1.1 Chemistry for life

1.1.1 Chemistry for life

1 Ionic bonds: strong forces of attraction hold together the positive and negative ions formed when atoms give or receive electrons.

Covalent bonds: the atoms involved in the reaction share electrons, forming very strong bonds.

2 Ionic substances: formed when atoms are joined by ionic bonds. The positive or negative ions formed when the atoms lose or gain electrons form an ionic compound.

Polar substances: compounds formed with covalent bonds where there is a slightly unequal sharing of the electrons across the bond, giving a covalent molecule with slight dipoles that can affect intermolecular bonding.

3 Water is a polar molecule because the electrons are held closer to the oxygen atom than to the hydrogen atoms, so the oxygen has a very small negative charge and the hydrogen atoms have very small positive charges. As a result the slightly negative region of one water molecule is attracted to the slightly positive region of another water molecule, and this weak electrostatic attraction is a hydrogen bond. Therefore: water has relatively high melting and boiling points and solid water is less dense than liquid water.

4 Excellent solvent: covalent nature means water dissolves covalent compounds, polar nature means it dissolves ionic compounds, so ideal solvent for chemical reactions in biological systems and makes excellent transport medium.

Slow to absorb and release heat so very stable medium for life.

A liquid at room temperature so cannot be compressed, therefore can be used in hydraulic systems.

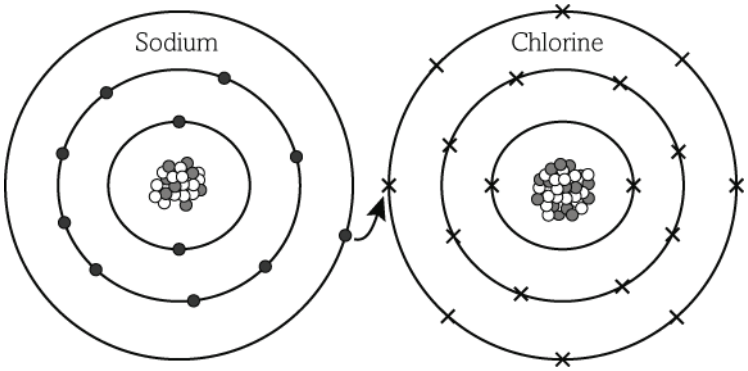
Water molecules are cohesive (so stick together) and adhesive (so stick to other substances). Both are important properties in the movement of water up the xylem of plants.

High surface tension means water surface acts as a skin; this is very important in water being drawn up the phloem of a plant and of life at the surface of ponds, lakes and other water masses.

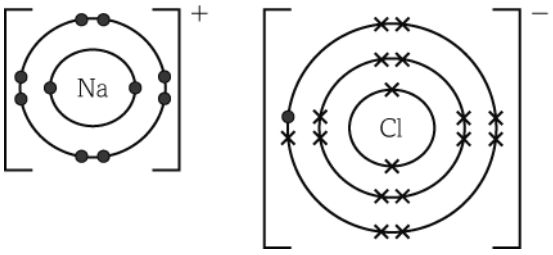
Also award marks for any other sensible points.

1.1 Answers to Exam-style questions

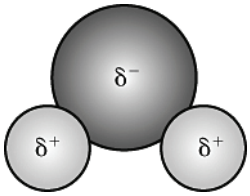
1 See below for answers to parts (a) and (b).



(c) This is how we would draw the ions:



2 (a) One water molecule:



(b) The electrons are held closer to the oxygen atom because it has eight protons in its nucleus, which is more then the hydrogen atom, which only has one proton. Therefore the negative electrons are attracted to this more positive area.

(c) The dipolar charges on the water will attract to the ionic charges of the sodium chloride (δ^+ to the Cl^-, δ^- to the Na^+). This will make it easy for the water molecules to dissolve the ionic lattice of the solid sodium chloride. The dipolar charges make water an excellent solvent for ionic compounds.

3 Answers are shown in **bold** below.

Water molecules are described as **(di)polar/dipoles** because they have a slight positive charge at one end of the molecule and a slight negative charge at the other end. This makes water a good **solvent** for salts and substances such as sugars.

Bonds that form between water molecules are called **hydrogen/H** bonds.

Water is a good coolant because it has a high **(specific) heat capacity,** which means that it takes a lot of heat to change it from a liquid to a gas.

Water also has a high **(specific) heat capacity**, which means that a lot of energy is needed to cause a small rise in its temperature.

Water is most **dense** at 4 ºC, which aids life in aquatic habitats.

4 Answers are shown below. Award one mark for each two correct boxes.

Name of ion	Symbol	Function in plants
Nitrate	NO_3^{2-}	Formation of DNA/RNA/amino acids
Phosphate	PO_4^{2-}	Formation of ATP/ADP/DNA/RNA/nucleic acid
Calcium	Ca^{2+}	Calcium pectate (in the middle lamella)
Magnesium	Mg^{2+}	Needed to produce chlorophyll

5 (a) C, polar molecules

(b) B, anions

(c) A, cations

(d) B, anions

(e) D, non-polar molecules (this is an uncharged molecule!)

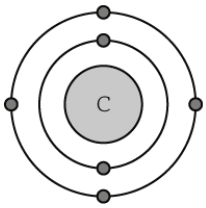
(f) B, anions

6 HCO_3^- is the ion, so it attracts H^+ ions to itself; fewer H^+ in solution means less acidity.

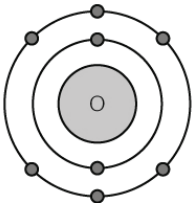
7 (a) Water is a solvent for the water-based ink, so dissolved the ink causing it to smudge. However, biro is *not* water-based, so did not dissolve and therefore did not smudge.

(b) Any **two** from the following:
- Graphite in pencil lead is a non-polar substance.
- Graphite will not dissolve or smudge in water.
- Graphite will not dissolve or smudge in other solvents such as alcohol.

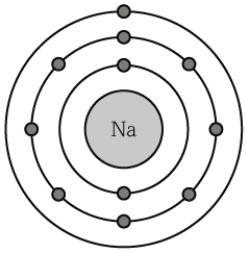
8 (a) (i) Carbon:



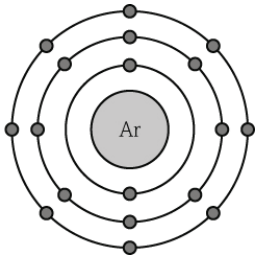
(ii) Oxygen:



(iii) Sodium:



(iv) Argon:



(b) (i) Carbon – 6 electrons so 6 protons

(ii) Oxygen – 8 electrons, so 8 protons

(iii) Sodium – 11 electrons, so 11 protons

(iv) Argon – 18 electrons so 18 protons

(c) The number of protons in the nucleus of oxygen is greater than carbon, so there is a greater positive charge; this draws the electrons from the hydrogens closer to the oxygen nucleus, causing the dipole.

(d) The mass number is larger than the atomic number because the atom nucleus also contains uncharged particles with mass called neutrons. Each neutron has a mass equivalent to the mass of a proton.

(Note: the mass of an electron is extremely tiny – $\frac{1}{1836}$ the mass of a proton – therefore the mass of electrons is usually ignored!)

(e) The number of bonds is determined by the electrons that need to be gained or lost to form a full outer shell:

(i) Carbon requires four extra electrons to fill its outer shell, and thus can form four bonds.

(ii) Oxygen requires two extra electrons, so can form two bonds.

(iii) Sodium loses an electron (it does not gain seven!) and forms a Na^+ ion, which then forms an ionic bond… but only one!

(iv) Argon already has a full outer shell, so (living up to its name argon – from the Greek *aergos* meaning 'lazy') does not form bonds, hence is unreactive.

9 Water is most dense at 4 ºC so ice will float.
Deep water will ensure that the pond does not freeze solid.
Water has a high specific heat capacity, so is slow to absorb or release heat energy.
Large volume minimises temperature fluctuations.

10 Water cannot be compressed; so more energy is transferred to movement.

11 Water molecules form hydrogen bonds with each other; because of the dipole between the oxygen and the hydrogen. These attractions between water molecules are stronger than between water and the air; therefore water molecules form a thin skin of surface tension.

1.2 Biological molecules 1

1.2.1 Carbohydrates 1 – monosaccharides and disaccharides

1 Each carbon atom can make four bonds and so it can join up with four other atoms. Carbon atoms bond particularly strongly to other carbon atoms to make long chains. The tetrahedral shape often seen in the four bonds of a carbon atom leads to the formation of branched chains, or rings, or any number of 3-D shapes, which are important in living things. In some carbon compounds, monomers bond to other similar units to make polymers. This ability to make large complex molecules is the basis of all life.

2 A glycosidic bond is formed by the removal of a hydrogen atom (–H) from one monosaccharide and a hydroxyl group (–OH) from another monosaccharide to form a disaccharide and water.

1.2.2 Carbohydrates 2 – polysaccharides

1 They are compact and can be stored in cells without affecting the water balance of the cell, as they do not affect osmosis. They form a lot of bonds, which make energy available when they are broken in cellular respiration.

2 Starch is formed from amylose, which is a straight-chain molecule, and amylopectin, which is a branched-chain molecule. Both are formed from alpha glucose molecules joined by 1-4 or 1-6 glycosidic bonds, and result in compact globular molecules. Cellulose is formed from beta glucose molecules held together by 1-4 glycosidic bonds. As a result cellulose has hydroxyl molecules sticking out on either side of the molecule, so hydrogen bonds form easily between the individual, long, straight chain molecules, holding them together and making cellulose very strong. Animals can digest starch, breaking it down into glucose, which can be used in cellular respiration. Most animals do not make the enzymes needed to digest cellulose, so it is not usually an energy providing food for animals unless their digestive system contains bacteria that do have the enzymes needed to break down the cellulose molecules into glucose.

1.2.3 Lipids

1 A saturated lipid contains fatty acids that only have single bonds between the carbon atoms in the chain. An unsaturated lipid contains fatty acids that have one or more double bonds within their carbon chain. This means that saturated lipids are more likely to be solids at room temperature. In the body saturated and unsaturated lipids have different effects, e.g. saturated fatty acids in the diet are more likely to lead to plaque forming in arteries.

2 Triglycerides are formed by condensation reactions between one glycerol molecule and three fatty acids. As each of the three ester bonds is formed, one molecule of water is lost.

1.2.4 Proteins

1 The structure of a protein is determined by a variety of bonds between amino acids within the polypeptide chains. Different amino acids can form different weaker bonds (such as hydrogen bonds, sulfide bonds and ionic bonds) with other amino acids, depending on how they are placed in the amino acid chain of the protein. These bonds determine the secondary, tertiary and (possibly) quaternary structure of the protein. So a change in a single amino acid can alter the structure of the whole protein.

2 There are many more hydrogen bonds because they can form between any two amino acids.

3 The tasks that proteins carry out in the body are often dependent on their three-dimensional shape. The weak bonds between amino acids in the protein create this shape. These bonds may be affected by changes in conditions, such as temperature and pH, which will change how well the protein works. So, for good protein functioning, conditions need to be kept stable.

1.2 Answers to Exam-style questions

1 (a) A
(b) C
(c) C
(d) D
(e) D
(f) C
(g) A

2

	Lactose	**Maltose**	**Amylose**
Component monosaccharides	Glucose and galactose	Glucose	Glucose
Bonds between monosaccharides	β 1–4	α 1–4	α 1–4

3 Students answers should include reference to the following:
- breaking of glycosidic bond;
- addition of/using water;
- breaking large molecule(s)/(named) disaccharide/(named) polysaccharide into smaller molecules/(named) monosaccharide/(named) disaccharide;
- reference to hydrolytic/named enzyme.

4 Answers are shown in **bold** below.

Lipids are insoluble in water because they are **hydrophobic/non polar/not charged**.

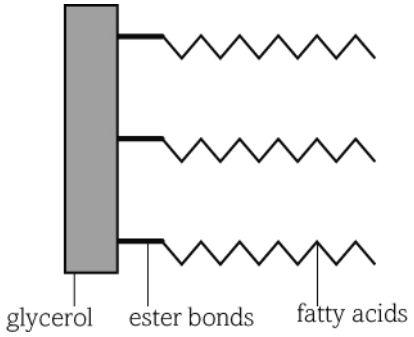
A triglyceride is one type of lipid. A triglyceride consists of one **glycerol/propan-(1,2,3)-triol** molecule with three **saturated/unsaturated fatty acid** molecules joined to it by **ester** bonds. Triglycerides have important roles in living organisms, including waterproofing and **insulation/buoyancy/energy store/protection/source of metabolic water**.

5 (a) Students draw:
- one glycerol, two fatty acids, one phosphate group;
- fatty acids joining to glycerol with ester bond;
- one phosphate group joined to glycerol with ester bond.

(b) hydrophilic: soluble/can dissolve in water

(c) Any **two** from:
- form a (phospholipid) bilayer
- phosphate/hydrophilic region interacts with aqueous environment/surroundings/cytoplasm;
- fatty acids/hydrophobic region restricts/eq movement of charged/polar/water soluble molecules/ions into cell/out of cell/eq.

6 (a)



(b)

Statement	Tick (✓) or cross (✗)
Triglycerides are building blocks of polysaccharides	✗
Triglycerides can contain a small amount of nitrogen	✗
Triglycerides can be modified into phospholipids	✓
Triglycerides release water during hydrolysis	✗

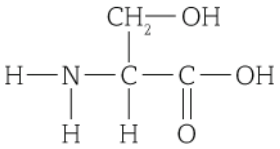
a(c) Saturated means there are no C=C/double bonds, so only single bonds in chain.

7 All amino acids have an amino group (–NH2) and a carboxyl group (–COOH) attached to a C atom. Also attached to this C atom is another group (R group). As the R group varies, this produces the different amino acids.

8 (a) (i) the sequence/order of amino acids

(ii) hydrolysis

(b)



(c) Award 1 mark for each correct row to a maximum of 3 marks.

	Collagen	Insulin
1	Fibrous	Globular
2	Three polypeptide chains in a triple helix	Two polypeptide chains, with disulfide bridges
3	Repetitive/repeating sequence/eq	No repetitive sequence

1.3 Biological molecules 2

1.3.1 Nucleotides and ATP

1 A mononucleotide is a pentose sugar (either ribose or deoxyribose) with an attached phosphate and an attached organic nitrogenous base (either adenine, thymine, guanine or cytosine in DNA, or adenine, uracil, guanine or cytosine in RNA).

2 ATP is found in all species of organisms and all cells in exactly the same form. If ATP synthesis or breakdown is inhibited, cells and therefore organisms cannot function. When ATP is broken down to form ADP and inorganic phosphate, the forming of the new bonds releases more energy than the breaking of the bond in the ATP. This energy is available for use by all cell enzymes. ADP and inorganic phosphate can be reformed into ATP by ATPase using energy from universal reactions, such as redox reactions, within the cell. (Award marks for any other valid points.)

1.3.2 Nucleic acids

1 They are made up of long chains of monomer units called nucleotides. Adenine, cytosine and guanine are common to both DNA and RNA.

2 (a) The complementary base pairs in DNA are adenine and thymine, and guanine and cytosine. Hydrogen bonds link the bases in a complementary pair that are bonded to opposite strands. This makes the 'rungs' of the DNA helix. As there are many base pairs in a DNA molecule, and therefore many hydrogen bonds, the two strands are held firmly together in the helical structure by the hydrogen bonds.

(b) The size of the combination of the two molecules is crucial. If a purine and a pyrimidine base join by hydrogen bonds, they fit between the two sugar/phosphate backbones of the two strands of the DNA molecule. Pyrimidine bases (cytosine and thymine) are too small for hydrogen bonds to form between a pair of them; they would be far apart. Purine bases (adenine and guanine) are too large to pair up together; they would overlap and hence not make effective hydrogen bonds.

1.3.3 How DNA works

1 DNA helicase breaks the hydrogen bonds between complementary base pairs of DNA.

→ The molecule of DNA is unzipped.

→ Free DNA nucleotides form hydrogen bonds with matching exposed bases on the DNA molecules.

→ DNA polymerase and DNA ligase cause bonds to form between the nucleotides.

→ A new DNA strand results on each exposed DNA strand.

2 Meselson and Stahl showed that after one replication in a medium containing light nitrogen, the density of the DNA produced was halfway between that of DNA containing all heavy nitrogen and DNA containing all light nitrogen. This could only be explained by the DNA having one strand containing light nitrogen and one containing heavy nitrogen; which is what you get after semiconservative replication. If there had been conservative replication they would have found half the DNA all heavy and the other half all light. After this work no reasonable scientist could support any theory other than semi-conservative replication.

1.3.4 The genetic code

1 The sequences of three base pairs in the DNA that carry the genetic information from one generation to another

2 Areas of DNA that do not code for proteins; this makes up about 98% of the genome

3 (a) It allows for any arrangement of amino acids to be coded for – there are no limitations from an overlap of the code. Also, point mutations would only impact a single amino acid rather than two or three if the code overlapped.

(b) Often only the first two of the three nucleotides in a codon determine which amino acid is added to a protein. As a result, if the final base in a codon is lost or damaged by mutation, the amino acid structure of the proteins remains the same. So having part of the code that doesn't really code helps protect organisms from the damage caused by mutations.

1.3.5 DNA and protein synthesis

1 DNA contains the sugar deoxyribose and the bases adenine, guanine, cytosine and thymine. The molecule forms a very large, complex double helix.

RNA contains the sugar ribose, the bases adenine, guanine, cytosine and uracil. It forms a single helix and does not form the enormous structures of DNA, but it can form different shaped molecules to carry out different functions in the cell.

2 (a) The DNA contains the genetic code for the protein.

(b) The DNA unwinds at the point where the gene for the protein occurs. The coding (antisense) strand of the gene attracts nucleotides to matching base pairs and these join to form a strand of messenger RNA (mRNA). When it is released from the DNA, the mRNA molecule passes out of the nucleus and attaches to a ribosome, taking the information coded on the DNA molecule out from the nucleus into the cytoplasm of the cell.

(c) Transfer RNA molecules bring matching amino acids to the ribosome and attach to the messenger RNA so that the amino acids are aligned correctly to form the polypeptide chain.

(d) Ribosomal RNA makes up around 50% of the ribosome and it holds together the mRNA, the tRNA and the enzymes controlling the process of protein synthesis on the surface of the ribosome.

1.3.6 Gene mutation

1 A point mutation is a change within a gene. This may be a deletion of a single base pair or a change to a base pair. A change may not affect which amino acid is coded for, so this won't have any impact on the organism as the protein formed will have the same amino acid arrangement. A change to a base pair may change the amino acid coded for, and if this amino acid doesn't form the same bonds as the original one, then the protein will not have the same 3D shape and will not work in the same way as the original one which will affect the organism. A deletion will affect not only the triplet in which it occurs but also all the triplets following it and so change many of the amino acids coded for. This will change the protein formed and so affect how the body works.

2 The change in a single base in one codon changes one amino acid in the chain of 147 amino acids in the haemoglobin molecule. This is enough to change the nature of the protein and the way it folds in the red blood cells so it forms rigid rods. As a result the red blood cells have a sickle shape and cannot pass through the small blood vessels and cause blockages, which in turn can lead to pain and even death.

1.3 Answers to Exam-style questions

1 (a) A phosphate group

B pentose group

(b) (i) Adenine 29%; Guanine 21%; Cytosine 21%

(ii) Thymine and adenine are base pairs so adenine will also be 29%. That leaves 42% to be split equally between the base pair of guanine and cytosine.

2 (a) Ring drawn around one phosphate group, a pentose sugar and a base.

(b) Adenine and guanine.

(c) (i) In the nucleus.

(ii) RNA nucleotides from the nucleoplasm align next to the exposed DNA strand. DNA-directed RNA polymerase catalyses the formation of phosodiester bonds between the sugars and phosphate groups of the RNA nucleotides. The mRNA chain then separates from the DNA strand.

(d) (i) Antisense drugs – translation

Triplex drugs – transcription

(ii) UCAGUA / TCAGTA

3 (a) $2.5 \times 10^{-8} \times 7 \times 10^{9}$;
=175 mutations

(b) $175 \times 50 = 8750$ mutations

(c) Only 2% of DNA (a small fraction of genome) codes for proteins;
some amino acids have similar codons, so if the mutation is in third base of codon same amino acid is selected /eq;
even if amino acid is changed, this may have no effect on active site / eq.

4 (a) The DNA helix unwinds and the strands separate as hydrogen bonds are broken. One strand acts as a template and RNA nucleotides line up against it. DNA-directed RNA polymerase catalyses the formation of phosodiester bonds between the sugars and phosphate groups of the RNA nucleotides. The mRNA chain then separates from the DNA strand.

(b) During translation, mRNA becomes associated with ribosomes. The ribosome moves along the mRNA reading the codons and matches these to tRNA anti-codons, which have amino acids attached to them. Peptide bonds are formed between the amino acids to synthesis the specific protein.

(c) (i) T1 = GGG; T2 = CGC; T3 = UCG; T4 = AAA.

(ii) Glycine – arginine – serine – lysine

(iii) one of ATT, ATC or ACT.

6 (a) a phosphodiester bond

7 (b) GGCUUUGCUGAG

8 (b) antisense strand

9 (a) (i) unwinds the two DNA strands
breaks hydrogen bonds between bases
note: those students who have done background reading might talk about 'active' and 'passive' helicases: the 'active' helicases require ATP e.g. ATRX;

(ii) Adds new nucleotides to new strand
semi conservative replication
pairing complementary bases;
works from 3' end to 5' end of DNA strand

(iii) joins phosphate group of new nucleotide to (deoxyribose) sugar of growing strand
forms phosphodiester bond

(b) (after first round, ^{14}N:hybrid $^{14}N/^{15}N$:^{15}N is 0:2:0, second round is 2:2:0, third round therefore is 6:2:0, six double helices out of eight. It's easier if you draw it out first!)
proportions of strands is 3/4

(c) radioactive isotopes lose mass / become different atoms;

(d) semiconservative replication produces

1.4 Enzymes

1.4.1 Enzymes

1 yeast cells

2 An intracellular enzyme is produced by a cell for action within the cell. An extracellular enzyme is produced by a cell and then excreted so that it acts outside the cell.

3 Student's own research.

1.4.2 How enzymes work

1 (a) The key characteristics of enzymes:
- globular protein with complex 3-D shape and a critical shape to the active site;
- catalysts: speed up the rate of a reaction but are left unchanged at the end of the reaction and don't affect the reaction in any other way;
- form an enzyme/substrate complex where the substrate(s) fits the active site of the enzyme by inducing a change in the shape of the enzyme; the shape of the active site makes it easier to break existing bonds within the substrate(s) or to form new bonds between products;
- present in very small amounts;
- specific to one or small number of reactions of similar-shaped substrate molecules;
- rate of reaction affected by concentration of substrate only up to a certain point;
- rate of reaction affected by temperature and pH because these affect the shape of the enzyme and its active site.

(b) How each characteristic provides evidence for the induced-fit hypothesis:
- 3-D shape needed for the shape of the active site to be critical.
- The shape of the enzyme is left unaffected when the products are released at the end of the reaction.
- The role of the active site is to make the formation of bonds between substrates, or the breaking of bonds within the substrate, easier.
- Only small amounts are needed because they catalyse the reaction so quickly.
- Specific because the substrate(s) fits within the active site, so shape of molecules important.
- Substrate concentration increases rate of reaction up to the point where all active sites on enzyme molecules are occupied. After this point, increase in substrate concentration has no further effect.
- Temperature increases the rate of reaction by increasing the energy in all molecules up to the point where it starts to affect the weak bonds within the enzyme and so the shape of the active site. After that point, further increase in temperature denatures the enzyme and so slows the reaction rate.
- pH also affects the weak bonds within a protein molecule, so affecting its 3D shape and the shape of the active site. Different weak bonds are affected differently by changes in pH, so different enzymes work better at different pHs.

2 Students' plans should include suitable method, identifying equipment, variables measured and controlled to increase reliability and validity of results. Look for the following:
- awareness of need for control, reliability, etc.
- consideration of maintaining all other factors constant
- need for water bath
- suitable temperatures chosen – awareness of normal biological range, etc.
- appropriate and manageable number of temperatures
- appropriate number of repeats of each temperature
- suitable enzyme with simple test to illustrate activity, etc.
- risk assessment.

1.4.3 Enzyme inhibition

1 Reversible inhibition occurs when an inhibitor affects an enzyme in a way that is not permanent – if the inhibitor can be removed, the inhibition is reversible. Irreversible enzyme inhibition takes place when the inhibitor forms permanent covalent bonds with the enzyme that cannot be reversed; the enzyme is permanently inactivated.

2 In reversible competitive inhibition the inhibitor is similar in shape to the substrate of the enzyme controlled reaction and so they compete for the active site. The inhibitor has its effect by taking up active sites, which cannot therefore bind to the real substrate and catalyse the reaction.

In reversible non-competitive inhibition, the inhibitor forms a complex with either the enzyme or the enzyme/substrate complex. It does not bind to the active site but to somewhere else on the enzyme structure, indirectly deforming or changing the shape of the active site so the enzyme can no longer catalyse the reaction.

1.4 Answers to Exam-style questions

1 (a) Award marks for:
- reference to use of iodine solution/iodine in potassium iodide solution;
- observation/colour change described. e.g. orange to blue/black colour;
- any valid experimental details, e.g. use of pipette/sample removed form reaction solution.

(b) Students' answers should refer to:
- overall decrease in activity;
- increasing concentration (of copper ions) up to 4 au increases the activity of amylase;
- increasing concentration from 4 au (to 32 au) reduces activity;
- reference to change in activity at 20 au;
- correct manipulation of data (this means you have worked out the *difference* between two named concentrations, or some kind of percentage change, not just stated the values on the graph).

(c) Students' answers should include the following points:
- copper ions/inhibitor block the active site/eq;
- idea that inhibitor is the same shape as substrate;
- preventing starch/substrate binding with amylase/active site/enzyme;
- the more copper ions/inhibitor, the more active sites are blocked;
- reduces enzyme activity.

(d) (i) Students' answers should mention:
- it allows a comparison to be made (with and without copper ions);
- reference to starch/substrate concentration being the same (with and without copper ions);
- the rate of reactions changes with time/eq because substrate is being used up/eq.

(ii) Maximum rate/V_{max} (with copper ions present) is lower (than without inhibitor)/if it was active site-directed it would take longer to reach same maximum rate

2 (a) (i) Activation energy: idea that energy needed for a chemical reaction to being/eq; enzymes reduce it

Catalyst: (chemical that) speeds up/increases rate of a reaction; without itself being changed/used over and over again/not used up/does not alter the product

(ii) Curve shows same energy levels at start and finish as on original graph; activation energy is lower

(b) (i) hydrolysis

(ii) peptide

(iii) 126; correct division by 36 to give 3.5 (arbitrary units per hour)

(iv) Most of the protein/substrate is already broken down/used up/digested (by 36 hours); after 36 hours the reaction is slowing because the protein/substrate concentration is now a limiting factor/eq; before 36 hours, idea of more collisions/eq (so rate is fast).

3 (a) (i) Students' answers should include the following points:
- protein/substrate and enzyme collide/bind/reference to formation of enzyme-substrate complex/eq;
- peptide bonds broken/eq;
- reference to/description of hydrolysis;
- reference to formation of smaller peptide chains/amino acids.

(ii) Smaller peptides/amino acids are soluble/dissolve, whereas protein did not/eq

(b) (i) Activity increases between pH 5 and 8/eq; most activity takes place at pH 8/eq; activity drops between pH 8 and pH 10; correct manipulation of figures (note: this requires a calculation, not just quoting figures from graph)

(ii) Students' answers should include the following points:
- pH is determined by H^+ concentration/eq;
- reference to ionisation of R groups/side chains;
- reference to bonds/appropriate named bond breaking/eq;
- reference to change in shape of active site;
- substrate/protein cannot bind to active site/eq.

(c) Students' answers should include the following:
- to keep the temperature (of the reaction) constant;
- reference to (45 ºC) optimum temperature of trypsin/fastest rate;
- reference to a change in the temperature changes the rate of reaction, e.g. idea that change in temperature changes the kinetic energy of the molecules/changes the number/energy/frequency of the collisions.

2.1 Eukaryotic cells

2.1.1 Observing cells

1 Magnification is a measure of how much bigger the image is than the original object and it is very important. But the other important factor is resolving power (or resolution), which is a measure of how close together two objects must be before we see them as one – or how far apart before we see them as two. If the resolution is poor, the image will appear fuzzy and so we cannot see the details of cells clearly.

2 Light microscope: cells and tissues are stained with dyes, which are taken up by different parts of the cell making it easier to see them, e.g. the nucleus, chromosomes, lignin-containing material. It is the biological material itself that is stained.

Electron microscope: colour is used to make it easier to identify cell components, but it is added to the image after it has been taken – it does not reflect staining on the cells themselves.

3 $\frac{5\text{ mm}}{40} = 0.125\text{ mm}$

$\frac{12\text{ mm}}{100} = 0.120\text{ mm}$

$\frac{13\text{ mm}}{100} = 0.130\text{ mm}$

Mean diameter = $\frac{0.125 + 0.120 + 0.130}{3} = 0.125\text{ mm}$ (125 μm)

2.1.2 Cell membranes

1 They control the movement of substances in to and out of a cell or organelle; site of chemical processing – hold enzmyes and substartes in same areas, allow cells to change shape/give flexibility, used for packaging substances made in cell or engulfed by cell; any other sensible suggestion.

2 Phospholipids make up the main bilayer of the membrane, separating an aqueous layer on one side from an aqueous layer on the other by a hydrophobic region that makes diffusion difficult for substances that are not lipid-soluble or very small.

Large proteins that sit within or across the membrane act as controls or gates for the passage of ionic and larger molecules across the membrane.

Glycoproteins on the outside of the membrane are part of the cell recognition system.

3 Allows movement of cells, e.g. endocytosis, phagocytosis, increases in water content, red blood cells in capillaries, etc. Also allows channels to be open or shut, new protein pores to be opened, carrier molecules to move through the membrane, and the membrane to fuse to form vesicles. Accept any other sensible suggestions.

2.1.3 Eukaryotic cells 1 – common cellular structures

1 Provides structure for the cytoplasm, holding organelles in place. Also involved in cell movements due to contractile proteins, and transport within the cell.

2 Enables different functions to be carried out in different areas, making the cell more efficient. Enzymes can be held next to each other in sequence. Membrane folding gives increased surface area for enzyme action. Avoids substances/enzymes interacting and causing problems. Accept any other valid points.

3 Transmission EM: high magnification, detail; scanning EM: 3-D image.

Transmission EM gives you detailed information about internal parts of organelles, etc. Scanning EM gives 3-D picture of the cell and the relationships of one organelle to another.

2.1.4 Eukaryotic cells 2 – protein transport

1 Likely questions and ways of finding the answers include:
- What is the detailed structure? Using electron microscopy helps us understand more about the structure of the different types of ER.
- Are substances made in the ER or do they travel through it? Using radioactive labels to track substances through the different areas of ER, e.g. labelled proteins would show up in RER but not in SER, labelled lipids in SER and not in RER. Centrifuge tissue to investigate different areas of ER– check for labelled substances, etc.

Accept any other sensible suggestions.

2 RER – enzyme proteins are formed on ribosomes then moved into cavities of RER and transported through the system. Vesicles containing the enzymes are pinched off from the RER, and moved by cytoskeleton to Golgi stacks. Membrane of vesicles fuse to form Golgi. Enzymes move through the Golgi and may be modified. Finally, they are enclosed in another membrane vesicle. Some remain in the cell as lysosomes containing digestive enzymes or are released into the cytoplasm (intracellular enzymes). Others move to cell surface membrane, fuse and release enzymes by exocytosis to the outside of the cell (extracellular enzymes). Packaging products within a cell is important as it means that enzymes only work in the appropriate place, and chemicals do not mix when they shouldn't. Controls enzyme cascades and makes sure all the reactions of metabolism occur in the right sequence. Allows materials to be transported to specific regions.

3 Apoptosis is programmed cell death. It is used to get rid of cells that are ageing and coming to the end of their life, as well as those which contain mutations, damaged cells, etc. So healthy levels of apoptosis allow new cell growth and also prevent the development of cancers and other problems from damaged cells. If there is too much apoptosis, this can lead to arthritis, damage after heart attacks and probably many other conditions. If there is too little apoptosis, this can lead to cancers, as cells containing mutations are not destroyed.

Also accept any other valid points based on students' own research.

2.1.5 Eukaryotic cells 3 – plant cell structures

1 Cell walls provide strength to the plant and prevent cells from bursting when they are bathed in a solution that is more dilute than their contents. The cellulose microfibrils are strong and not easily stretched, so they help to maintain cell size and shape. The matrix of hemi-celluloses and other carbohydrates hold the microfibrils in position but keep the structure flexible, so that the plant can bend with the wind, etc.

2 The primary cell wall formed when the cell divides is flexible and can stretch in some directions as the cell swells and the plant grows. As the cell gets older, more cellulose microfibrils are laid down at angles to each other, to make a more rigid box that prevents the cell changing shape any further but provides extra strength for the plant. If the cell wall becomes lignified later, this makes the structure even stronger and more rigid.

3 Plasmodesmata are cytoplasmic connections between cells though the cell wall. This means that substances from one cell can pass more easily into another cell without having to pass through the cell surface membrane and cell wall. This allows communication between the cells.

2.1.6 Eukaryotic cells 4 – plant organelles

1 Amyloplasts are structures that store starch in plant cells. Chloroplasts have a complex structure of folded membranes that contain chlorophyll, which traps the energy from sunlight so that the plant can make its own food.

2 Typical plant and animal cells have a nucleus, mitochondria, a cell surface membrane and cytoplasm. Animal cells may have temporary vacuoles, but a typical plant cell has a cell wall, permanent vacuole, sometimes chloroplasts and sometimes amyloplasts.

3 Chloroplasts trap sunlight, so plant cells that don't receive enough light would be wasting energy if they made chloroplasts. If a potato tuber, which is usually underground and so is white, is removed from the soil it starts to turn green. The cells on the surface of the potato must be able to make chloroplasts and the green pigment chlorophyll that is found in them.

2.1.7 The organisation of cells

1 (a) Squamous epithelium lining an alveolus: very thin and flat, so diffusion distances are kept to a minimum

(b) Ciliated epithelium lining a bronchus: cilia move mucus carrying bacteria away from the lungs

(c) Muscle tissue in the biceps muscle: contracts to allow muscle to move bone

2 (a) Any system – correct naming of cells, tissues and organs

(b) Clear and accurate explanation relating to the body system chosen

2.1 Answers to Exam-style questions

1 (a) Students' answers should include: production of ATP/eq; reference to aerobic respiration; reference to Krebs cycle/electron transport chain/oxidative phosphorylation.

(b) Award marks for:
- correctly drawn shape of mitochondrion;
- several non-stylised cristae drawn;
- correct size (double length of photograph: the original was 7.2 cm long, so 14.0–14.6 cm is fine);
- matrix *and* crista labelled correctly.

2 (a) **A**: starch grain; **B**: granum

(b) Award marks for:
- correct measurement between line X and Line Y (ideally in mm);
- correct division by 5;
- correct magnification (originally $\frac{99–104\ \text{mm}}{5\ \mu\text{m}}$, so 19 800 to 20 800).

(c) palisade/guard/spongy/mesophyll

3 (a) Award marks for:
- envelope/double membrane clearly shown;
- granum clearly shown;
- granum/thylakoid(s) labelled;
- stroma/ribosomes/starch grain/DNA/lipid droplet/double/inner/outer membrane/envelope/intergranal lamellae correctly labelled.

(b) (i) Award marks for: correct length (50 mm); divided by 50 000; correct length in μm (1 μm).

(ii) Acceptable answers include: vacuoles/vesicles/lysosomes/glycogen granules/ribosomes/lipid droplets/centrioles/spindle fibre/microtubules.

(iii) Acceptable answers include: resolution not high enough/eq/damage/angle of section/eq/poor printing of photograph/eq.

4 Answers are shown below.

Name of cell structure	Description of cell structure	Diagram of cell structure
Nucleolus	1. Darkly-stained region in the nucleus. 2. Where ribosomal RNA is made.	
Centrioles		Pair of cylinders; at right angles to each other
Lysosome	spherical (structures); single membrane; containing hydrolytic/eq enzymes	
Microtubules;	1. Hollow cylinders made of protein. 2. Form spindle fibres.	

5 (a) Award marks for: size: drawing is correct length; shape is accurate; cell content – nucleus drawn in correct position with nucleoli shown.

(b) 1. {fatty acids / tails} are {hydrophobic / non-polar / eq} ; 2. (so orientate themselves) away from {water / polar environment / eq} ; 3. {phosphate/heads} are {hydrophilic / polar / eq} ; 4. (so orientate themselves) towards {water / polar environment} ; 5. idea that phospholipids arranged in bilayer due to aqueous environment on both sides of membrane / eq ;

6 (a) Symbiotic relationships are when organisms live together and both benefit.

(b) Both have 70S ribosomes like prokaryotic organisms.

(c) Bacteria have a single membrane, and when they are absorbed a vacuole forms around them, like a second membrane. This could explain through endosymbiotic theory why mitochondria and chloroplasts have double membranes.

(d) This is because flagella have no membrane, nor any DNA, nor any ribosomes.

7 (a) Three from: centrioles, microtubules, microfilaments, lysosomes, rough and smooth endoplasmic reticulum, Golgi body

(b) Two from: nucleus, chloroplasts, and mitochondria

(c) Sections in electron microscopes have to be extremely thin (transmission microscope) or fractured (scanning microscope). A vacuum is also needed for the electron microscope to work, which precludes the ability of cells to successfully respire

8 Three from: *Primary cell wall*:
- middle lamella forms when cell divides;
- middle lamella is made of pectin;
- pectin combines with calcium ions to form calcium pectate;
- cellulose microfibrils build up either side of the middle lamella.

Three from: *Secondary cell wall:*
- more cellulose microfibrils laid at an angle to original microfibrils;
- this increases rigidity;
- hemicelluloses increase hardening;
- lignin added to increase hardening.

2.2 Prokaryotic cells

2.2.1 Prokaryotic cells

1

Structural features	**Eukaryotic**	**Prokaryotic**
Average size μm	10–100	0.5–10
Genetic material	DNA	DNA
Outer layers	Lipoprotein cell surface membrane May have cell wall containing cellulose or chitin	Cell surface membrane and bacterial cell wall made of peptidoglycan with other compounds such as teichoic acid, lipopolysaccharides May have slime capsule or layer
Main inclusions	Nucleus containing genetic material (DNA), 80S ribosomes, mitochondria, Golgi body, lysosomes, vesicles, cytoplasm, centrioles, cytoskeleton, vacuoles, endoplasmic reticulum (RER and SER), etc.	Cytoplasm, genetic material (DNA), plasmids, mesosomes, 70S ribosomes
Movement	Varies – may not move, may be amoeboid, may use cilia, flagella, etc.	May have flagellae

2 Gram-positive bacteria (e.g. *methicillin-resistant Staphylococcus aureus, MRSA)* cell walls contain a thick layer of peptidoglycan containing chemicals such as teichoic acid within their net-like structure.

The cell walls of Gram-negative bacteria (e.g. *E.coli)* have a thin layer of peptidoglycan with no teichoic acid between the two layers of membranes. The outer membrane is made up of lipopolysaccharides.

The way they infect cells and cause disease is different and the way they react to antibiotics is different, so need to know to treat bacterial diseases effectively.

3 (a) Gram positive bacteria have a thick layer of peptidoglycan containing chemicals such as teichoic acid within a net-like structure on top of the plasma membrane. Gram positive bacteria have a thin layer of peptidoglycan between two layers of membrane. Some antibiotics, e.g. penicillin (beta lactams) inhibit the production of the peptidoglycan layer; this has a much bigger effect on Gram positive bacteria because of their thick peptidogycan wall compared to Gram negative bacteria. Glycopeptide antibiotics are large polar molecules so they cannot penetrate the membrane of the Gram negative bacteria but can attack Gram positive bacteria with their exposed cell wall. Polypeptide antibiotics interact with the phospholipids in the outer membrane of Gram negative bacteria, so they are effective against them and less effective against Gram positive that don't have the membranes.

(b) Streptomycin would be the best to choose because it has the lowest inhibitory dose for both Gram positive and Gram negative bacteria.

2.2.2 Viruses

1 They are small so can be inhaled, swallowed, etc., and get into cells easily.

Viral genetic material adapted to take over host cell mechanisms e.g. viralDNA, acts directly as a template for both new viral DNA and for the mRNAs needed to induce synthesis of viral proteins. Viral RNA directs the synthesis of reverse transcriptase, which proceeds to make DNA molecules corresponding to the viral genome, which is used as a template for new viral proteins and ultimately a new viral RNA genome.

Simple structure of protein coat and genetic material means it can withstand harsh conditions, drying, etc., and retain infectivity.

Have VAPs for attachment to specific cells.

Award marks for any other valid points.

2 (a) They reproduce, contain genetic material, undergo evolution, obligate intracellular parasites that can only exist and reproduce as parasites in the cells of other living organisms.

(b) They don't feed, respire, excrete, move, show any sensitivity; the only characteristic of living things shown is reproduction.

3 Lytic: viral genetic material is replicated independently of the host DNA straight after entering the host; mature viruses are made by host cell, which eventually bursts, releasing large numbers of new virus particles to invade other cells; virus is virulent (disease causing) straight from infection.

Lysogenic: viruses non-virulent when they first get into the host cell; viruses insert their DNA into the host DNA so it is replicated every time the host cell divides; no mRNA produced from the viral DNA because one of the viral genes causes the production of a repressor protein, which makes it impossible to translate the rest of the viral genetic material; virus spends time dormant while simply part of the reproducing host cells; viruses in lysogenic state can become lytic.

4 Students' tables should contain the following points:

Positive ssRNA viruses	Negative ssRNA viruses	RNA retroviruses
Single strand of RNA	Single strand of RNA	Single strand of RNA
Sense strand	Antisense strand	Cannot be used as RNA
Translated at ribosome to make viral structural proteins and RNA polymerase that replicates the viral RNA to make new viruses	Transcribed to sense strand by RNA replicase	Viral RNA translated into viral DNA by reverse transcriptase in the cytoplasm of the host cell
	Translated at ribosome to make viral structural proteins, RNA replicase and RNA polymerase that replicates the viral RNA to make new viruses	Viral DNA incorporated into host DNA in nucleus. Directs the production of new viral RNA, mRNA and structural proteins
		New viruses assembled and leave cell by exocytosis. Viral DNA remains in host DNA so the process is repeated

2.2.3 Controlling viral infections

1 There are no really effective antiviral drugs. Vaccines are not always effective because of the rapid mutation of viruses. Preventing the spread of disease is therefore particularly important as we cannot cure or prevent it effectively.

2 If people feel better they are more likely to go out and about, e.g. to work, and spread the virus.

3 (a) Students' answers should make reference to the following points:
- mass vaccination (if vaccine available);
- identify the infectious organism and develop an effective test;
- if bacterial, use of correct antibiotic;
- nurse in isolation if a serious disease, to prevent transmission from one individual to another;
- follow simple measures such as regular hand washing, hand washing before and after every contact with patients by health workers and families, and care in handling body fluids;
- sterilise or dispose of equipment and bedding after use;
- when dealing with dangerous and highly infectious viruses, health workers should wear facemasks, gowns, gloves and goggles to protect the eyes (the slightest contact of infected material with the eyes is enough to lead to infection); the gloves should be washed and disinfected before removal and then the hands washed as well;
- identify those who have been in contact with infected people and monitor their health so they can be treated and/or isolated rapidly if they show signs of disease.

(b) It was particularly difficult to control Ebola because:
- it was a long time before the disease was identified;
- conditions in the countries affected – poor sanitation, poor health infrastructure, no facilities for nursing in isolation, funeral rituals that involved intimate contact with the body, lack of education and understanding of the methods of spread of the virus and how to control it – made spread more likely.

Award marks for any other sensible points.

4 (a) early phase research → preclinical testing on cells and tissue cultures → testing on animals → clinical trials → regulatory review→ scale up to manufacturing → Post market monitoring

(b) final clinical trials, regulatory review

5 Trying a new drug that has not completed testing and regulation carries a risk that side effects will show up when it is used on a large population. The risk to the population from the disease must be higher than the risk of trying a new drug; there must be no effective treatment that has been tested; and normal disease control measures must be proving ineffective or difficult to implement.

6 For: Students should present arguments clearly considering factors such as the spread and mortality of the disease, problems of the countries affected, etc.

Against: Students should present ethical issues of using untested drugs, not using people as guinea pigs, dangers of untested medicines, etc.

7 Students need to demonstrate understanding of the ethical consideration of using unlicensed treatments, balancing the potential benefits and the risks of unknown side-effects and imprecise treatment plans. Students need to compare and contrast the situation between the circumstance of Sasha and the community in Sierra Leone. Sasha was an individual from a developed country and her treatment was supervised by an expert medical team. The community in Sierra Leone had considerably poorer medical care. Both situations involved a potential fatal infection, with each person deserving the right to the best possible treatment. It would be much easier to get informed consent from an individual rather than across a community.

2.2 Answers to Exam-style questions

1 Award 1 mark for each two correct responses.

Feature	Prokaryotic cell	Eukaryotic cell
Nuclear envelope	×	✓
Cell surface (plasma) membrane	✓	✓
Mitochondria	×	✓
Golgi apparatus	×	✓

2 (a) DNA. Candidates should show evidence that they have considered the ratio of dry mass to number of molecules present, e.g. one molecule (of DNA) has highest dry mass/each molecule (of DNA) represents 1.55% of dry mass/dividing dry mass by number of molecules is greatest (for DNA)/eq.

(Note that this is a 'read the whole question' task, since 'molecular mass' is defined in the first part of the question.)

(b) Any two from:
- glycogen consists of one type of monomer/only glucose/eq;
- a protein consists of up to twenty amino acids/eq;
- amino acids can be arranged in many different sequences/eq.

(c) Any two from:
- reference to any two types of RNA (e.g. mRNA, tRNA, and rRNA);
- idea that each amino acid has a different tRNA/eq;
- idea that different mRNA for each protein produced/eq.

3 Award 1 mark for any two cells correctly completed.

Stage of Gram staining	Appearance of Gram-negative bacteria	Appearance of Gram-positive bacteria
Cells heat fixed onto slide	Colourless	Colourless
Slide flooded with crystal violet	Purple	Purple
Slide flooded with Gram's iodine	Purple	Purple
Slide rinsed with alcohol or acetone	Colourless	Purple
Slide counterstained with safranin/ carbol fuchsin	Pink/red	Purple

4 Award 1 mark for each cell correctly completed.

Feature	λ phage	TMV	HIV
Type on nucleic acid	DNA	RNA	RNA
Shape of protein coat	Complex	Helical	Polyhedral

5 Award 1 mark for each cell correctly completed.

Structure	Type of microorganism
Nucleus	Eukaryote
Capsid	Virus
Flagellum	Eukaryote/Prokaryote
Peptidoglycan (murein) cell wall	Prokaryote

6 (a) (i) Award marks for: circular DNA; small/70S ribosomes.

(ii)

Features present in mitochondria	Feature present (✓) or absent (×) in chloroplasts
Surrounded by a double membrane	✓
Crista present	×
Circular DNA	✓
Matrix	×
Glycogen granule	×
Stalked particles	×

(b) R, S, P, T, Q

Award 4 marks maximum; deduct 1 mark per error.

2.3 Eukaryotic cell division – mitosis

2.3.1 The cell cycle

1 When the cell is not dividing, the chromosomes are very diffuse and the DNA is translucent, so it cannot be seen. As the cell goes into mitosis the chromosomes condense. The DNA molecule winds around positively charged proteins known as histones to form dense clusters, which then coil around each other. These coils form supercoils that produce very dense structures, which will take up stain and become visible under the microscope.

2 Interphase: 38 hours; mitosis: 8 hours; cytokinesis: 2 hours

2.3.2 Mitosis

1 Interphase: stage before mitosis begins when DNA replicates.

Prophase: chromosomes coil and condense so take up stain and become visible as a pair of chromatids held together by a centromere. Nucleolus breaks down and centrioles begin to separate to form a spindle.

Metaphase: nuclear membrane breaks down, spindles formed by centrioles, chromatids line up on equator/metaphase plate of spindle.

Anaphase: centromeres separate and chromatids move to opposite poles along spindle tubules.

Telophase: chromatids reach poles of cell, and are now chromosomes again. Nuclear membrane reforms, cytoplasm begins to divide. Nucleoli reform, centrioles present; two separate cells result.

2 Root tips are particularly suitable because they contain many rapidly dividing cells in growing region. The cells contain no pigment so it is easy to see the stain taken up by the chromosomes. As plant material is used there are no ethical issues.

2.3.3 Asexual reproduction

1 Award marks for students providing as many different examples as possible of common forms of asexual reproduction along with a brief statement of what is involved.

2 Yes, because microorganisms reproduce asexually and there are more of them than any other living organism.

3 It has been thought that asexual reproduction in vertebrates is very rare and an almost freak occurrence. The observation of the same phenomenon in two unrelated females who have shown the ability to breed sexually suggests it is a normal adaptation to isolation from males. Finding that it also occurs in pit vipers suggests that this adaptation (which would be a very advantageous adaptation for many species) may well be fairly common in reptiles who are at risk of isolation. If it occurs in reptiles, it may also occur in other groups such as amphibians, fish and birds, and so parthenogenesis in vertebrates may be far more common than scientists have thought.

2.3.4 Growth and repair

1 Linear dimensions do not necessarily measure true growth;

wet mass: amount of water in cells varies (plants particularly), in animals amount of water drunk, amounts of urine and faeces etc. vary;

dry mass: accurate but involves killing organisms and requires large numbers of genetically identical or very similar organisms, so potentially expensive and ethical issues with animals.

Award marks for any other valid points.

2 Growth involves cell division. Mitosis is the process by which cell division takes place. Growth also requires assimilation of material and cell expansion, which mitosis does not affect.

3 Height is the measurement of the exoskeleton, which increases in limited amounts each time as the exoskeleton hardens after moulting. Mass can increase between moults as more body cells are made within the exoskeleton.

2.3 Answers to Exam-style questions

1 (a) Metaphase occurs after prophase and before anaphase

(b) Award marks for: two chromatids and centromere shown; centromere correctly labelled; chromatids correctly labelled.

(c) Students' answers should include reference to the following:
- (sister) chromatids/centremeres have separated/eq;
- spindle fibres visible between chromosomes/shorter;
- chromosomes are shorter/(in late anaphase) longer;
- groups/clusters of chromosomes towards each pole of cell/eq.

2 (a) (i) Award mark for cell in anaphase correctly identified.

(ii) Award mark for cell in telophase correctly identified.

(iii) Two in every three cells

(b) Students' answers should include reference to the following:
- during prophase chromosomes/chromatids become visible;
- centrioles move to opposite poles (of cell);
- formation of spindle/spindle fibres/microtubules;
- disappearance of nucleolus/nucleoli;
- breaking down of nuclear envelope/membrane (in prophase) or nuclear envelope is broken down by metaphase/eq;
- (at metaphase) chromosomes/centromeres attached to spindle fibres;
- chromosomes/chromatids lined up at equator.

3 (a) Award 3 marks maximum from:
- cell cycle is shorter in A than B/eq;
- interphase/eq is shorter in A than B/eq;
- mitosis/eq is shorter in A than B/eq;
- S phase/eq is the same duration;
- comparative figures.

(b) Award 2 marks maximum from:
- cells preparing to divide/eq;
- reference to S phase;
- reference to replication (of DNA);
- reference to semi-conservative (replication) or a description of it;
- idea that new cells will have same quantity of DNA as parent/eq.

(c) Award 2 marks maximum from:
- chromosomes move to/at opposite poles of cell/eq;
- reference to formation of nucleus/eq;
- reference to formation of cell plate/wall;
- cell splits in two/eq/reference to cytokinesis.

4 (a) (i) Root tip/shoot tip/meristematic tissue/eq; because dividing cells are present/eq.

(ii) Acceptable answers include: acetic/acid orcein/Feulgen's/acetocarmine/Schiff's reagent/ lactoproprionic acid/toluidine blue/eq.

(iii) Students' answers should refer to the idea of getting a single layer/eq of cells.

(b) (i) B; D; A; C

(ii) A: anaphase; C: telophase

2.4 Meiosis and sexual reproduction

2.4.1 Sexual reproduction and meiosis

1 Climate change; introduction of new predator; new disease; shortage of food or water; any other sensible idea. In any situation where conditions change, the majority of organisms are adapted for status quo. Different phenotypic features are needed to survive in changed conditions. Sexual reproduction introduces variety and so an increased possibility that at least some of the offspring will have adaptations that increase the chance of survival in the new situation.

In very stable conditions, asexual reproduction removes any risk of not finding a mate and ensures that advantageous adaptations are passed to offspring.

2

Stage of meiosis	Main events
Prophase 1	Each chromosome appears in the condensed form with two chromatids Homologous pairs of chromatids associate
Metaphase 1	Spindle forms and pairs of chromosomes line up along the metaphase plate Crossing over takes place
Anaphase 1	The centromeres do not divide and pairs of chromatids move to each end of the cell, resulting in a halving of the chromosome number or each new cell
Telophase 1	The nuclear membrane reforms and the cells begin to divide which may continue to full cytokinesis with a brief or even prolonged interphase but no further DNA replication
Metaphase 2	New spindles form and the chromosomes, still made up of pairs of chromatids, line up on the metaphase plate
Anaphase 2	The centromeres now divide and the chromatids move to opposite ends of the cell
Telophase 2	Nuclear envelopes reform; the chromosomes return to their interphase state and this is followed by cytokinesis to give four daughter cells, each with half the chromosome number of the original cell

3 Variety introduced in a number of ways:
- replication of the DNA – scope for errors (mutations) which introduce variety;
- crossing over where internal chromatids cut and rejoined by enzymes, which introduces different arrangements of alleles;
- mutation possible during crossing over when mistakes are made
- random assortment of the chromosomes as the new cells form, which means each gamete contains a different mixture of chromosomes.

2.4.2 Mutations

1 Crossing over is a normal part of meiosis, when chromatids of homologous chromosomes break and rejoin. This introduces variation.

Translocation is a form of chromosome mutation, when parts of non-homologous chromosomes break and join together.

If the translocation is unbalanced it may be incompatible with life.

2 Polysomy – three or more copies of a particular chromosome present in the cells of an individual

Monosomy – only one member of an homologous pair of chromosomes present in an individual

They occur when one of the pairs of chromosomes fails to separate during anaphase II of meiosis, resulting in gametes that have either two copies of a particular chromosome or no copies.

2.4.3 Gametogenesis

1 Gametes carry the genetic information from male and female parents, which joins together to form a new individual.

2 Meiosis introduces variety and reduces the chromosome number by half. In animals meiosis takes place in the ovary and the testis – it takes place constantly in testes throughout life in humans, and it takes place in the ovary every month in the production of mature ova. In ova, meiosis isn't completed unless fertilisation occurs.

In plants meiosis only takes place in the anthers and ovary. It takes place in the formation of pollen grains and ovules, and is followed by a number of mitotic divisions that produce a number of different types of haploid nuclei.

3 Human male gametes: there are many of them, so there is huge wastage as very few reach the fertile ovum; very small as only need to carry genetic material to egg; nucleus contains condensed genetic material so takes up minimum space and needs minimum energy to transport it; long whip-like tail to produce movement and keep sperm in suspension; microtubules of contractile proteins produce whip-like movements of the tail to move the sperm/keep it in suspension; the middle section contains many mitochondria to provide the ATP needed for the movements of the tail; the acrosome contains enzymes, which break down the protective layers around the ovum prior to fertilisation.

4 Female gametes in mammals: these are relatively large compared to male gametes; there are no adaptations for movement as they are moved by cilia in the female reproductive tract; they contain food reserves for the early embryo; they have protective layers around the outside to prevent the penetration of more than one sperm; they contain a single nucleus suspended at metaphase of meiosis 2; meiosis is only completed if fertilisation occurs when haploid chromosomes fuse with haploid sperm nucleus; polar bodies all die at fertilisation.

Female gametes in plants: they are large compared to male gametes, which are simply nuclei within pollen grain; they contain no food stores for embryo – these form later after fertilisation; they contain a number of different nuclei, which fuse with pollen nuclei to form the embryo but also to form the endosperm; they attach to the wall of the ovary to allow the seed to develop securely once the ovule is fertilised.

2.4.4 Fertilisation in mammals and plants

1 (a) External fertilisation of gametes: huge numbers of male and female gametes to maximise chances of fertilisation; living in water; courtship rituals to ensure that male and female gametes are released close to each other to maximise chances of fertilisation.

(b) Internal fertilisation: often fewer female gametes than male; method for transfer of male gametes to female – either courtship rituals, packages of sperm or courtship/mating; male sex organ for placing sperm inside female when mating employed.

2 It ensures that pollen grains only germinate when on the stigma of the same species of plant, and often only when on a different plant than that from which they originated. This helps to ensure variety, but also that there isn't cross fertilisation, which would waste both pollen and ovule if they were from different species. If the pollen grain does not develop when it is on a different species, the ovule is still available to be fertilised, and this is to the advantage of the species as a whole.

3 (a) Mammals: enzymes in mitochondria release energy for the movement of the tails of the sperm; enzymes in the head of the sperm (acrosome) digest away the protective follicle cells and zona pellucida around the ovum to allow a sperm to penetrate.

(b) Plants: hydrolytic enzymes in the pollen tube break down the stigma and digest the tissues of the style and ovary to allow the pollen tube to penetrate the ovule.

4 Polyspermy is prevented initially by the opening and closing of various ion channels in the membrane, so that ions move to make the inside of the ovum positive with respect to the outside rather than negative. This repels the entry of further sperm. Then a tough fertilisation membrane forms around the fertilised ovum to completely block the entry of other sperm. If more than one sperm entered the ovum, it would become triploid or polyploid and unviable, so that an embryo would not develop, or if development started the embryo would die and not develop. This would waste the resources put into the egg and the sperm, and would waste an opportunity for successful reproduction on both the individual and the species level.

2.4.5 Embryo development in mammals

1 Totipotency is the potential to form all known cell types in an organism. Animal cells are totipotent in the earliest embryo cells; plant cells remain totipotent throughout life.

Pluripotency is the potential to form most of the cell types needed in an organism. Animal cells are pluripotent slightly later in embryo development.

2 Embryo transfer takes place 2–3 days after fertilisation of the eggs when there are four to eight cells. Up to three embryos may be transferred at a time. There is a risk they will not implant.

Blastocyst transfer takes place after around 5 days, when the embryo is a hollow ball of cells – this is the stage the blastocyst would implant in a natural pregnancy. It is harder to culture embryos to this stage, so only the strongest survive; these are more likely to implant so fewer are transferred, reducing the risk of multiple pregnancies. However, sometimes no embryos develop to the blastocyst stage.

2.4 Answers to Exam-style questions

1 (a) Students' answers should include reference to:
- insect;
- large petals/coloured petals;
- scent/nectar/nectary;
- to attract insects;
- position of anthers;
- position of stigma.

(b) Growth rate: increased (from 30) to 90 minutes; decreased from 90 (to 180) minutes; reached a maximum/peak at 90 minutes. Credit manipulated quantitative comments, i.e. the student has carried out a correct calculation on the data.

2 (a) Order of stages: E, D, C, B, A. Award 2 marks if all correct; lose 1 mark for each letter incorrect.

(b) (i) 46

(ii) 23

(c) Students' answers should include reference to:
- primordial (germ) cells/oogonia divide by mitosis;
- oogonia (develop to) form primary oocytes;
- primary oocytes divide by meioisis 1;
- to form a secondary oocyte;
- and a polar body;
- secondary oocyte divides by meiosis 2;
- to form an ovum.

3 Answers are shown in **bold** below:

During spermatogenesis, a diploid cell called a **primary spermatocyte** divides in meiosis 1 to form two **secondary spermatocytes**. Each of these then divides in meiosis 2, forming four haploid **spermatids**, which mature into spermatozoa.

The random fusion of gametes during fertilisation is one way in which **genetic** variation is increased.

4 (a) Students' answers should refer to: transfer/eq of pollen (grains); (from an anther) to a stigma/eq.

(b) (i) Award marks for the following:
- 90 (mean length at 12 hours) – 45 (mean length at 6 hours) or 45;
- ÷ 6 (to get the 'per hour'; 6 hours have elapsed between 6 hours and 12 hours);
- = 7.5 (units not needed).

(ii) Award marks for any two points from:
- (with boron) pollen tubes grow faster/longer/eq;
- (with boron) keep growing/no levelling off AND (without boron) stops growing/levels off/eq;
- manipulated quantitative comparison, e.g. at the end of experiment, pollen tubes are 3 times longer.

5 (a) (i) A= acrosome; B = flagellum;

(ii) Award marks for any two points from:
- has 23/half the (required) chromosome complement;
- (so at fertilisation) full complement/46 (of chromosomes) is restored/diploid number restored/eq;
- correct reference to allowing mixing of alleles/allowing for genetic variation/eq.

(iii) Award marks for any three points from:
- idea of jelly layer/eq hydrolysed;
- sperm nucleus/eq enters the egg cell/egg cell membrane penetrated (by sperm)/eq;
- reference to meiosis completes/eq;
- cortical granules/vesicles/eq (in egg) move towards/fuse with egg cell surface membrane;
- release contents/enzymes;
- zona pellucida hardens/eq;
- to prevent polyspermy/eq;
- egg nucleus envelope breaks down/eq;
- spindle forms/eq.

(b) (i) Award up to 2 marks for:
- length increases between 15 °C and 30 °C;
- decreases after 30 °C;
- correct manipulation of the data.

(ii) Award up to 2 marks for any three points from:
- mean pollen tube length increases as temperature increases (from 15 °C) to 30 °C for both;
- variety B has a greater mean pollen tube length than A (up to 30 °C)/allow converse;
- both have longest length/maximum length at 30 °C;
- correct comparative manipulation of the data, e.g. mean pollen tube length is 50% more for cotton variety B at 30 °C.

(iii) Possible answers include: pollen tube dies/enzyme(s) denature/eq.

3.1 Classification

3.1.1 Principles of classification

1 To give scientists a universal naming system so people of all languages know what organism is being discussed, and to make it possible to quantify biodiversity.

2 Students may organise diagrams differently but should show the following relationships:
Domain → Kingdom → Phylum/division (plants) → Class → Order → Family → Genus → Species

3 Domestic cat: Eukaryota Animalia; Chordata; Mammalia; Carnivora; Felidae; Felis; catus: *Felis catus*
Maize: Eukaryota plantae; Aniospermophyta; Monocotyledoneae; Commelinales; Poaceae; Zea; mays: *Zea mays*
Honeybee: Eukaryota; Animalia; Arthropoda; Insecta; Hymenoptera; Apidae; Apis; mellifera: *Apis mellifera*
Human being: Eukaryota; Animalia; Chordata; Mammalia; Primates; Hominidae; Homo; sapiens: *Homo sapiens*

3.1.2 What is a species?

1 To measure genetic diversity, to identify relationships between different species, to track the process of evolution, to monitor effects of human activities, etc.

2 Classic morphology: advantage – easy to see and measure differences; difficulty – visible differences don't always indicate different species, or lack of visible differences doesn't mean they are the same species.
Reproductive capability: advantage – successful breeding with fertile offspring is unequivocal in animals if it occurs; difficulty – can be very difficult to get evidence, particularly in slow-breeding organisms and those that live in different localities, different species of plants often crossbreed and produce fertile offspring.
Award marks for any other valid points.

3.1.3 Identifying individual species

1 DNA evidence is incontrovertible and is showing up unexpected relationships between species. Some organisms that look very similar are shown to be different species, while some organisms that look different in different environments turn out to be the same species. DNA evidence allows accurate definitions of species, including comparison of old specimens.

2 The development of the software and computing tools including the development of algorithms, mathematical models and statistical tests to organise and analyse the large amounts of raw biological data now being generated.

3 Because they are present in a wide range of different organisms, and so they can be compared. The genes mutate at a measurable and suitable rate, which allows the time since even relatively closely related organisms shared the same genes to be calculated.

3.1.4 New evidence for evolution

1 (a) Fossil evidence is limited as only a relatively small number of organisms have been fossilised and only a small number of fossils are found, many of which are not fully intact. There may also be similarities due to convergent evolution. Accept any other valid points.

(b) DNA starts to degrade immediately after death so this limits the validity. Mutation rates of different genes vary considerably so establishing a timeline can be very different depending on which gene is used.

(c) Evidence from any one source has limitations and potential inaccuracies that reduce its validity. If evidence from different sources gives similar results, the more valid are any conclusions drawn. Similarly, using different sources can show up discrepancies and prevent time and money being wasted on erroneous date. Any other valid point.

2 The answer should include some or all of the following points. Other points may be valid.
Publications and conferences help to validate new research by presenting it to peers for constructive criticism. When several teams produce similar results in relevant research, the validity of all their findings is confirmed. New ideas are aired and this stimulates discussion and debate, which enables cooperative research ventures to be created and different techniques to be exchanged.

3 The peer review process helps to validate new research as experts in the same field of research ensure that the techniques, results and conclusions are presented with sufficient detail to allow other scientists to repeat their research to test reliability. However the pressure to publish can influence scientists to release their research too early, or skew their results towards more positive outcomes. Student's own example of failed peer review.

3.1.5 Domains, kingdoms or both?

1 Molecular phylogeny involves analysing the DNA, RNA and other chemicals in organisms which may appear similar or very different. This analysis can be used to demonstrate genetic diversity between apparently similar organisms, or it may reveal surprising similarities.

2 (a) Gel electrophoresis is used to discover patterns in the DNA and RNA or organisms and to determine the exact amino acids involved in proteins. This enables us to build up relationships between organisms by comparing exact protein structures, e.g. haemoglobin, across a wide range of species and finding patterns in the DNA and RNA that show how closely related or far apart two species are by the similarities in their DNA bar codes, etc.

(b) Huge amounts of data can now be collected about DNA, RNA and protein structures in many different types of organisms and many different examples of the same species. Millions of base pairs are analysed in the breakdown of the genome of a single organism. Bioinformatics enables us to make sense of all of the data that is generated and spot patterns that would take years of work by humans alone.

3 There is a lot of different evidence that can be interpreted in different ways. Not all of the evidence supports all of the theories: fossil evidence and DNA evidence may point in different directions, for example; it depends on what you are looking for, what you are trying to prove, how you interpret data, etc.

Students may find evidence from the Natural History Museum and others that scientists are beginning to think there should only be two domains – Archaea and Bacteria – with Eukaryotes and a branch of the Archaea that include some Bacteria. They may use the similarities and differences between Bacteria, Archaea and Eukaryote to discuss the problems of deciding which is more closely related. Any sensible discussion, and evidence of reading around the subject, should be credited.

4 The development of the three-domain system made the old five kingdom classification system redundant because the prokaryotes were in two domains, destroying the old kingdom of the Monera and demanding a six kingdom classification system. Students may find evidence from the Natural History Museum and other sources that scientists are beginning to think there should only be two domains – Archaea and Bacteria – with Eukaryotes and a branch of the Archaea that includes some Bacteria.

3.1 Answers to Exam-style questions

1 (a) Prokaryote/Monera

(b) Pick two from: cell wall, capsule, flagellum, ribosome, pilus/pili, mesosome, plasmid, cell membrane.

(c) Any two from:
- DNA/RNA/nucleic acid
- organic molecules/proteins/enzymes/glycoprotein/reverse transcriptase.

(d) Possible answers include:
- new knowledge/eq;
- some organisms fit into more than one/do not quite fit (particular) groups/eq;
- people decide taxonomy;
- reference to appropriate examples that are difficult to classify, e.g. Archaebacteria.

2 (a) Eukarya/Eukaryote; Archaea; Bacteria

(b) Award marks for any two from:
- idea that the species is reproductively isolated;
- produce offspring that are sexually viable/fertile/eq;
- many features in common/reference to homologous.

3 (a) (i) C (Q and R)

(ii) B (Q)

(iii) Students should place a cross in the far right box.

(iv) Accept any one from: Bacteria/Eubacteria/Archaebacteria/Archaea.

(b) (i) (QWC – Spelling of technical terms must be correct and the answer must be organised in a logical sequence). Answer should include the following terms: cellulose; as microfibrils; cellulose molecules held together by hydrogen bonds; details of microfibrils (e.g. bundle /correct stated number of cellulose molecules); correct reference to arrangement of microfibrils (in primary cell wall); reference to matrix / hemicelluloses / pectins; reference to primary and secondary cell walls ; detail of different laying down arrangement (in secondary cell wall) /reference to lignin.

(ii)

Feature described	Name of feature
Site where there was no cell wall and the cytoplasm linked the two adjacent cells	plasmodesmata / plasmodesma ;
Dark line that is the boundary between one cell and the next cell	middle lamella ;

4 (a) (i) C; because mitochondria are present (and only Eukaryota possess mitochondria)

(ii) B; because it has more/most/three/any two named characteristics in common (with the eukaryotes/Group C) OR due to the idea that because A is sensitive to antibiotics, A must be Bacteria therefore B is Archaea/eq.

(b) (i) Students' answers should include reference to the following:
- stacks/eq;
- cisternae;
- smooth membranes/no ribosomes/eq;
- (cisternae) curved/flattened;
- idea of different sizes (cisternae);
- presence of vesicles.

(ii) Award up to 5 marks for the following points:
- protein/polypeptides produced by ribosome;
- ribosomes held on/attached to/eq rER;
- proteins stored/transported/within rER/eq;
- proteins folded/assume 3-D shape/tertiary structure within (lumen of) rER/eq;
- (rER) produce vesicles/packages proteins/eq;
- vesicles fuse with Golgi (apparatus)/eq;
- Golgi modifies/processes protein;
- details of modification, e.g. glycoprotein/carbohydrate added, trimming of carbohydrate;
- water removed (to concentrate)/eq;
- Golgi produces lysosomes/secretory vesicles.

Also award up to 1 mark for QWC – the spelling of technical terms must be correct and the answer must be organised in a logical sequence.

5 (a) C (Archaea, Bacteria and Eukarya)

(b) (i) Any two from:
- published in a scientific paper/journal/scientific magazine/eq (do not accept online, internet)
- at a conference/presentation/eq.

(ii) Award up to 2 marks for: idea of peer review; idea of repeating experiments to confirm or validate findings; an indication of further testing being carried out.

(iii) Students' answers should include reference to the following ideas:
- organisms with specific/particular/shared/common/similar/eq characteristics/features/traits/eq are placed in a group;
- taxonomic groups have specific differences;
- phylogeny describes evolutionary/genetic relationship;
- molecular phylogeny based on similarities in DNA/DNA sequence/proteins/eq (do not accept gene sequence).

3.2 Natural selection

3.2.1 Evolution and adaptation

1 Award marks for the following points:
- Summary of Darwin, for example evolution is a change in a population of organisms over several generations, as a result of natural selection acting upon variation, bringing about adaptations and in some cases leading to the development of new species. Limited by the knowledge of the time – no understanding of genetics or awareness of DNA.
- Modern version of the theory, e.g. the evolution of organisms occurs as a result of the differential fertility and survival of organisms with different genotypes (genetic variation) leading to different phenotypes within a specific environment. Those alleles that deliver the adaptations best suited to the environment are most likely to be passed on to the next generation.
- Consideration of the fact that the modern version takes in to account knowledge of DNA, genes, alleles, variants and also recognises that differential fertility is important – not simply that less well adapted organisms die out, but they are simply less successful in reproduction.

Award marks for any other valid points.

2 In their discussion students should:
- provide a definition of adaptation, e.g. a characteristic of an organism that makes it particularly well adapted to a niche, increasing the chances of survival and successful reproduction;
- describe different types of adaptations, e.g. anatomical (involving form and structure), physiological (involving how the body works) and behavioural;
- demonstrate understanding that these do not act in a vacuum, e.g. anatomical and physiological adaptations work often together and – as in diving animals – may produce a behavioural response.

3 A niche is the way an organism lives, including what it eats, whether it moves, etc. To be successful (i.e. grow and produce offspring) the organism needs to be well adapted to the conditions around it, and therefore its niche, so that it can find food and a mate.

4 (a) Time before the dive

(b) Approximately 4.5 minutes

(c) $\frac{160 - 20}{160} \times 100\%$ = c. 88%; without bradycardia = 4.5 min × 12% = c. 32 seconds

(d) It is a physiological adaptation – which enables the seal to stay underwater and hunt for food in a harsh environment where food is scarce, giving it a survival advantage over animals that do not have this bradycardic response.

5 More efficient hunting means that they get enough food to eat but in less time so that they are submerged in the cold water for as short a time as possible. They therefore minimise the energy they lose through hunting, so need to catch no more food than less efficient birds in warmer waters.

3.2.2 Natural selection in action

1 Changes in a niche or habitat may favour individuals with different adaptations to those that had been successful. Individuals with these different adaptations will survive and breed more successfully than individuals without them. So more individuals in later generations will show these adaptations as the allele frequency changes; over time the species will be seen to change.

2 The greatest decline was over two years. It took about 15 years for the dominant allele to become sufficiently dominant for the population numbers to begin to recover.

The change in the niche was the arrival of the disease; the adaptation was the increase in proportion of the population that was resistant to the disease.

3 Award marks for the quality of students' research findings.

3.2.3 The evolutionary race between pathogens and medicines

1 If a mutation gives a bacterium a new feature such as resistance to an antibiotic, or a slime capsule so it is less easily detected by the host immune system, or the ability to survive on a minimum medium (give credit for more than one example) then that bacterium will be at an advantage in specific conditions and will be more likely to reproduce and pass on the advantageous mutation.

2 Population of bacteria are susceptible to an antibiotic. Population contains random mutations → exposure to antibiotic A → most bacteria killed by antibiotic – small number of mutants survive as well as small number of normal genotypes by chance → grow and divide → new population has a higher proportion of resistant bacteria → exposed to antibiotic again → only resistant bacteria survive → now resistant to antibiotic A (apart from odd mutants → if exposed to another antibiotic the cycle repeats to build multiple resistance

3 (a) Over prescribing contributes to the development of resistance as bacteria meet antibiotics more regularly. The more frequently bacteria meet antibiotics the more likely they are to develop resistance. Using antibiotics unnecessarily increases this risk. It also tends to increase the variety of antibiotics bacteria are exposed to, raising the chance of multiple resistances.

(b) If individuals do not complete a course, bacteria with slight resistance to the antibiotic, which would be killed by the full course, will survive. They already have genes building resistance, so they are more likely to survive a second exposure to the drug. If the patient completed the course, all of the bacteria would be destroyed or inhibited and the allele for resistance would die out in that population.

4 A test that would a) confirm if an infection was bacterial or viral and b) confirm the type of bacterium would greatly reduce the development of antibiotic resistance. No antibiotics would be prescribed for viral diseases, avoiding the risk of exposing bacteria in the body to antibiotics unnecessarily, and when antibiotics were prescribed they would be the right one that would wipe out all the bacteria, so pockets of resistant bacteria would not survive.

3.2.4 Speciation

1 (a) Allopatric: geographical isolation, ecological isolation (could also include others while the groups are separated)

(b) Sympatric: seasonal isolation, behavioural isolation, mechanical isolation

2 Adaptive radiation takes place when one species evolves relatively rapidly to fill a number of niches; it increases the species richness considerably but not necessarily the genetic diversity.

3 They are genetically similar because they have all evolved from one ancestral species.

They are morphologically different because the selection pressure has been bill size and shape to increase success in different feeding strategies.

4 Sympatric speciation: fish have all evolved from a common ancestor by occupying different niches and becoming isolated through feeding in different places, different times when their food is at a peak, reproductive behaviour, etc., in several small lakes such as Lake Barombi MBo.

Allopatric: DNA evidence shows fish have common ancestors before lakes became separated, e.g. Lake Barombin Mbo has 11 species of cichlid with the closest relative the only cichlid found in streams surrounding the lake; this suggests in a flood season ancestors made it into the lake followed by adaptive radiation.

Award marks for any other valid points and examples.

5 They are geographically isolated but were at some point linked. They have a great variety of habitats. So the fish in all the lakes appear to have had common ancestors but have evolved independently in the different lakes for similar habitats.

3.2 Answers to Exam-style questions

1 (a) 63 chromosomes

Also award up to 2 additional marks from the following three marking points:
- cannot form gametes/eq;
- (because) chromosome pairing not possible/eq;
- during meiosis/eq.

(b) Isolating mechanisms prevent interbreeding (between species/populations)/barrier to reproduction/eq.

Also award up to 2 additional marks for: postzygotic mechanisms allow mating/fertilisation/eq; but prevent production of viable/fertile offspring/prevent offspring developing/eq.

(c) Award up to 2 marks for: idea that species is group of organisms that can interbreed to produce fertile offspring/eq; but mule is sterile/cannot produce offspring.

2 (a) (biotype) B

(b) Award up to 4 marks for the following points:
- populations of biotype A and B are separated by behavioural/reproductive/physiological isolation;
- isolation described, e.g. mate at different times;
- no gene flow between the populations/each population genetically isolated;
- natural selection described, e.g. biotype B flies with the gene for resistance to insecticide;
- the two gene pools become different/eq;
- reference to sympatric speciation.

(c) Reference to resistance to insecticides; no contamination (by chemicals); no need to reapply / it is longer lasting / reference to resurgence; correct reference to specificity of control; reference to organic status.

3 (a) Award up to 3 marks for the following points:
- male fish have unique DNA;
- they inherit DNA from male parent/eq;
- they share DNA fingerprint characteristics/eq;
- this doesn't change during lifetime/eq;
- reference to microsatellites/restriction enzymes cut DNA predictably.

(b) (i) $\frac{1.63}{68} \times 100$; OR 42.6 + 38.2 + 11.8

Accept the following percentages: 92.6% / 92.64% / 92.65% / 93%

(ii) Answers should include reference to:
- all females are more likely to mate with a male from the same population/eq;
- population A exclusively mates within the same population;
- populations B and/or C will breed with each other;
- limitations in data (e.g. small sample size in population C).

(c) Award up to 4 marks for reference to the following:
- definition of a species;
- all mating within population/eq;
- reproductive isolation;
- no gene flow;
- accumulation of differences/changes;
- more likely to become genetically different.

4 (a) Award up to 3 marks for the following:
- idea that individuals of a species can interbreed/eq;
- to produce fertile offspring/eq;
- the hybrids/offspring can flower and produce viable seeds/eq.

(b) (i) Award up to 2 marks for: variety/eq of alleles; in a gene pool/eq.

(ii) Different alleles in each of the two populations; each population / species is adapted to live in different environmental conditions / at different altitudes; there will have been different mutations in each population; reference to alleles from different species will mix.

(c) Award up to 6 marks for the following points:
- different alleles in each of the two populations/eq;
- each population/species is adapted to live in different environmental conditions/at different altitudes/eq;
- there will have been different mutations in each population;
- reference to alleles from different species/eq will mix/hybrids receive alleles from both species/eq.

3.3 Biodiversity

3.3.1 The importance of biodiversity

1 Because it doesn't take into account the genetic variation in populations, which is also important.

2

Species	**Number of organisms collected (n)**	**($n - 1$)**	**$n(n - 1)$**
holly	9	8	$9 \times 8 = 72$
bramble	3	2	$3 \times 2 = 6$
oak	3	2	$3 \times 2 = 6$
butcher's broom	5	4	$5 \times 4 = 20$
ivy	3	2	$3 \times 2 = 6$
yew	1	0	$1 \times 0 = 0$
Total	**24**		$72 + 6 + 6 + 20 + 6 + 0 =$ **110**

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

Using the data from the table:

$N = 24$ $\quad N - 1 = 23$ $\quad \sum n(n-1) = 110$

$$D = \frac{24 \times 23}{110} = \frac{552}{110} = 5.02 \text{ (to 2 d.p.)}$$

Diversity index = 5.02, which is relatively high.

3 High bird biodiversity means a large number of different species; high endemism means a large number of species that evolved in that place. High biodiversity may be the result of high endemism, but it may also be due to bird species from other areas moving into the area. An area of high endemism may only include a few species of bird that evolved in situ and not a large number of different species, as on islands, which might explain the high levels of endemism on the Indonesian islands which are not areas of high species-richness.

3.3.2 Biodiversity within a species

1 All of the different types of brassicas result from selective breeding of particular alleles that were already present in the original wild brassica species, so they had that level of genetic diversity even though it wasn't usually expressed.

2 The number of species and the amount of genetic variation within species are both important. The number of different species and the number of individuals of each species is key information for understanding an ecosystem and how it can best be conserved. However, genetic diversity is also important – it gives an indication of how robust a species will be at surviving changes. Using both measures is the best way to understand biodiversity.

Award marks for any other valid points and clear examples.

3.3.3 Ecosystem services

1 Award marks for any two ethical arguments, e.g. the importance of maintaining the beauty of the natural world for future generations; it is wrong to cause the extinction of a species that cannot be restored to life.

2 (a) Ecosystem services are services provided by the natural environment that bring benefit to people.

(b) Provisioning services: provide us with the things we need, e.g. cereal plants provide food (award marks for any other clear example)

Regulating services: processes that help to regulate the environment, e.g. trees act as carbon sinks

Supporting services: support vital processes such as soil formation or nutrient cycling in the environment to encourage the growth of food crops to feed people

Cultural services: support human culture and well being, e.g. national parks

3 Governments rarely do anything for goodness; there needs to be concrete benefit. If politicians can be made to see the benefits of ecosystem services to the economy, to the health and well-being of the population and to life in general, they are more likely to enact laws that protect the environment and maintain biodiversity at local and global levels.

3.3.4 Ex-situ and in-situ conversation

1 Conservation involves keeping and protecting a living and changing environment – it is dynamic and encompasses change, whereas preservation is static and keeps things exactly the same.

2 (a) In situ conservation takes place in the natural habitat of the organism; ex situ conservation is the conservation of living organisms away from their natural habitat – often in a different country

(b) Students should make reference to the following points:

- organisms can be removed from breeding in a safer environment and then returned to the wild to support the organism being conserved in situ
- ex situ conservation can increase the gene pool of a dwindling wild population
- ex situ conservation can keep the numbers going until such time as in situ conservation is viable.

3 Plants can be conserved as seeds. Plants make many seeds so collecting a few does not harm population numbers. When cooled and dried, most seeds will last several hundred years. If not seeds, tissue cultures can be conserved that will produce more plants when desired. These techniques do not take up much space and are not very expensive.

Animals are much harder to conserve. DNA is being conserved but so far we have no way of bringing that back into being a living animal. Conserving and breeding whole animals is very expensive, takes up a lot of space and is very time consuming.

Award marks for any other sensible points; there are many.

4 Advantages:
- helps save some of the rarest animals and plants;
- some species have been saved from extinction and returned to the wild;
- genetic variety can be maintained as much as possible to support captive breeding and wild populations.

Disadvantages:
- ecosystems once lost may never be restored – animals may never have somewhere to return to so reintroduction to the wild becomes impossible;
- animals are expensive to keep;
- it is difficult to provide the right conditions for breeding;
- animals bred and fed in captivity may be unable to adapt to life in the wild;
- expensive reintroduction programmes may fail.

Award marks for any other sensible points.

3.3 Answers to Exam-style questions

1 (a) (i) A

(ii) C

(iii) D; then accept any two reasons from:
- idea that endemic means species restricted to one (geographical) area;
- a species/flag shape only present in (Area D/Box 4);
- all other shapes appear in at least one other box/more than one area.

(b) (QWC – Spelling of technical terms must be correct and the answer must be organised in a logical sequence). General points include: to increase numbers/population size; to maintain / increase genetic diversity or reduce genetic drift; protect from predators / poachers; For captive breeding; inter-zoo animal movement; selection of mates / use of stud books / records kept of breeding programme; process involved described e.g. IVF / AI / use of surrogates / DNA profiling; For reintroduction: preparation for reintroduction described e.g. idea of reinforcing wild behaviour / idea of hacking out / reduce food intake to encourage hunting ; select habitat / reserves; raise awareness/educate of local population.

2 (a) (i) A; then accept any two reasons from:
- height controlled by many/eq genes/polygenic inheritance/eq;
- reference to continuous variation;
- reference to normal distribution/eq.

(ii) Any two from:
- water/humidity;
- light;
- minerals/soil type/pH;
- CO_2;
- temperature;
- altitude.

(b) (i) height of bar must be at 50, i.e. 2½ little squares above 40

(ii) Any two from:
- height (of yarrow plant) decreases (as altitude increases);
- non-linear/eq;
- correct manipulation of the data.

(c) (i) No change in/same height of plants at 700 m/reached their maximum height (of 50 cm)/eq

(ii) Decrease in/lower/different height of plants at 3000 m/25 cm at 3000 m and 50 cm at 700 m/eq

(iii) Removal of genetic variation/they are all genetically identical/eq

(iv) To act as a control/to see if there is a difference at the other heights/as a comparison/to check that the clones grow the same as the parent plants/eq

3 (a) (i) Award: 1 mark for each total (up to 3 max); 1 mark for correct $n - 1$; 1 mark for correct $n(n - 1)$

Species	Number of plants growing in 0.25 m^2 quadrat (n)	$n - 1$	$n(n - 1)$
Daisy (Bellis perennis)	2000	1999	3 998 000
Dandelion (Taraxacum officinale)	3000	2999	8 997 000
Red clover (Trifolium pratense)	3500	3499	12 246 500
Yarrow (Achillea millefolium)	2000	1999	3 998 000
Grass (Agrostis spp)	4000	3999	15 996 000
Grass (Festuca spp)	4500	4499	20 245 500
Bee Orchid (Ophrys apifera)	1	0	0
Totals	19 001	18 994	65 481 000

(ii) Award:

- 1 mark for the equation $\frac{N(N-1)}{[\Sigma n(n-1)]}$
- 1 mark correct substitution $\frac{19\,001 \times 19\,000}{(65\,481\,000)}$
- 1 mark correct resolution $\frac{5.51}{5.5}$.

(b) (i) Answers should include reference to:

- to get a representative sample (of plants in area);
- to ensure rarities (plants that appear in just one quadrat) are put into context/to avoid unbalancing overall pattern.

(ii) When calculating Simpson's Diversity, the 'n – 1' part of the calculation removes this one Bee Orchid from the calculation.

(c) (i) Answers should include reference to the following:

- dandelion numbers decreased/all died;
- because the selective pesticide kills them as they are broad leafed plants;
- grass plants increase in number;

plus one from:

- because there is less competition for correct *named* abiotic factor (light, water, minerals, space);
- grass plants have narrower leaves and are less affected by the herbicide.

(ii) More grass plants *and* less broad leaved plants; therefore *lower* biodiversity (2.26 is less than 5.5).

(Note: There are many ways of calculating Simpson's Index. The way in the specification goes from low numbers (= low biodiversity) to high numbers (= high biodiversity). Other methods do exist including $D = \Sigma\left(\frac{n}{N}\right)^2$. This last method goes from 0 to 1, where (confusingly) 1 means *low* biodiversity, and smaller numbers means *high* biodiversity. It's important to know which Simpson's Index you're using!)

4.1 Cell transport mechanisms

4.1.1 Transport in cells

1 Cells need a supply of glucose and oxygen for respiration. They need waste products including carbon dioxide removing. They need raw materials for synthesis and they need compounds produced removing. So they need mechanisms to move materials into and out of and around the cell.

2 Phospholipids make up the main bilayer of the membrane, separating an aqueous layer on one side from an aqueous layer on the other by a hydrophobic region, which makes diffusion difficult for substances that are not lipid-soluble or very small. However, this structure allows the passage of lipid soluble molecules and very small molecules, e.g. gases such as oxygen and carbon dioxide.

Large proteins that sit within or across the membrane allow the passage of ionic and larger molecules across the membrane. They also act as controls or gates so they can allow or prevent the entry or exit of substances as required.

Glycoproteins on the outside of the membrane are part of the cell recognition system that enables some substances to find the cell and to cause changes inside the cell, or open channels in the membrane, even if they are not directly taken in.

Accept any other valid point.

4.1.2 Diffusion and facilitated diffusion

1 The molecules need to be able to cross the membrane, and there needs to be a concentration gradient for those molecules from one side of the membrane to the other.

2 Water can't pass across the hydrophobic region in the middle of the membrane, and ions are not lipid-soluble.

3 Simple diffusion is through the lipid part of the membrane, so can happen at any part of the membrane. Facilitated diffusion can only happen where there are suitable carriers in the membrane.

4.1.3 Osmosis – a special case of diffusion

1 Students' definitions must include wording that covers the net movement of water/across a partially permeable membrane/by diffusion/down a water concentration gradient, with suitable examples chosen.

2 Isotonic: there would be no change to the cells because as many water molecules would diffuse into the cells from the solution as in the opposite direction.

Hypotonic: the cytoplasm of the cells is more concentrated than the solution outside the cells, so more water molecules would diffuse into the cells than out of them, and the cells would swell up and possibly burst.

Hypertonic: the cytoplasm of the cells is more dilute than the solution outside the cells, so more water molecules will diffuse out of the cells than into them, so the cells would shrink.

3 Students need to demonstrate clear understanding of what turgor is, the role of osmosis in maintaining turgor in plant cells, and the importance of tugor in the normal functioning of the cells and of the plant as a whole. Award credit for any extra understanding based on research including the use of turgor in stomatal opening and closing, the role of turgor in plant growth, role of turgor/wilting in plant survival strategies, etc.

4.1.4 Active transport

1 Active transport makes it possible to take in substances across the cell membrane against a concentration gradient, when diffusion would be impossible. It can also move substances that could not otherwise pass through the membrane.

2 ATP provides the energy needed for active transport. The carrier protein may need ATP to move a substance through the membrane, or to return to the original position. The enzyme ATPase is associated with active transport sites in the cell membrane.

3 Endocytosis and exocytosis involve the breaking and fusing of parts of the cell membrane. This is only possible because the membrane is fluid.

4.1 Answers to Exam-style questions

1 (a) Students' answers should include:
- reference to fluid mosaic structure;
- reference to phospholipid bilayer;
- phosphate/heads pointing outwards/eq;
- (fatty acid) tails pointing inwards/eq;
- reference to proteins;
- reference to intrinsic/extrinsic/channel/enzyme/eq protein;
- reference to cholesterol (within bilayer);
- reference to glycocalyx/eq.

(b) (i) Students' answers should include:
- A is the most and D is the least likely to cross/eq;
- reference to same ability of B and C to cross membrane;
- manipulation of permeability figures to quantify one of the above points.

(ii) Students' answers should include:
- substance A has a high (oil-water partition) coefficient/eq;
- therefore can dissolve in the lipid portion of the membrane/(phospholipid) bilayer;
- (more specifically) dissolves in the inner part of bilayer/hydrophobic region of bilayer/fatty acids;
- (can then pass through) by diffusion.

2 (a) Students' answers should include:
- fatty acids/tails are hydrophobic/non-polar;
- so orientate themselves away from water/polar environment/eq;
- phosphate/heads are hydrophilic/polar;
- so can interact with water/polar environment/eq;
- reference to cytoplasm/tissue fluid/eq as the polar environment.

(b) (i) Any two from: temperature, surface area/volume (of beetroot), part, age, variety, storage, source, volume of ethanol, same wavelength/filter.

(ii) Students' answers should include the following points:
- cells/membranes/eq damaged (by cutting up of pieces)/eq;
- (as a result pigment) could leak out of vacuoles/cells.

(iii) Rinse pieces (thoroughly)/dab pieces dry/eq

(c) (i) Increased ethanol concentrations, increases intensity/eq

(ii) Students' answers should include:
- reference to disruption/eq of membrane;
- ethanol is a (non–polar/organic) solvent;
- idea that lipids/eq dissolve (in alcohol);
- idea that increase in ethanol causes solution to be less polar;
- idea that orientation of phospholipids depends on water around it.

3 (a) Answers are shown in **bold** below.

Some molecules move across a cell surface membrane by passing down a concentration gradient, through the phospholipid bilayer. The movement of some polar molecules across the membrane involves carrier and channel **protein/glycoprotein** molecules. When this movement occurs down a concentration gradient, the process is called **facilitated diffusion** and when it occurs against a concentration gradient the process is called **active transport**/eq. Energy in the form of **ATP/adenosine triphosphate** is used in the movement of molecules against a concentration gradient.

(b) (i) Award marks for:

- $\frac{(77-70)}{77}$;

correct division by 77 (multiplied by 100) to give correct answer, e.g. 9.1 or 9.09 (ii) Students' answers should include:

EITHER:

- idea that not all of the juice/sugar washed off/idea that the strawberries were not dried after rinsing properly/idea that some water reabsorbed (during washing);
- loss of mass of strawberries not as high as it should have been/eq;
- (%) value too small/eq;

OR:

- idea that strawberry tissue/juice lost because washing too vigorous/tissue stuck to towel when drying/squeezing strawberries/juice absorbed from strawberries/water lost through evaporation/eq;
- loss of mass of strawberries higher than it should have been/eq;
- (%) value too high/eq.

(iii) Students' answers should include the following points:

- correct reference to water gradient (between sugar and strawberries);
- reference to osmosis (of water from inside of strawberry to outside);
- idea that water is found in cytoplasm/vacuoles (of strawberry);
- reference to water as a solvent (for the sugar);
- reference to (di)polar nature of water/eq.

4 (a) Students' answers should include the following points:

- rate is same for up to 30 minutes/eq;
- faster (uptake) for A than B/eq;
- (uptake of) A is linear throughout whereas (uptake of) B is not/eq;
- uptake of substance B levels off at 2.0 to 2.2 hours, whereas uptake of A does not/eq.

Also award credit for correct manipulation of comparative figures.

(b) Students' answers should include the following points:

- correct reference to diffusion (of substance B) occurring due to concentration difference/eq;
- idea of rate of uptake decreases;
- as the concentration gradient decreases/eq;
- (net) uptake stops/eq;
- when concentration inside cell equals that outside the cell/eq.

Also award up to 1 mark for QWC – the spelling of technical terms must be correct and the answer must be organised in a logical sequence.

(c) Any two from:

- active transport is against/eq concentration gradient/eq;
- active transport requires ATP/eq;
- reference to involvement of (membrane) proteins in active transport.

5 (a) Students' answers should include:
- reference to kinetic energy of molecules/eq;
- idea that molecules are moving randomly/eq;
- idea that overall movement of molecules is down the concentration gradient.

(b) Any three from:
- (at beginning) there is a concentration gradient/eq;
- as concentration of A decreases on outside, it increases on inside/eq;
- substance A moves from outside to inside;
- as concentration gradient/difference gets smaller, rate of change decreases;
- no change in concentration/eq when equal on both sides/it reaches equilibrium.

(c) (i) Any two from:
- active transport requires energy/ATP;
- active transport can move molecules against a concentration gradient;
- active transport requires a protein (pump).

(ii) Students' answers should include the following:
- rate of change would be (almost) linear/constant/eq;
- (changes) would occur faster/eq;
- idea that (overall) movement of molecules would not stop when concentrations equal, e.g. equilibrium would not be reached, concentration inside would be greater than outside.

4.2 Gas exchange

4.2.1 The need for gas exchange surfaces

1 The surface area of skin is not large enough in comparison with the volume of the animal (surface area : volume ratio is too small) to supply all that the animal needs within its body by diffusion.

The diffusion distances are too long so substances would take too long to diffuse to the cells in the centre of the body.

The metabolic rate of large organisms tends to be relatively high, so their requirements for oxygen and food, and the amount of waste produced are too high for simple diffusion.

2 The thousands of tiny air sacs and the many blood vessels surrounding them greatly increase the surface area for diffusion. Tiny air sacs are particularly important for maximising the surface area. Blood vessels also help maintain concentration gradient, as oxygen diffuses into the blood from the air in the lungs and carbon dioxide diffuses out of the blood into the air in the lungs. The fact that the blood vessels surround the alveoli keeps the diffusion distances short.

4.2.2 The mammalian gas exchange system

1 Humans are large multicellular organisms with a high metabolic rate to maintain body temperature and all the processes that keep cells alive. They need a rapid exchange of gases with all cells in the body to maintain the rate of respiration needed to support this metabolism. A complex internal respiratory system is needed to provide the large surface area required for this rapid rate of gas exchange with the body.

2 The nose has a larger surface area with a good blood supply and a lining covered in mucus and hairs. So the air entering through the nose is warmed, moistened and cleaned of dust and other particles before passing into the lungs. Air entering through the mouth gets little of this preparation and so will change conditions in the lungs more than air entering through the nose. It will be easier for pathogens to get to the lungs if air is breathed through the mouth than through the nose.

3 Breathing replaces air inside the lungs with air from outside that has a higher concentration of oxygen and a lower concentration of carbon dioxide. This maintains steeper concentration gradients for these gases between the air in the lungs and the blood, so that diffusion rates are maintained.

4 In normal breathing only part of the alveolar air mixes with inhaled air to form the exhaled air. So exhaled air contains a slightly higher proportion of oxygen and lower proportion of carbon dioxide than alveolar air, which is where the gas exchange takes place, removing oxygen and adding carbon dioxide to the air.

4.2.3 Gas exchange in insects

1 Gas exchange in insects takes place directly between the air in the tracheoles and the cells in the tissues. Air enters the spiracles, openings often controlled by sphincters along the side of the thorax and abdomen, which lead into chitin-lined tubes called tracheae. They carry air directly into the body and then branch into thousands of tiny tubules called tracheoles, which are extended cells with no chitin lining that penetrate between the body cells. This is where gas exchange by diffusion down a concentration gradient takes place, between the air in the tracheoles and the cells of the tissue of the insect.

2 Water can be reabsorbed form the ends of the tracheoles so that the air can penetrate deeper into the tissue.

Mechanical ventilation – the insects make pumping movements of the abdomen, which move more air in and out of the tracheal system.

Air reservoirs – some insects have collapsible air sacs that store extra air for when they are very active, or have tracheae that can collapse or extend depending on how much air is needed.

4.2.4 Gas exchange in fish

1 Students' answers should include reference to the following:
- large surface area for diffusion – gill filaments;
- good blood supply – maintains diffusion gradients to maximise gas exchange;
- thin walls between water and blood – short diffusion distances;
- constant flow of water over gills – maintains concentration gradients to maximise gas exchange;
- countercurrent exchange system – maximises diffusion between blood and water;
- overlapping gill filaments – slows down flow of water to maximise time available for gas exchange.

2 Operculum closed, mouth opens → Floor of buccal cavity lowered, expanding cavity → pressure drops in buccal cavity so water flows in → opercular valve opens so water flows into opercular cavity → opercular cavity expands as fills with water → lowers pressure in opercular cavity → floor of buccal cavity moves up increasing pressure in buccal cavity so water moves from buccal cavity over the gills → mouth closes and operculum opens → sides of opercular cavity move inwards increasing the pressure in opercular cavity → water forced out over the operculum → floor of buccal cavity continues to rise until mouth opens again and opercular valve closes → sides of operculum squeezing keep water flowing over gills until opercular valve opens again.

3 Give credit for all points covered; look for:
- similarities, e.g. large surface area, short diffusion distances, moist surfaces, etc.
- differences, e.g. insects have no blood pigments, fish take oxygen from water not the air, differences between lungs, gills and tracheae, etc.

4.2.5 Gas exchange in plants

1 Plants need oxygen for respiration and produce waste carbon dioxide *but* plants also need carbon dioxide for photosynthesis and produce waste oxygen, so the balance of gases exchanged changes throughout the day.

2 Leaves: large external surface area along with spongy mesophyll cells with large air spaces giving increased internal surface area for gas exchange.

Surface of spongy mesophyll cells moist so gases dissolve and diffuse freely between the cells and the air.

Under surface of leaf covered in stomata – pores that open and close to allow gas exchange depending on the demands of the tissues.

Stomata also found on stems.

Lenticels on woody stems allow gas exchange between the tissues below the woody stem with the external air so gas exchange can take place.

4.2 Answers to Exam-style questions

1 (a) red blood cell/erythrocyte

(alveolar) epithelial cell/epithelium/squamous epithelium

(b) Award up to 4 marks for the following points:
- thin/eq cells;
- decreases diffusion distance;
- permeable (to respiratory gases);
- (collectively) have a large surface area;
- increases diffusion;
- of respiratory gases/oxygen/carbon dioxide;
- (surrounded by) capillaries;
- idea that movement of blood maintains diffusion/concentration gradient;
- reference to the presence of/a description of surfactant.

(c) 8.1 (dm^3)

2 (a) Make any three of the following points: overall increase in number of deaths; 1920 – 1924: no change; slight increase between 1924 and 1936; sharp increase between 1936 and 1960; slight drop after 1969; correct manipulation of figures to quantify any of these points.

(b) (i) When one variable changes there is also a change in an accompanying variable.

(ii) Any two points from: the shape of the two graphs are similar; change in number of deaths from lung cancer similar to change in number of cigarettes smoked; idea that the changes in number of deaths is approximately the same number of years after the changes in cigarette smoking.

(iii) Any two from: number of people in survey, where the survey was carried out, information about their occupation, their family medical history, age, did they smoke, information on lifestyle.

(c) Award up to 4 marks for the following points:
- reduced diffusion (of gases);
- results in less/slower exchange of gases/oxygen/carbon dioxide/eq;
- decrease in surface area of alveoli/gas exchange surface;
- (destruction of capillaries results in) less surface area of capillaries/eq;
- (also) less blood flow/eq;
- less oxygen carried by blood/eq;
- suitable reference to effect on concentration gradient.

3 (a) Award up to 4 marks for the following points:
- reference to use of a nail varnish impression/peel off epidermis;
- mount on a (microscope) slide/eq;
- use of microscope/eq;
- count number of stomata in field of view/a given area;
- reference to calculating number per unit area (e.g. divide the number by the field of view or area);
- reference to repeating count and finding the mean number.

(b) (i) Students should note that:
- tobacco has the fewest/eq;
- castor oil has the most/eq;
- sunflower is in between/eq.

Also credit manipulated quantitative comparison (e.g. castor oil has 132 more per mm^2 than tobacco)/eq.

(ii) Castor oil; because it has more stomata/eq; and this would increase the rate of transpiration/ increase water loss.

4 (a) (i) Students' answers should include reference to the following; mark as paired points:
- presence of gills;
- to increase surface area/increase uptake of oxygen;
- presence of haemoglobin/respiratory pigment;
- with high affinity for oxygen;
- presence of siphon/(breathing) tube/eq;
to obtain oxygen (directly) from the air.

(ii) Any one of the following paired points:
- presence of claws/hooks/suckers;
- to attach to substrate/eq;
- flattened/streamlined/eq body/reference to burrowing;
less resistance to water flow/less likely to be washed away.

(b) It is an inverse relationship/eq.

Also credit a manipulated quantitative comment.

5 (a) Mark as paired points, i.e. adaptation; function:
- presence of haemoglobin/respiratory pigment;
- with a high affinity for oxygen;
- presence of breathing tube/eq;
- to obtain oxygen from the air;
- presence of gills;
- to increase surface area (for gas exchange).

(b) Students' answers should include reference to the following:
- flattened body/streamlined shape/eq;
- to reduce resistance to water/eq;
- presence of hooks/claws/eq;
- to hold on to substrate/eq.

6 (a) guard cell

(b) nucleus

(c) Award up to 4 marks for the following points:
- guard cells respond to carbon dioxide levels;
- potassium ions;
- actively transported into the guard cells;
- this increases the concentration of solutes (in the guard cell);
- this causes water to move in by osmosis;
- guard cells swell because of turgor pressure arrangement of cellulose fibres causes uneven bending.

(d) All three treatments stop transpiration.

Darkness stops the pumping of K^+ ions therefore there is no solute change in the guard cells; therefore there is no increase in solute concentration; therefore no movement in of water to cause guard cells to swell/open.

Poison stops the production of ATP, which prevents the active transport of K^+ ions; therefore there is no increase in solute concentration, and so no movement in of water to cause guard cells to swell/open.

No water, therefore epidermal cells will not have the significant difference of water to cause osmosis to happen; therefore guard cells will not swell/open.

4.3 Circulation

4.3.1 Principles of circulation

1 Students' answers should include reference to:
- system of vessels to carry substances – usually tubes, sometimes following specific routes, sometimes widespread and branching;
- a way of ensuring that substances move in the right direction;
- a means of moving materials fast enough to supply the needs of the organism, e.g. heart, OR: a way of maintaining a concentration gradient so substances move rapidly in the right direction, e.g. active transport to move other ions;
- a suitable transport medium.

2 Because fish only have a single circulation, where the blood passes through the delicate tissues of the gills before going directly to the rest of the body. High pressure would damage the gills. This doesn't matter because fish do not maintain their body temperature above that of the environment, so their rate of metabolism is lower than that of mammals and birds. As a result their cells need less oxygen and produce less carbon dioxide.

3 These animals need a higher rate of metabolism, to provide the energy needed for rapid movement against gravity and to provide heat. They need to supply plenty of oxygen faster to body cells to maintain a higher rate of respiration (and carbon dioxide needs removing from body cells faster too, so it does not build up and become toxic). This raised metabolism means extra heat needs to be dissipated. A double circulation means that the pressure of blood sent around the body can be higher than that to the lungs. So the delicate tissue of the lungs isn't damaged, but oxygen is delivered to body cells (and carbon dioxide removed) very efficiently and rapidly.

4.3.2 The roles of the blood

1 The main functions of the blood are:
- transport (of oxygen, carbon dioxide, nutrients, waste, hormones etc);
- defence (through phagocytosis and the immune system)
- the formation of tissue fluid and lymph which enables the movement of substances in and out of the body cells.

2 The white blood cells actively protect the body against pathogens that have entered, either by engulfing them or by making antibodies to kill them. They also produce antitoxins to destroy poisons produced by pathogens. The platelets and dissolved fibrinogen in the plasma help to protect the body after damage has occurred, by forming clots to block any leaks from blood vessels. White blood cells, platelets and fibrinogen are transported to the areas where they are needed in the blood.

3 As red blood cells do not have a nucleus, they have more space within the cell membrane and so can contain more haemoglobin. This makes them more effective as carriers of oxygen to cells. The nucleus contains the instructions for the cell, including its maintenance if it gets damaged. Without a nucleus, there are no instructions for mending blood cells, so they have a shorter life span than other cells.

4.3.3 Transporting oxygen and carbon dioxide

1 Haemoglobin is a large globular protein with four iron prosthetic groups. Each haemoglobin molecule transports four oxygen molecules. When oxygen is combined with haemoglobin it forms oxyhaemoglobin. The first molecule that binds to the haemoglobin changes the arrangement of the molecule, making it easier for subsequent molecules to bind.

2 Fetal haemoglobin has a higher affinity for oxygen than adult haemoglobin, which means that the fetal blood becomes oxygenated when it runs close to the mother's blood in the placenta, as the fetal haemoglobin combines with oxygen from the adult haemoglobin.

3 In the lungs, carbon dioxide diffuses out of the red blood cells and plasma in the capillaries down a concentration gradient into the alveoli, and oxygen diffuses from the alveoli down a concentration gradient into the red blood cells in the capillaries. In the rest of the body, oxygen diffuses out of the red blood cells in the capillaries down a concentration gradient into the cells, while carbon dioxide diffuses out of the cells down a concentration gradient into the plasma and red blood cells in the capillaries.

4 Similarities:
- Both are precursors – they are converted to another molecule as part of the clotting cascade by enzymes.
- Both are plasma proteins carried around the body in the plasma.

Differences:
- Prothrombin is a precursor of an enzyme. It is converted into the active enzyme thrombin in the clotting cascade. Both molecules are soluble.
- Fibrinogen is the soluble precursor of fibrin, an insoluble protein. The reaction is catalysed by the enzyme thrombin produced from prothrombin.

5 Vitamin K is important in the blood-clotting cascade; for example, it is needed to make prothrombin. The excessive bleeding in the rare condition may be linked to a failure of the clotting cascade as a result of a lack of vitamin K. By supplying all newborns with vitamin K, the babies who would otherwise suffer severe bleeding and perhaps die are protected because their clotting cascade can function.

4.3.4 Blood circulation

1 The blood in arteries is constantly being pushed away from the heart by the pressure of more blood coming out of the heart and by the elastic recoil of the arteries themselves. So there is no backflow in arteries. In veins, blood pressure is much lower, the force of blood leaving the heart has little effect and the blood is mostly flowing against the force of gravity up the body to the heart. As a result backflow is much more likely. Valves in the veins prevent this by closing as blood tries to flow backwards.

2 Arteries: carry blood away from the heart; usually carry oxygenated blood towards the cells of the body; have relatively high blood pressure, a relatively small lumen, smooth lining, thick layer of elastic fibres and smooth muscle to absorb the pressure from the pumping of the heart and give elastic recoil so artery returns to shape after the pulse of blood passes, external layer of connective tissue to maintain shape.

Veins: carry blood towards the heart; usually carry deoxygenated blood; have large lumen to carry large volume of blood, relatively low blood pressure, thin layer of smooth muscle with few elastic fibres, outer layer of connective tissue, no pulse, valves to prevent the backflow of blood.

Capillaries: link arterial and venous system; provide enormous surface area for the diffusion of oxygen and dissolved food from the blood into the cells and waste products including carbon dioxide from the cells into the blood; have a very small diameter and a wall single-cell thick, with relatively loose junctions that penetrate between body cells.

Award marks for any other sensible points.

3 The graph shows that blood pressure is highest in the arteries, drops rapidly in the arterioles and in the capillaries, and remains low in the venules and veins. The velocity of the blood is highest in the arteries, decreases in the arterioles and falls to a low level in the capillaries then increases again in the venules and veins. The total surface area of blood vessels is low in the arteries, increases in the arterioles to its highest level in the capillaries then decreases again through the venules to a low level in the veins.

Velocity is inversely related to surface area which causes friction (resistance to flow). So it is greatest in the arteries where blood pressure is greatest and surface area lowest, lowest in the capillaries where there is the largest surface area and so greatest resistance to flow, and greater again in the veins where surface area increases again, though not as great as in arteries because blood pressure is lower.

4.3.5 The human heart

1 Body capillaries to venules to veins to venae cavae to right atrium to right ventricle to pulmonary arteries (blood deoxygenated up to this point), pulmonary arteries to lung capillaries (blood is oxygenated in lung capillaries), lung capillaries to pulmonary veins to left atrium to left ventricle to aorta to arteries to arterioles (all oxygenated) to body capillaries (blood is deoxygenated in body capillaries).

2 (a) Semilunar valves are the valves between the ventricles and the blood vessels leaving them. They are called semilunar because of their shape and are formed from folds of the inner walls. They prevent backflow of blood when the heart relaxes by closing off the lumen.

(b) The muscle walls of the atria are thinner than those of the ventricles because they only have to push the blood into the ventricles, while the ventricles have to push blood out around the two circulations.

(c) The muscle wall of the left ventricle is thicker than that of the right because it has to provide the force that pushes the blood all around the body, not just to the lungs as the right ventricle does. The left side has to provide high pressure and overcome the elastic recoil of the arterial system.

(d) The tendinous cords are tough, to withstand the strain when the ventricles are receiving blood from the atria and the cords are stretched, and to make sure the valves are not turned inside out when the ventricles contract.

4.3.6 Controlling the heart

1 Natural pacemaker should send impulses regularly through the conductive tissue of the heart to the ventricles to trigger them to contract and pump blood out of the heart to lungs and round the body. When the sinoatrial node (SAN) fails, the artificial pacemaker delivers an electric shock to the ventricles triggering contraction in the ventricles, which replicates the intrinsic rhythmicity of heart.

2 Pressure in the atria increases as they fill. When the atria contract and force blood through into the ventricles, pressure increases in the ventricles and falls in the atrium, shutting the atrioventricular valves. The first heart sound is the blood hitting the closed atrioventricular valves. As the ventricles then contract and force blood out of the heart, initially the pressure in the ventricles increases as the volume decreases until the contraction ends and the ventricles relax and begin to fill again, when the pressure falls as the volume increases. As blood is forced out of the heart the semilunar valves in the aorta and the pulmonary artery close. The second sound is the backflow of blood hitting the valves as the ventricular cycle ends. Pressure in the aorta increases as the ventricles contract and force blood out of the heart into the aorta. As the ventricles contract, the atria fill with blood.

At the same time:

- P wave – electrical impulses travelling from SA node triggers atrial contraction;
- QRS complex – wave of excitation spreads from AV node through the bundle of His and through the ventricles triggering ventricular contraction;
- T wave – recovery of contractile tissue and the ventricle.

Note: it is important for students to indicate that this is a continuous process happening in a continuous sequence.

4.3.7 Atherosclerosis

1 Plaque formation can be caused by damage to the endothelial lining of an artery. This increases blood pressure making further damage more likely so more plaques form, and so on. Increased blood pressure can result in many problems in the kidney, eyes and brain, as well as aneurysms. Decreased blood flow through arteries partly blocked with plaques is dangerous in the coronary arteries and in the brain where it may cause damage to tissue beyond the blockage. Clots may form causing complete blockage of the blood vessel, which can be catastrophic.

2 (a) Atherosclerosis increases the risk of cardiovascular disease in a number of ways:

- Atherosclerosis narrows and/or stiffens the blood vessels, raising blood pressure. Raised blood pressure can damage small capillaries and increases the risk of damage to the endothelial lining
- Damage to the endothelial lining or an atheroma itself can attract platelets that can trigger the clotting cascade, including the release of thromboplastin, which catalyses the formation of thrombin from prothrombin, which then catalyses the formation of fibrin from fibrinogen in the blood. The fibrin produces a mesh that traps red blood cells and forms a clot. The clot may then block a blood vessel causing a thrombosis. In a coronary artery, this can lead to a heart attack; in the brain this may cause a stroke.

Award marks for any other sensible points, including the impact of high blood pressure caused by atheroma on health.

(b) Similarities: both may be caused by a blood clot (thrombosis) or the formation of an atheroma, or a combination of both; both may be fatal or cause long-term damage to health.

Differences: heart attack produces chest pain and may be triggered by exercise; stroke may affect many parts of the body through the damage caused to the brain and may also be caused by bleeding in the brain after an aneurysm bursts.

3 Students' plans should present the key information of how plaques are formed, how they cause reduced blood flow and increase blood pressure, and what the results of these may be, in a simple and clear way that is appropriate for young people.

4.3.8 Risk factors for atherosclerosis

1 Risk describes the probability that an event will happen; correlation is when two different sets of data appear to be similar or linked in some way; causation is when an event, act or behaviour directly causes a specific result.

2 There are many other causes of death than those related to smoking. A smoker may die from one of these before a smoking-related disease kills him or her. Some smokers will have their smoking-related disease cured. Not all smokers are adversely affected by smoking – their genetic makeup may mean smoking-related diseases will not affect them.

Award marks for any other sensible points.

3 Student's answers may include:
- smokers may not fully understand what the risk is;
- they may see older smokers who seem perfectly fit and underestimate the risk;
- they may be addicted to nicotine and find it very difficult to quit smoking.

Award marks for any other sensible points.

4 (a) Non-modifiable risk factors are beyond your control, while modifiable risk factors are factors you can do something about.

(b) Non-modifiable – any two from: genes, age, sex;

Modifiable – any two from: smoking, exercise, weight, stress, diet, or any other sensible lifestyle factor.

(c) For each factor given, students must provide a clear explanation of the link to atherosclerosis.

5 It doesn't matter which study students decide carries the most weight; look for evidence that they have considered such things as: numbers in the study; timescale of the study; where researchers come from; funding if they can find out, etc. Students need to use valid reasons to justify their choices.

6 (a) Look for evidence of good research, and check that students have found reliable reports on the research (and, if possible, the original paper and data). Students should know where the research was done, some of the scientists involved, and be able to explain the idea of a metadata study, etc.

(b) There is a variety of possible responses to this question but students' answers should include:
- people were upset and angry because they had modified their diet, depriving themselves of foods they enjoyed, thinking they were reducing their risk of suffering CVDs or dying young; the scientists apparently 'changed their minds' so participants 'needn't have bothered'; it undermined faith and trust in scientists;
- some people were happy because they saw it as meaning they could eat as much saturated fats, dairy produce, etc., as they liked.

(c) Importance to scientists:
- makes them aware of the results and ideas of others;
- gives them access to data from many different research projects;
- enables them to repeat investigations to see if they get the same results, or to use similar protocols but tweak them to investigate something else that is closely linked.

Importance to the population:
- enables science to move forward so the general population benefits;
- enables interested individuals to find out about research in detail;
- allows media to report stories in a way that people will understand, simplify the data, etc.

Students should look up and report on advice current at the time they are studying this – it is changing all the time!

4.3.9 Tissue fluid and lymph

1 Plasma: straw-coloured liquid containing dissolved gases and nutrients to be transported, waste products hormones and other chemicals, plasma proteins with red blood cells, white blood cells and platelets in suspension.

Tissue fluid: plasma without the plasma proteins and red blood cells but containing the other components of the blood.

Lymph: similar to tissue fluid but with lower oxygen and nutrients as they have been absorbed by the cells. Sometimes has high level of fatty acids from lacteals in the villi of the small intestine.

2 The return of the blood in the venous system to the heart depends on the squeezing of the skeletal muscles and a system of valves. The return of the lymph system relies on a similar system. If someone is still for a long time, the muscles do not squeeze the blood and lymph back to the heart effectively. Hydrostatic pressure builds up, so the tissue cannot return to the venous end of the capillaries and the lymph vessels, so the tissues become fluid-filled and swollen.

4.3 Answers to Exam-style questions

1 (a) Students' diagrams should include the following:
- thick wall drawn;
- two/three/four layers indicated;

plus two from the following, correctly labelled:
- lumen;
- endothelium/epithelium/endothelial layer/epithelial layer/tunica intima;
- (smooth) muscle/elastic fibres/elastin/tunica media;
- connective tissue/tunica adventitia.

(b) Any two from:
- idea of wide wall/eq (to withstand) blood under high pressure;
- reference to narrow lumen to maintain high pressure;
- reference to presence of elastic fibres/eq to allow vessel to stretch;
- recoil maintains pressure/squeezes blood;
- reference to (smooth) muscle contracts to squeeze/eq blood along;
- idea that smooth lining/eq reduces friction;
- folded lining/eq to allow artery to stretch/eq.

(c) Any two from:
- (walls of) veins more than one layer of cells and capillaries one layer/eq;
- (walls of) veins contain connective tissue/(smooth) muscle/collagen/elastic tissue, capillaries do not/eq;
- veins have valves in them and capillaries do not/eq;
- veins do not have pores but capillaries do/eq;
- veins have wide lumen, capillaries have narrow lumen/eq.

2 (a) Award 1 mark for any 2 correct; students have to put both crosses *and* ticks in to get the full 4 marks.

Name of blood vessel	Carries blood away from the heart	Carries oxygenated blood
Aorta	✓	✓
Vena cava	×	×
Pulmonary artery	✓	×
Pulmonary vein	×	✓

(b) (i) Any three from:
- (blood flows) from heart to gills;
- (blood flows) from gills to (rest of) body/eq;
- (blood flows) from body back to heart;
- reference to single circulation.

(ii) Students' answers should include reference to:
- blood flows faster/at higher pressure/eq (to the body);
- blood flows slower/at lower pressure/eq to the lung;
- idea that this reduces risk of damage to lungs;
- correct ref to more efficient exchange/transport of gases/eq.

(c) Any two from:
- correct reference to large surface area to volume ratios;
- idea that (all) cells/eq are very close to the blood/heart;
- idea that diffusion is fast enough for exchange of nutrients/gases/waste;
- idea of low metabolism;
- idea that movement of blood back into the heart is fast enough (to return blood back into the heart).

3 (a) Answers are shown in **bold** below

The mammalian heart consists of four chambers, two upper chambers called **atria/atrium** and two lower chambers called ventricles.

The **aorta** carries oxygenated blood away from the **left** ventricle to the cells of the body and the pulmonary **artery** carries deoxygenated blood to the lungs.

The **vena cava** returns deoxygenated blood back to the heart from the body.

(b) Diastole/atrial systole; because the atrioventricular/bicuspid/tricuspid valves are open/semi-lunar valves are closed.

4 (a) A: aorta/aortic arch; B: (right) atrioventricular valve/tricuspid valve

(b) Students' answers should include the following points:
- reference to coronary circulation;
- reference to coronary artery/coronary arteries;
- reference to capillaries (in wall of heart);
- oxygen transported/eq by red cells/haemoglobin;
- oxygen diffuses out of blood/red cells/capillaries (to heart muscle).

(c) Correct sequence of events:
- pacemaker/SAN sends impulse/eq (to atria);
- causing/eq atria to contract;
- impulse/eq reaches AVN;
- reference to delay at the AVN;
- idea that the impulse travels to ventricles via bundle of His/Purkinje tissue/eq.

(d) Students' answers should include the following points:
- increased demand for/eq oxygen/glucose/increased respiration;
- increased heart rate/heart beats faster/eq;
- increased stroke volume/cardiac output;
- increased production of carbon dioxide;
- reference to dilation of blood vessels in muscle;
- reference to adrenaline.

5 (a) (i) 0.6 to 0.65

(ii) 3.1 to 3.15

(b) Students' answers should include the following points:
- idea that oxygen is transferred from haemoglobin to myoglobin;
- myoglobin acts as a store/eq of oxygen;
- in muscle (tissue);
- oxygen released from myoglobin at (very) low partial pressures/during extreme/strenuous/eq exercise;
- this allows aerobic respiration to continue/eq.

(c) Students' answers should include the following points:
- idea that respiring tissues/cells produce carbon dioxide;
- reference to reduced affinity for oxygen;
- oxygen is released (more) readily/(more) oxygen is released/haemoglobin is less saturated with oxygen/percentage saturation decreases/eq;
- at a given/the same partial pressure of oxygen/eq;
- (oxygen released) to tissues/cells/muscle/eq.

6 (a) Students' answers should include the following points:
- capillaries have thin walls/made of flattened epithelium/thin cells/eq;
- reference to presence of pores;
- reference to basement membrane;
- reference to permeability of capillary wall/eq.

(b) Proteins are large (molecules); so cannot pass through capillary wall/eq.

(c) Students should describe reduced concentration of plasma proteins/eq; giving rise to reduced osmotic effect/eq.

4.4 Transport in plants

4.4.1 Transport tissues in plant

1 This is to prevent animals nibbling the soft young bark and destroying the transport tissue. If the bark is destroyed all around the trunk the plant will die, as no water can move up the trunk, and no food can move down to the roots.

2 Similarities:
- both are plant transport tissues;
- both have a lot of water moving through them;
- both found together in vascular bundles in plant.

Differences:

Xylem:
- water and mineral ions are transported in the xylem;
- xylem cells are living when first formed but become heavily lignified so cell contents die;
- comprises hollow tubes running through plants;
- water moves through xylem in transpiration stream carrying minerals with it;
- water leaves xylem through pits;
- provides important structural support for plant.

(Award marks for any other sensible points.)

Phloem:
- contains products of photosynthesis, e.g. sucrose transported in the phloem in solution in water;
- phloem sieve tubes are made of many cells joined together to form tubes with perforated sieve plates between them;
- phloem sieve elements are not dead but have lost most of their functions; they are a tube filled with phloem sap – cells have no nuclei;
- phloem cells only survive because they are supported by companion cells, which are very active and linked to phloem cells by many plasmodesmata.

(Award marks for any other sensible points.)

3 (a) Ringing experiment, removing the ring of bark by hand – this identifies the different roles of xylem and phloem but needs to be done carefully.

(b) Autoradiography – this uses radioactive isotopes, which are not suitable to use in school, and requires proper handling techniques.

(c) Placing cut end of a shoot in dye – a simple experiment that shows the role of vascular tissue in plants.

4.4.2 The uptake of water by plants

1 Similarities:
- transport water across the root from soil water to vascular tissue;
- at the Casparian strip, all routes have to pass through endodermis cell cytoplasm.

Differences:
- symplast pathway transports through cytoplasm (symplast), while apoplast pathway passes mainly through cellulose cell walls;
- symplast pathway involves osmosis down a concentration gradient, while apoplast pathway is based on the cohesion of water molecules and osmosis when the water crosses the cell membrane.

2 Root hairs have a large surface area, which increases the area for diffusion. They extend out into the soil, providing greater contact with the soil particles and soil water. They have short diffusion distances between the water in the soil and the cytoplasm of the cells.

3 Award marks for any suitable experiment that:
- identifies the condition being investigated;
- explains how all other factors are controlled;
- explains how the experimental set-up will allow valid and reliable results;
- includes a risk assessment.

4 Root pressure could be measured by the rate of water produced at the top of a stem where a plant has been cut off. Root pressure cannot explain the transport of all the water in a plant because it doesn't provide sufficient pressure to get water to the tops of most plants. Transpiration resulting from the evaporation of water from the surface of the leaves does provide enough pulling power to move water great distances and this can be shown experimentally.

4.4.3 Translocation of sucrose

1 Translocation in xylem:
- osmosis of water into root hair cells;
- diffusion across symplast route;
- osmosis across apoplast route;
- movement of mineral ions into cells by active transport;
- movement of mineral ions through cells by diffusion;
- movement of mineral ions into xylem by active transport.

Translocation in phloem:
- symplast pathway: sucrose moves by diffusion into sieve cells; water follows by osmosis;
- apoplast pathway: sucrose moves from wall spaces into the cytoplasm by active transport; water follows by osmosis; accumulation of sucrose leads to turgor pressure;
- sucrose moves out of the phloem into the cells by diffusion down a concentration gradient and water follows by osmosis.

2 Companion cells are very active. They have lots of mitochondria to provide energy for themselves and for the phloem sieve cells, and energy for the active loading of sucrose. Companion cells also have lots of infoldings of the membranes, over which they can transport sucrose into the sieve tube elements. They also have many plasmodesmata, providing cytoplasmic continuity with the sieve tube elements.

Award marks for any other sensible points.

3 Mass transport or mass flow hypothesis in a transport system involves the transport of materials from one point to another in a transport system with a transport medium and a pressure or force to bring about movement.

A simple physical model such as Munch's mass flow hypothesis explains a lot of what we see in plant transport systems, but there are aspects such as the great distances plants can move substances that cannot be explained by this simple model.

At one level translocation fulfils the criteria for mass flow:
- the phloem sap is the transport medium;
- the phloem sieve tubes are the system;
- sucrose and other assimilates are the materials to be moved;
- turgor pressure (hydrostatic pressure) in the system provides the force for movement;
- active transport adds to the 'pump'.

However, this simple model of mass flow does not take account of:
- active transport – the active loading of sucrose into the phloem sieve tubes, which changes the concentration gradient and can even alter the direction of flow;
- continuous loading of sucrose at one end and removal at another;
- the return route through the xylem;
- the fact that water can move into the tubes at any point by osmosis.

Therefore it is a good basic model but has shortcomings.

4.4 Answers to Exam-style questions

1 (a) Adhesion: water (molecules) sticks/attracted/bonded to (walls of) (xylem) vessels/tubes

Cohesion: water molecules stick together

(b) Mineral/inorganic salts/ions/nitrates/phosphates

(c) The water columns are pulled (from the top by transpiration stream rather than pushed)/under tension/the water columns contract as they are stretched/reference to reduced pressure (in xylem)/eq.

2 (a) Award up to 4 marks for any four from:
- apoplast pathway described;
- symplast pathway described;
- reference to the vacuolar pathway;
- reference to the endodermis and Casparian strip/layer of suberin/waxy layer;

function of the Casparian strip. (b) (i) Award up to 3 marks for any three from:
- reference to increase from 08.00/start until 10/12/14;
- reference to maximum at 14.00/peaks at 50 au;
- reference to decrease from 14.00;
- credit a manipulated quantitative comment.

(ii) 08.00 to 14.00: stomata open/increase in light (intensity)/increase in temperature/increase in wind speed/decrease in humidity;

14.00 to 20.00: converse of points above

3 (a) Xylem (vessel)

(b) Award up to 3 marks for the following points:
- endodermal cells have Casparian strip;
- reference to suberin/eq;
- which is waterproof/eq;
- stops movement of water in apoplast pathway/description;
- water directed into symplast pathway/description;
- reference to control of uptake/active transport of ions (into xylem).

(c) (i) Concentration increases as temperature increases/eq. Also award credit for a manipulated quantitative reference.

(ii) Students' answers should include the following points:
- uptake is active/eq;
- concentration in cells is higher than concentration in solution/converse;
- ions are taken up against concentration gradient.

4 (a) A = 10 / 6 = 1.67
B = 10 / 18 = 0.56
C = 10 / 2 = 5.00
D = 10 / 19 = 0.52
E = 10 / 20 = 0.50

(b) Stomata open in the light, but water can evaporate quicker in A compared to B because A has less water vapour surrounding the leaf compared to B; the more water that can evaporate, the faster the bubble moves.

(c) Light conditions will cause the stomata to open (to maximise the intake of carbon dioxide for photosynthesis) in B whereas in E the stomata are closed; therefore less water will evaporate from the plant in E; Some water will evaporate from cell walls in epidermis; Numbers are similar because the high humidity in B prevents water evaporating anyway.

Windy conditions will increase removal of water from around the plant; thus more water is lost form the plant in C; and more stomata are open in bright conditions (to allow more carbon dioxide in for photosynthesis); but in D the darkness means that more stomata are closed; thus water can only be lost from evaporation from cell walls of epidermis.