioural isolation occurs when organisms acquire distinctive behaviour routines, such as in courtship or mating, not matched by other individuals of their species; e.g. birds of Paradise, where bright, glittering and prominently posing males seek to secure the attention of females; competition between males results in changes in display and plumage, resulting in the progressive elaboration of plumage and performance; the genetic constitution of the next generation is strongly influenced by the few sexually successful males in each generation; female selection leads to isolation of populations and reproductive isolation, preventing hybridization in animal species.
[Max 7 marks]

(Questions 4–8 HL only)

4 Barriers that prevent interbreeding between closely related species occur either before fertilization can be attempted (pre-zygotic isolation) or after fertilization has occurred (post-zygotic isolation):

Pre-zygotic reproductive isolation	Post-zygotic reproductive isolation
prevention of mating due to habitat differences that prevent meeting	hybrids formed are not viable and die prematurely
behavioural differences, such as different mating rituals	hybrids formed are infertile because the chromosomes cannot pair up in meiosis and produce haploid gametes
temporal differences, such as being fertile at different times or seasons	hybrids are less fertile; with each successive generation, fewer survive, leading to all eventually dying out

Courtship displays can lead to sympatric speciation and prevent hybridization in animal species; differences in chromosome number lead to hybrid sterility (e.g. a mule is a sterile hybrid).
[Max 4 marks]

5 Both allopatric and sympatric speciation lead to reproductive isolation and speciation; isolating mechanisms that involve spatial separation, such as geographical isolation, are examples of allopatric speciation, whereas isolating mechanisms that occur within the same location, such as temporal and behavioural isolation, are examples of sympatric speciation.
[Max 5 marks]

6 Adaptive radiation is the diversification of an ancestral species into new species, characterized by great ecological and morphological diversity, filling different ecological niches; the finches of the Galápagos Islands are an example of adaptive radiation; variation in finch beak morphology is genetically controlled and reflects differences in feeding habits; closely related species of finch coexist without competing because of the differences in their beak morphology; the Galápagos Islands provided a large variety of different opportunities for the ancestral finch species landing on the islands; these different niches provided a range of different selection pressures which, over time, led to a variety of finch species, e.g. the warbler finch (*Certhidea olivacea*) has a different diet to the cactus finch (*Geospiza scandens*), meaning they do not compete and can coexist, thus increasing biodiversity.
[Max 3 marks]

7 A phylogenetic classification system is based on evolutionary relationships, not just similarities in physical traits that may or may not have evolutionary significance; through the process of evolution, organisms have changed into groups with a common ancestry and common characteristics; by grouping organisms using biochemical information, such as DNA, changes in species though time can be mapped, showing the interconnections and true evolutionary relationships between species; the relatedness of different groups of organisms can be assessed using the amount of difference between the base sequence of genes in DNA; biochemical changes such as DNA mutation can occur at a constant rate and can be used as a molecular clock, where the rate of change records the time that has passed between the separation of evolutionary lines; a molecular clock is a measure of evolutionary change over time, based on the mutation rate of DNA sequences and can be used for estimating how long ago two related organisms diverged from a common ancestor; parsimony is the concept that the simplest explanation that can explain the data is preferred: in the analysis of phylogeny, parsimony means that a hypothesis of relationships that requires the smallest number of character changes is most likely to be correct; parsimony analysis is used to select the most probable cladogram in which observed sequence variation between clades is accounted for with the smallest number of sequence changes; cladograms are produced which show evolutionary relationships between organisms.
[Max 5 marks]

8 Polyploidy is a process that results in more than two sets of chromosomes in the nuclear genome; it is also known as whole genome duplication (WGD); this abrupt change in the structure or number of chromosomes may lead to a new species; interspecific hybridization (allopolyploidy) results in new genetic combinations that can be acted upon by natural selection and results in rapid evolution; an allopolyploid plant is the result of two distinct genomes combining: this occurs by interspecific hybridization followed by either chromosome doubling or fusing of gametes, or by interspecific hybridization of two tetraploids (i.e. genomes created when a diploid gamete fuses with another diploid gamete); hybrids often show improved biological function compared to either parent species ('hybrid vigour') and are generally larger in size and are more fertile, and more invasive, compared to the parent species; invasive species are more likely to be polyploid than native species, and the proportion of polyploids increases with more advanced invasion; the plant genus *Persicaria* (in the family Polygonaceae) shows many instances of allopolyploid speciation, with many species of allopolyploids; a diploid species, *Persicaria lapathifolia* (pale smartweed) has been involved in at least six cases of allopolyploid speciation; this species is geographically and ecologically widespread and also bears numerous conspicuous flowers, which may explain its ability to hybridize with other species. Japanese knotweed (*Reynoutria japonica*) is also a polyploid; extensive hybridization has occurred between native and other introduced taxa; hybrids are of three types: interspecific and intraspecific hybrids (involving giant knotweeds), hybrids between Japanese knotweed and *Fallopia baldschuanica*, and hybrids between Japanese knotweed and Australasian endemics of the genus *Muehlenbeckia*.
[Max 7 marks]

A4.2 Conservation of biodiversity

Paper 1

1 B

2 B

3 C

4 C

5 C

6 B

7 a Both areas have the same richness as they have the same number of species/total of individuals; moorland area 1 has similar abundance across all four species and therefore similar evenness; moorland area 1 has more evenness as it has a more even distribution of numbers among the four species.
[Max 2 marks]

b Moorland area 1 would have the greater Simpson's reciprocal index/diversity/biodiversity; area has greatest evenness between species; both areas have the same species richness but the greater evenness in area 1 indicates a higher species diversity.
[Max 3 marks]

c Area 1 may be older/a more complex ecosystem than area 2; in area 2, certain species can dominate the community, resulting in lower evenness and species diversity; area 2 may be a disturbed site/affected by human activities, e.g. logging/pollution/introduction of an invasive species.
[Max 2 marks]

8 a The larger the forest area, the more forest-interior bird species there are, as there are more habitats/niches.

b Different sampling methodologies between different sites; different number of habitats in different forests; variation in climatic conditions/seasonal effects; time of sampling/life cycles of birds vary and sampling may coincide with e.g. breeding period/emergence of fledglings.
[Max 1 mark]

c Complexity of the ecosystem/number of available habitats; height of forest/forests with greater height/taller trees will offer greater number of niches for forest birds; presence of predators in forest may reduce diversity/number of species.
[Max 3 marks]

Paper 2

1 a Cod spawning increases between 1963 and 1971; overall decline in cod spawning between 1971 and 1993; increase in spawning from 1993 to 1997.
[Max 2 marks]

b As exploitation rate/rate of fishing increases, spawning rate decreases; overexploitation removes mature fish from population and so reduces spawning; since approximately 1990, exploitation rate has declined, leading to a recovery of fish stocks and spawning rate.
[Max 3 marks]

c Management techniques lacking/inadequate between 1971 and 1993; the amount of fishing has been reduced (since about 1990), reversing the decline in spawning; management techniques from 1990 onwards have been successful in increasing spawning; with time, this trend may allow stocks to recover completely.
[Max 3 marks]

2 Raise awareness/gain widespread public/political support for conservation actions; breed Amur leopard/endangered species in captivity (for reintroduction into the wild); education/research opportunities; lower maintenance/cost than in situ conservation; protect an endangered species; other strengths and limitations outlined in the table below:

Strengths	Limitations
individual animals can be exchanged between collections to prevent inbreeding and to maintain genetic diversity	it is difficult to maintain genetic diversity and so the gene pool of a species may be small
allows predators and diseases to be controlled	does not directly conserve natural habitat diversity of the species (conservation of habitat should lead to conservation of species)
populations can build up quickly as habitat and food are abundant	Amur leopard may not breed easily in captivity
abundant food and habitat reduce competition	released animals may be easy targets for predators
	aesthetic values can lead to an imbalance in conservation activity, so that popular and charismatic species are conserved (e.g. Amur leopard) but small and less popular animals may not be part of a conservation programme (e.g. the endemic Madagascan hissing cockroach)
	some countries may have technical or economic difficulties in establishing programmes

[Max 5 marks]

3 a Decline in virulence between years 0 and 3, with decreasing rate between year 3 and 4; virulence shows no reduction between years 4 and 6/virulence shows a plateau.

b Initially, a small number of the population of rabbits had immunity; as their vulnerable relatives were killed off, the immune rabbits prospered from the diminished competition for grass; rapidly, the bulk of the population were immune and any that failed to develop immunity were quickly taken out.

c The decline in rabbit mortality and the plateau in virulence indicates that the eradication programme was ultimately unsuccessful; rabbits that were immune to the virus survived and continued to reproduce; the rabbit population continues to exist/was not eradicated.

4 Name of alien species AND where introduced; how/reason alien species was introduced; introduced alien species can escape into local ecosystems

OR how it became invasive; (reference to principle of) competitive exclusion

OR take over the niche of other organisms; can reproduce more than native species; relationship with predators; reduction in the numbers of endemic species/decrease in biodiversity; description of another effect on this alien species; evolution is the cumulative change in the heritable characteristics of a population; evolution is the development of new types of living organism from pre-existing types by the accumulation of genetic differences over many generations through the process of natural selection of chance variations; adaptations that give a survival advantage are selected; by altering its environment/biotic interactions, an invasive species may have altered the evolutionary pathways of native species.
[Max 7 marks]

5 Both methods protect species diversity and seek sustainable management of biodiversity; both methods seek to ensure the ongoing survival of species.
[Max 2 marks for similarities]

	Strengths	Limitations
protected area/ in situ conservation	can conserve whole ecosystems; allows research and education; preserves many habitats and species; prevents hunting and other disturbance from humans; allows for in situ conservation	can be very expensive; difficult to manage; subject to outside forces that are difficult to control; difficult to establish in the first place due to political issues/vested interests
breeding programme/ ex situ conservation	allows controlled breeding and maintenance of genetic diversity; allows research; allows for education; effective protection for individuals and species	historically for popular animals, not necessarily those most at risk; problem of reintroducing zoo animals to wild; does not preserve native habitat of animals/plants; limits freedom of animals/ethical issues

[Max 5 marks for differences]

Theme B Form and function

B1.1 Carbohydrates and lipids

Paper 1

1 B

2 C

3 D

4 C

5 A

6 C

7 D

8 A

Paper 2

1 a All have a higher concentration of triglyceride at Site 1 than at Site 2; HT (and WS) highest at both sites/at Site 1; MW lowest at Site 1 and AR lowest at Site 2.
[Max 2 marks]

b Triglyceride higher at Site 1 because more fat deposition/HT eats more; butyrate higher at Site 2 because more fat/triglyceride utilized/HT fasts more.
[Max 2 marks]

c (Data supports hypothesis) because triglyceride levels higher at Site 1/butyrate levels higher at Site 2/more fat deposited at Site 1/more fat utilized at Site 2/more fasting at Site 2.
[Max 2 marks]

d **Advantage**: need to capture bird only once to get data/no need to mark and catch birds again; more specific informative data can be gathered/information in named component in blood can be obtained.
Unqualified 'more precise' not accepted.

Disadvantage: removal of blood is more stressful/risky for the bird than weighing; danger of infection/spread of disease/harm to birds; extra time/money/laboratory equipment is needed to analyse results; could include fat/triglyceride/butyrate from previous/long-term feeding; nutrients from food eaten at these sites may not have been absorbed yet.
[Max 2 marks]

2 a Starch is composed of α-glucose molecules; starch contains amylose, which is a linear/helical molecule; starch contains amylopectin, which is a branched molecule; cellulose is an unbranched/straight chain of glucose molecules; formed from β-glucose; hydrogen bonds form between cellulose chains to form microfibrils. Thus starch is a branched polymer, while cellulose is a linear polymer; this difference makes starch more digestible than cellulose; starch is used for energy storage, whereas cellulose is used primarily as structural support and mechanical strength in plant cell walls; the orientation of β-glucose molecules in cellulose allows hydrogen bonds to form between parallel strands, and between adjacent glucose units in the same strand, which strengthens the cellulose polymer and enables it to carry out its function in the cell wall of plants.
[Max 5 marks]

b Cellulose is a polymer of β-glucose molecules combined together by 1-4 glycosidic bonds; cellulose fibres are straight and uncoiled; successive glucose units are linked at 180º to each other: this structure is stabilized and strengthened by hydrogen bonds between adjacent glucose units in the same strand and, in fibrils of cellulose, by hydrogen bonds between parallel strands; additional strength comes from the cellulose fibres laid down in layers that run in different directions; hydrogen

bonds strengthen the cellulose polymer and enables it to carry out its function in the cell wall of plants.
[Max 3 marks]

3 Carbohydrates are used for short-term storage whereas lipids are used for long-term storage; glycogen can be broken down into glucose, which is soluble in water (unlike lipids), making carbohydrates easy to transport around the body (from and to a store); carbohydrate in the form of glucose is the main source of energy for most metabolic processes in the body/respiration; lipids provide essential fatty acids for the body.
[Max 3 marks]

B1.2 Proteins

Paper 1

1 C

2 B

3 A

4 B

5 B

(Questions 6–12 HL only)

6 D

7 C

8 A

9 C

10 B

11 C

12 D

Paper 2

1 a 0.2 (arbitrary units)

b Cyclic increase and decrease of activity; approximately every 20 minutes; increase in 10, 30, 50 minutes; decrease in 0, 20, 40, 60 minutes; maximum in 30 minutes.
[Max 2 marks]

c When stressed, bacteria produce more proteins but only at certain times/experimental group usually makes more proteins/higher rates; stressed/experimental group has greater maximums; less protein in control except 20 and 40 minutes/control usually lower rates; greatest activity at 30 minutes for experimental/at 10 and 50 for control; slower cycle for control/cycle every 50 minutes; (similarity) both show fluctuations/greater fluctuations in the experimental group.
[Max 3 marks]

2 a The entire set of proteins expressed by a genome/all of the proteins produced by a cell, tissue or organism.

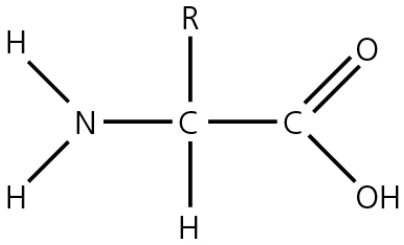
b Ribosomes

c $20^5 = 3\ 200\ 000$ possible amino acid sequences

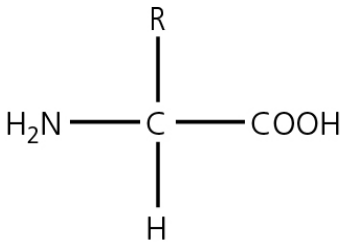
3 a COO^- or COOH group at one end; NH_2 or NH_3^+ at the other; CH in middle with H or R-group attached.

If shown expanded, then carbonyl oxygen must attach to C; if shown non-expanded, N of amine group must attach to C

e.g.



OR



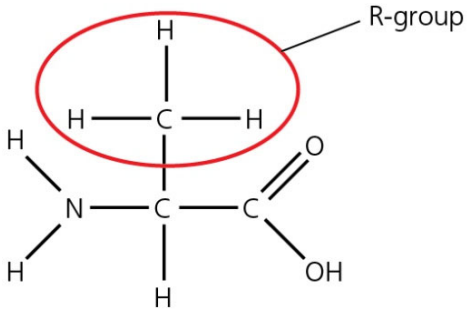
[Max 3 marks]

b Enzymes that catalyse/speed up/control (the rate and direction of) metabolic reactions; proteins can be hormones, which are chemical messengers to cells; proteins that transport through the membrane such as channel/carrier/pumps that regulate what enters/leaves the cell; haemoglobin in red blood cells that transports/binds oxygen; membrane proteins for cell/tissue recognition/cell adhesion/communication; structural elements of muscle fibre/actin/myosin for movement *OR* spindle fibres move chromosomes; histones condense DNA into chromosomes.
[Max 5 marks]

4 Denaturation is a structural change in a protein that alters its three-dimensional shape; rises in temperature or a small deviation in pH from the optimum can denature proteins; the three-dimensional structure of a protein is stabilized by bonds or interactions between R-groups of amino acids within the molecule; exposure to heat causes atoms to vibrate violently and this disrupts weak intermolecular forces (i.e. noncovalent bonds) within proteins; small changes in pH of the medium similarly alters the shape of proteins; extremes of pH cause ionic bonds within the protein to break or cause new ionic bonds to form; the structure of an enzyme may spontaneously reform when the optimum pH is restored, but exposure to strong acids or alkalis irreversibly denatures enzymes.
[Max 4 marks]

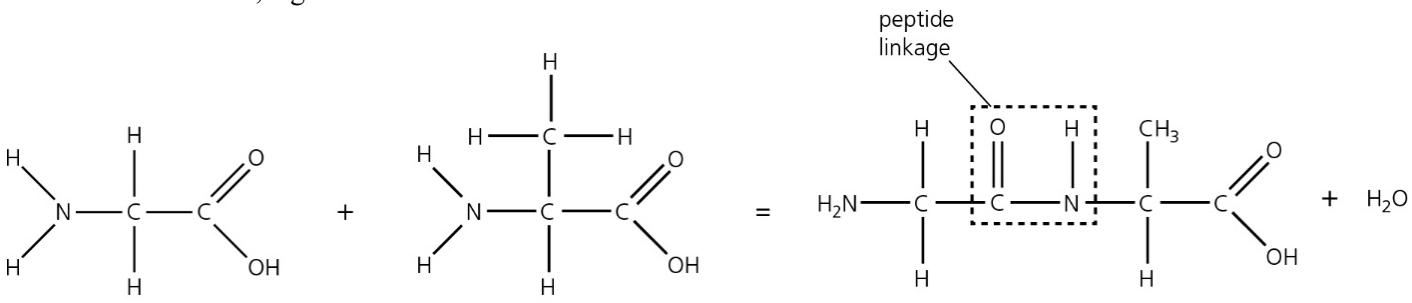
5 Many of the properties of proteins depend on the three-dimensional shape of the molecule; a small part of the surface of a globular protein is an active site; here the precise chemical structure and physical configuration of the protein are critical; provided the active site is unchanged, substrate molecules can bind and reactions can be catalysed.
[Max 3 marks]

6 a



alanine

b Circle drawn around OH group of glycine and around either of the Hs on NH_2 of alanine to show removal of water molecule; result molecule with peptide linkage/bond labelled; water molecule removed; e.g.



glycine **alanine** **dipeptide**

[Max 3 marks]

(Questions 7–11 HL only)

7 a Secondary structure includes α-helices/β-pleated sheets; secondary structure (of this protein) consists (mainly) of α-helices; spiral coils (of polypeptide chain) held together by hydrogen bonds; between oxygen (C=O) and hydrogen atoms (N–H) of amino acids (on backbone); (some) β-pleated sheets present in this protein.
[Max 3 marks]

b The primary structure of a protein is the linear sequence of amino acids in the molecule; proteins differ in the variety, number and order of their constituent amino acids; changing an amino acid in the sequence of a protein alters its properties; the primary structure determines how a protein folds/determines secondary and tertiary structure; the shape of a protein determines its function/properties.
[Max 3 marks]

8 The side chain or 'R' part of an amino acid is variable between different amino acids; amino acids have the same basic structure, but are different in character because of the different R-groups; categories of amino acids found in cell proteins are:

- acidic amino acids: having additional carboxyl groups (e.g. aspartic acid)
- basic amino acids: having additional amino groups (e.g. lysine)
- amino acids with hydrophilic properties (water soluble): have polar R-groups (e.g. serine)
- amino acids with hydrophobic properties (insoluble): have non-polar R-groups (e.g. alanine).

The combining together of different amino acids in contrasting combinations produces proteins with different properties; the properties of proteins depend on the different amino side chains; some proteins are hydrophobic or non-polar (the electrical charge of the molecule is evenly distributed across the molecule); some proteins are hydrophilic or polar (positive and negative poles are formed in a molecule);

some amino acids are basic (with an amino group in the side chain) and some are acidic (with a carboxyl group in the side chain).
[Max 5 marks]

9 Polar amino acid side chains tend to be displayed on the outside of the folded protein where they can interact with water, whereas the non-polar amino acid side chains are buried on the inside; amino acids with polar R-groups have hydrophilic properties: when these amino acids are built into protein in prominent positions, they may influence the properties and functioning of the proteins in cells; amino acids with non-polar R-groups have hydrophobic properties; in globular proteins that are soluble in water, hydrophobic amino acids are clustered in the protein's core; integral proteins have regions with hydrophobic amino acids, helping them to embed in membranes; integral membrane proteins are permanently embedded within the plasma membrane; the portions of the proteins found inside the membrane are hydrophobic, while those exposed to the cytoplasm or extracellular fluid tend to be hydrophilic; the fatty acid tails that form the interior of the membrane are non-polar and do not repel the hydrophobic (non-polar) parts of the integral proteins.
[Max 4 marks]

10 The quaternary structure of proteins arises when two or more polypeptide chains or proteins are held together forming a complex, biologically active molecule; conjugated proteins are a combination of proteins and non-protein prosthetic groups; non-protein groups include carbohydrates (e.g. the glycocalyx of cell membranes), lipids, bound metal ions and other organic groups; haemoglobin is a conjugated protein consisting of four polypeptide chains (two 'α-chains' and two 'β-chains'), held around a non-protein haem group (the prosthetic group), in which an atom of iron occurs; non-conjugated proteins are proteins not associated with non-protein prosthetic groups; insulin and collagen are examples of non-conjugated proteins.
[Max 3 marks]

11 Fibrous proteins take up a tertiary structure that is a long, much-coiled chain, with long, narrow shapes; examples of fibrous proteins are collagen, a component of bone and tendons, and keratin, found in hair, horn and nails.

Collagen is a structural protein that occurs in skin, tendons, cartilage, bone, teeth, the walls of blood vessels and the cornea of the eye; the collagen molecule consists of three polypeptide chains, each in the shape of a helix; chains are wound together as a triple helix forming a stiff cable, strengthened by numerous hydrogen bonds; many of these triple helices lie side by side, forming collagen fibres, held together by covalent cross-linkages; the ends of individual collagen molecules are staggered so there are no weak points in collagen fibres, giving the whole structure high tensile strength; this makes the protein well suited to provide structural support in skin, tendons and cartilage.

Globular proteins have a spherical shape; examples include enzymes (e.g. lysozyme and catalase) and hormones (e.g. insulin).

Insulin is a very small protein, allowing it to move quickly through the blood; its shape is recognized by specific receptors on its target cell surfaces.

The surface of enzymes has a small region that forms the active site; here the precise chemical structure and physical configuration of the protein are critical; provided the active site is unchanged, substrate molecules can bind and reactions can be catalysed.

[Max 7 marks; answer must include reference to both globular and fibrous proteins – if only one type of protein referred to, max 4 marks]

B2.1 Membranes and membrane transport

Paper 1

1 B

2 D

3 C

4 D

5 A

6 B

7 D

8 D

(Questions 9–14 HL only)

9 C

10 B

11 C

12 D

13 a Membranes that contain only phospholipids show sudden changes in membrane fluidity; this phase transition is broadened for membranes that contain significant quantities of cholesterol, and the corresponding change in membrane fluidity occurs more gradually and over a wider temperature range.
[Max 2 marks]

b Cholesterol affects membrane fluidity by forming strong interactions with phospholipids; cholesterol in the bilayer orientates itself with its polar head group facing the aqueous external cell environment and its non-polar region facing the interior of the membrane; one of cholesterol's functions is to reduce the fluidity of the membrane by forming strong interactions with phospholipids using its rigid steroid ring structure; cholesterol lowers membrane fluidity at high temperatures; cholesterol increases membrane fluidity at low temperatures; at high temperatures, these interactions harden the membrane and interfere with phospholipid mobility; at low temperatures, the flexible, nonpolar tail of cholesterol interferes with the tight packing of adjacent phospholipid chains maintaining membrane fluidity.
[Max 7 marks]

c Cholesterol increases membrane fluidity at low temperatures; at the high concentrations found in most animal cell cytoplasmic membranes, cholesterol prevents the hydrocarbon chains of lipids from packing together; this interference with packing broadens the phase transition that occurs during freezing, so there is no rapid change in membrane fluidity; the effects of cholesterol at low temperatures is due to cholesterol's kinked tail, which disrupts lipid packing; cholesterol acts as a buffering molecule in the membranes of animal cells that prevents abrupt changes in membrane fluidity over a range of temperatures; animals with cholesterol in their membranes that live in Arctic areas can therefore maintain membrane fluidity.
[Max 3 marks]

14 a Little change in saturated fatty acids between 0 °C and 10 °C; rapid increase in saturated fatty acids between 10 °C and 15 °C; steady increase in unsaturated fatty acids between 0 °C and 10 °C; decrease in unsaturated fatty acids from 10 °C to 20 °C; unsaturated fatty acids have higher relative percentage than saturated fatty acids at lower temperatures/lower than 14 °C, whereas unsaturated fatty acids have higher relative percentage at higher temperatures/greater than 14 °C; there is a significant shift from saturated to unsaturated fatty acids between 10 °C and 14 °C; between 14 °C

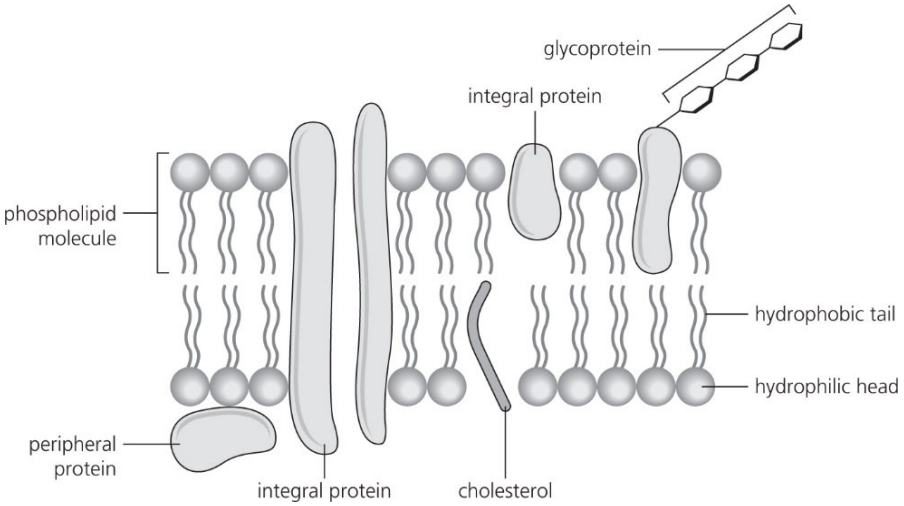
and 20 °C there are only minor variations within the relative proportions of individual fatty acids.
[Max 3 marks]

b Membranes contain a mixture of phospholipids, with some phospholipids containing saturated fatty acid tails (no double bonds between a pair of carbon atoms) and some unsaturated fatty acid tails (double bonds between carbon atoms); unsaturated fatty acids in lipid bilayers have lower melting points, so membranes are fluid and therefore flexible at lower temperatures; unsaturated fatty acids melt at a lower temperature because their unsaturated hydrocarbon tails do not pack so closely together in the way those of saturated fatty acids do; an excess of unsaturated fatty acid tails makes the membrane more fluid at lower temperatures; saturated fatty acids have higher melting points and so make membranes stronger at higher temperatures; membranes need to be sufficiently fluid for many of the proteins present to move about and function correctly; if the temperature of a membrane falls it becomes less fluid, and a point may be reached when a membrane will solidify; some organisms, such as *Chryseobacterium frigidisoli* PB4, can vary the balance between saturated and unsaturated fatty acids as ambient temperatures change.
[Max 7 marks]

c Antarctic glacier soils are exposed to a hostile environment with very low temperatures; to survive under those conditions, micro-organisms adapt by altering their cell membrane fatty acid composition; at lower temperatures, the higher relative percentage of unsaturated fatty acids maintains membrane fluidity, whereas at higher temperatures, the relative percentage of saturated fatty acids increases, making the membranes stronger.
[Max 3 marks]

Paper 2

1 a



Individual phospholipid molecules should be shown using the symbol of a circle with two parallel lines attached. A range of membrane proteins should be shown, including glycoproteins.
[Max 4 marks; max 1 mark for each correctly drawn and labelled component.]

2 a The phosphate heads of phospholipids are hydrophilic and interact with the surface of the water whereas the tails are hydrophobic so are repelled; hydrophilic heads are directed out into the water and the hydrophobic tails pointing away; hydrophobic hydrocarbon chains form the core of the membrane; the core of the membrane has low permeability to large and hydrophilic molecules, including ions and polar molecules; membranes therefore function as effective barriers between aqueous solutions, across which all substances entering and leaving the cell pass, such as metabolites that move between the cytoplasm and the interior of the cell; oxygen and carbon dioxide are very small molecules and can diffuse through the phospholipid bilayer; cholesterol maintains membrane

fluidity; the presence of cholesterol disturbs the close packing of the bulk of the phospholipids of the bilayer; the quantity of cholesterol present may vary with the ambient temperatures that cells experience; antenna-like carbohydrate molecules form complexes with certain membrane proteins (forming glycoproteins) and lipids (forming glycolipids); glycolipids (and glycoproteins) are found on the extracellular side of membranes and are used in cell–cell recognition; e.g., T-cell receptor on membranes of T-cells and how it helps to recognise peptide: MHC on antigen-presenting cells.
[Max 6 marks]

b Facilitated diffusion by channel proteins; active transport by protein pumps *OR* protein pumps, e.g. sodium–potassium pump; cell recognition by glycoproteins/protein receptors; communication/receptors for hormones/signal molecules; cell adhesion.
[Max 5 marks]

3 Simple diffusion is passive movement of molecules/ions along a concentration gradient; facilitated diffusion is passive movement of molecules/ions along a concentration gradient/down a concentration gradient through a protein channel (without use of energy); osmosis is the passage of water through a membrane from lower solute concentration to higher; water can move though the phospholipid bilayer or through aquaporins; active transport is movement of molecules/ions against the concentration gradient (through membrane pumps) with the use of ATP/energy; sodium–potassium pumps use active transport to move sodium and potassium ions against their concentration gradient.

HL only: endocytosis is the infolding of membrane/formation of vesicles to bring molecules into a cell with the use of energy *OR* exocytosis is when vesicles fuse with the membrane to release molecules from the cell with use of energy; chemiosmosis occurs when protons diffuse through ATP synthase (in the membrane) to produce ATP.
[Max 6 marks]

(Question 4 HL only)

4 **a** X = endocytosis; Y = exocytosis.

b Endocytosis is the formation of vesicles as the plasma membrane pinches inward, taking material into the cell; exocytosis is the process where vesicles fuse with the membrane and material is exported out of the cell; the strength and flexibility of the fluid mosaic membrane make this activity possible; energy from metabolism (ATP) is required; when solid matter is being taken in (phagocytosis), part of the plasma membrane at the point where the vesicle forms is pulled inwards, and the surrounding plasma membrane and cytoplasm bulge out, and so solid matter becomes enclosed in a small vesicle; phagocytes engulf the debris of damaged or dying cells by endocytosis and dispose of it; white blood cells that produce antibody molecules secrete them by exocytosis; another example of exocytosis is the release of neurotransmitter chemicals, such as acetylcholine, into the synaptic cleft between neurons.
[Max 5 marks]

B2.2 Organelles and compartmentalization

Paper 1

1 B

2 B

(Questions 3–6 HL only)

3 A

4 B

5 A

6 C

Paper 2

1 The stroma.

2 A protein-lined channel in the nuclear envelope; regulates the transport of molecules between the nucleus and the cytoplasm.

3 a Carbon is a relatively small atom with four electrons in its second shell and can form four strong, stable covalent bonds; a single covalent bond is formed when two atoms share a pair of outer electrons; covalent bonds provide great stability to biological molecules (many of which are very large); carbon has an essential role in the cell because of its ability to form four strong covalent bonds with other carbon atoms to form stable chains, branched chains and cyclic structures (rings); at least two and a half million organic compounds exist: organic compounds include amino acids, which form proteins, fatty acids (a component of lipids) and carbohydrates such as glucose; carbon compounds that contain carbon=carbon double bonds are unsaturated, e.g. unsaturated fatty acids; organic molecules are molecules that are made of carbon and hydrogen, such as urea $CO(NH_2)_2$, proteins, sugars and lipids, which are found in living organisms; hydrocarbons such as methane, CH_4, are organic, although not found in living organisms; some simple carbon compounds are not considered organic, such as carbon dioxide (CO_2), carbonic acid (H_2CO_3) and hydrogen carbonate ions (HCO_3^-).
[Max 7 marks]

b Each organelle has a different function, carrying out a specific biological process and a different set of chemical reactions; compartmentalization (the division of the interior cell into separate discrete areas) allows the correct concentration of metabolites to be present for specific metabolic processes and the appropriate enzymes to be present; compartmentalization allows incompatible biochemical processes to be separated; separating the reactions of life by compartmentalization means that they can be controlled and do not interfere with each other; organelles in eukaryotic cells include mitochondria, chloroplasts, nucleus, lysosomes; rough endoplasmic reticulum (RER), smooth endoplasmic reticulum (SER) and Golgi apparatus; e.g. lysosomes illustrate the role of compartmentalization in cells; lysosomes are tiny spherical vesicles bound by a single membrane and contain digestive enzymes in an acidic environment; the hydrolytic enzymes are active only in the lysosome's acidic interior, the pH of the cell is neutral to slightly alkaline, and so the enzymes' acid-dependent activity protects the cell from self-digestion in case of lysosomal leakage or rupture; this is an example of how the compartmentalization provided by lysosomes allows functions to occur that would not be possible or controllable in the wider interior of the cell.
[Max 4 marks]

c Classification of species ensures that new species are placed correctly within the classification system; allows for genetic variation within a species and ensures that clear parameters can be set when deciding whether an individual belongs to one species or another; classification is essential to biology due to the many different living organisms that need to be organized into manageable categories; there are currently approximately 1.8 million described species, and so a process is needed to divide organisms into groups of similar species; the scheme of classification is flexible, allowing newly discovered living organisms to be added where they fit best; given the great diversity of life, there is a need to classify organisms in order to provide a framework for biological knowledge; classification reveals functional and structural similarities and differences between organisms; the classification system shows evolutionary relationships between organisms; the binomial system allows for effective and accurate taxonomic communication throughout the world/by using the same methodology and language to describe and group species, collaboration between scientists around the world is made possible.
[Max 4 marks]

4 The nuclear membrane keeps DNA separate from the other parts of the cell so that the DNA is protected from the many cellular reactions that occur in the cytoplasm; separating the nucleus and cytoplasm allows gene transcription and translation to be kept separate; post-transcriptional modification of mRNA can happen in the nucleus before the mRNA meets ribosomes in the cytoplasm: this is an advantage for

eukaryotic cells as variants of a protein can be produced from a single gene, due to gene splicing; communication between nucleus and cytoplasm is important via nuclear pores; nuclear pores transport proteins in their folded conformation and ribosomal components as assembled particles: this distinguishes the nuclear transport mechanism from the mechanisms that transport proteins into most other organelles.
[Max 5 marks]

5 Organelles are discrete (separate) subunits in cells, and include the nucleus, chloroplasts, mitochondria, vesicles, ribosomes and the plasma membrane; most organelles are made from membrane (membrane-bound organelles), such as the rough endoplasmic reticulum, smooth endoplasmic reticulum, Golgi apparatus and the double membrane that surrounds the nucleus; the nucleus contains DNA, which controls the functions of the cell; nuclear pores allow mRNA to travel from the nucleus to the cytoplasm, where it is used for protein synthesis (at ribosomes); ribosomes are the site of protein synthesis; ribosomes can be free-floating in the cytoplasm where they are used to synthesize proteins for use within the cell; ribosomes can be embedded in endoplasmic reticulum, forming rough endoplasmic reticulum (RER) where proteins can be stored and exported from cells via vesicles; lysosomes are small spherical vesicles bound by a single membrane that contain digestive enzymes in an acidic environment; lysosomes break down and destroy foreign particles; mitochondria are the site of aerobic respiration in cells; mitochondria contain enzymes that are used in aerobic respiration; mitochondria have an internally folded membrane to increase the surface area for respiration; chloroplasts contain chlorophyll, which traps sunlight energy for photosynthesis; chloroplasts have an internally folded membrane to increase the surface area to trap light.
[Max 6 marks]

6 Centrifugation is used as a preparative technique to separate one type of material or substance from others, and as an analytical technique to measure physical properties (e.g. molar mass, density, shape and binding ability) of macromolecules; centrifuges spin fluids at very high speeds, separating particles depending on their density; more-dense particles settle at the bottom of the tube, less-dense particles rise to the top; centrifugation allows the separation of animal cell homogenates (a suspension of cell fragments) into the various organelles, according to their densities; centrifugation separates organelles based on their relative density, not their size; centrifugation has allowed biologists to study biological processes free from all the complex side reactions that occur in a living cell, by using purified cell-free systems; e.g. the mechanism of protein synthesis (translation) was discovered in experiments that used a cell homogenate that could translate mRNA molecules to produce proteins; ultracentrifugation was used in the Meselson and Stahl experiment.
[Max 7 marks]

7 Membranes form most cell organelles (membrane-bound organelles) such as RER, SER, Golgi apparatus, mitochondria and chloroplasts; compartmentalization allows the correct concentration of metabolites to be present for specific metabolic processes and the appropriate enzymes to be present, so that incompatible biochemical processes can be separated; materials can be transported from one organelle to another using vesicles (which are made from membrane), e.g. proteins transported from RER to Golgi apparatus; membranes can fuse with other membranes, which enables transport through the cell to occur via vesicles; the double membrane that forms the nuclear envelope allows the contents of the nucleus to be separated from the cytoplasm; the nuclear membrane keeps DNA separate from the other parts of the cell so that the DNA is protected from the many cellular reactions that occur in the cytoplasm; separating the nucleus and cytoplasm allows gene transcription and translation to be kept separate.
[Max 7 marks]

(Questions 8–12 HL only)

8 a A = nuclear pore; B = nuclear envelope/nuclear membrane; C = rough endoplasmic reticulum (RER); D = ribosomes on the RER; E = ribosomes free in cytoplasm; F = smooth endoplasmic reticulum (SER).
[All correct = 3 marks; 5 correct = 2 marks; 3–4 correct = 1 mark; <3 correct = 0 marks]

b Polysomes are groups of ribosomes that are translating the same mRNA; polysomes allow many copies of a particular polypeptide to be produced simultaneously; indicating the cell needs multiple copies of a particular polypeptide.

9 **Similarities**:

Structural similarity	Function
the presence of electron carriers on the thylakoid membrane and mitochondrial inner membrane	movement of electrons via the electron carriers releases energy to create a proton gradient for the synthesis of ATP
the presence of a proton pump on the thylakoid membrane and mitochondrial inner membrane	pump protons from the stroma to thylakoid space in chloroplasts, and matrix to inter-membrane space in mitochondria, to create a proton gradient
the inner membrane of mitochondria and the thylakoid membrane are extensively folded	to increase surface area for attachment of e.g. electron carriers/photosynthetic pigments
both contain ATP synthase on the thylakoid membrane and mitochondrial inner membrane	to allow the facilitated diffusion of protons to generate ATP to allow phosphorylation of ADP to ATP
both contain circular DNA	contain genes that code for proteins/enzymes involved in photosynthesis and respiration
both contain 70S ribosomes	for translation of mRNA into proteins/enzymes involved in photosynthesis and respiration
both have a double membrane	for compartmentalization and localization of enzymes for Krebs cycle and link reaction in mitochondria matrix, and Calvin cycle in chloroplast stroma

[Similarities: max 4 marks]

Differences: in chloroplasts, internal membrane is folded into thylakoids, which contain chlorophyll, whereas in mitochondria the internal membrane is folded into cristae to increase surface area for ATP production; liquid within chloroplasts is the stroma, which contains enzymes for light-independent reactions of photosynthesis/Calvin cycle, whereas mitochondria contain the matrix with enzymes for aerobic respiration/site of enzymes of Krebs cycle.
[Differences: max 3 marks]

10 Free ribosomes are located/free-floating in the cytoplasm and synthesize proteins for use within the cell, e.g. haemoglobin in red blood cells or contractile proteins in muscle cells; ribosomes of the rough endoplasmic reticulum produce proteins for export from the cell, or for use in membrane synthesis; proteins synthesized on membrane-bound ribosomes are transported to the Golgi apparatus via vesicles, where they are modified ready for export from the cell.
[Max 4 marks]

11 Clathrin is a specialized protein that causes the membrane to invaginate; membranes can separate or fuse together so that cells and organelles can bring in, transport and release molecules; many cells take up molecules through the process of receptor-mediated endocytosis; clathrin initially binds to a receptor on the cell surface; it polymerizes into a lattice network around the growing membrane bud to form a clathrin-coated pit; the invaginated membrane eventually breaks off and fuses to form a vesicle from either the Golgi body or plasma membrane.
[Max 4 marks]

12 The nucleus is surrounded by two membranes (the nuclear envelope); the outer membrane is continuous with the endoplasmic reticulum (ER), which makes it easy for the nucleus to obtain proteins made in the RER, so endocytosis is not needed; the nuclear envelope contains many pores; nuclear pores enable rapid movement of molecules between the nucleus and cytoplasm (such as mRNA) and between the cytoplasm and the nucleus (such as proteins, ATP and some hormones); the inner membrane contains the DNA and nucleolus; the inner nuclear membrane is lined by the nuclear lamina, which is a meshwork of filaments that extend into the interior of the nucleus and provide structural support; the lamina is present in animal cells but not plant or fungal cells, and is comprised of lamins, a type of fibrous protein; the double membrane therefore allows compartmentalization of the functions of the nucleus; during cell division (mitosis or meiosis), the nuclear envelope dissociates into small vesicles; dissociation enables the chromosomes to encounter the cytoplasm in the cell and the spindle apparatus, which is central to manipulating the chromosomes during mitosis and meiosis.
[Max 6 marks]

B2.3 Cell specialization

Paper 1

1 D

2 A

3 C

4 B

5 C

6 a The figures for mass are more readily available than the volume of each animal/mass easier to obtain than volume; the mass of the animal gives an indication of the relative size of each animal (as does volume).

b Surface area-to-mass ratio decreases as animals increase in size *OR* the converse.

c Larger animals have a smaller surface area compared to their size, which means they have more difficulty losing heat; larger animals are more likely to overheat (unless they have adaptations to reduce heat generation or increase heat loss); smaller animals have a larger surface area compared to their size and so lose heat at a faster rate; they are in danger of losing too much heat (unless they have adaptations to increase heat generation or reduce heat loss).
[Max 4 marks]

d Baby mammals have a larger surface area compared to their size/mass *OR* the converse.

e Babies have a larger surface area compared to their size compared with adults; thus they lose heat at a faster rate across their surface area; they can wear woolly hats/warm clothes/blanket to reduce heat loss; ensure correct temperature in room; skin-to-skin contact with mothers.
[Max 3 marks]

(Questions 7–12 HL only)

7 C

8 A

9 D

10 C

11 D

12 a Striated muscle fibres

b II = muscle fibre/muscle cell; III = nucleus

c (Muscle fibres are) multinucleate/contain many nuclei (whereas cells are expected to have only one/so muscle fibres are an exception to the cell theory); one cell membrane/sarcolemma enclosing a whole muscle fibre (as expected for cells); very large/much larger/longer/than most cells; muscle fibres formed by fusion of cells.
[Max 2 marks]

Paper 2

1 Stem cells are undifferentiated cells in the embryo or adult that can undergo unlimited division and can give rise to one of many different cell types; stem cells have the ability for endless repeated cell division; stem cells maintain an undifferentiated state (self-renewal), while also having the capacity to differentiate into mature cell types (potency) along different pathways; stem cells divide and form cells that develop into the range of mature cells of the organism; stem cells are found in all multicellular organisms; during embryological development, most cells lose the ability to divide as they develop into the tissues and organs that make up the organism, such as blood, nerves, liver, brain and many others; a few cells within these tissues keep many of the properties of embryonic stem cells (adult stem cells).

Embryonic stem cell	Adult stem cell
undifferentiated cells capable of continual cell division and of developing into all the cell types of an adult organism	undifferentiated cells capable of cell divisions; these give rise to a limited range of cells within a tissue, for example blood stem cells give rise to red and white blood cells and platelets only
make up the bulk of the embryo as it begins development	occurring in the growing and adult body, within most organs; they replace dead or damaged cells, such as in bone marrow, brain and liver

[Max 3 marks]

2 A stem cell niche is an area of a tissue that provides a specific environment where stem cells exist in an undifferentiated and self-renewable state, and where they receive stimuli to determine their behaviour; stimuli includes cell-to-cell and molecular signals: these either activate or repress genes and the subsequent transcription of proteins; stem cells are maintained in a dormant state, caused to self-renew, or commit to a more differentiated state; stem cell niches have a defined location in the body, e.g. bone marrow/hair follicles; the vascular niche (the site of blood vessels) in the adult bone marrow is a place for stem cell mobilization or proliferation and differentiation; the stem cell niche of hair follicles is located between the opening of sebaceous gland and the attachment site of the hair erector muscle (bulge hair follicle stem cells) which are multipotent and have the potential to increase rapidly; during the growth phase, hair follicle stem cells become activated to regenerate the hair follicle and hair, and hairs grow longer each day; during the resting phase, the stem cells are dormant and hairs can shed more easily.
[Max 4 marks]

3 Totipotent cells are the most versatile stem cells and are capable of giving rise to any cell type in an organism, including making more totipotent stem cells and the cells that become the placenta; pluripotent stem cells are able to develop into many different types of cells or tissues in the body, except for becoming placental cells or totipotent stem cells; multipotent stem cells can create, maintain and repair the cells of one particular organ or tissue.
[Max 3 marks]

4 a Cells exist at a wide variety of different scales, with each type of cell adapted to its function in part by its size; male and female gametes in humans are very different in size: the egg cell is around 110 µm, whereas the main body of the sperm is 5 µm; the larger cell body of the egg allows it to store nutrients for the early development of the fertilized egg, whereas the cell body of the sperm

only needs to hold the nucleus, for delivery to the egg, and so can be much smaller; red blood cells are much smaller than white blood cells; red blood cells are small so that they can fit through the small lumen of capillaries; red blood cells have a larger surface area compared to its size, allowing oxygen to diffuse in and out from the cell at a faster rate; the larger size of white blood cells allows them to either engulf and digest pathogens or produce sufficient numbers of antibodies that bind to the body's foreign invaders and destroy them; neurons (nerve cells) transmit electrochemical impulses through the body, allowing coordination and response to stimuli to occur, and are a variety of different lengths; the long length of neurons enables the electrical impulse to be sent without interruption over a long distance; response to stimuli, especially those concerned with pain, need to be dealt with quickly, and so fast transmission of the impulse is needed: this is achieved by the long length of the myelinated neuron; striated muscle fibres are multinucleated and formed by the fusion of many cells; the extended length of striated muscles allows them to coordinate contraction and has a significant effect on muscle force generation.
[Max 4 marks]

b As cells grow and increase in size, the volume increases faster than the surface area; the surface area-to-volume ratio decreases as cells increase in size; with increasing size of a cell, less cytoplasm has access to the cell surface for exchange of gases, supply of nutrients and loss of metabolic waste products; the exchange of materials across a cell surface depends on its surface area, whereas the need for exchange depends on cell volume; the smaller the cell, the more quickly materials can be exchanged between its cytoplasm and environment; cells cannot therefore grow larger indefinitely: when a maximum size is reached, cell growth stops and the cell may then divide.
[Max 5 marks]

5 Following fertilization, a zygote is formed; the zygote grows and divides, at first producing unspecialized cells and then forming many specialized cells; specialized cells eventually form the adult organism; during early-stage embryo development, complex mechanisms of gene expression determine the ways cells differentiate and take on specific roles; a small number of genes determine body patterns during the embryo's development; morphogens are specific signalling molecules that are involved in gene expression; morphogens are extracellular and occur across a gradient of concentrations; the gradient of the morphogen drives the process of differentiation of unspecialized stem cells into different cell types; where there is a high concentration of morphogens, cells will change differently to cells where there is a lower concentration of morphogens; the initiation or inhibition of gene expression is a result of different concentrations of morphogens, which controls the way cells differentiate and develop into specific tissues; the concentration of the morphogen in each cell is important as it determines a series of subsequent signals (cascades); responses to these signals determine the direction and extent of cell growth and development, ultimately forming all the tissues and organs of the body; the expression of such gradients also controls the length of body structures such as toes and fingers, the location of the nose, and other body patterns; stem cells are cells that have the ability for endless repeated cell division; stem cells maintain an undifferentiated state, while also having the capacity to differentiate into mature cell types (potency) along different pathways; during embryological development, most cells lose the ability to divide as they develop into the tissues and organs that make up the organism, such as blood, nerves, liver, brain and many others; a few cells within these tissues keep many of the properties of embryonic stem cells (adult stem cells).
[Max 7 marks]

(Questions 6–9 HL only)

6 a i Pneumocytes are specialized cells that occur in the alveoli of the lungs; type I pneumocytes are involved in the process of gas exchange between the alveoli and the capillaries; type II pneumocytes produce a detergent-like mixture of lipoproteins and phospholipid-rich secretion called surfactant that lines the inner surface of the alveoli; surfactant lowers the surface tension, permitting the alveoli to flex easily as the pressure of the thorax falls and rises.
[Max 2 marks]

ii The wall of an alveolus is one cell thick to minimize diffusion distance; type I cells have a flattened shape, and so are extremely thin to minimize diffusion distance (of oxygen and carbon dioxide); the cells are tightly connected to prevent leakage of tissue fluid into alveolar air space.
[Max 3 marks]

b The air in the alveolus has a higher concentration of oxygen than the blood capillary; blood entering the capillary has a low concentration of oxygen because it is bringing blood from the body where respiration has occurred; oxygen diffuses from the alveolar air into the red blood cells in the capillary; there is a greater concentration of carbon dioxide in the blood of the capillary than the alveolar air; respiration has produced carbon dioxide in body tissues, this is then removed by blood and transported to the lungs; carbon dioxide diffuses from the blood into the alveolar air.
[Max 3 marks]

7 Cardiac muscle consists of cylindrical branching columns of fibres, forming a three-dimensional network; this allows for contraction in three dimensions and for the contraction signal to spread more quickly; fibres are surrounded by a special plasma membrane (the sarcolemma), and are well supplied by mitochondria and capillaries; capillaries supply oxygen and glucose for respiration, and mitochondria supply ATP needed for continual contraction of the cells; the structure of cardiac muscle cells allows propagation of stimuli through the heart wall; cardiac muscles have intercalated discs to allow easy transfer of electrical impulses between cells; intercalated discs also hold cells together so they cannot separate; gap junctions form channels that allow continuous flow of cytoplasm between cells; this direct electrochemical coupling between cells allows waves of depolarization to pass through the entire network, synchronizing contraction of the muscle, as if in a single cell; the branching structure of the cardiac muscle allows connection to multiple cells and provides a larger surface area of contact between cells, allowing groups of cells to work together and synchronize their activity; although cardiac muscle fibres form an interconnected network, the network system of the walls of the atria is entirely separate from that of the ventricles, ensuring a transmission delay of electrical signal between atria and ventricles.
[Max 7 marks]

8 Both sperm and eggs are haploid cells (have one set of chromosomes); sperm are smaller than egg cells; sperm are small and mobile cells, with a long flagellum and middle piece packed with mitochondria; their streamlined shape enables them to swim rapidly through fluid; egg cells are larger and contain more cytoplasm, to provide nutrients needed for the growth and development of the zygote; egg cells are not streamlined and are moved by cilia in the fallopian tube; sperm have an acrosome at the tip of the head, containing digestive enzymes to facilitate entry into the egg; the egg cell contains cortical granules which prevent polyspermy during fertilization.
[Max 7 marks]

9 Models are simplified versions of complex systems; the surface area-to-volume relationship can be modelled using cubes with different side lengths; although the cubes have a simpler shape than real organisms, scale factors operate in the same way; cells are too small to investigate directly and so models can be used as an alternative; cubes can be created using agar/jelly; substances, e.g. acid, can be used to measure the rate of diffusion of substances into different sized cubes (cubes contain indicator which changes colour in acid); different shapes can be created to investigate the effect of surface area-to-volume ratio and rate of diffusion; the relationship between the volume and surface area of different three-dimensional shapes can be investigated, e.g. spheres have a small surface area-to-volume ratio and therefore diffusion/rate of movement across their surface will be lower than shapes with a larger surface area-to-volume ratio, e.g. flatter objects; models can be used to investigate how organisms can minimize heat loss if they live in a cold environment, for example, or water loss if they inhabit a dry environment, and what their optimum shape would be.
[Max 7 marks]

B3.1 Gas exchange

Paper 1

1 D

2 C

3 A

4 a i Negative correlation between the number of leaves removed and transpiration rate *OR* as more leaves are removed the transpiration rate drops.

ii Transpiration does not only occur in the leaves *OR* transpiration through stem/shoot.

b Number of leaves (removed).

c Using a potometer; leafy shoot attached to a reservoir and a graduated (capillary) tube; as transpiration increases water uptake (by roots) also increases; distance/time for bubble (in capillary tube) to travel is used to measure transpiration rate.
[Max 2 marks]

5 a Four breaths in 10 s = 4 × 6 (breaths min^{-1}) *OR* six breaths in 15 s = 6 × 4 (breaths min^{-1}); 24 breaths min^{-1}.

b Measure a volume difference for an individual breath *OR* maximum − minimum for an individual breath; repeat for several breaths and determine a mean.

c Increased due to increased demand for ATP/energy (from muscle activity).

d Diaphragm *OR* external intercostal muscles.

6 a Age/height/fitness level/weight/room temperature/rest in between tests/model or type of bike.

b In both sea level and 4000 m, ventilation rate while exercising (at all intensities) is (significantly) more than at rest *OR* both sea level and 4000 m show an increase in ventilation rate (dm^3 min^{-1}) as exercise intensity increased; ventilation rate at 4000 m (slightly) higher than at sea level for all conditions *OR* higher ventilation rate at 4000 m, but not (significantly) different as error bars overlap.
[Max 2 marks]

c (Data logging) with spirometer *OR* chest belt; (tidal) volume recorded for a given period of time *OR* average (tidal) volume found and multiplied by number breaths per minute.

7 a 25 − 22 = 3 breaths in 2 min = 1.5 breaths per min/0.025 breaths per sec.

b Exercise increases/results in higher rate of respiration; exercise produces more carbon dioxide/consumes more oxygen; increased tidal volume excretes more carbon dioxide/obtains more oxygen; increased tidal volume increases gas exchange (across alveoli); concentration gradient(s) of gases is maintained.
[Max 3 marks]

(Questions 8–9 HL only)

8 B

9 B

Paper 2

1 a Spirometer

b Tidal volume × ventilation rate *OR* litres $breath^{-1}$ × breath min^{-1}; 186 L (min^{-1}).

c Both ventilation rate and tidal volume increase with increase in treadmill speed/intensity of exercise; at low treadmill speed/below 14.2 km h^{-1}, the tidal volume increases more steeply than ventilation rate *OR* at high treadmill speed, ventilation rate increases more steeply than tidal volume *OR* tidal volume plateaus while ventilation rate does not.
[Max 2 marks]

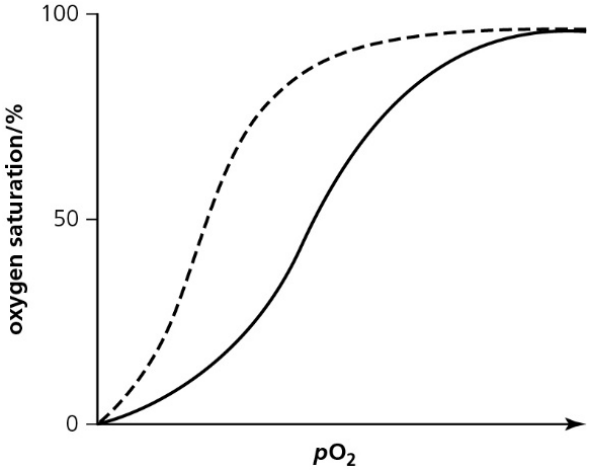
2 Diaphragm contracts/moves downwards/flattens; external intercostal muscles contract; (muscle contraction) moves the rib cage upwards and outwards; increases volume of the thorax/lungs; difference in pressure/decreasing pressure causes air to flow into lungs/lungs inflate.
[Max 4 marks]

3 Oxygen diffuses into blood and carbon dioxide diffuses out from blood; blood entering the alveoli is high in carbon dioxide/low in oxygen *OR* air in alveolus is high in oxygen/low in carbon dioxide; diffusion (in either direction) takes place due to concentration gradients; concentration gradients maintained by ventilation/blood flow; large surface area created by many alveoli/spherical shape of alveoli for more efficient diffusion; rich supply of capillaries (around alveoli) allows efficient exchange; type I pneumocytes are involved in the process of gas exchange between the alveoli and the capillaries; alveolar wall is thin to allow easy diffusion/short distances; gases must dissolve in liquid lining of alveolus in order to be exchanged; type II pneumocytes secrete surfactants to reduce surface tension/prevent lungs sticking together; type II pneumocytes create moist conditions in alveoli.
[Max 7 marks]

4 Ventilation/inhaling brings fresh air/air with high oxygen concentration to the lungs *OR* ventilation/exhaling gets rid of stale air/air with high concentration of carbon dioxide; ventilation due to muscle contractions causing pressure/volume changes in the thorax; contraction of external intercostal muscles *AND* diaphragm occurs during inspiration *OR* contraction of internal intercostal muscles/abdomen wall muscles during (forced) expiration; alveoli surrounded by (many) capillaries; blood flow/pumping of heart (brings blood to/takes blood away from alveoli/lungs); concentration gradients (of oxygen/carbon dioxide) maintained (by ventilation/blood flow); oxygen *AND* carbon dioxide diffuse; carbon dioxide from capillaries/blood/vessel to alveolus/air *AND* oxygen from alveoli into capillaries/blood/vessel; large numbers of alveoli increase surface area; short distance so rapid diffusion/gas exchange; (type I pneumocytes)/alveolus wall/capillary walls are one cell thick/very thin; alveoli (lining) moist for dissolving of gases/rapid diffusion *OR* type II pneumocytes keep the (lining of) the alveolus moist; (type II pneumocytes secrete surfactant to reduce surface tension/prevent alveoli from collapsing).
[Max 7 marks]

(Questions 5–7 HL only)

5 a Curve has to be towards the right and with same starting point as the given curve:



Must start together but can finish slightly below the original curve

b Increased levels of carbon dioxide lower the pH of the blood; (which results in) decreased affinity of the haemoglobin for oxygen/greater release of oxygen; this shifts the oxygen dissociation curve to the right/Bohr shift.
[Max 2 marks]

6 Haemoglobin occurs in the red blood cells and is built of four interlocking polypeptide subunits; one molecule of oxygen combines with each haem group at the concentration of oxygen that occurs in our lungs; each haemoglobin molecule can transport four molecules of oxygen; the affinity of haemoglobin for oxygen is measured experimentally by finding the percentage saturation with oxygen of blood exposed to air mixtures that contain different partial pressures of oxygen, resulting in an oxygen dissociation curve; an oxygen dissociation curve is a graph of % saturation (with oxygen) of haemoglobin against concentration of available oxygen; the oxygen dissociation curve is S-shaped (sigmoid curve); this is because in the complex haemoglobin molecule, the first oxygen molecule attaches with difficulty but, once it has, the second combines more easily until all four are attached and the molecule is saturated *OR* the more oxygen is bound to haemoglobin, the easier it is for more oxygen to bind, until all binding sites are saturated; the amount of oxygen held by haemoglobin therefore depends on the partial pressure of oxygen; from an oxygen dissociation curve, the haemoglobin in red cells in the capillaries around the alveoli in the lungs are about 95% saturated, whereas in respiring tissues, the oxygen partial pressure is much lower due to aerobic respiration there; at these partial pressures, oxyhaemoglobin breaks down, releasing oxygen in solution and this rapidly diffuses into the surrounding tissues.
[Max 5 marks]

7 The blood circulation also transports carbon dioxide from respiring tissues, where it is at relatively high partial pressures, to the lungs; an increase in carbon dioxide concentration shifts the oxygen dissociation curve to the right; this is called the Bohr effect; where the carbon dioxide concentration is high (in actively respiring cells), oxygen is released from oxyhaemoglobin even more readily; carbon dioxide lowers the pH, caused by protons from the dissociation of carbonic acid, which causes haemoglobin to release its oxygen; an increase in carbon dioxide therefore causes increased dissociation of oxygen; the Bohr effect benefits cells with increased metabolism, such as respiring tissues, by allowing greater amounts of carbon dioxide (a product of cell respiration) to be released; haemoglobin releases its oxygen (required for aerobic cell respiration) at regions of greatest respiratory need.
[Max 7 marks]

B3.2 Transport

Paper 1

1 A

2 D

3 D

4 C

5 B

6 a Independent: mass; dependent: (vertical) diameter/length.

b Width/section depth/slice of the ring (any wording referring to the longitudinal section); same animal/age/freshness/temperature.
[Max 1 mark]

c Veins have thinner walls (than arteries); veins sustain lower (blood) pressure (than arteries); when stretched, veins become longer (than arteries); veins have less muscle/elastic (fibre in their) walls (than arteries); veins have lower elasticity/recover less/remain more stretched (than arteries) after weights removed.

Inverse accepted for arteries in all cases.
[Max 3 marks]

(Questions 7–12 HL only)

7 A

8 C

9 A

10 B

11 A

12 C

Paper 2

1 a Arteries carry blood at high pressure; rupture of arteries is prevented by thick muscular/elastic walls; narrow lumen to maintain a high blood pressure; elastic tissue allows artery to stretch and recoil (to even out pressures); arteries have muscle layers that contract to increase/control the blood flow; folding in the endothelium allows stretching *OR* smooth endothelium reduces friction.
[Max 3 marks]

b

	Artery	Vein	Capillary
outer layer (tunica externa) of elastic fibres and collagen	present (thick layer)	present (thin layer)	absent
middle layer (tunica media) of elastic fibres, collagen and involuntary (smooth) muscle fibres	present (thick layer)	present (thin layer)	absent
endothelium (inner lining) of pavement epithelium – single layer of cells fitting together like jigsaw pieces, with smooth inner surface that minimizes friction	present	present	present
lumen	smaller	larger	very small
valves	absent	present	absent

[Max 6 marks]

2 Plasma membrane in phloem/sieve tubes but not in xylem/vessels *OR* xylem/vessels are dead/acellular whereas phloem/sieve tubes are alive; xylem vessels have thicker walls than phloem; xylem vessel walls are lignified whereas phloem walls are not; phloem vessels have sieve plates whereas xylem vessels have no cross walls; xylem/vessels are wider/larger than phloem/sieve tubes; companion cells in phloem but not in xylem.
[Max 5 marks]

3 Water moved/transported in xylem vessels; transported under tension/suction/pulled up (in xylem vessels); transpiration/loss of water (vapour) generates pulling forces/low pressure/tension; tension/pull generated when water evaporates from cell walls (in mesophyll); transpiration is loss of water vapour from leaf (surface)/stomata; cohesivity/cohesion in water due to hydrogen bonding/attractions between water molecules; cohesion/*OWTTE* so chain/column of water (molecules) does not break/remains continuous; transpiration stream is a column/flow of water in xylem from roots to leaves.
[Max 7 marks]

(Questions 4–8 HL only)

4 a Semilunar/sigmoid/pulmonary and aortic valve.

b Action potential of atrium precedes the ventricle *OR* the phases happen later in ventricle *OR* atrium contracts before the ventricle; atrium has a shorter phase 2/longer phase 2 in ventricle *OR* atrium action potential falls abruptly in phase 2/ventricle shows a plateau in phase 2; phase 3 is more distinct/falls more abruptly in ventricular action potential; ventricular phase is overall longer than atrial phase.
[Max 2 marks]

5 **Similarities**: both mammals and fish have a closed circulation; blood is pumped by a heart and circulated in a continuous system of tubes under pressure; circulatory system consists of a heart, arteries, veins and capillaries.
[Similarities: max 1 mark]

Differences: bony fish have a single circulation/blood enters and leaves the heart once; blood enters from the body and then leaves to the gills, where blood is oxygenated, and then moves to the rest of the body where oxygen is delivered to tissues; mammals have a double circulation/blood travels through heart twice; heart in mammals has four chambers whereas bony fish have two; in mammals, heart is divided into right and left sides: blood flows from the right side of the heart to the lungs, then back to the left side of the heart; the role of the right side of the heart is to pump deoxygenated blood to the lungs; oxygenated blood in mammals is separated from deoxygenated blood, whereas in fish the oxygenated and deoxygenated blood mix/no separation; mammalian circulatory system can pump blood to the body/systemic circulation under high pressure and blood to lungs/pulmonary circulation under lower pressure.
[Differences: max 3 marks]

6 The heartbeat originates in part of the muscle wall of the right atrium, called the sinoatrial node (SAN) or pacemaker; from here, a wave of excitation (electrical impulses) spreads out across both atria; in response, the muscle of both atrial walls contracts simultaneously (atrial systole); this stimulus does not spread to the ventricles immediately, due to the presence of a narrow band of non-conducting fibres at the base of the atria; these block the excitation wave, preventing its conduction across to the ventricles; the stimulus is picked up by the atrioventricular node (AVN), situated at the base of the right atrium; after a delay (of 0.1–0.2 s), the excitation is passed from the AVN to the base of both ventricles by tiny bundles of conducting fibres (the Purkinje tissue); when stimulated by the bundles of His, the ventricle muscles start to contract from the base of the heart upwards (ventricular systole); the delay that occurs prevents the atria and ventricles from contracting simultaneously; after every contraction, cardiac muscle has a period of insensitivity to stimulation (the refractory period)/a period of enforced non-contraction/diastole; in this phase, the heart begins, passively, to refill with blood; medulla (oblongata of brain) can change/increase/decrease the rate; through nerves/named example of nerve/autonomic/sympathetic/parasympathetic nervous system; one nerve increases the rate and the other decreases it; epinephrine increases heart rate/force of contraction; epinephrine prepares the body for vigorous activity/is part of fight or flight response.
[Max 5 marks]

7 Endodermal cells of the root contain a waterproof substance (suberin) that blocks the apoplast pathway, directing water through the symplast pathway; this ensures water flows into the xylem and not out, enabling the plant to control water movement; endodermal cells pump salts into the xylem; this lowers the water potential of the xylem/increases solute concentration, enabling water to move down a water potential gradient; a positive pressure potential is created, moving water and dissolved minerals a short distance up the xylem.
[Max 5 marks]

8 Tissue fluid is a mixture of water and solutes, forced out of the blood by ultrafiltration and it surrounds body cells; tissue fluid is forced from capillaries through small gaps in the endothelium/wall of capillary, under hydrostatic pressure; at the arteriole end of the capillary bed, the force applied to the blood by the

heart creates sufficient hydrostatic pressure to overcome osmotic water uptake; at the arteriole end, blood pressure is significantly higher than at the venule end; as blood flows through the capillary bed there is progressive loss of hydrostatic pressure and so osmotic movement of water/osmotic water uptake into the capillary can occur; as a result, much of the tissue fluid is returned to the plasma *OR* further along the capillary bed there is a net inflow of tissue fluid to the capillary *OR* lower pressure in the venules allows tissue fluid to drain back into capillaries; not all tissue fluid is returned to the blood circulation by this route – some enters the lymph capillaries.
[Max 7 marks]

B3.3 Muscle and motility (HL only)

Paper 1 (HL only)

1 C

2 B

3 B

4 A

5 D

6 C

Paper 2 (HL only)

1 a W = myosin, X = actin. [*Both needed for 1 mark*]

b Myofibril is contracting in Figure 3/relaxing in Figure 2; movement of actin fibres between myosin fibres.

c Interact with/move/touch tropomyosin (allow troponin as alternative); to reveal binding sites on actin; allowing myosin (heads) to bind/touch actin/actinomyosin formed; activate ATPase/energy released from ATP.

2 a Small light band; reduced/little/no thick filament/myosin only region; ends of thin filaments/actin close together; little/no thin filament/actin-only region; dark band occupies nearly all sarcomere; thick filament/myosin close to Z line; large zone of thick–thin overlap.
[Max 2 marks]

b Allows myosin to detach from actin/to break cross-bridge; [allow attach and detach]; releases energy to recock/swivel/activate myosin head/drive power stroke.
[Max 2 marks]

3 a Muscle tissue contains many muscle fibres; muscle fibres consist of a single multinucleated muscle cell.
[Max 1 mark]

b Muscle fibres are composed of myofibrils; myofibrils are a rod-like organelle of a muscle cell.
[Max 1 mark]

c Myofibrils are composed of sarcomeres, which contain two different proteins: actin and myosin; myosin forms thick filaments within a sarcomere.
[Max 1 mark]

4 The myofibril is stimulated to contract by the arrival of an action potential; this triggers the release of calcium ions from the sarcoplasmic reticulum, which surrounds the actin molecules; calcium ions react with the protein troponin; activated troponin triggers the removal of the blocking molecule, tropomyosin; the binding sites on actin are now exposed; each bulbous head of myosin, to which ADP and P_i are attached (a charged bulbous head), reacts with a binding site on the actin molecule beside it; the

phosphate group (P_i) is dislodged (removed) from the head at this moment; ADP is then released from the bulbous head and this is the trigger for the rowing movement of the head, which tilts by an angle (about 45°), pushing the actin filament along; during this power stroke, the myofibril has been shortened (contraction); ATP binds to the bulbous head; the protein of the bulbous head includes the enzyme ATPase, which catalyses the hydrolysis of ATP; the ADP and inorganic phosphate (P_i) formed remain attached/the bulbous head is 'charged'; the charged head detaches from the binding site and straightens.
[Max 7 marks]

5 Titin is a large mechanical protein in muscle cells that has a main function as a molecular spring in the sarcomeres; antagonist muscles are muscles that work as one of a pair: as one muscle contracts the other muscle relaxes/lengthens; the muscle that is contracting is called the agonist and the muscle that is relaxing/lengthening is called the antagonist; titin is located within the sarcomere of striated (and cardiac) muscle; titin is extended when sarcomeres of a skeletal muscle are (passively) stretched by antagonist muscle contraction/contraction of the opposite muscle; e.g. titin in external intercostal muscles in the chest is extended and stretched when the internal intercostal muscles contract; antagonistic muscles are needed because muscle tissue can only exert force when they contract; after stretching, the titin recoils (like a spring), shortening the sarcomere after it is stretched; titin is used to stabilize the myosin and centre it between the thin actin filaments; titin prevents overstretching of the sarcomere; titin binds at several sites along its length to the actin filaments in the sarcomere, mainly at the edges of the Z line, which serves an anchoring function.
[Max 5 marks]

B4.1 Adaptation to environment

Paper 1

1 A

2 D

3 B

Paper 2

1 a Between 1930 and 1968 the population numbers reduced; after 1968/in the 1970s the numbers increased; in 1990s/1995 the numbers decreased again; lowest in 1968 and highest in 1990.
[Max 3 marks]

b Relative rates of natality; disease/lack of food; competition for the same resources; immigration/emigration/migration.
[Max 2 marks]

2 a i (30 − 26 =) 4 °C; *answers accepted between 3 and 5 °C.*

ii Maximum temperature occurs just when rainfall begins/at the onset of the rainy season/monsoon *OR* negative relationship (as maximum temperature drops, rainfall increases) *OWTTE.*

iii Rainfall concentrated between April to December/peaks in June–August (followed by months with little/no rainfall) *OWTTE.*

b Dry season/Jan/Feb; (drop leaves) to prevent water loss/transpiration (since no rainfall for almost four months).

3 Reef-building corals have a symbiotic relationship with zooxanthellae; because zooxanthellae need light to photosynthesize, coral can only grow at relatively shallow depth (most reef-building corals occur in less than 25 m of seawater); temperature of the water is a limiting factor that affects algal survivorship; hard corals prefer water temperatures that range between 23 and 29 °C.
[Max 4 marks]

4 a

Ecosystem	Numeral
Tropical rainforest	IV
Desert	II
Tundra	I

[All 3 correct: 2 marks; 2 correct: 1 mark; 1 correct: no marks]

b Litter is dead plant material on the ground; conditions in tropical rainforests are ideal to decompose plant material *OR* conditions in taiga do not favour decomposition of litter; decomposition returns nutrients to soil *OR* nutrients in taiga remain in the litter and not in the soil; tropical rainforests have more saprotrophs/decomposers *OR* taiga have fewer saprotrophs/decomposers.
[Max 3 marks]

5 a (32 × 79 =) 2528

b Same bat may be recorded more than once; some bats may not fly over (the recording station) *OR* only bats flying over the station are recorded; two bats flying close/together might be recorded as one.
[Max 1 mark]

c i 82/82.1/82.14 (% decline)

ii **Conclusion supported**: (2008 to 2009) *M. lucifugus* declines more (than *L. cinereus*) *OR* (2007 to 2009) *M. lucifugus* declines whereas *L. cinereus* increases/fluctuates/did not decline *OR* more affected than unaffected bats in 2007 and 2008 but more unaffected in 2009.

Conclusion not supported: Other factors could be causing the difference between the species/the decrease in *M. lucifugus OR* there will be differences between the two bat species apart from WNS infection *OR* both species decreased from 2008 to 2009.
[Max 2 marks]

d Later date of death with longer/bigger intervals (between hibernation emergence)/with less frequent interruptions (to hibernation).

e **Arguments for a causal link**: there is a trend/correlation/relationship (shown by the data in the graph); explanations of how more frequent emergence from hibernation could cause earlier death (are plausible)/example of an explanation.

Arguments against a causal link: there is a correlation but this does not show a causal link/correlation does not prove causation; more data/further research is needed to show the causes; there is (much) variation/spread in the data; other factors can affect the date of death.
[Max 2 marks]

f Differences in body mass *OR* differences in reserves/stores of food/energy/fat; bats may be predated during a flight/chance events might affect the date of death; more effective/stronger immune system/immunity (in some bats); more resistance to cold (in some bats); larger bats lose heat less rapidly; infected at a different/later date.
[Max 1 mark]

g Higher mortality/more deaths; shorter life expectancy/premature death/death before reproduction; extinction/reduction in (size of) of bat populations; *L. cinereus*/species of bats not affected by WNS may increase *OR L. cinereus*/species of bats not affected by WNS may experience less competition; infection may affect birth rates/fertility; bats will emerge more from hibernation/in winter; bats will use up food/energy reserves faster in winter/faster due to (more) interruptions; bat (populations) develop/evolve greater resistance to WNS.
[Max 3 marks]

6 **Hot desert**: when the conditions are too extreme, parent organisms die but leave behind tough seeds or eggs; avoid extreme temperatures by changing activity from day to night or from above ground to below ground, e.g. kangaroo rats sleep in burrows during the hot day; adaptations enable plants and animals to survive in this extreme environment, e.g. cacti; cacti have no leaves to reduce surface area; cacti have rounded and spherical shapes to reduce surface area-to-volume ratio, which limits water loss through transpiration; thick waxy cuticle prevents water loss through their surface; cacti can store large quantities of water in collapsible-water storage cells found in the stem and are covered with needles to prevent mammals eating the flesh of the cactus and getting access to water stores; cacti have wide-spread root systems, to ensure that any water falling is rapidly absorbed before it evaporates; deposits stored by animals in their tails and other tissues can be used as a respiratory substrate, releasing water; water can be stored in the roots, stems and/or leaves of plants (succulents, e.g. cacti).

Tropical rainforest: tropical rainforest has a complex structure with a number of layers from ground level to canopy; the dense canopy means that only 1% of sunlight may reach the floor and the shrub layer may be sparse with most productivity in the canopy; the range of different conditions and the complexity of the ecosystem means that organisms display a wide range of adaptations to survive in this highly competitive environment;

pitcher plants are carnivorous plants, with some found in the canopy of tropical rainforest and in areas with nutrient-poor soils (*Nepenthes* species); pitcher plants lack nutrients e.g. nitrates from the immediate environment; they can survive in areas of low nutrients by catching and digesting insects; insects provide nitrogen needed to synthesize proteins;

the extended vertical dimension of tropical rainforest provides an alternative form of locomotion; species have developed adaptations to glide from tree to tree, e.g. *Draco* species; living above the forest floor enables prey to evade predation (and saves energy by not having to regularly run away from danger); the gibbon (*Hylobates* species) have elongated forearms to help them swing from tree to tree (brachiation); their body is adapted to their arboreal (living in trees) habitat; gibbons also have hook-like fingers and high mobility in their shoulder joints to help with the swinging motion;

mimicry (one species copies the appearance of another) is a strategy to survive in rainforest; e.g. the orchid mantis (*Hymenopus coronatus*) mimics the look of the orchid flower; other animals that use this type of camouflage in tropical rainforests include beetles, caterpillars, moths, lizards, snakes and frogs.

[Max 5 marks; if only one ecosystem considered, max 3 marks]

7 Organisms have limits of tolerance and zones of stress; listing any two or more abiotic factors; example of named abiotic factor and how it affects distribution of plant/animal species; example of another named abiotic factor and how it affects distribution of plant/animal species; example of a third named abiotic factor and how it affects distribution of plant/animal species.

e.g. light limiting photosynthesis (in a forest); dissolved oxygen affecting respiration in an aquatic animal; salinity affecting osmosis in an estuarine species; most organisms require a suitable temperature range for their metabolism.
[Max 6 marks]

8 Evolution occurs when natural selection acts on the genetic variation in a population and changes the frequency of traits in that population over many generations; variation caused by random mutations in DNA creating alterations in the genetic makeup of members of the species (new alleles) *OR* genetic mutations in an ancestral mantis species created variation in the population; mutations/new alleles conferred a selective advantage; those individuals which more resembled the orchid flower/were camouflaged were less likely to be eaten by predators; these mantises survived and reproduced; traits that provide an individual with an advantage/resemblance to the orchid flower were selected to be passed on to the next generation; over a large number of generations the orchid mantis evolved.
[Max 7 marks]

9 **a** ecosystem; **b** population; **c** abiotic factor; habitat; **d** community; biomass; **e** biomass; **f** abiotic factor; habitat; **g** abiotic factor
[1 mark for each correct question, max 7 marks]

B4.2 Ecological niches

Paper 1

1 C

2 B

3 B

4 **a** Both *Galium* species grow healthy populations on both soil types when grown by themselves. In experiments where both plant species are grown together, one species outcompeted the other, as they do in the wild.
[Max 2 marks]

b These results demonstrate that the fundamental niche of both species of *Galium* includes a wider variety of soil types than they inhabit in the wild; both can grow in an alternative soil type to the one in which they are found in the wild (*G. saxatile* on basic/alkaline soils and *G. sylvestre* on acidic soils); interspecific competition restricts the realized niche of each species, so that they are limited to a narrower range of soil types; *G. saxatile* outcompetes *G. sylvestre* on acidic soils/*G. sylvestre* outcompetes *G. saxatile* on basic/alkaline soils, and so the realized niche is restricted compared to the fundamental niche (where both plant species can grow in both soil types).
[Max 3 marks]

5 **a** Fundamental niche is all potential conditions a species could live in, whereas realized niche is the actual conditions under which the species lives.

b April

c **i** Limited effect on low/stable population size from January to March; large effect increases population size from March to April; niche conditions decrease from January to March; niche conditions improve from March to April.
[Max 2 marks]

ii Factor e.g. temperature; explanation e.g. as temperature increases in spring (March to April) so the conditions for the species are more favourable.

6 **a** No two species can occupy the same niche; competition between them would cause one species to drive the other out *OR* one of the two species would need to adapt and evolve accordingly.

b Different food/prey; different predators; active at different times of the day; present at different times of the year; different nest sites; different temperatures.
[Max 2 marks]

c The realized is the actual niche and the fundamental is in the absence of competition; with no competition *D. castanea* would have a larger habitat/more food *OR D. castanea* could occupy the niches currently occupied by the other warbler species.
[Max 2 marks]

Paper 2

1 a

	Detritivores	Decomposers
Similarity	both are fed by heterotrophic nutrition/are heterotrophs	
Difference	ingest and digest food internally/have a gut/enzymes secreted on to food within/inside organism	secrete enzymes on to food/digests food externally/feeds by saprotrophic nutrition

[1 mark for similarity; 1 mark for correct difference; max 2 marks]

b Mixotrophic nutrition is a form of nutrition that is both autotrophic and heterotrophic; *Euglena* is an obligate mixotroph/always carries out both forms of nutrition; *Euglena* contains chloroplasts/chlorophyll, which enable it to photosynthesize; *Euglena* carries out heterotrophic nutrition by taking e.g. bacteria into food vacuoles; the contents of the food vacuoles are digested by hydrolytic enzymes from lysosomes.
[Max 3 marks]

2 Anaerobes respire in the absence of oxygen; aerobes respire in the presence of oxygen; obligate anaerobes are organisms that only respire in the absence of oxygen; facultative anaerobes are organisms that normally respire aerobically but have the facility to switch to anaerobic respiration in the absence of oxygen; obligate aerobes are organisms that can only respire aerobically.
[Max 5 marks]

3 The archaea include a variety of photosynthetic, chemosynthetic and heterotrophic organisms; some archaea use sunlight as a source of energy; oxygen-generating photosynthesis does not occur; archaea e.g. halobacteria use light-activated ion pumps to generate ion gradients by pumping ions out of the cell across the plasma membrane: the energy stored in these electrochemical gradients is then converted into ATP by ATP synthase; some organisms are autotrophic but do not use sunlight to produce glucose, instead using energy generated from chemical reactions (chemoautotrophs); e.g. methane-producing archaea (methanogens), which release energy for ATP synthesis by producing methane gas; heterotrophic archaeans include marine species that feed on the lignin from woody plants washed out to sea: by digesting the lignin, these bacteria help to recycle plant remains and contribute to the carbon cycle.
[Max 3 marks]

4 a Two different examples of plants, each with linked adaptations for harvesting light. For examples, see section B4.2 of the Student's book, pages 376–7.
[Max 2 marks]

b Three different examples of animals and plants, with linked adaptations of herbivores for feeding on plants and of plants for resisting herbivory. For examples, see section B4.2 of the Student's book, pages 372–3.
[Max 3 marks]

c Two different examples of predators, with adaptations for finding, catching and killing prey, and two different examples of animals and their adaptations for resisting predation. For examples, see section B4.2 of the Student's book, pages 373–6.
[Max 4 marks]

5 Gorillas are mainly herbivores, feeding on large amounts of vegetation; chimpanzees are omnivores, feeding on fruit, vegetation and occasionally meat; gorillas have more developed canines and incisors than humans, similar to chimpanzees; gorillas have larger premolars and molars for grinding the tough vegetation; australopithecines are an extinct group of Hominidae, e.g. the species *Paranthropus robustus* which fed on vegetation/herbivorous diet; *P. robustus* had large (megadont) cheek teeth, with thick

enamel for tough vegetation; large molars and premolars helped in powerful chewing motion; human ancestors (seven million years ago) had teeth similar to those of modern chimpanzees, with relatively large incisors and long/pointed canines; developed incisors and canines allow food to be grasped and bitten; in modern humans, incisors are relatively small, narrow and vertical; human canines are short (almost level with the other teeth) and relatively blunt; molar teeth in humans are small, and 'wisdom teeth' may be partially hidden or impacted due to the shortening of the jaw; premolars and molars in humans are relatively flat with low, rounded cusps (bumps) on the grinding surface; changes in/the evolution of human dentition demonstrate less reliance on tough vegetation and transition to a more omnivorous diet.
[Max 7 marks]

6 Each species plays a unique role within a community because of the unique combination of its spatial habitat and interactions with other species; niche refers to the role played by a species in its community, which includes its abiotic requirements and tolerances, and its interactions with other organisms; a species' niche depends not only on where it lives (its habitat), but also on what it does: for example, the niche of a lion includes its habitat, courtship displays, grooming, alertness to prey, when it is active, interactions with other species, etc.; human activities, e.g. habitat loss/pollution/introduction of invasive species/overharvesting of wild populations, are impacting on biodiversity/decreasing population sizes of species/leading to extinction; loss of habitat and interactions with other species can lead to the reduction in population size or possible extinction of a species; to understand the effect that human activities are having on ecosystems, the role/niche of species must be understood; conservation activities aim to slow the rate of extinction caused by the knock-on effects of unsustainable exploitation of natural resources and to maintain biotic interactions between species; by understanding a species' niche, conservation measures can be implemented that ensure the maintenance of (abiotic and biotic) factors that determine/are required for the niche; *credit examples included of species that are threatened by human disturbance and how understanding of their niche can help conserve the species* e.g. *EDGE (Evolutionarily Distinct and Globally Endangered) species/those which disproportionately represent threatened phylogenetic diversity*; understanding a species niche can help with ecosystem restoration/rewilding projects, e.g. the United States National Park Service began to reintroduce the grey wolf (*Canis lupus*) into Yellowstone National Park in the mid-1990s, which lowered the local elk population (*Cervus canadensis*) population and their overgrazing of plants.
[Max 7 marks]

Theme C Interaction and interdependence

C1.1 Enzymes and metabolism

Paper 1

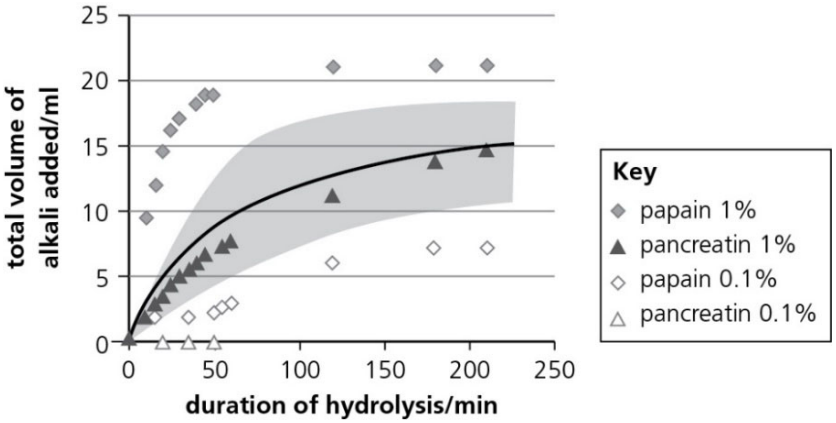
1 D

2 B

3 A

4 **a** Positive correlation *OR* faster hydrolysis at higher concentration.

b *Curve with similar shape between papain 0.1 % and 1 %*



Curve to start at 0. A similar-/same-shaped curve to papain 1%, to be anywhere within the shaded area shown on the graph.

c Hydrolysis of protein produces hydrogen ions/amino acids; pH decreases/increased acidity; causing denaturation of enzyme/pancreatin/papain; decrease of reaction (rate)/no hydrolysis; enzymes work best at the optimum pH/*OWTTE.*
[Max 3 marks]

(Questions 5–7 HL only)

5 D

6 B

7 A

Paper 2

1 Each enzyme is a globular protein with a structurally and chemically specific active site; the specific shape is due to the specific sequence of amino acids in the primary structure, which determines the types of bonds and location of R-groups (variable side chains) present on the amino acids in the protein; the conformation (shape) of the active site of each enzyme will change when pH changes; when the pH increases beyond the optimal pH, positively charged R-groups at active sites can be neutralized by the hydroxide ions (OH^-) in the solution; as the pH decreases to a low pH (high H^+), negatively charged R-groups at the active sites can be neutralized by the hydrogen ions (H^+) in the solution; both lead to disruption of ionic bonds and hydrogen bonds, which in turn disrupt the secondary and three-dimensional conformation (tertiary) and (if relevant) quaternary structures of the enzyme; the conformation of the active site can no longer be maintained and the substrate no longer fits into the active site as the enzyme is denatured.
[Max 4 marks]

(Questions 2–5 HL only)

2 Competitive inhibitor (slows the reaction rate as it) competes for the active site *OR* competitor has similar shape/structure/composition to substrate (and slows the reaction rate); binding of competitor is reversible; (as the substrate concentration increases) more substrate binds to the active site than the competitor (and reaction rate increases); (as the substrate concentration increases) the reaction rate reaches the maximum plateau (same as with no inhibitor).
[Max 2 marks]

3 Enzymes increase rate of reaction/speed up reaction; lower activation energy; a specific enzyme for each reaction/substrate; metabolic process/pathway blocked if an enzyme is inhibited/absent; end-product inhibition can control metabolic pathways; differences in metabolism as cells produce different enzymes during differentiation.
[Max 4 marks]

4 Metabolism is chains/web of enzyme-catalysed reactions *OR* metabolic pathway is a chain of enzyme-catalysed reactions; end product/inhibitor is final product of chain/pathway; inhibits/binds to/blocks the first enzyme in chain/pathway; non-competitive inhibition; end-product/inhibitor binds to an allosteric site/site away from the active site; changes the shape of the active site/affinity of the active site (for the substrate); prevents intermediates from building up *OR* prevents formation of excess (end) product/stops production when there is enough *OR* whole metabolic pathway can be switched off; negative feedback; binding of the end product/inhibitor is reversible *OR* pathway restarts if end product/inhibitor detaches/if end product concentration is low; isoleucine inhibits/slows (activity of first enzyme in) threonine to isoleucine pathway.

Can show mark points in clearly annotated diagrams.
[Max 4 marks]

5 Different amino acids possess side chains of different chemical and physical properties and are held by peptide bonds; the polypeptide chains of proteins are held together by hydrogen bonds, ionic bonds and hydrophobic interactions between side chains of each amino acid; primary structure refers to the specific number and sequence of amino acids; secondary structure is maintained by hydrogen bonds between peptide bonds; e.g. in haemoglobin, the secondary structure is repeated coiling of a polypeptide chain into α-helices; tertiary structure refers to the unique three-dimensional conformation/shape/structure as a result of further coiling and folding of secondary structures of one of the polypeptide chain; the tertiary structure is held together by hydrogen bonds, ionic bonds and hydrophobic interactions between side chains of each amino acid; some enzymes have a quaternary structure, which arises when two or more polypeptide chains or proteins are held together forming a complex, biologically active molecule; e.g. haemoglobin is a quaternary globular protein made up of four polypeptide chains;

the three-dimensional shape of a protein determines its properties; interactions between the amino acids within the overall three-dimensional structure of an enzyme ensure that the active site has the necessary properties for catalysis; properties of enzymes include binding on to the substrate molecule, holding on to it while the chemical reaction takes place and lowering the energy of the transition state; exposure to temperature outside the optimum of an enzyme causes atoms to vibrate violently and this disrupts weak intermolecular forces (i.e. noncovalent) within proteins; small changes in pH away from the optimum similarly alter the shape of protein/enzyme; the structure of an enzyme may spontaneously reform when the optimum pH is restored, but exposure to strong acids or alkalis is usually found to irreversibly denature enzymes;

amino acids with polar R-groups have hydrophilic properties; when these amino acids are built into protein in prominent positions, they may influence the properties and functioning of the proteins in cells; amino acids with non-polar R-groups have hydrophobic properties; hydrophobic amino acids are clustered in the core of globular proteins that are soluble in water; integral proteins have regions with hydrophobic amino acids, helping them to embed in membranes; integral membrane proteins are permanently embedded within the plasma membrane; the fatty acid tails that form the interior of the membrane are non-polar and do not repel the hydrophobic (non-polar) parts of the integral proteins.

Other valid examples of the effect of structure on function of proteins accepted.
[Max 9 marks]

C1.2 Cell respiration

Paper 1

1 C

2 A

3 C

4 B

5 a The data logger measures the differences in oxygen concentration *OR* the oxygen concentration is measured before and after the water passes through the respirometer; over time; the mass of fish needs to be measured.
[Max 2 marks]

b Greater body mass, less consumption of oxygen *OR* indirect/negative relationship.

c Higher temperature, more oxygen consumption; (more oxygen consumption) is due to more respiration/metabolism; less oxygen can dissolve in warmer water so less (aerobic) respiration *OR* more carbon dioxide dissolved so less oxygen for respiration.
[Max 2 marks]

6 a Allow gases to pass between mouse and soda lime; prevent mouse from being in contact with soda lime; prevent mouse from being in contact with faeces/urine/droppings.
[Max 1 mark]

b More oxygen in inhaled air than in exhaled air *OR* mouse uses oxygen in respiration; carbon dioxide exhaled/produced by mouse is absorbed by the soda lime; difference in volume is oxygen used by mouse *OR* the volume/concentration/pressure of oxygen in the jar falls; (this) sucks the coloured liquid up the tube; volume of oxygen consumed equals the increase in volume of coloured water in the tube.
[Max 3 marks]

c Oxygen is released during photosynthesis; plants use carbon dioxide (released by respiration); if carbon dioxide is too low in concentration then photosynthesis will be eliminated/reduced; results in an inaccurate/low measure of the oxygen that is consumed; perform experiment in dark to prevent photosynthesis *OR* cover with a bell jar to exclude light to prevent photosynthesis.
[Max 3 marks]

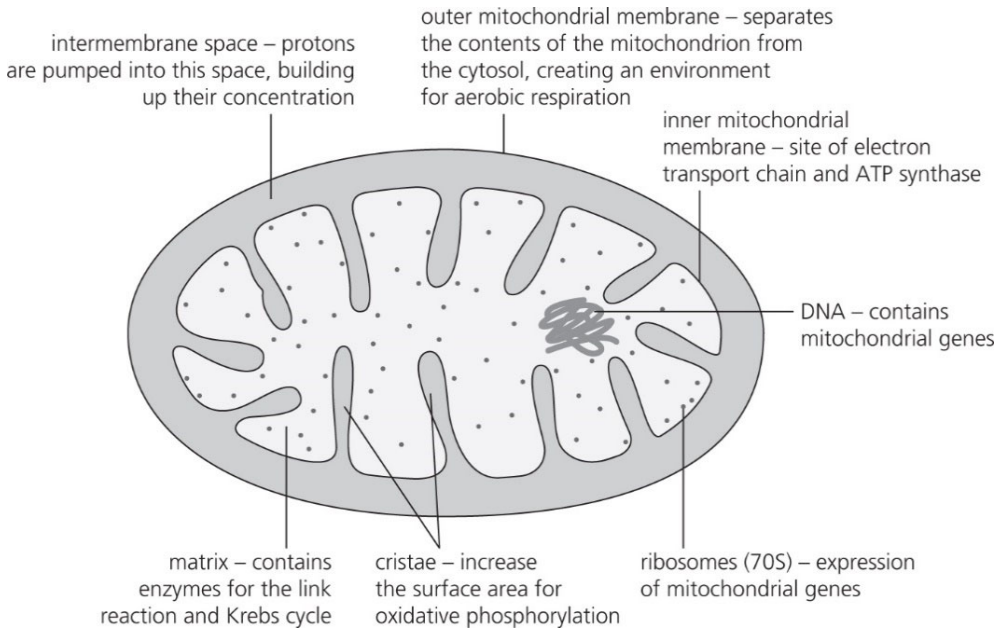
(Questions 7–10 HL only)

7 A

8 B

9 B

10 **a**



[1 mark for each correctly drawn and annotated feature; max 3 marks]

b ×17 500

c **i** Pyruvate and oxygen (ADP and Pi).

ii Pyruvate by facilitated diffusion (if moving from higher concentration in cytoplasm) *OR* active transport (if moving from lower concentration in cytoplasm); oxygen by diffusion.

d Chemiosmosis is the process by which the synthesis of ATP is coupled to electron transport via the movement of protons, using ATP synthase; protons concentrated in the space between the inner and outer mitochondrial membranes flow back into the matrix, via channels in the ATP synthase enzyme (ATPase) (also found in the inner mitochondrial membrane); as the protons flow down their concentration gradient, through the enzyme, the energy is transferred as ATP synthesis occurs; ATP synthase couples release of energy from the proton gradient with phosphorylation of ADP; the ATPase has a rotational mechanism; energy generated by the rotation of the enzyme leads to the production of ATP.
[Max 5 marks]

Paper 2

1 Adenosine triphosphate (ATP) is a nucleotide, present in every living cell, formed in photosynthesis and respiration from ADP and Pi; ATP functions in metabolism as a common intermediate between energy-requiring and energy-yielding reactions; ATP provides a direct source of energy for many life processes within cells; ATP is used in active transport of molecules and ions across membranes by membrane pumps; synthesis of macromolecules (anabolism); movement of the whole cell; movement of cell components, e.g. chromosomes.
[Max 3 marks]

2

	Anaerobic respiration	Aerobic respiration
oxygen requirement	absence of oxygen	presence of oxygen
products	lactic acid	carbon dioxide and water
location	cytoplasm	mitochondria
quantity of ATP produced	small quantity	large quantity
duration	short-term energy supply	long-term energy supply

[1 mark for each correct difference]

3 Determination of the rate of cell respiration can be made using a respirometer; respiration rate is measured by the uptake of oxygen per unit time; a manometer detects change in pressure or volume of a gas; place soda lime in chamber and insert mesh platform above it; place organisms (e.g. germinating seeds/fly maggots) on mesh platform (ensuring no contact with soda lime); close screw clip to seal the chamber/ensure no air can enter or leave; respiration by organisms in the chamber of the respirometer alters the composition of the gas there; organisms produce carbon dioxide, which is absorbed by soda lime; oxygen is absorbed by organisms and used in (aerobic) respiration; pressure in chamber decreases, which sucks/draws liquid up the manometer; rate of movement of air bubble/liquid in manometer is used to estimate rate of respiration; distance travelled by the fluid is measured in e.g. 10 minutes; the volume of oxygen absorbed and respired is calculated using the radius of the capillary tube, r (mm) and the distance moved by the manometer fluid, d (mm) in a minute using the formula: $\pi r^2 d$ (volume of a cylinder); average rate of oxygen consumption is calculated by dividing the volume of oxygen consumed by 10 (the number of minutes); experiment is repeated (at least five times) to obtain reliable data; independent variables include e.g. size of organism/supply of substrates for respiration/temperature.
[Max 7 marks]

4 At the molecular level, energy released by respiration is used in the synthesis of macromolecules (anabolism), e.g. protein synthesis/synthesis of nucleic acid;

at the cellular level, energy/ATP is used in the active transport of molecules and ions across membranes by membrane pumps; pumping of sodium and potassium ions in opposite directions across the plasma membrane of neurons; movement of cell components such as chromosomes/contraction of spindle fibres; cell division e.g. mitosis and meiosis; movement of whole cells e.g. sperm;

at the organism level, energy is used in movement/muscle contraction; energy used in cardiac muscle contraction/heart contraction, which pumps blood around the body, maintaining concentration gradient of e.g. oxygen between blood and air in alveoli; respiration releases energy which maintains body temperature/homeostasis; energy is needed for reproduction;

at the ecosystem level, energy is transferred from one organism to another in a food chain; only some of the energy transferred becomes available to the next organism in the food chain; energy is lost between trophic levels in a food chain; energy is lost due to inefficient transfer of energy in respiration/heat loss; only about 10% of what is eaten by a consumer is converted into new biomass; energy loss results in short food chains/limited to four or five trophic levels; as a result, feeding relationships of a food chain may be structured like a pyramid/pyramids of energy.
[Max 9 marks]

(Questions 5–8 HL only)

5

	Cytoplasm	Mitochondria
ATP production	2 ATPs produced	38 ATPs produced
use of oxygen	not required	required/oxygen is terminal electron acceptor
release of CO_2	glycolysis does not release CO_2	link reaction releases 2 CO_2 Krebs cycle releases 4 CO_2

[1 mark for each correctly identified difference]

6 (Cell) respiration is the (controlled) release of energy from organic compounds to produce ATP; (cell respiration) involves the oxidation and reduction of electron carriers; in the link reaction, pyruvate is converted into acetyl coenzyme A, CO_2 is released and NAD is reduced; in the Krebs cycle, a 4C molecule combines with acetyl CoA; decarboxylation releases 2 CO_2 molecules for each pyruvate/conversion of 6C to 5C/5C to 4C releases CO_2; (3) reduced NAD and (1) reduced FAD are produced; ATP is generated in the Krebs cycle; reduced molecules/FAD/NAD are carried to the cristae/inner membrane of the mitochondria; transfer of electrons between carriers in the electron transport chain in the membrane of the cristae is coupled to proton pumping; protons accumulate in intermembrane space/between cristae/inner membrane and outer membrane *OR* proton/electrochemical gradient between intermembrane space and matrix is established; protons diffuse through ATP synthase to generate ATP; chemiosmosis is the use of a proton/electrochemical gradient to generate ATP; oxygen is the final electron acceptor.

Any points accepted if included in a correctly annotated diagram.
[Max 8 marks]

7 NAD/FAD carries/is reduced by gaining (two) H (atoms)/(two) electrons; reduced NAD produced in glycolysis/link reaction/Krebs cycle; reduced NAD/FAD delivers electrons/hydrogen (atoms) to electron transport chain (ETC); ETC is in mitochondrial inner membrane/cristae; electrons release energy as they flow along the chain/from carrier to carrier; electrons from ETC accepted by oxygen/oxygen is the final electron acceptor; proteins in the inner mitochondrial membrane/electron carriers act as proton pumps; protons pumped into intermembrane space/proton gradient across inner mitochondrial membrane/proton concentration higher in intermembrane space than in matrix; energy (from electrons) used to pump protons into intermembrane space/generate a proton gradient/high H^+ concentration is a store of (potential) energy; ATP synthase in inner mitochondrial membrane/cristae; energy released as protons pass down the gradient/through ATP synthase; ATP synthase converts ADP to ATP/phosphorylates ADP; oxidative phosphorylation (is ATP production using energy from oxidizing foods).
[Max 8 marks]

8 The double membrane allows for compartmentalization and localization of enzymes for the Krebs cycle and link reaction in mitochondrial matrix; the external double membrane is permeable to pyruvate, CO_2, O_2 and coenzymes involved in the Krebs cycle and other processes of aerobic respiration; the cristae of the inner membrane increase surface area to provide space for the electron transport chain; the inner membrane is impermeable to protons (H^+) moving in from the matrix; proton pumps in the inner membrane pump protons from the matrix into the intermembrane space; intermembrane space is a relatively small space between inner and outer membranes which allows for the accumulation of protons to generate a large concentration difference with matrix, facilitating ATP synthesis; proton pumps create a proton gradient; ATP synthase allows the facilitated diffusion of protons to generate ATP/to allow phosphorylation of ADP to ATP; the matrix contains enzymes of the Krebs cycle and hence allows the enzymes and substrates to interact.
[Max 9 marks]

C1.3 Photosynthesis

Paper 1

1 B

2 C

3 D

4 a Chlorophyll *a OR* β-carotene.

b Horizontal axis for both is wavelength/colour *OR* (for a chloroplast/cells/leaves/plants extract) they will have the same/similar shape; an action spectrum shows the rate of photosynthesis (in chloroplasts/cells/leaves/plants) and an absorption spectrum shows the absorption of light.

c i The pigment didn't dissolve/was insoluble when the pigments from the algae were extracted; the pigment was not moved by/was insoluble in the solvent used to separate the pigments.

ii Orange/yellow/green/blue/violet.

(Questions 5–7 HL only)

5 B

6 A

7 a Photosynthesis/light independent reaction (of photosynthesis).

b The jars closer to the light had more purple colours *OR* the jar the furthest from the light was yellow *OR* purple to yellow.

c High light (intensity) increases photosynthesis; photosynthesis consumes CO_2; (more photosynthesis/less CO_2) increases pH/decreases acidity; less light means more respiration (than photosynthesis); respiration produces CO_2 *AND* lowers pH/increases acidity.

Answers can be the converse.

[Max 3 marks]

d Temperature/volume of indicator/identical jars/number of beads/size of beads/density of *Chlorella*/*other reasonable answer*.

Paper 2

1 a Oxygen production/release; (not 'count bubbles'); production/increase/change/measurement of biomass.

[Max 1 mark]

b High/higher than optimum temperatures denature enzymes (of Calvin cycle); ribulose bisphosphate carboxylase/RuBisCo stops working/does not bind substrate; wilting/withering/loss of water/decrease in turgor/increased transpiration; closure/reduced aperture of stomata; lower CO_2 level inside leaf/reduced CO_2 diffusion/uptake into leaf.

[Max 2 marks]

c Rate decreases/drops (to zero) with drought and increases when re-watered/recovering.

d Slight decrease/constant initially then falls/falls increasingly rapidly/decreases exponentially (in drought/up to day 35); increases almost to original level/but doesn't reach original level/rapidly at first then less rapidly/increases then reaches plateau (during recovery/after day 35).

[Max 2 marks]

e Higher/greater (emission) at 35 °C than 25 °C during both drought and recovery; both at (approximately) same level at end of drought period/at 35 days; both increase during recovery but not to original level; less/little difference in emission between temperatures during recovery/after watering/*converse*.

[Max 2 marks]

2 An action spectrum shows the range of wavelengths of light over which a process such as photosynthesis takes place; an absorption spectrum is a graph showing the relative absorbance of different wavelengths of light by a pigment; an action spectrum shows the wavelengths that are responsible for carrying out photosynthesis, whereas the absorption spectrum shows the wavelengths that are absorbed when light is passed through a pigment; the action spectrum shows rate of photosynthesis on the *y*-axis whereas absorption spectrum shows the (percentage of) light absorbed.
[Max 4 marks]

3 Cut a strip of chromatography paper so that it fits into a gas jar; rule a pencil line across the strip of paper 3 cm from one end; pour some solvent (acetone and petroleum ether) into the gas jar and seal it, so the atmosphere is saturated with solvent vapour; using a mortar and pestle, grind up fresh leaves (e.g. spinach) in pure acetone (propanone may also be used), producing as concentrated a pigment solution as possible and then filter the solution; using a very thin capillary tube or the head of a pin, place a drop of the pigment solution at the centre of the pencil line; allow the pigment spots to dry (place near a heat source, e.g. a lamp, or use a fan); place a second drop on the first and repeat for at least 15 minutes so that a small but concentrated spot of pigment has built up; pour further solvent into the gas jar to a depth of approximately 1.5 to 2 cm and place a lid over the gas jar so that the atmosphere inside remains saturated with vapour; place the bottom edge of the chromatography paper into the solvent so that it is just touching, ensuring the pigment spot is not immersed: the chromatography sheet should be placed so that the origin is just above the level of solvent; R_f value is a constant distance that a particular substance moves up a chromatogram relative to its solvent front; R_f value is calculated using the distance travelled by the solvent front and the distance from the origin to the centre of each spot.
[Max 5 marks]

4 Carbon dioxide-enrichment experiments are a means of predicting future rates of photosynthesis and plant growth; they include enclosed greenhouse experiments and free-air carbon dioxide-enrichment (FACE) experiments; enclosed greenhouse experiments manipulate variables that can affect photosynthesis, such as sunlight, wavelength of light and temperature, using greenhouses (or polytunnels) to control other variables; data gathered does not directly relate to changes that would be seen in natural ecosystems; FACE experiments pump carbon dioxide into the air to raise the local concentration of the gas in forests, grasslands and agricultural fields; compared to enclosed greenhouse experiments, FACE experiments are in natural ecosystems, and can investigate the effects of carbon-dioxide enrichment on large producers such as trees; unlike greenhouses, other variables cannot be controlled (such as rainfall and sunlight) and so need to be monitored.
[Max 6 marks]

5 A limiting factor for photosynthesis is an environmental factor that, when in short supply, affects the rate of photosynthesis; limiting factors include concentrations of carbon dioxide, light intensity and temperature.

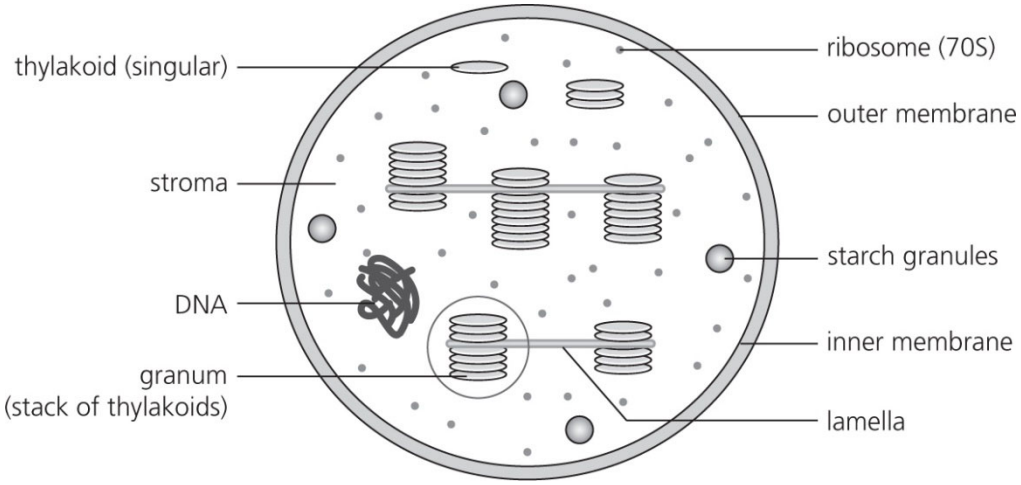
Controlled experiments to investigate the effect of limiting factors are discussed in Section C1.3 of the Student's book, pages 434–7. Details of how each independent variable is changed, how the dependent variable is measured, and how variables are controlled, are needed for each experiment.
[Max 3 marks per experiment, max 7 marks in total]

(Questions 6–11 HL only)

6 Photoactivation of photosystem I *AND* production of ATP.

[*Both needed for 1 mark*]

7



[1 mark for each correctly drawn and annotated feature; max 3 marks]

8 Hydrogen ions (and oxygen) are obtained from photolysis of water; (excited) electrons (from photosystem II) contribute to generate a hydrogen ion/proton gradient *OR* protons build up in the thylakoid space/inside the thylakoid; ATP synthase generates ATP by chemiosmosis/using the proton gradient/by movement of protons from the thylakoid space to the stroma; (two) high-energy/excited electrons (from photosystem II) are passed through an electron transport chain; NADP accepts H^+ (from the stroma)/electrons to produce $NADPH^+$/reduced NADP; ATP/reduced NADP/$NADPH^+$ are used by light-independent reactions/Calvin cycle in the stroma; (in Calvin cycle) carbon fixation to ribulose bisphosphate/RuBP produces G3P; ATP is used to transform G3P to TP; reduced NADP/$NADPH^+$ is used to transform G3P to TP.
[Max 7 marks]

9 **Similarities**: both processes occur in an organelle within a cell; both involve an electron transport chain; both involve chemiosmosis; both involve reduction–oxidation reactions; both use and produce ATP in reactions that are carried out on membranes and are controlled by enzymes.

Differences:

	Cellular respiration	Photosynthesis
location	mitochondria	chloroplasts
function	release of energy	capture and conversion of light energy to chemical energy for storage
metabolic process	catabolic	anabolic
source of energy	glucose	(sun)light
electron carriers	FAD and NAD	NADP
products	water and carbon dioxide	glucose and oxygen
occurrence	occurs in all organisms	occurs only in autotrophs

For differences in chemiosmosis see answer to question 10 below.
[Max 7 marks]

10 **Similarities**: both processes involve a proton gradient across membrane surfaces; both involve an electron transport chain (to generate proton gradient) and ATP synthase.

Differences: in respiration, protons and electrons used for ATP synthesis are derived from oxidation involving organic compounds; whereas in photosynthesis they are derived from light absorbed by photosynthetic pigments/photolysis of water; in respiration, the proton pool is maintained in the intermembrane space in mitochondria; whereas in photosynthesis it is in the thylakoid space in chloroplasts.
[Max 7 marks]

11 Photosystems are arrays of pigment molecules (with associated proteins) that can generate and emit excited electrons; photosystems are located in membranes and occur in cyanobacteria and in the chloroplasts of photosynthetic eukaryotes; light-harvesting complexes (antenna complex; LHC) are an array of protein and chlorophyll molecules embedded in the thylakoid membrane of plants, algae and cyanobacteria, which transfer light energy to one chlorophyll *a* molecule at the reaction centre of a photosystem; photosystem I is a chlorophyll–protein complex that uses light energy to release excited electrons, replacing each lost electron by one in the ground state (electrons are received from photosystem II); photosystem II is a membrane super-complex of proteins and several hundred chlorophyll molecules, plus accessory pigments, that carries out the initial reaction of photosynthesis; in photosystem II, light from the Sun excites electrons, which pass down an electron transport chain to photosystem I: these electrons are replaced by splitting water to release protons and electrons; proteins are used in the electron transport chain (e.g. cytochromes) and are able to accept electrons from one substance and donate them to another; the Calvin cycle is a cycle of reactions in the stroma of the chloroplast by which some of the product of the light-independent reactions is reformed as the acceptor molecule for carbon dioxide (ribulose bisphosphate); Rubisco (RuBisCo) is an enzyme involved in the first major step of carbon fixation and is the central enzyme of photosynthesis; CO_2 is combined with an acceptor molecule in the presence of RuBisCo (the 6-carbon product immediately splits into two 3-carbon molecules of glycerate 3-phosphate).
[Max 9 marks]

C2.1 Chemical signalling (HL only)

Paper 1 (HL only)

1 B
2 A
3 C
4 A
5 C
6 C
7 C
8 B
9 D
10 A

Paper 2 (HL only)

1 a Muscle/liver/adipose cells.

b 1. Insulin activates RTK receptors.
2. Relay proteins are activated, which travel to vesicles within the cell.
3. Vesicles contain glucose transporter proteins (channel proteins known as GLUT4, or glucose transporter type 4)
4. Vesicles fuse with the plasma membrane, and the GLUT4 proteins become incorporated in the membrane, where they transport glucose into the cell.

c Insulin functions as an extracellular messenger molecule (hormone), informing cells that glucose levels are high; cells that express insulin receptors on their surface respond to this message by increasing glucose uptake; cells responding to insulin increase glycogen and triglyceride synthesis, and/or by decreasing gluconeogenesis; glycogen synthase molecules are activated, which will catalyse the synthesis of glycogen from glucose (glycogenesis).
[Max 3 marks]

2 In cell signalling, ATP donates a phosphate group to a target protein, catalysed by protein kinases; this causes the target protein to undergo a conformational change and convert from the inactive to active form, which leads to signal transduction; ATP is also used as a substrate for the formation of cAMP by adenylyl cyclase; cAMP acts as second messenger that leads to signal transduction.
[Max 3 marks]

3 **Advantage**: amplification of signalling cascade: one signal gives rise to multiple cellular responses;

Disadvantage: prone to error: error along any part of the cascade would result in undesirable consequences; non-specificity of response causes wastage of energy/metabolic resources.
[Advantage 1 mark and disadvantage 1 mark, max 2 marks]

4 Enzymes that catalyse the addition of phosphate groups from ATP to a protein, causing conformation change and the activation of the protein; when a kinase is activated, it phosphorylates the next kinase, which continues sequentially down the pathway in a phosphorylation cascade.
[Max 2 marks]

5 Insulin is released from beta islet cells in the pancreas; insulin binds to RTK (tyrosine kinase) receptors; on target cells to increase absorption of glucose and lowers blood glucose levels; glucagon is released from alpha islet cells in the pancreas; glucagon binds to GPCRs (G protein-coupled receptors); on target cells; to release glucose from glycogen and increase the levels of blood glucose.
[Max 6 marks]

6 **Similarities**: both use chemicals to transmit information/are chemical messengers;

Differences:

	Hormones	Neurotransmitters
system	endocrine system	nervous system
transmission	through blood	across the synaptic cleft
site of release	endocrine gland	end of a neuron/presynaptic membrane
site of action	distant site from where it is produced	released close to site of action
speed of action	relatively slow	fast
period of action	longer periods of time	short-lived

response	responses affect the body after binding to receptors has ceased	responses only have effect while neurotransmitter is bound to receptor

[Similarities max 1 mark, differences max 6 marks; max 7 marks]

7 Cells respond to changes in their environment by receiving and integrating signals from other cells; in this way, communication takes place between different biological systems in the organism; most cell signals are chemical signals/ligands; bacteria use chemical signalling/quorum sensing; in multicellular organisms, chemical signals include growth factors, morphogens, cytokines and hormones that may have come from neighbouring cells or from more distant sources; neurotransmitters are chemical signals that cross the synapses of adjacent neurons to allow fast response to stimuli; hormones are released by endocrine glands and travel to target cells through the blood plasma, and have a slower but longer-lasting effect on the body; hormones include insulin, which controls blood sugar concentration, and epinephrine, which is responsible for the fight-or-flight response; oestradiol, progesterone and testosterone control secondary sexual characteristics/play a role in sexual reproduction; in cell differentiation, morphogens occur across a gradient of concentrations: these gradients drive the process of differentiation of unspecialized stem cells into different cell types; different concentrations of the morphogen result in the initiation or inhibition of gene expression, which in turn determine the way in which cells differentiate and develop into specific tissues; the concentration of the morphogen in each particular cell then determines a series of subsequent signals (cascades): responses to these signals determines the direction and extent of cell growth and development, ultimately forming all the tissues and organs of the body; expression of such gradients also controls the length of body structures, such as toes and fingers, the location of the nose, and other body patterns; the pattern of morphogen distribution therefore communicates to cells the timing and degree of specialization; cells can detect signals because of receptors in their plasma membrane to which the ligand binds, which then triggers an internal response; this change of signal is termed signal transduction and the cell's response to a chemical signal (ligand) may be fast or slow; receptors are typically transmembrane proteins which, on binding with the signal molecule, activate internal signalling pathways; some receptors occur within the cell nucleus; these intracellular receptors are stimulated by ligands (non-polar molecules) that pass through the plasma membrane; the activation of a receptor (internal or external) initiates a chain of responses (often amplified) and often involving a second messenger.
[Max 9 marks]

C2.2 Neural signalling

Paper 1

1 B

2 C

3 A

(Questions 4–7 HL only)

4 A

5 C

6 C

7 D

Paper 2

1 a In both myelinated and unmyelinated fibres, speed of conduction increases with increased diameter of fibre; there is variation in conduction speed in both myelinated and myelinated examples; overall, myelinated fibres have faster conduction speeds, although there are exceptions; some species with unmyelinated fibres, e.g. giant squid, have faster conduction speeds than myelinated species, e.g. species of frog.
[Max 4 marks]

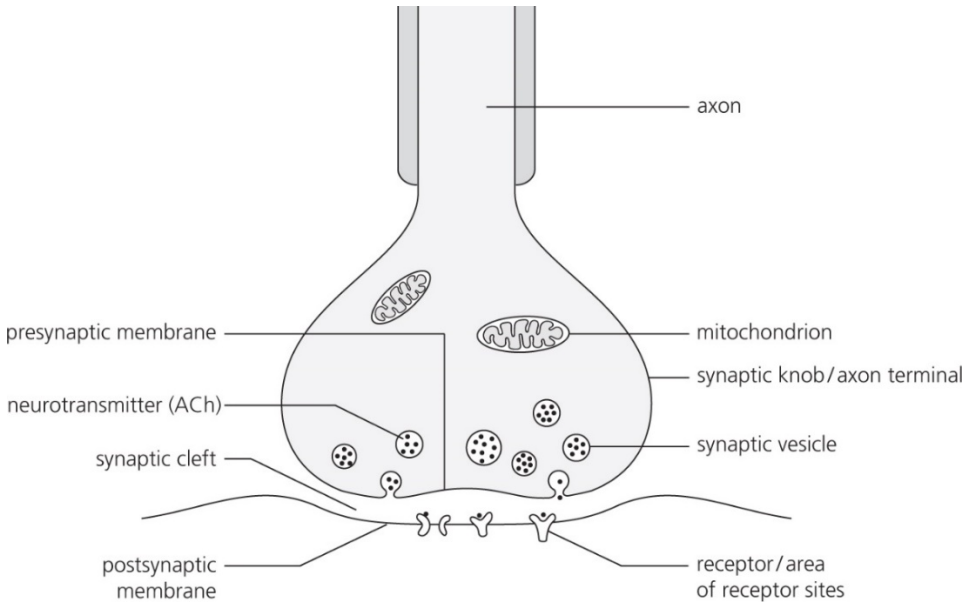
b The myelin sheath speeds up transmission of the action potential because the axon membrane is only exposed at nodes of Ranvier; the action potential can 'jump' from node to node/saltatory conduction occurs; electrical resistance of the myelin sheath prevents reversal of the axon polarity at the nodes of Ranvier; in unmyelinated fibres, the action potential must move step-by-step along the entire surface of the fibres and is therefore a relatively slow process; action potential propagation (or conduction) velocity is directly correlated with axon diameter; the larger the axon diameter, the higher the action potential propagation velocity; there is less resistance facing the ion flow; speed of transmission depends on the resistance offered by the axoplasm within; resistance is related to the diameter of the fibre; the narrower the fibre, the greater its resistance to ion movement, and the lower the speed of conduction of the action potential; a larger diameter means there can be more ion channels around the axon/there are more ion channels per unit length of axon.
[Max 7 marks]

2 a Synapse/synaptic cleft

b Depolarization of presynaptic membrane/action potential/nerve impulse arrives; uptake of calcium/calcium ions diffuse in/calcium channels open; structures containing neurotransmitter/vesicles move to/fuse with membrane; neurotransmitter/acetylcholine released by exocytosis into cleft/binds to postsynaptic membrane/receptors.
[Max 3 marks]

3 During the resting potential, sodium ions are predominantly outside the neuron and potassium ions mainly inside (resting potential); a resting potential produced by the active transport of potassium ions (K^+) into the axon across the membrane and sodium ions (Na^+) out across the membrane; this is generated by a K^+/Na^+ pump, using energy from ATP; three Na^+ are pumped out for every two K^+ pumped in; the tissue fluid outside the neuron therefore contains many more positive ions than are present in the axon; a negative charge is developed inside, compared to outside/the resting neuron is polarized; an impulse/action potential is a momentary reversal in electrical potential difference in the membrane/a change in the position of charged ions between the inside and outside of the membrane of the nerve fibres.
[Max 4 marks]

4



[2 correct labels per mark; max 3 marks for correctly annotated drawing]

When action potential arrives at axon terminal Ca^{2+} moves into synaptic knob; synaptic vesicles fuse with presynaptic membrane; neurotransmitter/ACh released by exocytosis; diffuses over synaptic cleft; ACh binds to receptors on postsynaptic membrane; causing the protein channels to open/Na^+ gates open; Na^+ flows in through channels; so depolarizing the postsynaptic membrane; with sufficient depolarization, an impulse/action potential is generated in the postsynaptic neuron; some comment on the breakdown of ACh by (A)Ch-esterase; diffusion back into axon terminal through presynaptic membrane/use of ATP for resynthesis and packaging.
[Max 5 marks]

Diagram and explanation [Max 8 marks]

5 Answer which includes reference to material from across the syllabus: nerve cells (neurons) structure and function; adaptations of neurons; different types of neuron (sensory, relay, motor); reflex arc; role of the nervous system in homeostasis (i.e. temperature control); membrane structure; membrane proteins: protein pumps (carrier proteins), channel proteins, gated channel proteins; protein receptors; complementary shapes; facilitated diffusion; active transport; surface area-to-volume ratio; effect of temperature on diffusion; vesicles; exocytosis; enzymes; mitochondria/ATP.
[Max 9 marks]

(Questions 6–10 HL only)

6 a 10–25%

b G1 always respond more than 25% (except control), while G2 and G3 always respond 25% or less; G1 always responds more than G2 and G3/all of the others.
[Max 1 mark]

c Oscilloscope

d Mouse chemicals cause action potentials (in all six neurons) while control ones cause none (remain in resting potential)/mouse chemicals cause greater responses.

e Both chemicals cause action potentials *OR* both chemicals respond in the majority of/five/most neurons; stoat scent causes a higher action potential/longer/bigger response than mouse alarm compound (in each neuron) *OR* neuron 2 reacts strongly to the stoat scent but has a minimal/no response to the mouse alarm compound.
[Max 2 marks]

f There is a positive relationship/correlation between the size of neural traces and the percentage of responding G1 neurons *OR* the chemicals that cause stronger/higher neural traces also cause the greatest percentage of responding G1 neurons [or vice versa]; fox and stoat scents have (approximately) the same/similar neural traces and the same percentage of responding neurons/>75%; mouse alarm compounds cause smaller neural traces and smaller percentage of responding neurons/25–75%; control chemicals have no response in both cases *OR* no percentage of (G1 neurons) response and no action potential (in neural traces).
[Max 2 marks]

7 a Brain cells/neurons carry out a large amount of metabolic activity; maintenance of resting potential requires energy/ATP *OR* functioning of Na/K pumps requires energy/ATP.
[Max 1 mark]

b (Measures brain activity by) detecting changes associated with blood flow; more active parts of brain receive more blood flow; activity leads to change in magnetization between oxygen-rich and oxygen-poor blood; scans/images are taken while the subject is exposed to a stimulus/activity.
[Max 2 marks]

8 Neonicotinoids are a type of pesticide that completely block synaptic transmission at cholinergic synapses; cholinergic synapses are synapses that have receptors that are activated when they bind to acetylcholine; neonicotinoids bind to acetylcholine receptors in synapses in the CNS of insects, blocking the binding of acetylcholine; this inhibits synaptic transmission; neonicotinoids cannot be broken down by acetylcholinesterase and so their effects are irreversible.
[Max 5 marks]

9 Cocaine is an exogenous chemical/chemical that originates outside the body; cocaine primarily affects dopamine/a neurotransmitter that plays a role in the brain's 'reward and reinforcement' systems (it also affects the neurotransmitters serotonin and norepinephrine); cocaine prevents neurotransmitter molecules from being taken back up into the cell/blocks reuptake of neurotransmitters; cocaine binds to transporters that normally remove excess neurotransmitter from the synaptic gap; it prevents them from being reabsorbed by neurons and therefore increases their concentration in the synapses; the natural effect of the neurotransmitter on the postsynaptic neurons is amplified; the group of modified neurons produce more dependency (from dopamine), feelings of confidence (from serotonin) and energy (from norepinephrine) typically experienced by people who take cocaine; in chronic cocaine consumers, the brain relies on cocaine to maintain the high degree of pleasure associated with the artificially elevated levels of neurotransmitters; the brain responds to increased dopamine levels by synthesizing new dopamine receptors; if cocaine consumption ceases and dopamine levels return to normal, this increased level of sensitivity produces cravings and depression.
[Max 5 marks]

10 Neurotransmitter attaches to receptor site, initiating transmission; nerve impulses are action potentials propagated along the axons of neurons; resting potential is more negative inside/−70 mV/more positive outside the membrane *OR* a resting potential has greater concentration of Na^+ ions outside than K^+ ions inside the axon; (voltage-gated) channels open and Na^+ ions diffuse in; causes depolarization of the membrane/−70 mV to +40 mV; local currents affect adjacent channels/cause action potential; depolarization is followed by repolarization of the neuron; (voltage-gated) channels open and K^+ ions diffuse out/repolarize the membrane; Na^+/K^+ pumps restore Na^+/K^+ balance/resting potential; myelin around the neuron insulates the axon *OR* speeds the transmission; myelin permits saltatory conduction *OR* permits jumping from node to node.
[Max 7 marks]

C3.1 Integration of body systems

Paper 1

1 A

2 C

3 C

4 A

5 D

6 C

(Questions 7–10 HL only)

7 C

8 B

9 D

10 B

Paper 2

1 **Similarities**: both used for communication between cells/tissues/organs/parts of the body; both cause a response/change in specific/target cells *OR* both use chemicals that bind to receptors/hormones and neurotransmitters are both chemicals; both can stimulate or inhibit (processes in target cells); both can work over long distances/between widely separated parts of the body; both under (overall) control of the brain/CNS; brain (has role in) sending hormones and nerve impulses; both use feedback mechanisms/negative feedback/both used in homeostasis.
[Max 2 marks for similarities]

Differences:

Hormones	Nerves
chemical (messenger)	nerve impulse/electrical (signal)
transported in blood	transported by neurons
slower	faster
carried throughout body	carried to single/specific cell/muscle fibre
all/wide range of tissues/organs affected	only muscles/glands receive signals
(usually) long term (persistence/response)	short duration/short-lived (responses)
chemical (messenger)	nerve impulse/electrical (signal)

[Max 5 marks for differences, max 7 marks in total]

2 Unconscious processes are automatic and involuntary, whereas conscious processes are deliberate and voluntary; conscious processes include voluntary muscle movements, thought and speech; unconscious processes include heart rate, swallowing, breathing and movement of food through the digestive system;

reflexes are unconscious responses to stimuli that protect the body from harm, e.g. pain reflex.
[Max 3 marks]

3 a A stimulus is detected by a sensory receptor in e.g. the skin of the fingers; the sensory receptor changes energy from touch to an electrical impulse (action potential) in the axon of the sensory neuron; sensory neurons convey messages from receptor cells to the central nervous system; the electrical signal travels along the axon to the spinal cord and the brain; the electrical signal causes the release of a neurotransmitter at a synapse between the sensory neuron and an interneuron; the neurotransmitter stimulates the interneuron to form an action potential in its dendrites and cell body; the action potential travels along the axon of the interneuron, which results in neurotransmitter release at the next synapse with another interneuron; neurotransmitter release at a synapse followed by an action potential occurs many times as interneurons in higher parts of the brain (e.g. the cerebral cortex) are activated; once interneurons in the cerebral cortex are activated, perception occurs and the stimulus, for example a pen, is sensed as the fingers touch it.
[Max 3 marks]

b A stimulus in the brain causes an action potential to form in the dendrites and cell body of an upper motor neuron; the upper motor neuron synapses with a lower motor neuron further down in the CNS; the action potential travels down the axon of the upper motor neuron; the action potential causes neurotransmitter release in the synapse between the upper and lower motor neurons; the neurotransmitter generates an action potential in a lower motor neuron (a type of motor neuron that directly supplies skeletal muscle fibres); the action potential in the lower motor neuron causes neurotransmitter to be released at neuromuscular junctions formed with e.g. skeletal muscle fibres; the neurotransmitter stimulates e.g. muscle fibres to form muscle action potentials; the muscle action potentials cause muscle fibres to contract, bringing about a response to the stimulus.
[Max 3 marks]

4 **Similarities**: both contain a cell body, dendrites and an axon.
[Max 1 mark]

Differences: sensory neurons are nerve cells carrying impulses from a sense organ or receptor to the central nervous system; motor neurons are nerve cells that carry impulses away from the central nervous system to an effector (e.g. muscle, gland); in a motor neuron, the cell body is at one end of the neuron whereas in a sensory neuron it is part way along the neuron; sensory neurons have a cytoplasmic fibre/dendron running to the cell body whereas motor neurons consist of an axon only.
[Max 5 marks for differences, max 6 marks in total]

5 Baroreceptors are sensory receptors responding to stretch in the walls of blood vessels; they monitor blood pressure; chemoreceptors are receptors that monitor blood pH and concentrations of oxygen and carbon dioxide in the blood; the medulla coordinates responses and sends nerve impulses to the heart to change the heart's stroke volume and heart rate; nerves supplying the cardiovascular centre bring impulses from baroreceptors located in the walls of the aorta, in the carotid arteries, and in the wall of the right atrium when change in blood pressure at these positions is detected; when blood pressure is high in the arteries, the rate of heartbeat is lowered by impulses from the cardiovascular centre, via the vagus nerve; when blood pressure is low, the rate of heartbeat is increased; chemoreceptors in the carotid arteries, aorta and brain monitor the level of carbon dioxide in the blood and pH level; increased carbon dioxide or decreased pH level causes the chemoreceptors to signal the heart to beat faster; by increasing blood flow, carbon dioxide can be moved more quickly to the lungs where it is removed by diffusion into the alveolar spaces; this lowers carbon dioxide levels and returns blood pH to safe limits.
[Max 5 marks]

6 Emergent properties are properties gained by a complex system when the individual parts work together; cells, tissues, organs, organ systems and ecosystems have their own properties and represent a hierarchy of subsystems;

at molecular level: each macromolecule in a cell determines the structure and function of the cell; nucleotides form nucleic acids containing genes that determine an organism's characteristics; interactions

between genes and amino acids determine which proteins are formed and the ultimate function of the cell;

at cellular level: the basic unit of life is the cell, which is formed by interactions between macromolecules; organisms arrange cells into tissues, which are groups of similar cells that work together to perform a particular function; e.g. a single epithelial cell cannot form a protective layer whereas multiple epithelial cells can form layers and other structures that can carry out functions such as protection, secretion, absorption, filtration and sensory reception; different types of tissues combine to form organs that perform specialized functions; properties of an organ depend on the properties that emerge as a result of interactions between tissues and other previous levels of organization; e.g. DNA determines how cells form tissues and how tissues form organs;

at organism level: multicellular organisms, such as humans, have properties that emerge from the interaction of their cellular components; organs form organ systems; e.g. the digestive system is formed from interactions between the mouth, oesophagus, stomach, liver, pancreas, gall bladder, small intestine and large intestine; when they work together, they allow the whole organ to carry out the emergent properties of peristalsis, digestion, food absorption and transport; e.g. the stomach cannot digest food without the enzymes and digestive fluids that the gallbladder, liver and pancreas make; interactions between the organs in a system are controlled at the molecular level;

at ecosystem level: organisms of the same species form populations: the characteristics that emerge in a population depend upon the species' genetics and its environment; communication and cooperation of individuals within a population are emergent properties that result from the struggle of individuals to survive; interactions of two or more populations result in the formation of communities; carrying capacities for all the species together in an ecosystem's biological community are an emergent property of the ecosystem; this is because the food supply for each species is a consequence of what happens in other parts of the ecosystem.

Answer must be illustrated with an appropriate named species: see the example using the cheetah in Table C3.1.1 of the Student's book, page 493. [Max 7 marks]

(Questions 7–9 HL only)

7 Tropisms are growth responses of plants in which the direction of growth is determined by the direction of the stimulus; coleoptiles/young plants/shoots can be grown to investigate the effect of stimuli on plant growth/tropisms; qualitative data could involve drawing diagrams to record observations of seedlings/illustrate tropic responses; quantitative data could include measuring the angle of curvature of seedlings as they respond to external stimuli; precision in tropism experiments can be improved by carrying out the same methodology in exactly the same way for each repeat; calculating standard deviation can assess levels of precision/small ranges or standard deviation indicates high precision; to ensure accuracy, other variables must be controlled; other factors that can affect the growth of plants must be kept the same, e.g. volume of water given to seeds/number of seeds in each sample/distance between each seed/the temperature seeds are grown in; repeats showing similar results indicate low variability in data.
[Max 5 marks]

8 a 45 (pmol g^{-1})

b Less auxin as the leaves become older/larger *OR* negative correlation from L1 to L4 [or vice versa]; L4 and L6 leaves have least auxin concentration *OR* L4 and L6/older leaves have about the same concentration of auxin/do not have significantly different concentrations.
[Max 2 marks]

c NPA decreased the (mean) number of roots per rooted cutting (by about 5); NPA decreased the (mean) length per root (by more than half); NPA decreased the (mean) total root length per planted cutting (to about 2% of control); NPA inhibited the formation of roots *OR* decreased all three measures.
[Max 2 marks]

d **i** Both decrease up to 6 hours/initially; NPA-treated decrease more/at a faster rate than control (up to 6 hours); after 6 hours, control increases while NPA treated continues to fall.
[Max 2 marks]

ii NPA (appears to have) no effect on concentrations/transport of auxin in L6 as control and NPA-treated remain at same (low) level; NPA (probably) inhibits the auxin efflux pumps/transport (in the leaves) as the levels drop in the NPA-treated stem base (but not in control); the transport of auxin to the stem base must occur from younger leaves *OR* L6 is not the source of auxin in the stem base; NPA inhibits the auxin pumps/transport (in the leaves) as the levels drop in the NPA-treated stem base.
[Max 2 marks]

e L1 has the highest concentration of auxin so appears to be/is the main source/the producer of auxin; as leaves age, they (appear to) decrease the production of auxin [or vice versa]; the stem base is an auxin sink as seen by the accumulation in the control stem base (where roots form); high concentration of auxin (in the stem base) promotes root formation.
[Max 3 marks]

9 Auxin promotes growth/bends towards (brightest) light/Sun; auxin moves from lighter to shadier side (of shoot/stem tip/apex); moved by auxin efflux pumps; auxin promotes cell elongation/cell growth; auxin causes cell wall acidification/loosening; more growth on shady side of stem (due to auxin concentration gradient); binds to auxin receptors (in target cells); auxin/auxin receptors promote expression of genes (for growth)/for H^+ secretion into wall.
[Max 5 marks]

C3.2 Defence against disease

Paper 1

1 A

2 C

3 B

4 C

5 D

6 B

7 D

Paper 2

1 Clotting factors (are proteins) that initiate the clotting cascade/process; fibrin (is a protein that) permits blood clotting *OR* allows the formation of a clot; (the protease) thrombin converts fibrinogen to fibrin; fibrin forms a mesh/clot that prevents the entry of pathogens/antigens into the blood; antibodies are (specific) proteins that lymphocytes make; each antibody corresponds to a specific pathogen/antigen *OR* antibodies are specific (to certain pathogens/antigens); antibodies create specific immunity; plasma cells produce large amounts of (specific) antibodies *OR* memory cells retain the ability to produce (specific) antibodies; immunoglobulins are antibodies against pathogens; enzymes in phagocytic white blood cells may digest pathogens.
[Max 8 marks]

2 **a** Cell wall; pili/flagella; 70S ribosomes; nucleoid/circular DNA *OR* naked DNA; plasmids
[Max 3 marks]

b Phagocytes/lymphocytes are white blood cells; TB bacterium has a specific antigen; this antigen is recognized by white blood cells; a clone of lymphocytes/plasma cells/B-cells are produced; antibodies are produced by lymphocytes; each lymphocyte produces just one type of antibody; (this is) specific immunity; (part of the) antibody/immunoglobulin binds to the antigen/specific antibody binds to the specific antigen; antibodies are proteins/immunoglobulins; (some) plasma cells become memory cells; memory cells reproduce quickly; memory cells prevent infection in the future.
Annotated diagrams can be used to explain the process. [Max 7 marks]

c Antibiotics block bacterial processes; example of bacterial process e.g. cell wall formation; variations exist naturally in a population/some are naturally resistant to the antibiotic; bacteria that are not resistant to this antibiotic will die/only resistant bacteria will survive (when antibiotic given); this characteristic could be passed to next generation; (natural selection) leads to changes in the proportions/frequency in the population; human population will be exposed to antibiotic-resistant bacteria and will not have antibiotic to kill them; (antibiotic-resistant bacteria) may pass resistance to other bacteria species/types by means of plasmids (so other bacteria species become resistant too).
[Max 5 marks]

3 Innate immune system responds to broad categories of pathogen and does not change during an organism's life; it responds the same way for every antigen encounter/not specific to any pathogen; carried out by phagocytes that can engulf and destroy (by phagocytosis) many different foreign organisms.
[Max 2 marks]

4 Vaccination is the deliberate administration of antigens that have been made harmless (after they are obtained from disease-causing organisms) or nucleic acids, in order to give future immunity; vaccination triggers active immunity/active immune response; antigens are detected by the immune system, triggering antibody-producing B-cells and helper T-cells that support antibody production; antigen presenting cells/macrophages present antigen to specific CD4 T-cells and B-cells; specific B-cells activated to proliferate and differentiate into plasma cells and memory B-cells; plasma B-cells produce antibodies; memory cells retain the ability to produce the specific antibodies to quickly respond to reinfection by the pathogen.
[Max 3 marks]

5 **Immunological memory**: traditional vaccination involves the introduction of a preparation of a dead or weakened form of the disease-causing pathogen (or its antigenic protein) into a person to stimulate their immune system; the adaptive immune system is primed to mount a more rapid and effective response in a subsequent encounter with the pathogen/secondary response; via the production of memory B- and T-cells that carry B-cell receptors that are specific to the antigen in the vaccine and the natural pathogen;

herd immunity: by vaccinating a critical proportion of a community against a contagious disease, susceptible members of a population can be protected because the immunised individuals act as a barrier against the infection, preventing its spread; the greater the number of people in a population immune to a disease, the lower the risk of someone who is susceptible becoming infected, as the transmission of the disease is greatly impeded; the minority of the population who are not vaccinated are protected by the majority who have been vaccinated; the proportion of vaccinated individuals needed for herd immunity depends on the nature of the disease-causing organism and its method of transmission.
[Max 4 marks]

6 Evolution by natural selection is the process where genetic variation in organisms is selected for by their environment, ultimately leading to speciation; patients who are infected with a bacterium are treated with an antibiotic to help them overcome the disease; antibiotics are very widely used; in a large population of that bacterium, some individual bacteria may carry a gene for resistance to the antibiotic, typically on a plasmid; such genes arise by spontaneous mutation (or may be acquired through bacterial conjugation); most of a bacteria population is not adapted to the antibiotic, but an unusual or mutant variety of the population is suited and has a selective advantage; when the antibiotic is present, most bacteria of the population are killed; the resistant bacteria survive and will be the basis of the future population; in the

new population, all individuals now carry the gene for resistance to the antibiotic; the evolution of bacteria that are resistant to antibiotics means that careful use of antibiotics is necessary to slow the emergence of multi-resistant bacteria.
[Max 7 marks]

7 Medical science uses inductive reasoning, which starts with specific observations that lead to a hypothesis that is then generalized; e.g. the discovery of the smallpox vaccine; smallpox was caused by one of two virus variants, Variola major and Variola minor; it was eradicated by 1980 with a global vaccination programme; a scientist (Edward Jenner) observed at the end of the eighteenth century that individuals who milked cows and were exposed to cows with cowpox were immune to human smallpox infection; he reasoned from this observation that a vaccine made from cowpox lesions could be protective; as a result the smallpox vaccine was invented; careful observations during nineteenth-century epidemics of cholera in London and childbed fever (due to an infection after childbirth) in Vienna led to breakthroughs in the control of infectious disease; cholera is an infectious disease caused by bacteria/cholera bacterium carried in water; a scientist (John Snow) mapped the deaths from cholera and observed that the people who had died had mainly lived near to a water pump; his observations convinced the local council to remove the handle from the water pump to prevent its use; as a result, the number of deaths from cholera reduced significantly; the pump had been polluted by sewage, including faeces, which had contaminated the water; in the nineteenth century, many women died after childbirth from puerperal septicaemia (childbed fever); a scientist (Ignaz Semmelweis) observed more deaths from puerperal septicaemia occurred in the ward where male medical students delivered the babies compared to a ward where female midwives performed the deliveries; he observed that medical students also worked in the autopsy rooms, dissecting and examining the bodies of women who had died of childbed fever; they then moved into the maternity ward, often without washing their hands; midwives did not carry out autopsies; he found a clear correlation between deaths and autopsies; he proposed that anyone delivering a baby should wash their hands beforehand, to prevent transmission; childbed fever is caused by a bacterium, and so washing hands helps to prevent transmission of this microbe.
[Max 6 marks]

C4.1 Populations and communities

Paper 1

1 D

2 C

3 A

4 D

5 A

6 A

7 C

8 a i Lincoln index/capture–mark–release–recapture technique.

ii Damselflies are captured (using a net) and counted; damselflies are marked (e.g. on wing using coloured pen); marking should be non-obtrusive/not attract predators; marked insects are released back into ecosystem; sampled population is allowed to mix with rest of population; after a period of time (e.g. 24 hours) a second (random) sample is taken in the same location; the total number of damselflies is counted and the number of those marked also recorded; total population size is estimated using the Lincoln index equation; population size = (M × N)/R, where M = number of animals captured (marked and released), N = number of animals recaptured, R = number of marked animals recaptured.
[Max 4 marks]

iii Mixing may not be complete, so marked individuals are not spread evenly throughout the population; marks may disappear; marks may be harmful and may increase predation risk by making marked individuals more visible; it may not be equally easy to catch each individual; there may be immigration or emigration from the sample site; there may be births or deaths in the population between the times of sampling.
[Max 3 marks]

b Quadrats are used to study the abundance of plants and sessile animals; this is because sessile animals and plants do not move from the sample site; mobile/motile species cannot be sampled with quadrats and so are caught using trapping techniques e.g. nets/pitfall traps/light traps; a sample is taken which is representative of the population, from which an estimate of population size can be made; animals are captured, marked, released and then resampled; a calculation is made that uses the relationship between two ratios: the number of marked animals compared to the size of the resampled population, and the ratio of sampled population (captured and marked) compared to the total population/the 'capture–mark–release–recapture' method.
[Max 3 marks]

Paper 2

1 Mutualism is an interaction in which both species derive benefit and is a specific type of symbiotic relationship e.g. *Rhizobium* bacteria that live in the root nodules of legumes e.g. clover plants; pathogenicity is the capacity of a microbe (e.g. bacterium/fungus/protist) to cause damage in a host resulting in disease, e.g. amphibian disease chytridiomycosis, caused by the fungus *Batrachochytrium dendrobatidis,* which has caused decline in amphibian species in Central America; parasitism is a relationship where the parasite organism benefits at the expense of the host organism from which it derives its food, e.g. ticks that feed on the blood of mammalian hosts.
[Max 3 marks]

2 a Indirect; negative (effect); top-down.
[Max 2 marks]

b Sea otters have a positive (indirect) effect as sea otters feed on crabs, which feed on isopods that feed on algae; fewer crabs means more isopods, so less algae; less algae means more seagrass *OR* less competition between algae and seagrass.
[Max 2 marks]

c The positive (bottom-up) effect is due to the availability of nutrients; (nutrients) increase abundance/plant growth rates; the negative (bottom-up) effect as excess of nutrients causes a bloom in algae growth/eutrophication/competition; limited nutrients have negative effect on seagrass (growth); (excess) algae cause seagrass to die/decompose/replenish nutrients.
[Max 3 marks]

3 a The coral polyp provides the algae with carbon dioxide for photosynthesis; carbon dioxide produced by respiration in polyp (a metabolic waste product); algae/zooxanthellae produce oxygen, using the coral's waste carbon dioxide, by photosynthesis (producing glucose); polyp feeds on glucose produced by algae and uses in respiration (and other metabolic processes).
[Max 2 marks]

b Symbiotic relationship between animal polyps and algae; animals benefit from supply of food/glucose from algae and algae receive shelter/supply of carbon dioxide for photosynthesis.
[Max 2 marks]

c Zooxanthellae/algae need (high) light levels to photosynthesize; corals only grow at relatively shallow depth (less than 25 m); deeper levels do not have sufficient light intensity and so insufficient light for photosynthesis.
[Max 2 marks]

4 a Ideal environment/unlimited resources/below carrying capacity; little disease/few predators; high natality/birth rate *AND* immigration; natality and immigration greater than mortality and emigration. [Max 3 marks]

b Carrying capacity is maximum population size/number of individuals that environment can support *OR* carrying capacity varies with abundance of limiting resources; population growth slows/fluctuates as the carrying capacity of environment reached. [Max 2 marks]

5 Invasive species are alien species that have increased rapidly in number, having a negative effect on the environment and on native species; if the alien species lacks natural predators, it can outcompete the native species and become invasive. [2 marks]

Valid example given: e.g. the grey squirrel and red squirrel (section C4.1 of the Student's book, page 568–9); lionfish, water hyacinth (section A4.2 of the Student's book, page 173). [1 mark]

Correct explanation of why it is an alien species. [1 mark]

Correct explanation of why the species became invasive. [1 mark]

Correct explanation of which endemic species is/are affected. [1 mark]

Correct explanation of effect on population size of endemic species. [1 mark]

Correct discussion on the impact of the species on the biodiversity of the ecosystem in which it is found. [2 marks]
[Max 9 marks in total]

6 Models are often simplifications of complex systems; they can be used to understand and interpret biological structures and systems; they are useful when direct observation or experimentation is difficult; benefits of models in biology include increasing knowledge about biological systems/estimating or predicting variables of interest/helping explain how something works or to describe how something is structured/making predictions or to explain observations/simplifying complex or abstract systems.

Models are used at every level of biological organization:

- **at molecular level**: models in the form of sketch graphs can be evaluated using results from enzyme experiments; the induced-fit model indicates how enzyme and substrate interact/shows how the active site of the enzyme and substrate undergo conformational changes to improve binding; the first model of DNA revealed the double helix was made of two antiparallel strands of nucleotides; biochemical reactions can be demonstrated using either physical or digital molecular models, e.g. condensation reactions forming dipeptides and longer chains of amino acids, or polysaccharides from sugar monomers;
- **at cellular level**: the fluid mosaic model of the plasma membrane shows the relationship between peripheral and integral proteins, glycoproteins, phospholipids and cholesterol; models can be used to investigate surface area-to-volume ratios and constraints on cell size; e.g. surface area-to-volume relationship can be modelled using cubes of different side lengths: although cubes have a simpler shape than real organisms, scale factors operate in the same way;
- **at organism level**: *HL only*: the sliding filament model helps explains the contraction of all muscles, including cardiac and skeletal muscle; *HL only*: some organisms are used as model organisms in research e.g. gene knockout organisms;
- **at ecosystem level**: climographs are graphical models showing the relationship between temperature, precipitation and ecosystem type, used to predict the geographical distribution of ecosystems; population growth is modelled using S-shaped (sigmoid) population growth curves, showing population slowing as it reaches the carrying capacity of the environment; food chains/webs are models that show interrelationships between species in an ecosystem; pyramids of energy are models of energy flow in an ecosystem; pyramids of energy show the energy loss/transfer between trophic levels and permits a quantitative comparison between ecosystems; a mesocosm is a model

environment used to investigate the effect of variables on ecosystem sustainability; sexual and natural selection can be modelled based on experimental control of selection pressures, e.g. John Endler experiments on guppies.

[Up to 3 marks available for each level of organization, max 9 marks in total]

C4.2 Transfers of energy and matter

Paper 1

1 A
2 C
3 C
4 D
5 C
6 A
7 B
8 A
9 C
10 D
11 C

Paper 2

1 a As light level changes so does the percentage cover (of blackberry); distribution is higher at intermediate/moderate light intensities; little growth at low light intensities *OR* little growth at high light intensities; distribution is bell shaped.
[Max 2 marks]

b Only energy can be lost/gained/exchanged/transferred (with the exterior) *OR* only matter is constant/recycled.

c **Advantages**: can show the energy loss/transfer between trophic levels; permits a (quantitative) comparison between ecosystems; shows change over time;

Disadvantages: are difficult to produce accurately; require destructive methods to obtain the data; do not show all the interactions/food chains/feeding relationships (between different members of the community); cannot represent organisms that feed at different trophic levels.

[Max 4 marks; if only advantages or only disadvantages discussed, max 3 marks]

2 a Models are simplifications of complex systems; they can be used to understand and interpret biological structures and systems; the food web is a simplified model of a real ecosystem; a food web shows interactions between different organisms and food webs and can be used to understand interrelationships in a community; it is difficult to include all species and interactions.
[Max 3 marks]

b Any valid food chain containing at least three organisms e.g. diatoms → sponge → crab → blenny → seabirds.

c Seabirds are at several different trophic levels depending on the food chain in which they appear; e.g. secondary consumer (e.g. attached micro algae → rough edible winkles → seabirds); tertiary consumer (e.g. diatoms → barnacle → blenny → seabirds); quaternary consumer (e.g. attached macro algae → topshell → crab → blenny → seabirds); 5th order consumer (e.g. attached micro

algae → limpet → dog whelk → crab → blenny → seabirds).
[Comment on seabirds being at more than one trophic level *AND* an example of a food chain they are in needed for 1 mark]

3 a (Aerobic/cellular) respiration; gas exchange/diffusion.
[Max 1 mark]

b Photosynthesis; absorption of (dissolved) carbon dioxide/(hydrogen) carbonate directly from the oceans.
[Max 1 mark]

c Light energy is converted to chemical energy (in carbon compounds/sugars) by photosynthesis; (chemical) energy (in carbon compounds) flows by means of feeding/through food chains/webs; only (approximately) 10% of energy is passed to the next trophic level; energy released as heat (by respiration); energy is not recycled; after death, energy may remain trapped as undigested detritus/fossils/fossil fuels.
[Max 3 marks]

d Advantage of large size is ability to eat/catch large prey; (advantage as) lower rates of predation of large jellyfish; (advantage as) can produce more reproductive cells; (disadvantage as) moves more slowly to escape from predators/capture prey; (disadvantage as) needs more energy/nutrients to maintain structure/move/grow; (disadvantage as) low surface area-to-volume ratio and thus possibly difficulty with materials/gas/nutrient exchange; (disadvantage as) more prone to mechanical damage during storms.
[Max 1 mark]

4 Nutrients provide chemical elements for molecules; biological molecules are made from carbon, hydrogen, oxygen and nitrogen (as well as other elements, e.g. phosphorus); carbon, hydrogen and oxygen are present in carbohydrates, lipids and proteins, and nitrogen is present in proteins; decomposers play an essential role in recycling; decomposers include bacteria and fungi, which feed by saprotrophic nutrition; decomposers break down detritus and other waste products into simple inorganic chemicals which are released into the environment; these inorganic molecules are absorbed by organisms and used to synthesize complex biological molecules.
[Max 7 marks]

5 Energy is lost between the trophic levels; transfer between levels is only usually 10% efficient *OR* energy transformations take place in living organisms/the process is never 100% efficient; energy is lost by the organism/used in respiration/released as heat/movement; energy is lost as waste/faeces/urine/undigested food/uneaten parts; as energy is lost between trophic levels, (higher levels) have less biomass/energy available for next level.
[Max 3 marks]

6 (Detritivores) obtain nutrition from detritus/waste/dead bodies; are heterotrophic; remove large waste/clean up the ecosystem *OR* help control spread of disease; facilitate further decomposition; contribute to the supply of (inorganic) nutrients for autotrophs/nutrient cycling *OR* improve soil conditions/aeration.
[Max 4 marks]

7 Carbon dioxide is produced by the combustion of biomass/fossilized organic matter/fuels; releases carbon dioxide into the atmosphere; since the start of the industrial revolution, carbon dioxide has been released at an increasing rate; before industrialization, the amount of atmospheric carbon dioxide was maintained by a balance between the fixation of carbon dioxide during photosynthesis and release of carbon dioxide into the atmosphere by respiration, combustion and decay by micro-organisms; increased combustion due to human activities/burning fossil fuels/combustion of biomass and peat has increased the concentration of carbon dioxide in the atmosphere; increased carbon dioxide dissolving in the oceans; increased carbon dioxide concentrations are the cause of ocean acidification; increased ocean acidification leads to the suppression of calcification in corals; reduction in corals results in reduced photosynthesis by zooxanthellae/symbiotic algae in coral; increased carbon dioxide in atmosphere can

lead to increased rates of photosynthesis; increased temperatures due to greenhouse effect/effect of increased carbon dioxide (which is a greenhouse gas) can lead to increased rates of decay/decomposition; increased rates of decay/decomposition lead to increased respiration by decomposers, further increasing carbon dioxide levels.
[Max 7 marks]

8 Species have a range of tolerance for limiting factors such as temperature, salinity, pH and availability of water; the law of tolerance states that an organism or population has certain minimum, maximum and optimum environmental factors that determine success; biomes are groups of ecosystems with similar communities due to similar abiotic conditions and convergent evolution; abiotic factors determine terrestrial biome distribution; for any given temperature and rainfall pattern, one natural ecosystem type is likely to develop; specific climate conditions characterize e.g. tropical forest, temperate forest, taiga, grassland, tundra and hot desert biomes; light intensity, rainfall and temperature are limiting factors for the rate of photosynthesis and therefore productivity; primary production is the accumulation of carbon compounds in biomass by autotrophs; biomes vary in their capacity to accumulate biomass, depending on the climatic conditions where they are found; e.g. tropical rainforests have high levels of light throughout the year, high levels of rainfall/precipitation and high (but not too high) temperatures and therefore high rates of photosynthesis, so high productivity; rainforests have the highest levels of primary productivity and therefore accumulation of biomass; rainforests therefore have many available niches due to high levels of available resources (e.g. food); tropical rainforests have the greatest range of niches due to complexity of the ecosystem; complexity of ecosystem results high evenness between species and large number of available niches results in high species richness; this leads to high levels of biodiversity; biomes with low levels of productivity have low levels of biodiversity, e.g. hot deserts.
[Max 9 marks]

9 Food chains are models that represent the flow of energy through an ecosystem; in food chains, arrows point to the consumers and so indicate the direction of energy flow; food webs are models that represent the interconnections between different food chains and therefore the different/diverse pathways energy can take through an ecosystem; energy pyramids are a graphical model; pyramids of energy show quantitative differences between the trophic levels in an ecosystem; pyramids of energy model the energy flow through ecosystems and represent the flow of energy through trophic levels; energy is lost through respiration and heat loss; as energy is lost at each trophic level and gradually diminishes throughout the food chain, these diagrams are always pyramid shaped (unlike pyramids of numbers and biomass); pyramids of energy can be used to show energy flow through different ecosystems/biomes, and to explain differences in numbers of trophic levels/species.
[Max 9 marks]

Theme D Continuity and change

D1.1 DNA replication

Paper 1

1 D

2 D

3 D

4 C

5 **a** 1.717

b Half ^{14}N and half ^{15}N *OR* one/new strand ^{14}N and one/old strand ^{15}N *OR* half labelled.

c (As replication is semi-conservative) each new strand is built on parental/old/template strand; generation 3 shows DNA that is mostly made of ^{14}N; when *E. coli* replicates, half of its new DNA must always contain ^{14}N when growing in an ^{14}N growth medium; every new generation of *E. coli* always has a smaller proportion of (labelled) ^{15}N in its DNA (than the previous generation); each new generation has half the amount of ^{15}N in previous generation. [Max 3 marks]

d

Semi-conservative	Conservative
(daughter) DNA is half parental	(daughter) DNA is all parental *OR* all (daughter) DNA is new
one strand of the (daughter) DNA is new	(daughter) DNA is all parental *OR* all (daughter) DNA is new
both strands of parental DNA are separated	both strands of parental DNA remain together

[Max 2 marks]

(Questions 6–8 HL only)

6 C

7 C

8 D

Paper 2

1 Negatively-charged DNA fragments migrate to the positively-charged electrode; through an agarose gel/matrix; DNA fragments separated by size/molecular mass/molar mass/shorter fragments move faster than longer ones; invisible DNA bands revealed under UV light by staining the gel with a dye such as ethidium bromide.
[Max 2 marks]

2 PCR is a process used to amplify DNA/synthesize large amounts of DNA from a minute amount of starting material; thermostable, DNA polymerase/bacterial *Taq* polymerase is used; two DNA primers/single-stranded DNA molecules, which are complementary to the flanking sequence/start and end of the segment to be amplified; denaturation: heating it to 95 °C and involves denaturation of double-stranded DNA into single-stranded DNA/breaking of hydrogen bonds between nitrogenous bases of the two strands; DNA primers attach to the template DNA: temperature lowered to 50–60 °C allows primers to attach to the template DNA via complementary base pairing due to hydrogen bonding; elongation: temperature increased to 72 °C and *Taq* polymerase adds nucleotides to free 3′–OH end of

primers using the DNA molecule as a template; sequential process of denaturation-primers attaching to the template DNA-elongation is repeated many times products of the previous reaction are used as reactants in the next cycle;

Advantages of PCR: large amounts of DNA can be produced from a very small amount of starting materials; large amounts of DNA can be produced in a short period of time; specific sequences of DNA can be amplified by using specific primers;

Limitations of PCR: knowledge of the DNA or amino acid sequence of desired gene or protein is needed to synthesize flanking nucleotide primers; non-target DNA sequence may be amplified instead of the desired sequence as primers are short nucleotide sequences and may not be specific enough; *Taq* polymerase, of bacterial origin, does not perform proofreading, thus, there may be mistakes in complementarity of the nucleotides added.

[Max 7 marks; if only an advantage given but no limitation, or vice versa, then max 6 marks]

3 Sample of DNA obtained from person/hair/blood/mouth/crime scene; PCR used to amplify/make copies of DNA (in sample); using *Taq* DNA polymerase/using DNA polymerase from thermophilic bacteria; tandem repeats amplified/used; gel electrophoresis used to separate DNA (into bands); separation according to length of fragments/number of repeats

OR fragments of same length/number of repeats travel same distance; pattern of bands/number of repeats in the profile/is unique to the individual; example of application/forensics/crime investigation/paternity.
[Max 4 marks]

(Questions 4–8 HL only)

4 Presence of DNA ligase in lagging strand to ligate Okazaki fragments; presence of Okazaki fragments in lagging strand; presence of more than one primer/primase in the lagging strand; strands are synthesized in opposite directions.
[Max 4 marks]

5 Leading strand: forms the DNA strand, beginning at the RNA primer; attaches nucleotides to the RNA primer, forming a fragment; lagging strand: forms short DNA strands (Okazaki fragments), starting from each RNA primer; proofreading: removes any nucleotide from the 3′ terminal with a mismatched base; replaces with a correctly matched nucleotide.
[Max 4 marks]

6 a No effect, this strand is synthesized as a continuous length of DNA; no DNA ligase is needed.

b The Okazaki (short or discontinuous) fragments would be synthesized; Okazaki fragments would remain as short pieces since there is no enzyme to covalently bond them together.

7 Proofreading is the process by which DNA polymerase corrects its own errors as it moves along DNA; DNA polymerase III removes any mismatched base from the 3′ terminal; DNA polymerase III then replaces mismatches with a correctly matched nucleotide; DNA proofreading ensures that any mismatched nucleotides are removed before DNA replication proceeds; proofreading is carried out by a nuclease that cleaves the phosphodiester bond; polymerization and proofreading are coordinated, the two reactions are carried out by different catalytic domains in the same polymerase molecule.
[Max 4 marks]

8 Helicase uncoils/unwinds the DNA/double helix; helicase separates/unzips/breaks hydrogen bonds between the two strands of DNA; (DNA) primase adds an RNA primer/short length of RNA; DNA polymerase III adds (DNA) nucleotides/replicates DNA/synthesizes complementary strand in a 5′ to 3′ direction; DNA polymerase III starts replication/adding nucleotides at the primer; DNA polymerase I removes the primer *OR* replaces RNA with DNA; (DNA) ligase links sections of replicated DNA *OR* links Okazaki fragments; DNA polymerase I/DNA polymerase III proofreads for mistakes.
[Max 7 marks]

D1.2 Protein synthesis

Paper 1

1 C

2 B

3 B

4 D

5 D

(Questions 6–13 HL only)

6 D

7 C

8 A

9 D

10 C

11 B

12 A

13 a (25.0 − 2.1)/14; = 1.6 kb [1 mark for working; 2 marks for correct answer]

b Generally the longer or larger the gene size, the greater the number of introns; there are exceptions to this trend as shown by phenylalanine hydroxylase/albumin gene.

Paper 2

1 a (Three bases on mRNA) coding for one amino acid (in a polypeptide).

b Met-Ser-Arg-Arg *OR* Start-Ser-Arg-Arg *OR* Met-Ser-Arg-Arg-Stop *OR* Start-Ser-Arg-Arg-Stop.

c TAC TCG GCT TCC ATC GAC

2 RNA nucleotides linked together to form a strand/chain; RNA strand assembled on DNA template/antisense strand/copy made of sense strand; RNA polymerase carries out transcription/links RNA nucleotides; uncoiling/separation of DNA strands; 5′ end of nucleotides linked to 3′ end of (growing RNA) strand; complementary base pairing (is the basis of copying the base sequence); uracil instead of thymine in RNA; starts at/RNA polymerase binds to a promoter; regulated by transcription factors/DNA binding proteins/nucleosomes.

Annotated diagrams can be used. [Max 5 marks]

3 DNA is transcribed *AND* mRNA is translated; transcription produces RNA *AND* translation produces polypeptide/protein; RNA polymerase used only in transcription and ribosomes only in translation; transcription in the nucleus (of eukaryotes) and translation in the cytoplasm; tRNA needed for translation but not transcription; nucleotides linked in transcription and amino acids in translation *OR* sugar-phosphate/phosphodiester bonds in transcription and peptide bonds in translation.
[Max 4 marks]

4 Translation converts a sequence of mRNA nucleotides/codons to a sequence of amino acids/polypeptide/protein; (triplets of) nucleotides/bases on (activated) tRNA pair with complementary (triplets of) nucleotides/bases on mRNA *OR* vice versa; base pairing occurs when adenine/A pairs with uracil/U and guanine/G pairs with cytosine/C; specific amino acids are attached to specific tRNA; mRNA has codons *AND* tRNA has anticodons.
[Max 3 marks]

(Questions 5–12 HL only)

5 a Telomeres are special nucleotide sequences, typically consisting of multiple repetitions of one short nucleotide sequence; occur near the ends of DNA molecules and 'seal' the ends of the linear DNA; protect the organism's genes from being lost with each cycle of DNA replication, due to a gap at the 5′ end of each replicated DNA strand; protect chromosomal ends from degradation by binding proteins to form telomere caps; prevent ends of chromosomes attaching to each other, which stops the chromosomal ends from activating the cell's system for monitoring DNA damage (therefore avoiding apoptosis); recognition sites for telomerase enables telomeres to lengthen; telomerase allows the generation of telomeres lost at each cell division, which allows cancer cells to divide continuously and indefinitely.
[Max 4 marks]

b Bacteria have circular chromosomes so no degradation of chromosome ends at each replication of DNA/no end-replication problem.

6 Spliceosome recognizes/binds splice site; brings about the removal of introns/spliced exons join together to form mature mRNA.

7 mRNA binds to the small subunit of the ribosome (so two tRNAs can bind simultaneously to the large subunit); start codon signals the start of translation; three bases on the mRNA correspond to a codon; each codon on mRNA codes for a specific amino acid; the stop codon (UAG, UAA, UGA) terminates translation (by allowing the binding of a release factor that adds a water molecule to the polypeptide chain).
[Max 3 marks]

8 a Regulator of gene expression/introns/telomeres/genes for tRNA/rRNA/promoter/enhancer/silencer/site for primer to bind/codes for mRNA primer.

b Binding/entry of tRNA carrying amino acids/aminoacyl tRNA/charged tRNA/site of transfer of growing polypeptide chains/peptide bond formation.

c ATP (hydrolysis) provides energy for amino acid attachment; they attach a specific amino acid to the (3′) end/free CCA of a tRNA; they do this repeatedly/they attach amino acid to all of the tRNA molecules that have anticodon corresponding to that amino acid.
[Max 2 marks]

9 A, P and E binding sites are on the large subunit of the ribosome; initiation of translation starts with binding of met-tRNA to the start codon; large subunit binds with (start) tRNA in the P site; A binding site holds the tRNA with the next amino acid to be added; peptide bond is formed between the amino acids of the A site and the polypeptide at the P site; polypeptide is transferred to the tRNA in the A site; the tRNA (with polypeptide) in A site then moves to P site *OR* P binding site holds the tRNA attached to the growing polypeptide ; E binding site (exit) is where the tRNA (from P site without amino acid) leaves the ribosome.

Annotated diagrams can be used. [Max 5 marks]

10 Introns are non-coding regions within a gene, hence pre-mRNA introns will be spliced out via spliceosomes; splicing removes all introns and joins together all exons to form one polypeptide from a gene; alternative splicing joins together different combinations of exons to form different types of polypeptides from a single gene; spliceosome recognizes highly conserved regions/splice sites between the 3′ end of the exon and 5′ end of the intron and cleaves the phosphodiester bond between the nucleotides; after the synthesis of the polyadenylation signal (AAUAAA), terminal transferase will bind to the 3′ end of the pre-mRNA; attach a long chain of nucleotides with the base adenine, forming the poly-A tail, which is not encoded in the genome; 5′ end of the pre-mRNA will be capped by the addition of a 5′ modified guanine nucleotide; formation of mature mRNA which will be protected from enzymatic degradation and exported out of nucleus for translation.
[Max 7 marks]

11 Prokaryote ribosomes are smaller (70S) than those of eukaryotes (80S); in prokaryotes, there is no (nuclear) membrane between the chromosome, where mRNA is formed, and the cytoplasm; in prokaryotes, protein synthesis can begin immediately the mRNA is released, whereas in eukaryotes it is delayed until mRNA moves to the cytoplasm via nuclear pores; in eukaryotes the mRNA is typically modified; eukaryotes' genes have introns and exons, whereas in bacteria there are no introns; in eukaryotes, introns are removed during mRNA processing and exons joined/splicing occurs in eukaryotes but not in prokaryotes; in eukaryotes, processing of the 3′ end of mRNA adds a poly-A tail to the RNA molecule (polyadenylation); the poly-A tail allows the mature mRNA molecule to move out of the nucleus and be translated in the cytoplasm into a protein by ribosomes; the 5′ end is capped by the addition of a 5′ modified guanine nucleotide.
[Max 7 marks]

12 Translation occurs on ribosomes; tRNA-activating enzymes attach amino acids to tRNAs; small and large ribosome units assemble on mRNA *OR* translation/polypeptide synthesis starts at a start codon; each tRNA arriving at the ribosome binds to the A site; anticodon (on tRNA) binds to codon (on mRNA); according to complementary base pairing/A with U and G with C; ribosome moves along the mRNA/mRNA moves over ribosome; tRNA shifts from the A site to P site/from the P to the E site; peptide bond between amino acids (on tRNAs at A and P sites); tRNA released from ribosome at E site; cycle repeats with other tRNAs; polypeptide grows as tRNAs bring more amino acids; until stop codon on mRNA is reached; components are disassembled/polypeptide leaves the ribosome.

Annotated diagrams can be used. [Max 7 marks]

D1.3 Mutation and gene editing

Paper 1

1 C

2 C

3 D

4 B

(Questions 5–7 HL only)

5 B

6 A

7 C

Paper 2

1 Gene mutations are the changes in the nucleotide base sequence of the genes; substitution: replacement of one nucleotide base pair with another base pair in a gene; results in missense mutation/nonsense mutation/significant change in the encoded protein/silent mutation/no effect/little effect on the encoded protein; insertion: addition of one or more nucleotide base pairs in a gene; deletion: loss of one or more nucleotide base pairs in a gene; insertion and deletion both result in a frameshift mutation, whereby codons are grouped differently; inversion: a sequence of nucleotides becomes separated from the allele, it rejoins the original position but inverted.
[Max 5 marks]

2 Frame shift/alters reading frame (after mutation); (so) all amino acids different after mutation; 3D shape/tertiary structure of protein changed; (whereas) 21 base-pair deletion loses 7 amino acids/no frame shift; (whereas) substitution, may change only one amino acid/may be silent.
[Max 3 marks]

3 If the substitution occurs in a non-coding region of DNA, the mutation may have a neutral effect on the proteome of the cell; if the mutation is in a regulatory region that directs expression of a gene, a mutation may prevent expression of the gene and so have a significant effect on the proteins found in a cell; some changes result in a 'nonsense' mutation, so the changed genetic code cannot be read/has no meaning; if the change results in a different amino acid being coded for, then this is a 'missense' mutation; because of the degeneracy of the genetic code, base substitutions may not always change an amino acid in a polypeptide; each amino acid has several different codons and if the base substituted matches one of these alternative codons then there will be no effect on the proteome of the cell.
[Max 5 marks]

4 A deletion mutation is a type of mutation that involves the loss of one or more nucleotides from a segment of DNA; e.g. delta 32 mutation of the *CCR5* gene; this mutation prevents the functional expression of the CCR5 protein co-receptor normally used by HIV-1 to enter CD4+ T-cells; T-cells (T-lymphocytes) are responsible for cell-mediated immunity: CD4+ T-cells are infected by HIV; HIV can no longer bind to this co-receptor and so cannot efficiently enter cells; *CCR5* mutation does not lead to complete resistance, although it lessens the likelihood of infection.
[Max 7 marks]

(Questions 5–8 HL only)

5 Gene knockout (KO) is a technique that produces a genetically engineered organism with one non-functional gene, allowing researchers to investigate the function of that gene; KO destroys the function of a gene (usually by introducing a deletion) so that the effect on the phenotype can be observed; stem cells are used where the gene is replaced with a homologous non-functional sequence; the cell is fused with an embryo, creating a chimera (an organism with genetically different cells); the adult organism is bred until a pure breeding offspring is obtained; once homozygous organisms are obtained, it is possible to study the function of the knocked out gene; a model organism is a non-human organism that can be used to understand simple and complex biological functions; e.g. gene knockout is used on the mouse (*Mus musculus*); KO created the p53 KO mouse, which had a mutated version of the *p53* gene; usually, the *p53* gene directs the synthesis of a protein that regulates the cell cycle but, when the protein is absent, tumour cells are created, increasing the risk of bone and other cancers in mammals.

Other examples of model organisms can be used (see Student's book pages 643–4). [Max 5 marks]

6 CRISPR sequences are sequences in the genomes of some prokaryotes that act as a genomic record of previous viral attack; Cas9 enzyme is a bacterial endonuclease that forms a double-strand break (cuts) in DNA at a specific target site within a larger recognition sequence, or target site; Cas9 recognizes target DNA via a guide RNA; CRISPR technology inserts specific sequences of a genome into the Cas9 protein; this allows for adding, replacing and removing genetic sequences from genes; the precise specificity of the CRISPR system reduces the risk of accidentally affecting other genes; CRISPR can be used to edit out genetic defects that result in e.g. cystic fibrosis, sickle cell disease, haemophilia and muscular dystrophy, and can be used for developing more targeted and effective cancer treatments.
[Max 7 marks]

7 CRISPR/Cas9 has the potential to treat many genetic diseases, although it has raised serious concerns within the scientific community relating to possible unintended effects; unintended effects include possible off-target mutations (unintended mutations) in the genome, which may be deleterious; the cost of germ line-editing technology is very high, so that only families from rich countries might afford it; CRISPR may be misused; potential uses of CRISPR raise issues that must be addressed before implementation, e.g. genome editing in human embryos could have unpredictable effects on future generations; technology could be used for non-therapeutic modifications, leading to loss of human diversity and eugenics; scientists in different countries are subject to different regulatory systems so there must be efforts to harmonize regulation of the application of genome-editing technologies.
[Max 7 marks]

8 Conserved sequences are identical or similar sequences in nucleic acids (DNA and RNA) across species or a group of species that have remained essentially unchanged throughout evolution; one explanation for conserved sequences are the functional requirements for the gene products; highly conserved sequences are usually required for basic cellular stability, function and reproduction, and so must be maintained from one generation to the next and throughout evolutionary history; another explanation is that there are slower rates of mutation than the background mutation rate; mutation rate is linked to level of gene expression, so that highly transcribed genes generally show lower mutation rates than less expressed genes; the transcribed strand shows a lower mutation rate than the non-transcribed strand; the impact of gene expression on mutation rate may be due to enhanced proofreading and therefore repair mechanisms for these sections of DNA; LUCA (Last Universal Common Ancestor) passed genes to future generations which included conserved sequences/LUCA would have contained conserved genes present in all cells; the likely structure and function of LUCA can be hypothesized using conserved sequences found in bacteria; genetic sequences for conserved genes typically involve proteins associated with ribosomes, where the genetic code is translated into proteins; because protein synthesis is the most energy-intensive activity of a cell, these conserved genes indicate that LUCA released and used energy; LUCA contained a gene for reverse gyrase (an enzyme that helps maintain DNA's structure and stability), found today in extremophiles existing in high-temperature environments including hydrothermal vents.
[Max 7 marks]

D2.1 Cell and nuclear division

Paper 1

1 C

2 A

3 C

4 A

5 a i A = metaphase; B = anaphase.

ii In metaphase, chromosomes become arranged at the equator of the spindle; in anaphase, chromosomes move away from one another to opposite poles of the cell; chromosomes in metaphase are double stranded/comprised of sister chromatids whereas in anaphase the chromatids are separating/pulled to opposite poles.
[Max 3 marks]

b i Cells at root tip are rapidly dividing/undergoing mitosis.

ii Tissue is isolated and stained with an orcein ethanoic (acetic orcein) stain; stain shows chromosomes; tissue is squashed so one cell thick and examined under the high-power lens of a microscope.

(Questions 6–9 HL only)

6 C

7 C

8 C

9 a Mitotic index = the number of cells undergoing mitosis divided by the total number of cells visible

= 37/100 = 0.37 (*OR* 37%).

b The mitotic index is used to differentiate benign from malignant tumours; tissue with a high mitotic index indicates a rapidly dividing cell mass, which is a possible indicator of tumour formation; the mitotic index can also be used to investigate the response to chemotherapy in most types of cancer

(i.e. a reduction in the mitotic index indicates that treatment has been successful in reducing the cancer).
[Max 3 marks]

Paper 2

1 Lack of centrioles/microtubules to separate the chromosomes during anaphase; a circular chromosome does not allow for separation, unlike linear chromosomes.
[Max 2 marks]

2 A haploid cell contains one set of chromosomes, whereas a diploid cell contains two sets (one from each parent); haploid cells are gametes/generative cells, whereas diploid cells are body/somatic cells; a sex cell has a haploid nucleus formed as a result of meiosis, whereas a zygote, and body cells formed from it by mitosis, have a diploid nucleus.
[Max 3 marks]

3 Transcription (of specific genes); reference to gene switching; protein/polypeptide synthesis/translation; lymphocytes (B-cells and T-cells) are produced; producing clone/many cells.
[Max 3 marks]

4 Formation of two nuclei, with same number of chromosomes as the parent cell; during replication, each strand acts as template for synthesis of new daughter strands; via complementary base pairing, A–T base pair have two hydrogen bonds, C–G base pair have three hydrogen bonds; separation of sister chromatids at anaphase ensures the distribution of genetic material to both daughter cells; genetically identical daughter cells with no genetic variation (unless mutation occurs); production of clones during asexual reproduction to colonize; no genetic variation and equal distribution of genetic material to daughter cells ensures genetic stability.
[Max 7 marks]

5 Meiosis is nuclear division with daughter cells (gametes) containing half the number of chromosomes of the parent cell; crossing over occurs in prophase I and is the exchange of genetic material between two homologous chromosomes during meiosis; random orientation refers to the way chromosomes line up in the centre (equator) of the cell during meiosis (metaphase I), with each chromosome of a given pair behaving independently of the chromosomes in other pairs; it results in each sperm and each egg having different combinations of chromosomes from the mother and father; crossing over and random orientation (independent assortment) generate variation; because the fusion of male and female gametes during fertilization is random, each offspring is genetically different; natural selection is the process where organisms better adapted to their environment survive and produce more offspring than competitors; it is the mechanism through which evolution occurs; variation in a population produces individuals that are better adapted than others; individuals better adapted to their environment/selection pressures will survive and pass on adaptive alleles to the next generation; an individual's success in reproduction will result in certain alleles being passed on to the next generation in greater proportions than other alleles; over time, the genome becomes sufficiently distinct from the original population that a new species is created/evolution has occurred.
[Max 7 marks]

(Questions 6–10 HL only)

6 Growth: allows the growth and development of a zygote into a multicellular organism; forming new cells that are genetically identical to the existing cell(s);

Repair: produces new cells required to repair worn out or damaged tissues; to return a tissue to its former condition.
[Max 3 marks; if only growth or repair outlined, max 2 marks]

7 a Interphase, which includes G_1, S and G_2 phases; G_1 phase: the synthesis of new organelles takes place in the cytoplasm; intense biochemical activity in the cytoplasm and organelles, and accumulation of energy store before nuclear division occurs again: S phase: synthesis of DNA (each chromosome makes a copy of itself/replicates); G_2 phase: second phase of growth, which is a continuation of the earlier time of intense biochemical activity and increase in amount of cytoplasm; interphase is followed by division of the nucleus (mitosis) that results in two nuclei, each with an identical set of chromosomes; the final stage is division of the cytoplasm and whole cell (cytokinesis).
[Max 3 marks]

b The cell cycle is regulated by a molecular control system; there are key checkpoints where signals operate/stop points that have to be overridden; three checkpoints are recognized: at G_1, G_2 and in M; e.g. at G_2 checkpoint, if the 'go-ahead' signal is received here, the cell goes through to M then C; kinases and cyclins are the molecular control signal substances in the cytoplasm of cells; kinases are enzymes that either activate or inactivate other proteins; kinases are activated by specific cyclins (cyclin-dependent kinases/CDKs); cyclin concentrations in the cytoplasm change constantly: as the concentrations of cyclins increase, they combine with CDK molecules to form a complex that functions as a mitosis-promoting factor (MPF); as MPF accumulates, it triggers chromosome condensation, fragmentation of the nuclear membrane and, finally, spindle formation (mitosis is switched on); by anaphase of mitosis, destruction of cyclins commences (but CDKs persist in the cytoplasm); the concentration of different cyclins increases and decreases during the cell cycle and a threshold level of a specific cyclin is required to pass each checkpoint in the cycle.
[Max 5 marks]

8 They are able to divide continuously but not excessively/uncontrollably; cell division of stem cells can be regulated; stem cells will only divide when necessary, e.g. presence of growth factors; as they obey cell cycle control/stop appropriately at cell cycle checkpoints when conditions at previous stage are not met; arrest/stopping of cell cycle to repair DNA damage/cells undergo apoptosis when DNA damage is irreparable; tumour-suppressor genes and proto-oncogenes are both functional/not mutated.
[Max 3 marks]

9 Accumulation of somatic mutations is needed to produce all the changes characteristic of a cancer cell; gain of function mutations in proto-oncogenes, where only one allele needs to be mutated into an oncogene, and loss of function mutations in tumour-suppressor genes, where mutations must be in both alleles; gene for telomerase is activated, expression of telomerase in cancer cells removes a natural limit on the number of times the cells can divide; cancer cells escape normal confines of epithelial layer and invade tissue immediately around it, blood vessels form via angiogenesis to bring oxygen and nutrients to the cancer cells; cancer cells enter bloodstream or lymphatic systems and travel to other tissues/organs; at these new locations, when cancer cells cross epithelium barriers, metastasis has occurred.
[Max 3 marks]

10 A gene mutation is a change in the sequence of bases of a particular gene; a mutation can alter the sequence of amino acids in a polypeptide; changing an amino acid in the sequence of a protein alters its properties; the primary structure of a protein is the linear sequence of the amino acids in the molecule; proteins differ in the variety, number and order of their constituent amino acids; changing an amino acid in the sequence of a protein alters its properties; the primary structure determines how a protein folds/determines secondary and tertiary structure; the shape of a protein determines its function/properties;

sickle-cell anaemia results from a point mutation, causing sickle-cell haemoglobin molecules to clump together into long fibres, distorting red blood cells into sickle shapes; in this condition, red blood cells cannot transport oxygen and sickle cells stick together causing anaemia, blocking smaller capillaries and preventing the circulation of normal red blood cells; insertions can result in repeating base sequences of three nucleotides, expanding trinucleotide repeat sequences leading to conditions such as Huntington's disease, a neurodegenerative disorder caused by an abnormality in the *HTT* gene; the delta 32 mutation

of the *CCR5* gene is a deletion mutation, where people with two copies of the mutation are less susceptible to HIV-1 infection; phenylketonuria (PKU) is a recessive genetic condition caused by mutation in an autosomal gene that codes for the enzyme needed to convert phenylalanine to tyrosine; phenylalanine hydroxylase is not synthesized, phenylalanine builds up in the body; high blood phenylalanine levels cause disruptions in neurotransmitters such as serotonin and dopamine in the brain, leading to neurological symptoms (seizures, abnormal muscle movements, tight muscles, involuntary movements or tremors) and without treatment, most people with PKU develop severe brain damage;

cancers can be caused by mutations; gain of function mutations in proto-oncogenes, where only one allele needs to be mutated into an oncogene, and loss of function mutations in tumour-suppressor genes, where mutations must be in both alleles; cancers disrupt the functioning of tissues and organs; cancer cells can enter bloodstream or lymphatic systems and travel to other tissues/organs, at these new locations, when cancer cells cross epithelium barriers (metastasis) leading to secondary tumours; unchecked, cancerous cells ultimately take over the body at the expense of the surrounding healthy cells, leading to malfunction and death;

mutation in bacteria can lead to antibiotic resistance; resistant bacteria survive and pass on resistance to next generation: in the new population, all individuals now carry the gene for resistance to the antibiotic.
[Max 7 marks]

D2.2 Gene expression (HL only)

Paper 1 (HL only)

1 C

2 A

3 D

4 C

5 a Both show methylation patterns; the variation in the levels of methylation between the twins increases with age; hypomethylation is higher away from the ends of the chromosomes; levels of both hypermethylation and hypomethylation increase with age; chromosome 3 shows the greatest variation in methylation at both ages; chromosome 17 shows the least change with age.
[Max 3 marks]

b The twins will have experienced different environmental stimuli, which will in turn cause different levels of methylation on different chromosomes; genes, in terms of numbers, size and roles, vary between chromosomes; some chromosomes will vary more than others in their degree of methylation and how they are affected by time and the environment; methylation inhibits transcription: as cells age they becomes more specialized due to higher levels of inhibited and promoted DNA.
[Max 4 marks]

Paper 2 (HL only)

1 Lactose/(allolactose) acts as an inducer that binds the lac repressor; lac repressor is inactivated and dissociates from the operator; RNA polymerase can bind to the promoter, resulting in transcription of structural genes.

2 DNA methylation leads to a more compact chromatin structure with a closed/less accessible conformation; addition of methyl group to certain bases (usually cytosine) of DNA; DNA methyltransferase catalyses the transfer of a methyl group to DNA; transcription factors and RNA polymerase are unable to bind to DNA; methylated DNA attracts other proteins, which in turn recruits histone deacetylation enzymes.
[Max 3 marks]

3 Monozygotic twins are identical twins resulting from the fertilization of a single egg by a single sperm, with the fertilized egg then splitting into two. Identical twins share the same genomes and are always of the same sex; they can be used to investigate whether differences between individuals are due to genetic factors, environmental factors, or a combination of genetic and environmental factors; studies compare twins that have been brought up together or separately, with measurements of specific phenotypic traits being made and variation attributed to genotype or the environment (or a combination of both); if separated twins show similar characteristics then the cause of the trait is probably genetic, whereas if there are significant differences then it is probably due to the environment; in twin studies, results for monozygotic twins can be compared to those for dizygotic twins; in these studies, many pairs of twins are studied to gather an accurate estimate of the relative importance of genes and the environment; monozygotic twins share all their genes and so differences between twins can therefore be due to non-shared environmental influences; if both monozygotic and dizygotic twins resemble each other closely, this must be due to shared environmental influences; if monozygotic twins resemble each other more closely than dizygotic twins, then it suggests that genetic factors may play a role; monozygotic twins can be used to investigate epigenetic inheritance; studies show epigenetic changes in monozygotic twins, when identical genes may be expressed differently due to differences in methylation patterns influenced by the environment.
[Max 7 marks]

4 During early-stage embryo development, gene expression determines the ways in which cells differentiate, which leads to diversification of cell and tissue type, and to the development of organs and organ systems; the basis for differentiation is different patterns of gene expression often triggered by changes in the environment; gene expression determines which genes are switched on or off at any one time; genes are selected for expression to produce specific proteins needed by the cell; morphogens are signalling molecules that are involved in gene expression; morphogens occur across a gradient of concentrations that drive the process of differentiation of unspecialized stem cells into different cell types; different concentrations of morphogen result in the initiation or inhibition of gene expression, which in turn determines the way in which cells differentiate and develop into specific tissues; the concentration of the morphogen in each particular cell determines a series of subsequent signals (cascades): responses to these signals determines the direction and extent of cell growth and development; expression of such gradients controls the length of body structures such as toes and fingers, the location of the nose, and other body patterns; methylation of DNA and histones affects gene expression in cells; epigenetic tags (e.g. methyl or acetyl groups) are added directly to DNA or on to histone proteins to regulate gene expression, blocking or allowing access to a gene's 'on' switch; the effect is to change the activity of the gene – usually extensive methylation inactivates a gene, repressing transcription and therefore expression of the gene downstream; removal of methyl groups may turn genes back on again; methylation of amino acids in histones either enables or disables the recruitment of regulatory proteins to the chromatin, causing transcription to be repressed or activated; phenotypic plasticity is the capacity to develop traits suited to the environment experienced by an organism by varying patterns of gene expression; phenotypic plasticity is not due to changes in genotype, and the changes in traits may be reversible during the lifetime of an individual.
[Max 7 marks]

5 Inhibition in enzymes can be non-competitive or competitive; in non-competitive inhibition, specific substances can bind to an allosteric site in the enzyme, causing interactions within an enzyme that lead to changes in the enzyme shape, altering the active site enough to prevent catalysis; competitive inhibition occurs when an inhibitor binds reversibly to the active site and is in competition with the enzyme's substrate; some metabolic pathways are regulated by feedback inhibition; in end-product inhibition, as the product molecules accumulate, the steps in their production are switched off, but product molecules may now become the substrates in subsequent metabolic reactions; e.g. isoleucine is an end product that acts as an inhibitor of an enzyme used in the initial stage of the pathway;

mechanism-based inhibition is the result of chemical changes to the active site caused by the irreversible binding of an inhibitor; e.g. the effect of penicillin on bacterial cell walls where penicillin inhibits DD-transpeptidase; by inhibiting transpeptidase, the cell walls are not cross-linked so are weak, and without a

strong cell wall, a bacterial cell is vulnerable to the movement of water into the cell by osmosis, which kills the bacteria by lysis;

contact inhibition is the control of proliferation of cells in tissues; when the number of cells in a tissue reaches a limit, contact inhibition enables cells to stop proliferation and growth when they contact each other; this characteristic is lost when cells undergo mutation, leading to uncontrolled proliferation and tumour formation, which can lead to the development of cancer;

in populations, numbers of individuals increase until a carrying capacity is reached; density-dependent factors push the population back towards the carrying capacity; intraspecific competition affects the carrying capacity of a population: populations with higher density will experience more intraspecific competition and therefore have a lower carrying capacity due to the lower amount of food available; in interspecific competition, species with similar niches will compete for similar resources, lowering the carrying capacity of one or both of the species; further population growth is inhibited and the population size kept to sustainable limits; overproduction of offspring and competition for resources, such as food and other factors that may limit carrying capacity, promotes natural selection.
[Max 9 marks]

D2.3 Water potential

Paper 1

1 B

2 C

3 C

4 a i Solution hypotonic/cell has higher osmotic concentration than solution/cell has fewer water molecules; entry of water/osmosis (causes cells to swell).
[Max 2 marks]

ii Solution isotonic/cell and solution have same osmotic concentration/same number of water molecules; no net entry/loss of water.
[Max 2 marks]

iii Solution hypertonic; solution has higher osmotic concentration than cell; water leaves the cell by osmosis (causes cell to shrink).
[Max 2 marks]

b Water enters cells by osmosis, causing them to swell; increasing pressure causes cells to burst/lyse.
[Max 2 marks]

(Questions 5–8 HL only)

5 A

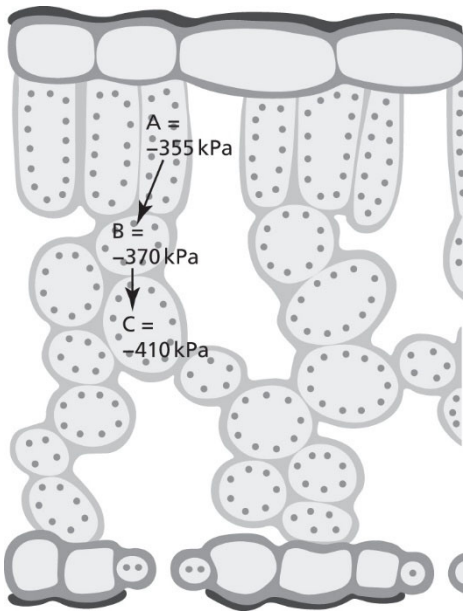
6 D

7 a Side A = −400 + 300 = −100 kPa

b Side B = −500 + 300 = −200 kPa

c Water moves from left (side A) to right (side B).

8 a i



[*Both arrows correct for max 1 mark*]

ii Water moves from higher to lower water potential/less negative to more negative water potential; cell A has a higher water potential than B, so water moves from A to B by osmosis; cell B has a higher water potential than cell C, and so water moves by osmosis from cell B to cell C.
[Max 2 marks]

b i Water potential of cell X = −1800 + 1000 = −800 kPa
[1 mark for correct working, 1 mark for correct answer, max 2 marks]

ii Cell X is turgid/cell membrane pushing against cell wall; water has moved into the cell by osmosis; cell Y is plasmolysed/cell membrane has pulled away from cell wall; water has moved out from cell Y by osmosis; in cell Y, pressure potential is 0 and so there is no pressure exerted by cytoplasm/vacuole on cell membrane.
[Max 5 marks]

Paper 2

1 a Level of solution on the right-hand side will go up and left-hand side go down.
[Max 1 mark]

b Solute concentration/osmotic concentration on the right-hand side is higher/solution is more concentrated than the solution on the left-hand side; water moves from left-hand side to right-hand side through the partially permeable membrane by osmosis; from a more dilute to more concentrated solution.
[Max 3 marks]

2 Osmosis refers to the movement of water only whereas facilitated diffusion refers to the movement of a range of different molecules or ions (not water); facilitated diffusion occurs through channel/carrier proteins whereas osmosis occurs through the phospholipid bilayer.
[Max 2 marks]

3 Jam has a high solute concentration/osmotic concentration; the cytoplasm of bacteria has a lower solute concentration/osmotic concentration than the jam; water moves from the bacteria to the jam/from a more dilute to more concentrated solution; the bacteria become dehydrated and die.
[Max 3 marks]

4 When the external solution is less concentrated (hypotonic) than the cell solution, there is a net inflow of water into the cell by osmosis, and the cell solution becomes diluted; the permanent vacuole swells due to water uptake, and the membrane of the vacuole is pushed against the cytoplasm which in turn presses hard against the cell wall, increasing turgor pressure; the cell is turgid; the pressure that develops (due to the stretching of the cell wall) eventually becomes so great it prevents further uptake of water; the cell wall protects the cell contents from damage due to osmosis, but the tissue may be quite rigid due to the internal pressure.
[Max 5 marks]

5 Cut tissue to specific size, e.g. potato chips; take mass of tissue; put tissue in a range of different solute concentrations, e.g. sucrose or salt; leave the tissue for at least 24 hours and reweigh tissue (after first drying tissue); calculate percentage change in tissue; plot solute concentration (x-axis) against percentage change in mass (y-axis); identify the point where there is no change in mass (where line of best fit crosses the x-axis); the point where there is no change in mass indicates isotonicity, i.e. osmotic concentration of the tissue is the same as the solution, which gives the solute concentration of the tissue.
[Max 7 marks]

6 The hydrophobic hydrocarbon chains that form the core of a plasma membrane have low permeability to large molecules and hydrophilic/charged particles, including ions and polar molecules; membranes function as effective barriers between aqueous solutions; osmosis is the diffusion of free water molecules from a region where they are more concentrated (low solute concentration) to a region where they are less concentrated (high solute concentration) across a partially permeable membrane; water can diffuse across the plasma membrane via aquaporins in the membrane and via tiny spaces between the phospholipid molecules; ions can be pumped across the membrane to increase the osmotic concentration in a cell; water is drawn into a cell by osmosis if the solute concentration inside the cell is higher than outside it; water cannot be pumped directly across the membrane but changes in ion/solute concentration across the membrane can draw water into a cell from a lower to higher osmotic concentration/from a dilute to concentrated solution; this process maintains the osmotic concentration of cells; there is net movement of water if the environment of a cell is hypotonic or hypertonic; in an isotonic environment there is dynamic equilibrium rather than no movement of water.
[Max 9 marks]

(Questions 7–8 HL only)

7 Sea water has a low water potential/high osmotic concentration; salt water has a more negative/lower water potential than plant tissue; plant tissue in salt water loses water; water moves from a higher water potential (in the plant) to a lower water potential (in the sea); plants become dehydrated and die; plants in salt water need specific adaptations to overcome osmotic problems (e.g. mangrove).
[Max 5 marks]

8 The concentration of a solute determines the water potential of a solution; the pressure within a cell also determines the movement of water, with a higher pressure resulting in greater potential energy and therefore water potential; water potential can be calculated using the equation $\psi_w = \psi_s + \psi_p$; where ψ_w = water potential, ψ_s = solute potential, and ψ_p = pressure potential; adding a solute to a solution lowers the water potential; pressure potentials are generally positive inside cells; this is because of the movement of water molecules pushing against the cell membrane and cell wall of plant, fungi and prokaryote cells; negative pressure potentials can occur, however, inside xylem vessels where sap (mainly water) is being drawn up the plant under tension.
[Max 7 marks]

D3.1 Reproduction

Paper 1

1 B

2 B

3 C

(Questions 4–6 HL only)

4 C

5 B

6 D

Paper 2

1 a i The drawing should be similar to the diagram in Figure D3.1.9 on page 703 of the Student's book. It must show sepals located at the base of the flower/ovary's origin; three/four petals; possibly guidelines drawn on petals; nectaries at base of petals; stamen (larger than carpel) with anther and filament; carpel containing a stigma, style and ovary; stalk/petiole and receptacle.
[Max 4 marks]

ii Bees/other valid example.

iii Coloured/attractive petals; scented flowers; nectary is present; large petals.
[Max 2 marks]

b Cross-pollination/insect-pollinated flower; insect takes pollen grains when searching for nectar; pollen attaches to abdomen/legs/other part of insect; insect then flies/moves to another flower; the pollen will adhere to the sticky surface of the other flower's stigma; accidental delivery of pollen to the stigma by insects.
[Max 4 marks]

2 a Luteinizing hormone (LH)

b Oestradiol

c Progesterone

3

Feature	Sexual reproduction (meiosis)	Asexual reproduction (mitosis)
common in bacteria		✓ (binary fission)
plants do it	✓	✓
most animals do it	✓	
needs two parents	✓	
needs only one parent		✓
gametes made	✓	
cell fusion involved	✓	
no cell fusion involved		✓
variety in offspring	✓	

offspring are clones		✓

[Max 3 marks]

4 Paternal and maternal chromosomes are randomly assorted into new haploid cells; gametes, due to random assortment and crossing over, have a unique sequence of alleles that were not present in either parent; fusion of gametes is random, with any male gamete fertilizing any egg; the egg has a unique set of alleles not present in any other egg; fertilization produces new combinations of alleles that are unique to the new organism.
[Max 4 marks]

5 Down-regulation, the first step in IVF, shuts down the menstrual cycle by stopping secretion of the pituitary and ovarian hormones; the process takes about two weeks and allows better control of superovulation; down-regulation is done with a drug, frequently taken in the form of a nasal spray; high doses of FSH are then injected to stimulate the development of multiple follicles (superovulation); superovulation allows the collection of multiple eggs from the woman; when follicles reach 15–20 mm in diameter, an injection of hCG (human chorionic gonadotropin hormone) is given to start maturation process; after approximately 36 hours, follicles (typically 8–12) are collected from the ovaries under a general anaesthetic; prepared eggs (i.e. removed from the follicles) are combined with sperm in sterile conditions; successfully fertilized eggs are then incubated before implantation; for approximately two weeks before implantation the woman takes progesterone (which maintains the endometrium) to aid implantation: this treatment is continued until pregnancy test, and if positive, until 12 weeks of gestation.
[Max 5 marks]

6 Crossing over during prophase I in meiosis; recombinant chromosomes produced by crossing over increases variability; random orientation of homologous chromosomes during metaphase I/random orientation of chromatids in metaphase II; separation of homologous chromosomes during anaphase I/sister chromatids during anaphase II are all completely random processes; there is independent assortment in meiosis; this random orientation in humans gives 2^{23}/more than 8 million possible combinations of alleles; daughter cells differ from parental cells; fertilization/mating processes/sexual reproduction also increase genetic variability; mutations (spontaneous changes occurring in the gamete-producing cells), leading to the possibility of new characteristics in the offspring.
[Max 7 marks]

(Questions 7–11 HL only)

7 **a** The placenta is adapted for diffusion in a similar way to other exchange organs; it has a large surface area (with lots of villi-like projections) to maximize diffusion; it is only a few cells thick, so there is a short diffusion pathway; it has a constant blood supply that maintains the concentration gradient between the mother's blood and the blood of the foetus.
[Max 3 marks]

b Respiratory gases (oxygen diffuses across the placenta from the maternal haemoglobin to the foetal haemoglobin, and carbon dioxide diffuses in the opposite direction); water; glucose; ions and amino acids; excretory products, including urea, leaving the foetus; antibodies.
[Max 2 marks]

c Diffusion: respiratory gases and urea; osmosis: water; facilitated diffusion: glucose; active transport: ions and amino acids.
[Max 2 marks]

d Mother and foetus may have different blood types/blood types are incompatible; if blood from mother enters the foetus, antibodies in the maternal blood will attack/destroy the foetal blood cells.
[Max 2 marks]

8 Mitosis proliferates cells that will then undergo meiosis (multiplication phase), in the ovaries and testes; developing sex cell undergoes a growth phase; the maturation phase involves meiosis and results in the formation of the haploid gametes; the products of meiosis I are secondary spermatocytes and secondary oocytes; the products of meiosis II are spermatids and ova; in spermatogenesis four sperm cells are produced, whereas in oogenesis one ovum is produced and three polar bodies; in oogenesis, the second meiotic division (meiosis II) begins but it does not go to completion; meiosis II is completed on fertilization.
[Max 6 marks]

9 Spermatogenesis is the development of sperm whereas oogenesis is the development of ova; other differences:

Spermatogenesis	Oogenesis
spermatogonia are formed from the time of puberty, throughout adult life	oogonia (female sex cells) are formed in the embryonic ovaries, long before birth
all spermatogonia develop into sperm, nurtured by the nutritive cells of the seminiferous tubules of the testes	oogonia become surrounded by follicle cells, forming tiny primary follicles, and remain dormant within ovary cortex; most fail to develop further – they degenerate
millions of sperm are formed daily	from puberty, a few primary oocytes undergo meiosis I to become secondary oocytes each month; only one of these secondary oocytes forms a follicle (the others degenerate)
four sperm are formed from each spermatogonium	one ovum is formed from each oogonium (the polar bodies degenerate)
sperm are released from the body by ejaculation	the follicle releases a secondary oocyte into the oviduct at ovulation
meiosis I and II go to completion during sperm production	meiosis II reaches prophase and then stops until a male nucleus enters the secondary oocyte, triggering completion of meiosis II
sperm are small, mobile gametes	a fertilized ovum is non-motile and becomes lodged in the endometrium of the uterus, where cell divisions lead to embryo formation

[Max 3 marks]

10 Human chorionic gonadotrophin (hCG) is initially secreted by the cells of the blastocyst, but later it comes entirely from the placenta; hCG maintains the corpus luteum as an endocrine gland (secreting progesterone) for the first 16 weeks of pregnancy; when the corpus luteum breaks down, the placenta secretes oestradiol and progesterone; progesterone maintains the lining of the uterus, and therefore maintains the continuation of the pregnancy; without maintenance of hormone levels, conditions favourable to a foetus are not maintained in the uterus and a spontaneous abortion results; continuity of pregnancy is maintained by progesterone secretion initially from the corpus luteum and then from the placenta, whereas the changes during childbirth are triggered by a decrease in progesterone levels; this allows increases in oxytocin secretion due to positive feedback; immediately before birth, the level of progesterone declines sharply; as a result, progesterone-driven inhibition of contraction of the muscle of the uterus wall is removed; at the same time, the posterior pituitary begins to release oxytocin; oxytocin relaxes elastic fibres that join the bones of the pelvic girdle, especially at the front, and thus aids dilation of the cervix for the head of the baby to pass through; oxytocin also stimulates rhythmic contractions of

the muscles of the uterus wall; subsequently, control of contractions during birth occurs via a positive feedback loop; the resulting powerful, intermittent waves of contraction of the muscles of the uterus wall start at the top of the uterus and move towards the cervix; progressively during this process (labour), the rate and strength of the contractions increase, until they expel the offspring.
[Max 7 marks]

11 Chemical signalling is the release of chemicals (ligands) that bind to a specific molecule that delivers a signal within the cell or to another cell; the chemical signalling process ensures that important activities occur in the correct cells, at the right time, and in coordination with other cells in the organism; hormones are extracellular signal molecules that are secreted and transported via the bloodstream to target tissues where they cause a specific effect; this is an example of long-distance chemical signalling; the steps in a chemical signalling pathway may be controlled by feedback regulation; in positive feedback, changes increase and amplify conditions further away from the starting point (i.e. away from equilibrium) whereas in negative feedback, the feedback loop leads to a return to the initial conditions; steroid hormones (e.g. progesterone) are lipid soluble and diffuse from the bloodstream across the hydrophobic plasma membrane into the cells, where their receptors are located (in the nucleus); pregnancy is controlled by human chorionic gonadotrophin (hCG), which maintains the corpus luteum as an endocrine gland; continuity of pregnancy is maintained by progesterone secretion initially from the corpus luteum and then from the placenta, whereas the changes during childbirth are triggered by a decrease in progesterone levels; secretion of oxytocin controls childbirth; oxytocin binds to receptors on elastic fibres that join the bones of the pelvic girdle, relaxing them; oxytocin stimulates uterine contractions in childbirth.
[Max 7 marks]

D3.2 Inheritance

Paper 1

1 B

2 B

3 A

(Questions 4–8 HL only)

4 B

5 C

6 D

7 B

8 a Expected phenotype ratio is 3 red flower plants : 1 white flower plant; total number of plants = 200, and so expected number of red flowers = 0.75 × 200 = 150, and
expected number of white flowers = 0.25 × 200 = 50;

Calculation of χ^2:

Category	Predicted	O	E	(O − E)	$(O - E)^2$	$(O - E)^2/E$
red-flowered plants	3	156	**150**	**6**	**36**	**0.24**
white-flowered plants	1	44	**50**	**6**	**36**	**0.72**
total						**0.96**

$\chi^2 = 0.96$ [Max 2 marks]

b Degrees of freedom = (number of rows − 1)(number of columns − 1) = 1
Critical value at $p = 0.05$ and 1 degree of freedom is 3.84;
Chi-squared value is lower than the critical value, and so result is not significant at $p = 0.05$ / difference between observed result.
[Max 2 marks]

c There is no significant difference between observed and expected frequencies; observed results match expected values, and so phenotypes are in ratio 3:1; both parents are heterozygous; red is dominant allele and white is recessive; P generation were pure bred/homozygous for their respective alleles.
[Max 3 marks]

Paper 2

1 a i Different version of the same gene.

ii Allele that is expressed along with another allele in a phenotype.

b i I^AI^A or I^Ai

ii I^BI^B or I^Bi

iii ii

iv I^AI^B

c Phenotypes of parents are blood groups A and B, so to produce an offspring of blood type O, both parents must be carrying the allele i for blood type O; genotypes of parents are therefore: I^Ai and I^Bi;
Offspring of parents can be shown in a Punnett square:

	I^B	i
I^A	I^AI^B	I^Ai
i	I^Bi	ii

Offspring with blood type A has genotype I^Ai; offspring with blood type O has genotype ii.
[Max 4 marks]

2 a Discontinuous variation is when individuals in a group either have the particular characteristic or don't have it; discontinuous variation is controlled by alleles of a single gene and is not affected by the environment; for continuous variation, a complete range of values may be present between two extremes; it is due to polygenic inheritance and is also affected by the environment.
[Max 2 marks]

b Autosomes are somatic chromosomes; they control the body's characteristics; sex chromosomes are found in germ-line cells/gametes; they determine the sex of an individual.
[Max 2 marks]

c An X chromosome is one of the two sex chromosomes; two X chromosomes are present in females; the Y chromosome is the gender-determining chromosome; the sex chromosomes present in males are XY.
[Max 2 marks]

3 There is a complete range of range of measurements; refers to polygenic inheritance; for example, skin colour; this is controlled by more than 2 genes/between 2 and 20 genes affect skin colour; more dominant alleles present influence the production of melanin; skin colour is also affected by the environment; many different types of skin colour; they create a normal distribution curve.
[Max 4 marks]

4 a i Gene/allele

ii DNA/chromosomes/nucleus

b Haploid: cells with nuclei containing one set of chromosomes; diploid: cells with nuclei containing two sets of chromosomes.
[Max 2 marks]

c i Homozygous: having two identical alleles of a gene; plants in the parental generation are homozygous for either smooth coat seeds or wrinkled coat seeds; heterozygous: having two different alleles of a gene; the F1 plants are all heterozygous but showing smooth coat as their phenotype.
[Max 2 marks]

ii Dominant allele: an allele that has the same effect on the phenotype whether it is present in the homozygous or heterozygous state; the allele for seeds with a smooth coat is dominant, as shown by the fact that all the seeds of the F1 generation had a smooth coat; recessive allele: an allele that only has an effect on the phenotype when present in the homozygous state; plants with wrinkled seed coats contain the recessive allele for seed coats.
[Max 2 marks]

iii Genotype: the alleles of an organism; being homozygous or heterozygous refers to the organism's genotype; phenotype: the characteristics of an organism; presenting smooth or wrinkled seeds refers to the phenotype.
[Max 2 marks]

d Appropriate symbols must be used, e.g. smooth seeds in parental generation RR and wrinkled rr; Punnett grid correctly constructed for F1 and F2; representing phenotype, genotype and gametes of parental generation; description of the obtained phenotypes in F1 and F2 as percentages; ratios explained in F1 and F2; F2 parental generation showing both as heterozygous; showing offspring in F2 with their genotype and phenotype.
[Max 4 marks]

(Questions 5–9 HL only)

5 a A monohybrid cross refers to only one gene; both parents contribute with two alleles each; a dihybrid cross involves two (traits) genes; it is also a prediction of how two genes will be present in the offspring when crossing the two parents.
[Max 2 marks]

b Linkage refers to the genes present in the same chromosomal pair; the genes cannot assort individually; crossing over produces recombinant gametes/chromosomes; it happens during meiosis between homologous chromosomes.
[Max 4 marks]

c Multiple alleles refers to the variation of alleles in the same gene; alleles of the same gene control one trait; polygenes refers to several/many genes controlling one trait; the trait can also be affected by the environment.
[Max 4 marks]

6 a *Drosophila* is a commonly occurring insect, found around rotting vegetable materials, in a form called the 'wild type' and as various naturally occurring mutants; *Drosophila* has four pairs of chromosomes, and a generation time of about 14 weeks; one female produces hundreds of offspring (producing statistically significant results); the flies are relatively easily handled, cultured on sterilized artificial medium in glass bottles, and can be temporarily anaesthetized for setting up cultures and sorting progeny.
[Max 3 marks]

b i In breeding experiments with plants, exact ratios may not be obtained because of parasite damage or by the action of browsing predators on the anthers or ovaries in some flowers; or because some pollen types fail to be transported by pollinating insects as successfully as others; all these accidental events may be quite common.
[Max 3 marks]

ii Predicted ratios among the progeny can only be expected if three conditions are met: that fertilization is entirely random; that there are equal opportunities for survival among the offspring; and that very large numbers of offspring are produced; in experiments with *Drosophila*, the exact ratio may not be obtained because, for example, more male flies of one type may have succeeded in fertilizing females than of another type; more females of one type may have died before reaching egg laying condition than of another type; or fewer eggs of one type may have completed their development than of another type.
[Max 3 marks]

7 Correct genotype in F1 for normal fly with red eyes and normal wings $w^+w^+vg^+vg^+$ and wwvgvg for recessive type (*other valid notations are equally acceptable*); gametes present as w^+vg^+ and wvg; F1 all individuals with genotype w^+wvg^+vg; F1 individuals all show phenotype of red eyes and normal wings; gametes for F2 as w^+vg^+, w^+vg, wvg^+ and wvg; Punnett grid showing gametes only; each individual should be correctly notated; the results of the Punnett grid with 9 : 3 : 3 : 1 ratio; 9 with red eyes and normal wings, 3 red eyes and vestigial wings, 3 scarlet eyes and normal wings and 1 with scarlet eyes and vestigial wings.
[Max 7 marks]

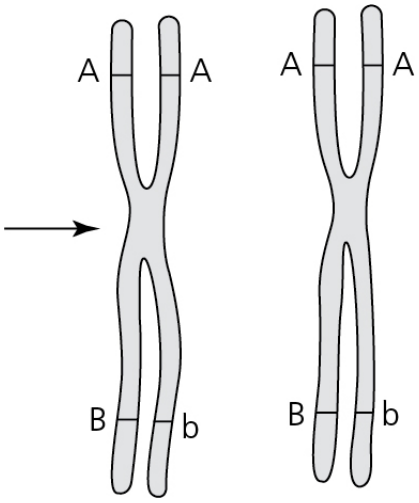
8 a i Parental alleles shown as X^H and X^h (female) and X^H and Y (male); Punnett grid with genotypes of offspring shown as X^HX^H and X^HY and X^HX^h and X^hY;

	X^H	Y
X^H	X^HX^H	X^HY
X^h	X^HX^h	X^hY

[Max 2 marks]

ii X^H X^h

b i All four upper arms with one A and both chromosomes with one B and one b on the lower arms.



ii Prophase I

c Located on the same chromosome; genes/gene loci close together (on the same chromosome); do not follow (the law of) independent assortment; more chance of recombination if genes are further apart; inherited together unless crossing over/recombination occurs; ratios of offspring in dihybrid crosses are different from expected/non-Mendelian *OR* more offspring with parental phenotype combinations than expected.
[Max 2 marks]

d Cortical reaction (after first sperm nucleus enters the egg); vesicles/cortical granules release their contents/enzymes (from the egg/zygote); zona pellucida/glycoprotein coat/outer coat

hardened/fertilization membrane formed; enzymes of sperm/acrosome cannot digest (hardened coat) *OR* glycoproteins (in zona pellucida) altered so sperm cannot bind.
[Max 2 marks]

9 Unlinked genes are on different chromosomes/vice versa; unlinked alleles migrate/segregate/are inherited independently (during meiosis)/vice versa; (in unlinked inheritance) there is an equal chance for all four options to occur/AB, Ab, aB, ab/vice versa; (dihybrid crosses involving) linked genes do not produce Mendelian ratios; (excluding recombinants) there is a 1:1 chance of inheriting the different options/AB or ab; in linked characteristics alleles might not migrate together if there is crossing over/recombinants are formed; crossing over occurs in prophase I of meiosis; when the sister chromatids migrate in meiosis II the characteristics forming gametes are different/Ab, aB; formation of recombinants causes changes in ratio/probability of inheritance/genetic variation; correct named example of inheritance of linked/unlinked characteristics; Punnett/paired diagrams of both unlinked and linked characteristics; genes that are linked but are far apart on the chromosome can display independent assortment.
[Max 7 marks]

D3.3 Homeostasis

Paper 1

1 D

2 B

3 A

(Questions 4–6 HL only)

4 B

5 C

6 C

Paper 2

1 Negative feedback is the type of control in which conditions are brought back to a set value when it is detected that they have deviated from it; negative feedback returns homeostatic variables to the set point from values above and below the set point; e.g. glucose regulation (see Figure D3.3.4, page 763 of the Student's book), thermoregulation (see Figure D3.3.6, page 768 of the Student's book) and osmoregulation (HL only, see Figure D3.3.13, page 776 of the Student's book); examples should include correct identification of receptor, effector and details of feedback mechanism for specific example given.
[Max 5 marks]

2 Regulation of body temperature involves controlling both heat loss across the surface of the body and heat production within the body; it is an example of a negative feedback loop where conditions are brought back to a set value as soon as it is detected that they have deviated from it; temperature changes are detected by peripheral thermoreceptors in the skin and hypothalamus; effectors include the skin, liver and muscles.
[Max 1 mark]

If there is an increase in temperature: arterioles supplying blood to the skin dilate, allowing increased blood flow to the capillaries in the skin (vasodilation); this leads to increased radiation of heat away from the body; muscles attached to hairs in the skin relax, so hairs lie flat on the surface of the skin, allowing radiation of heat from the body; sweat glands are activated to produce increased sweat, which evaporates from the skin and cools the body.
[Max 3 marks]

If there is a decrease in temperature: arterioles supplying blood to the skin constrict (vasoconstriction), causing decreased blood flow to the capillaries in the skin; this leads to decreased radiation of heat away from the body; muscles attached to hairs in the skin contract, causing hairs to be erect on the surface of the skin, trapping heat; sweat glands decrease production of sweat; skeletal muscles contract and relax rapidly causing shivering, which generates heat; the hypothalamus secretes thyrotropin-releasing hormone which, in turn, stimulates the pituitary gland to produce thyroid-stimulating hormone, which stimulates the production of thyroxin; thyroxin stimulates oxygen consumption and increases the basal metabolic rate of the body organs, which increases body temperature.
[Max 3 marks, max 7 marks in total]

3 **Control**: homeostasis is the maintenance of a constant internal environment; the pancreas produces hormones that control the levels of glucose; if glucose levels in blood are high, β cells (of the pancreas) produce insulin; (insulin) causes the cells to take up/absorb glucose; liver stores excess glucose as glycogen; if glucose levels in blood are low, α cells (of the pancreas) produce glucagon; (glucagon) causes the liver to break down glycogen into glucose; (glucagon) increase levels of glucose in the blood; negative feedback controls the glucose levels;
[Max 4 marks]

Consequences: if the pancreas produces little/no insulin, a person can develop type I diabetes; a person with type I diabetes (usually) needs/is dependent on injections of insulin; type II diabetes occurs when the body becomes resistant to insulin/cells do not respond to insulin; type II diabetes can (sometimes) be controlled by diet and exercise; named consequence of having diabetes (e.g. eye damage).
[Max 4 marks, max 8 marks in total]

4 Homeostatic mechanisms allow for continuity in body systems; e.g. control of body temperature allows enzymes to work at their optimum; water balance maintains osmotic concentrations within safe limits (HL only); thermoregulation allows animals to live in warmer/colder environments; sweating/vasodilation allows e.g. mammals to adapt when temperatures increase; vasoconstriction/increased thyroxin release leading to increased metabolic activity/shivering allows mammals to adapt to decreased temperatures; details of thermoregulation (see answer to question 2); details of osmoregulation (HL only, see answer to question 6); animals of arid or desert regions clearly survive with little or no liquid water in their diets, e.g. the kangaroo rat; desert animals excrete extremely concentrated urine and produce no sweat; camels can tolerate a body temperature of up to 42 °C; fat in the hump on the back of camels can be converted to metabolic water via respiration/produce metabolic water.
[Max 7 marks]

(Questions 5–6 HL only)

5 a i Blood proteins remain in the renal artery/740 mg per 100 ml of blood; glucose concentration is 90 mg per 100 ml of blood in the renal artery; urea concentration is 30 mg per 100 ml in blood.
[Max 1 mark]

ii There are no blood proteins inside the glomerulus; glucose concentration is 90 mg per 100 ml of blood in the glomerular filtrate; urea concentration is higher than in the renal artery, since it accumulates in the glomerular filtrate.
[Max 1 mark]

iii No proteins/glucose found in the loop of Henle; urea content is 30 mg per 100 ml of blood; urine contains 2000 mg of urea.
[Max 1 mark]

b ADH plays a role in osmoregulation/regulating blood solute concentration; ADH acts on the collecting ducts of the kidney; hypothalamus detects plasma/blood osmolarity/solute concentration; if plasma/blood is too concentrated/hypertonic, pituitary releases ADH; ADH stimulates insertion of aquaporins/water channels/increases permeability of collecting duct; water moves (through aquaporins) by osmosis into the medulla/blood; urine becomes more concentrated/smaller volume; negative feedback occurs; if blood is hypotonic, no ADH is released; water is not reabsorbed from

the collecting ducts/permeability of the collecting duct decreases; urine becomes more dilute/less concentrated/higher volume.
[Max 4 marks]

6 Osmoregulation is the regulation of water and solute/salt balance/solute concentrations; nephron (is the functional unit of the kidney/osmoregulates); ultrafiltration in glomerulus/glomerular filtrate collected by Bowman's capsule; loop of Henle establishes/maintains hypertonic conditions in medulla; osmosis/reabsorption of water (from filtrate) in the collecting duct; brain/hypothalamus monitors blood solute concentration/pituitary secretes ADH; ADH secreted when solute concentration of blood is too high/hypertonic/when dehydrated; ADH increases permeability of collecting duct to water; ADH causes more aquaporins (in membranes of collecting duct wall cells); more water reabsorbed resulting in more concentrated/hypertonic urine/less volume of urine; less/no ADH secreted when solute concentration (of blood) is too low/hypotonic; less water reabsorbed resulting in dilute/hypotonic urine/large volume of urine.
[Max 8 marks]

D4.1 Natural selection

Paper 1

1 C

2 C

3 C

4 B

(Questions 5–7 HL only)

5 A

6 B

7 B

Paper 2

1 **a** 78 (%)

b Advantage: camouflage *OR* disadvantage: visibility.

c More yellow in fields (than in woods)/vice versa; more unbanded in woods (than in fields)/vice versa; more overlap within banding than within yellow colour.

OR yellow colour range greater than banding range; very little overlap between fields and woods/some outliers.
[Max 2 marks]

d Brown most frequent; pink least frequent.
[Max 2 marks]

e **Evidence that colour plays a role**: few yellow adults (relative to juveniles) means that yellow juveniles do not survive into adulthood; frequent brown adults (relative to juveniles) means brown juveniles survive well into adulthood;

Evidence that colour does not play a role: similar numbers of adult and juvenile pink individuals means pink colour does not play a role; all three colours show wide variation/considerable overlap therefore evidence is not strong.
[Max 3 marks]

f Natural selection requires that snails become adults/live to reproduce their variations/undergo differential predation *OWTTE*; higher adult frequency of brown shows selection; but results for pink do not show selection; more brown juveniles survive into adulthood showing that brown is selected for/vice versa against yellow; not enough evidence alone to support theory of natural selection but may be added evidence to similar observations in other organisms.
[Max 3 marks]

2 (Scientists would accept) hypothesis A as the better one as mutations are random; scientists would reject hypothesis B because the idea that characteristics acquired during the lifetime of an individual can be inherited is Lamarckian/not part of the evolution by natural selection theory/not all mutations are heritable; (the resistance) mutation would be present in the population initially and not caused by the shampoo (as hypothesis B states); both hypotheses include variation in the population of lice (resistant and non-resistant); variation is necessary for natural selection to occur; frequency of the best adapted increases and these individuals reproduce/pass on resistance to their offspring, so the resistant population increases (so hypothesis A is better).
[Max 3 marks]

3 Variation in the skeletal structure; due to mutations/presence of different alleles; those with favourable phenotype (have a selective advantage) survive to reproduce; pass on the allele to offspring; those at selective disadvantage will not survive; an increase in frequency of the allele for the favourable phenotype.
[Max 5 marks]

4 **Similarities**: both utilize natural mutations that generate variation in populations; variation in both is generated by meiosis (random orientation and crossing over);

Differences: natural selection is the result of competition for resources, whereas sexual selection is the result of competition for mates; sexual selection enhances mating success, while natural selection tends to produce individuals that are well adapted to their environment; natural selection adapts individuals to their environment whereas sexual selection does not.
[Max 5 marks; if no similarities, max 4 marks]

5 Evolution is the cumulative change in the heritable characteristics of a population; genes are the heritable unit through which evolution occurs; evolution by natural selection is a process that selects favourable alleles that have been generated by random mutation;

at the **molecular level**, the sequence of amino acids in the polypeptide chain is controlled by the coded instructions stored in DNA, mediated via mRNA; changing only one amino acid in the sequence of a protein alters its properties; variation is also generated at the molecular level via sexual reproduction during meiosis in gamete formation and fertilization; variation is generated by random assortment of paternal and maternal chromosomes in meiosis (in the process of gamete formation); crossing over of segments of individual maternal and paternal homologous chromosomes results in new combinations of genes on the chromosomes of the haploid gametes produced by meiosis; random fusion of male and female gametes during fertilization also generates variation; variation in a characteristic is associated with variation in fitness (the average reproductive success of individuals with a given genotype relative to that of individuals with other genotypes);
[Max 2 marks]

at the **cellular level**, cells show great variety in shape, structure and function: this variety in structure reflects the evolutionary adaptations of cells to different environments and to different specialized functions, e.g. within multicellular organisms; multicellularity has the advantages of allowing larger body size and cell specialization; frequent occurrence of multicellularity is most probably due to strong selective pressures favouring it, the few genetic changes necessary to enable the change, or a combination of these factors;
[Max 2 marks]

at the **organism level**, because all individuals in a population are different, changes to the environment can lead to some having a selective advantage, with increased chance of survival, leading ultimately to changes in the gene pool of a species; reproductive isolation can lead to speciation/evolution of new species;
[Max 2 marks]

at the **ecosystem level**, geographical isolation can lead to speciation, where populations of a species are isolated and become subject to different environmental/selection pressures; biodiversity is the variety of life in all its forms, levels and combinations, including ecosystem diversity, species diversity and genetic diversity; increasing species diversity through speciation leads to increased genetic diversity. Increased diversity of producers leads to increased complexity of food webs and, ultimately, to increased ecosystem diversity; with varied adaptations of producers to trap sunlight, the flow of energy through ecosystems can be maximized, which increases the complexity of food webs and the stability of the ecosystem; at the ecosystem level, all these factors lead to an increase in biological diversity, generated through the process of natural selection.
[Max 2 marks]

[each level of organization needs to be included for max 7 marks]

(Questions 6–8 HL only)

6 Directional selection is natural selection in which an alternative phenotype is favoured over the majority phenotype, causing the allele frequency to shift over time in the direction of that phenotype; in these situations, the majority form of an organism may become unsuited to the environment because of change; some other phenotypes may have a selective advantage; an example of directional selection is the development of resistance to an antibiotic by bacteria.
[Max 2 marks for correct example and how it demonstrates directional selection]

Stabilizing selection occurs where environmental conditions are largely unchanging; stabilizing selection does not lead to evolution; it is a mechanism that maintains a favourable characteristic and the alleles responsible for it, and eliminates variants that are useless or harmful; most populations undergo stabilizing selections; human birth weight demonstrates stabilizing selection: there is optimum birth weight for babies, and those with birth weights heavier or lighter are at a selective disadvantage.
[Max 2 marks for correct example and how it demonstrates stabilizing selection]

Disruptive selection occurs when particular environmental conditions favour the extremes of a phenotypic range over intermediate phenotypes; as a result, the gene pool will split into two distinct gene pools; new species may be formed; this form of selection has been shown by feather colour in young (yearling, i.e. one year or less in age) male lazuli buntings (*Passerina amoena*), native to North America, where adult birds show bright plumage but yearling male birds take a year or two to develop full adult colouration; dullest and brightest yearling males obtain better territories whereas intermediate yearlings (i.e. with colour in between the two extremes) do not gain as good territories; male birds in high-quality territories generally pair with females more frequently than males in poorer territories, which leads to a bimodal pattern in pairing success; this is because females preferentially pair with males in high-quality territories (i.e. with brown or brightly coloured males); adult males see dull, brown-coloured yearlings as non-threatening, because they resemble females, and so allow them to become resident in their area; adult males leave brightly coloured yearlings alone, seeing them as a threat; therefore, both bright and dull yearling males can establish territories and attract females, whereas yearling males with intermediate plumage are more often attacked by adult males and fail to obtain territories and a mate.
[Max 2 marks for correct example and how it demonstrates disruptive selection]

7 The total of the alleles of the genes located in the reproductive cells of the individual; individuals makes up a gene pool; a sample of the alleles of the gene pool will contribute to form the genomes (gene sets of individuals) of the next generation; when the gene pool of a population remains more or less unchanged, that population is not evolving; if the gene pool of a population is changing (the proportions of particular

allele pairs is altered), then evolution may be happening; the change or constancy in gene pools can be detected using the Hardy–Weinberg formula; the Hardy–Weinberg formula is:

$p^2 + 2pq + q^2 = 1$; where

the general formula to represent the frequency of dominant and recessive alleles is:

$p + q = 1$

where p = frequency of the dominant alleles and q = frequency of the recessive alleles;

if genotype frequencies in a population do not fit the Hardy–Weinberg equation, this indicates that one or more of the conditions is not being met, e.g. mating is non-random or survival rates vary between genotypes; when the gene pool of a population remains more or less unchanged, this indicates that the population is not evolving; if the gene pool of a population is changing (the proportions of particular allele pairs is altered), then evolution may be happening; if allele frequencies remain unchanged and match Hardy–Weinberg conditions, then this indicates stability and continuity in the genotype.
[Max 7 marks]

8 Evolution by natural selection is the process by which genetic variation in organisms is selected for by their environment, ultimately leading to speciation; most of a bacteria population is not adapted to an environment that has changed (i.e. the addition of an antibiotic), but an unusual or mutant variety of the population is suited and, therefore, has a selective advantage; the resistant bacteria in the population have no selective advantage in the absence of the antibiotic and must compete for resources with non-resistant bacteria; when the antibiotic is present, most bacteria of the population will be killed; resistant bacteria survive and will be the basis of the future population; in the new population, all individuals carry the gene for resistance to the antibiotic; the genome has changed abruptly and can lead to the evolution of multi-resistant bacteria; this is an example of natural selection rather than artificial selection, because it produces individuals that are well adapted to their environment; artificial selection results in individuals that survive based on selected traits (e.g. better flavour, larger size) rather than on selective advantage; humans are not deliberately selecting for bacteria with specific traits; the traits that are emerge are not desired (i.e. leading to bacteria that are increasingly pathogenic); could argue that the evolution of antibiotic resistance in bacteria is an example of artificial selection because humans create the environment that leads to the evolution of these bacteria, rather than it being a natural process.
[Max 6 marks]

D4.2 Stability and change

Paper 1

1 C

2 A

3 C

(Questions 4–6 HL only)

4 B

5 C

6 B

Paper 2

1 Radioisotopes entered the sea/found in the water (in Japan); taken up by producers/phytoplankton/enter gills of fish; producers eaten by consumers/fish; (radioisotopes) are passed on up the food chain *OR* contaminated fish are eaten by tuna/other fish; radioisotopes are not easily excreted; at each level there is bioaccumulation/biomagnification.
[Max 3 marks]

2 **a** Plastic bottles *OR* fishing gear *OR* plastic bags *OR* plastic wrappers.
[Max 1 mark]

b Ingestion can reduce feeding *OR* false feeling of satiation; microplastics absorb toxins from water; filter feeders ingest the microplastics with the toxins; biomagnification/bioaccumulation.
[Max 2 marks]

c Microplastic density higher along the (north) western shore than the eastern shore *OR* wind blows plastics to opposite coast *OR* wind blows plastics away from their source/city/camping grounds *OR* wind increases degradation of macroplastics into microplastics; wind causes currents that move the plastics; macroplastic pollution less affected by wind than microplastic pollution.
[Max 2 marks]

d Improve city waste disposal; recycling programmes *OR* develop community service teams to collect plastics (around the lake)/*OWTTE*; place litter containers/garbage cans close to camping sites; fines for those causing pollution *OR* pass littering laws.
[Max 3 marks]

3 Sustainable communities/ecosystems allow continued survival of organisms/*OWTTE*; natural ecosystems can be sustainable over long periods of time/*OWTTE*; natural ecosystems/rainforest more sustainable than agricultural areas/plantations; diverse community/high biodiversity/higher biodiversity in natural ecosystems/rainforest *OR* less/low biodiversity in agricultural areas/agricultural soils; agricultural areas/monocultures more affected by pests/diseases; nutrient recycling (efficient) in natural ecosystems/rainforest; nutrients removed with crops/nutrients removed when crops are harvested *OR* less formation of humus/less organic matter in agricultural soils; more water recycling/more rainfall/more transpiration in natural ecosystems/rainforest; larger biomass/more carbon stored (in biomass) in natural ecosystems/rainforest; shallower soils/soil erosion/degraded soils/infertile soils in agricultural areas.
[Max 3 marks]

4 Keystone species are species that have disproportionately large effects on community structure relative to their abundance; there is a risk of ecosystem collapse if they are removed; e.g. the agouti of tropical South and Central America, which feeds on the nuts of the Brazil nut tree; agouti distribute Brazil nuts and the ones it does not feed on germinate and grow into adult plants; without the agouti, the Brazil nut would not be able to distribute its seeds and the species would eventually die out; without the Brazil nut tree, other animals and plants that depend on it would be affected, such as harpy eagles that use them for nesting sites.
[Max 4 marks]

5 Fertilizers are added to soils to increase productivity, e.g. nitrates and phosphates, which are used by plants to synthesize amino acids, DNA and other essential biological molecules; leaching of nitrates and phosphates from agricultural land into rivers can cause eutrophication; eutrophication is the natural or artificial enrichment of a body of water, particularly with respect to nitrates and phosphates; as more nutrients are added to the system, the biomass of algae increases due to the availability of nutrients; the growth of algae (algal bloom) gives lower light penetration, causing underwater plants to die and create more nutrients as they decompose; more nutrients leads to further growth of algae; increased death of algae and underwater plants leads to an increase in dead organic matter (DOM); increase in DOM leads to an increase in bacteria that feed on the dead biomass, causing it to decompose; bacterial respiration leads to increased BOD (biochemical oxygen demand), which causes a lowered oxygen content of water (hypoxia); oxygen-dependent organisms, such as fish, die due to a lack of oxygen.
[Max 5 marks]

6 Sustainability depends on the rate of harvesting being lower than the rate of replacement; if used sustainably, renewable resources can be used indefinitely.
[Max 1 mark]

Correct example of terrestrial plant species and the resource it supplies; explanation of how sustainable management can be assessed.
[Max 2 marks]

Correct example of marine fisheries and the resource it supplies; explanation of how sustainable management can be assessed.
[Max 2 marks]

See pages 806–7 of the Student's book for examples from terrestrial plant species and marine fisheries.

[Max 6 marks in total]

7 At the **molecular level**, covalent bonds are the strongest bonds found in biological molecules; this means they need the greatest input of energy to break them; covalent bonds provide great stability to biological molecules, many of which are very large; carbon atoms are also able to form covalent bonds with atoms of oxygen, nitrogen and sulfur, forming different groups of organic molecules with distinctive properties; the structure of glucose gives it stability, where the carbon atoms in the glucose ring each have four covalent bonds; the optimum angle between all these bonds in glucose is 109.5°, which results in a perfect tetrahedron, which is a very stable structure; in DNA, hydrogen bonding between complementary bases confers stability, making DNA the ideal molecule for the storage of information in cells; DNA's chemical stability makes the molecule easier to repair by enzymes; highly conserved sequences of DNA are usually required for basic cellular stability, function and reproduction, and so must be maintained from one generation to the next, and on through evolutionary history; enzymes require a certain level of water in their structures to maintain enzyme shape and stability, enabling them to function effectively; most naturally occurring enzymes cannot form their active versions without being immersed in water;
[Max 2 marks]

at the **cellular level**, cholesterol in plasma membranes maintains mechanical stability;
[Max 1 mark]

at the **organism level**, negative feedback counteracts any deviation from equilibrium and promotes stability; e.g. thermoregulation, regulation of blood glucose and osmoregulation (HL only);
[Max 2 marks]

at the **ecosystem level**, ecosystems with more complex food webs are more stable because, if one organism becomes extinct, it can be replaced by another; in mature ecosystems, increased biomass leads to an increased number of niches, which increases species and genetic diversity, resulting in greater stability; an ecosystem's capacity to survive change depends on diversity, which itself depends on the variety of species found in the ecosystem; transfer of energy and the recycling of nutrients contribute to the stability of ecosystems; a stable ecosystem is able to maintain its structure, ecological functions and processes; e.g. tall grass prairie in the USA has higher diversity and greater stability than a monoculture (i.e. one species with no variety) created by wheat farming; the greater diversity of tall grass prairie creates a more complex food web that is more resistant to change, and therefore results in a more stable ecosystem; in complex, diverse ecosystems, certain species perform essential functions; e.g. bird predation can maintain low numbers of insects, reducing levels of insect herbivory and therefore increasing productivity; pollinators are important for the functioning of ecosystems and without them many plant species would not be able to reproduce; keystone species are necessary to maintain the integrity and stability of ecosystem/a healthy balance of species and interactions; e.g. beavers are the keystone species in a wetland ecosystem/prairie dogs are the keystone species in a grassland ecosystem/grey wolves are the keystone species in the Yellowstone ecosystem.
[Max 2 marks]

[each level of organization needs to be covered for max 6 marks]

(Questions 8–12 HL only)

8 a Temperature/precipitation/rainfall/minerals/pH of soils/light/humidity/wind/slope (in this specific example).
[Max 1 mark]

b (Bare ground) colonized by micro-organisms/pioneer species; thin soil forms from rock fragments/decomposing organisms; soil retains water from melting permafrost/ice; grasses/small plants/herbaceous plants/moss grow; (larger plants) create habitat for animals; weather/climate may limit plant size/biodiversity *OR* climax community forms.
[Max 3 marks]

9 a (In the older sand dunes you would expect) more complex, deeper soil; build-up of organic matter; better water retention; higher nutrient content; supporting larger diversity of soil organisms; soil is less likely to be blown away *OR* soil is more stable; a different pH.
[Max 3 marks]

b Climate is defined by temperature and rainfall; absence of rainfall/water/humidity leads to desert; moderate amount of rainfall leads to grassland; high levels of rainfall leads to forest; temperature determines type of grassland/forest.
[Max 3 marks]

10 a Increases; at a greater rate early on; seems to plateau/level off.
[Max 2 marks]

b Forest developed; increase in biomass (over years) requires rainfall; water is a limiting factor for photosynthesis.
[Max 2 marks]

c Initially there is low competition for sunlight/resources; photosynthesis allows accumulation of biomass; biomass rises as larger plants replace smaller plants; (in later stages) biomass increase limited due to competition for resources *OR* biomass stabilizes as climax community reached.
[Max 2 marks]

d Development of mature trees requires xylem/wood; xylem/wood contributes to biomass but not respiration; photosynthesis/production greater than respiration; photosynthesis/production continues to accumulate biomass *OR* accumulated biomass remains/increases.
[Max 2 marks]

11 Primary succession is the formation of an ecosystem in an environment devoid of vegetation and lacking soil, for example bare rock; pioneer species arrive (e.g. lichens/mosses/bacteria); as pioneers die, soil is created; new species of plants arrive that need soil to survive, these new species displace pioneer species; growth of plants causes changes in the environment (e.g. light, wind, moisture); growth of roots enables soil to be retained; nutrients and water in the soil increase; nitrogen-fixing plants arrive, adding nitrates to soil; soil depth increases further, allowing shrubs and other taller plants to arrive; animal species arrive as species of plant they rely on become established; a climax community is established; examples of factors that change during a succession (*must include explanation – see page 817 of the Student's book*):

	Pioneer community	Climax community
size of plants	small	large
amount of organic matter	small	large
soil depth	shallow	deep
soil quality	immature/little organic material	mature/much organic matter
nutrients	external	internal
nutrient conservation	poor	good

role of detritus	small	large
stability	poor	good
niches	wide	narrow
species richness	low	high
species diversity	low	high
food webs	simple	complex
size of organisms	small	large
life cycles	simple	complex

[Max 6 marks]

12 Arrested succession (plagioclimax) occurs when human activity prevents the ecosystem developing a climax community; examples of human activity that can lead to plagioclimax include the use of fire in an ecosystem, agriculture, grazing pressure or resource use (e.g. deforestation); human activity can lead to a decrease in productivity through the removal of primary producers (e.g. logging); reduction in producers leads to reduced habitat diversity and fewer niches, which threatens more specialized species; deterioration in abiotic factors, leading to harsher conditions that fewer species can adapt to; species extinction, leading to shorter food webs; a less-complex community, leading to decreased stability; these activities divert the progression of succession to an alternative stable state so that the original climax community is not reached; any valid example, e.g. sheep grazing in the UK prevents the regrowth of woodland by destroying young saplings.
[Max 5 marks]

D4.3 Climate change

Paper 1

1 A

2 C

3 D

(Questions 4–6 HL only)

4 C

5 C

6 C

Paper 2

1 a 60 (%)

b Coral cover decreases as temperature rises (between 1996 and 1998/2000 and 2002)/negative correlation between temperature and coral cover/coral cover highest when temperature is lowest/vice versa; coral cover remains constant when temperature drops (between 1998/1999 and 2000)/remains (nearly) constant when temperature stops rising (between 2002 and 2003); no proof of causation/only a correlation/other factors could be affecting the coral.
[Max 2 marks]

c Increased carbon dioxide/methane in the atmosphere/carbon dioxide emissions from burning of fossil fuels/other specific source of a named greenhouse gas; increased greenhouse effect/more heat/long-wave radiation trapped in the atmosphere; heat transfer from atmosphere to ocean/ocean absorbs heat from atmosphere.
[Max 2 marks]

d Control of variables/pH/light/temperature/no predators of coral.
[Max 1 mark]

e Supports because there is more dead coral/less % cover at the higher temperature; (experimental data) does not support (observed data) because experimental temperatures were (all) higher/rose much faster.
[Max 1 mark]

2 a 2012

b A negative trend/downwards.

c Increased rate of deforestation/clearing of forest/reduction of carbon sink; increased burning of fossil fuels/energy consumption for homes, industries or transport; increased rearing of livestock; increase in concentration of greenhouses gases (carbon dioxide, methane) in the atmosphere results in more heat trapped, hence resulting in an increase in air, land and/or sea temperature, leading to the melting of Arctic ice sheets/decrease in snowfall/ice sheets form more slowly.
[Max 2 marks]

3 Carbon sequestration is the capture and storage of carbon dioxide from the atmosphere by physical or biological processes such as photosynthesis; agroforestry combines agriculture with forestry, allowing the farmer to continue cropping while using trees for animal food, fuel and building timber; trees protect, shade and fertilize the soil, decreasing rates of decomposition and related rates of respiration and increasing photosynthesis; such practices improve carbon sequestration in agricultural soils and above-ground biomass through a range of soil, crop and livestock management practices; such practices protect existing carbon in the system by slowing decomposition of organic matter and reducing erosion; forest regeneration is the process where new trees and forest species become established after forest trees have been harvested or have died from fire, insects or disease; forest regeneration ensures storage of carbon in trees increases through the process of photosynthesis; afforestation (the establishment of forests in an area where there was no previous tree cover) increases carbon sequestration; restoring rich peatlands lost during agricultural development enhances carbon sequestration of wetland ecosystems; carbon sequestration schemes ensure there are less greenhouse gases e.g. carbon dioxide in the atmosphere, which reduces the enhanced greenhouse effect/reduces climate change.
[Max 7 marks]

4 Arctic sea ice is decreasing (there may be no ice by summer 2060); Greenland ice is also in decline; loss of sea ice has impacts for animals that use the ice to feed and breed; e.g. the loss of sea ice habitat has affected walruses (*Odobenus rosmarus*) in the Arctic; walruses cannot swim continuously, so sea ice provides walruses with places for rest between dives to the seafloor where they feed on clams and mussels; sea ice floes are important for walrus calves; landfast ice is sea ice attached to the coastline, to the sea floor along shoals or to grounded icebergs; as temperatures increase, areas of sea ice break away from their attachment ('breakout'); early breakout of landfast ice in the Antarctic has implications for animals that live and breed in these regions, such as the emperor penguin (*Aptenodytes forsteri*); emperor penguins use landfast ice to live and breed, such as in the Weddell Sea; early melting of the sea ice leads to loss of their breeding grounds, which could severely impact their populations and the species' ongoing survival.
[Max 7 marks]

5 Positive feedback loops amplify change and drive systems away from stability/to where a new equilibrium is adopted; effects of permafrost thawing are magnified over time by positive feedback loops; as the atmosphere warms, more permafrost is expected to thaw; this releases large amounts of methane; the atmosphere will warm up even more quickly; this will cause (i.e. feedback) even more methane to be released by more melting permafrost; another example of positive feedback is the climate-

related drying of wetlands, which increases emissions of methane and carbon dioxide in peatlands and increases the potential for peat fires, which are difficult to extinguish; another example is decreased albedo on the surface of the Earth; increased temperature through global warming melts more of the ice in polar ice caps, glaciers and sea ice, leading to a decrease in the Earth's reflectivity (albedo); the Earth absorbs more of the Sun's energy, which makes the temperature increase even more, melting more ice; a further example is the increased incidence of fires: increased global temperatures leads to greater chance of droughts and increases the chance of fire; combustion of vegetation releases carbon dioxide into the atmosphere, which increases global warming still further.
[Max 6 marks]

6 a Melting of polar ice caps; rising sea levels; stress on freshwater supplies; heat waves; heavy rains; death of coral reefs; migration of fish and insects; release of greenhouse gases from frozen organic matter.

Any of the above with more detail.
[Max 3 marks]

b Tropical coral reefs require very specific abiotic factors to grow, including the ideal temperature; increase in greenhouse gas emissions traps heat in the atmosphere/warms atmospheric temperature absorbed by water bodies/ocean; at a higher water temperature, increased photosynthesis rate of zooxanthellae leading to excess by-product which is toxic; this damages coral causing coral polyp to expel zooxanthellae, which results in coral being bleached; ocean absorbs increased amount of carbon dioxide from the air, which causes ocean acidification/decrease in pH of the ocean; increased acidification damages calcium carbonate skeleton of coral (which is alkaline)/causes suppression of calcification in corals; loss of corals causes the collapse of reef ecosystems.
[Max 2 marks]

7 Increased burning of fossil fuels (for energy generation and transport) has led to release of carbon dioxide; deforestation has resulted in fewer trees and less photosynthesis, which has decreased uptake of carbon dioxide, resulting in more carbon dioxide in the atmosphere; with increased global temperatures, there is a greater chance that droughts will occur and, subsequently, increases the chance of fire, with combustion of vegetation releasing further carbon dioxide into the atmosphere; increase of cropping areas/husbandry; increase of livestock/cattle activities has led to increased release of methane, which in turn breaks down into carbon dioxide and water.
[Max 4 marks]

8 a Loss of coral reef leads to other species losing their niches and the coral reef losing its biodiversity; increased average global temperatures can lead to increased risk of forest fires leading to deforestation; distributions of many terrestrial organisms are shifting in latitude or elevation in response to changing climate, where montane species are at risk of extinction if they cannot undergo further upslope migration/are at the highest point in their range; melting of landfast ice leads to loss of breeding grounds of the emperor penguin (*Aptenodytes forsteri*) in the Antarctic and loss of sea ice habitat for walruses in the Arctic.
[Max 3 marks]

b The loss of one species might affect multiple connections in a food web; organisms can switch their diet when their primary food source is scarce; the consequences on a food web might take a long time to occur; it is difficult to identify trophic levels in a food chain because of the diverse feeding behaviours.
[Max 4 marks]

9 Climate change is the long-term change in global or regional climate patterns caused by natural or human factors;

at the **molecular level**, climate change can lower a population's genetic diversity through directional selection; changes in the environment will favour some individuals within a population and these will be selected for, altering the allele frequency and narrowing the gene pool;
[Max 2 marks]

at the **cellular level**, temperature has been shown to affect the fatty acid composition of adipose tissue: organisms have been found to vary the balance between saturated and unsaturated fatty acids (and the amount of cholesterol in their membranes) as ambient temperatures change; organisms maintain a properly functioning membrane, even at very low temperatures; e.g. the lake sturgeon (*Acipenser fulvescens*) has shown that when the temperature decreases, both mono- and polyunsaturated fatty acids of phospholipids significantly increase, and saturated fatty acids decrease; with global warming there may be a selection for fatty acid compositions that favours the increased average global temperatures;
[Max 2 marks]

at the **organism level**, physiology of mammals is adjusted as temperatures increase; e.g. evaporative cooling enables mammals to lose heat when exposed to extreme temperatures; homeostatic mechanisms enable animals to survive in a range of different environments; increased average temperatures may put these systems under stress, especially increased sweating if water sources become less abundant;
[Max 2 marks]

at the **ecosystem level**, changes to phenological seasonal events occur with climate change, e.g. the timing of budburst, nesting and migration; the timing of some life cycles can change, such as the increased incidence of reproductive cycles in bark beetles; evolution resulting from climate change has been observed in the tawny owl: the number of brown owls has been increasing because of the decrease in snow and rise in temperatures; food webs can be disrupted if species are lost from a food chain or new competitive species enter; interspecific relationships can disturb community structure because of the introduction of exotic, alien species; the niche of a species determines its distribution: if conditions vary to the extent that a species' niche can no longer be expressed, the species will become extinct; e.g. on mountain ranges, high-altitude species will have nowhere else to go as upslope shifts occurs due to climate change; species may shift, adapt to the environment or go extinct depending on their exposure, sensitivity and resilience to the new environment; when a species adapts, they may remain in a new environment but change genetic composition or use phenotypic plasticity; change in distribution, genetic composition and phenotypes may cause disruption in species interactions, ecosystem function and structure; the distribution of ecosystems, such as tundra, taiga, grassland, tropical rainforest, temperate deciduous forests and desert, depend on insolation, precipitation and temperature; changes in climate, e.g. average temperature, decreased rainfall and changes in seasonality, and extreme events (e.g. increased hot days, fire, increased frequency and intensity of heatwaves, and intensified wet seasons) can bring changes to biomes and the biodiversity they contain; tropical coral reefs require specific abiotic factors to grow, including the ideal temperature; increased temperatures leads to coral bleaching, which can bring about the collapse of coral ecosystems.
[Max 2 marks]

[each level of organization needs to be covered for max 7 marks]

(Questions 10–12 HL only)

10 Phenology is the research into the timing of seasonal or cyclical biological events, such as flowering/budburst and bud set/bird migration/nesting;
[Max 1 mark]

example of a phenological event affected by climate change (for examples see pages 834-6 of the Student's book); explanation of how climate change affects the phenological event; further example of a different phenological event; explanation of how climate change affects that phenological event.
[Max 4 marks, max 5 marks in total]

11 Changes in the environment can lead to changes in the selective pressure on species, resulting in evolution; for example, tawny owls (*Strix aluco*) in southern Finland are evolving because of milder winters over many decades; milder winters result in less snow, and so birds with lighter feathers are at a selective disadvantage as they are more visible to their prey and so catch less food; there has been an increase in dark brown tawny owls in a population usually dominated by pale grey owls; darker-coloured brown owls, which used to form only 30% of the tawny owl population in Finland, now form 50% of the population; when winter weather is more severe, there is a higher mortality rate in the brown owl

population; brown owls are more visible to predators when there is thick snow cover.
[Max 5 marks]

12 Several species of bark beetle attack spruce and pine forests; e.g. the great spruce bark beetle (*Dendroctonus micans*), which is a non-native (alien) pest of spruce and pine trees in Europe, and the Eurasian spruce bark beetle (*Ips typographus*), which is one of the most destructive forest insects in Europe; bark beetle females bore into the bark of the tree and tunnel through to the phloem, where they lay eggs underneath the bark layer – when the larvae emerge, they feed on the sap of the phloem as well as the tissue itself; larvae damage this tissue, which weakens the tree and can lead to its death; insects are sensitive to temperature, have short life cycles and are very mobile, so changes in temperature due to climate change affect their rate of development and geographical distribution; warming summer and winter temperatures increase the chance of outbreaks across the USA and Europe; increased temperatures lead to range expansion in some species (i.e. beetles spreading to new areas as temperatures warm); climate change may increase the risk of bark beetle outbreaks, particularly in old forests in northern Europe; in Norway, higher temperatures cause a transition from one to two generations per year in northern latitudes; with two generations per year, there will be two attack periods on spruce, one in the spring and one in July/August; the increased number of generations of beetles per year result in greater chance that the critical number of beetles needed to kill a tree will be reached; the second generation of bark beetles can more easily kill trees, as fewer beetles are needed to overwhelm less-resistant trees.
[Max 5 marks]