

Biology Units 3 & 4

Practice Examinations

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Exam 1 — Practice examination

Reading time: 15 minutes. Writing time: 2 hours 30 minutes. Section A: 40 questions, 40 marks. Section B: 10 questions, 80 marks. Total 120 marks. This examination covers Units 3 and 4. Answer all questions.

- No calculator may be used.
- No formula sheet, data sheet, dictionary or notes may be used.
- Diagrams in this examination are not drawn to scale.

Section A — Multiple choice

Every question in this section must be attempted. Select the response that is correct or that best answers the question. One mark is awarded for each correct response, and nothing is taken away where a response is wrong. Where two or more responses have been completed for the same question, no mark is awarded for it. No diagram in this section is drawn to scale.

Question 1

In a sample of double-stranded DNA, 18% of the bases are guanine. The percentage of the bases that are adenine is

- A. 32%
- B. 18%
- C. 36%
- D. 41%

Question 2

During translation, the anticodon that pairs with a codon on the mRNA is part of

- A. a ribosome.
- B. the template strand of the gene.
- C. a molecule of ribosomal RNA.
- D. a molecule of transfer RNA.

Question 3

In a eukaryotic cell, a cap and a tail are added to a pre-mRNA molecule

- A. in the nucleus, before the molecule leaves it.
- B. in the cytosol, after the molecule has left the nucleus.
- C. on the surface of a ribosome, as the polypeptide is assembled.
- D. inside the rough endoplasmic reticulum.

Use the following information to answer Questions 4 and 5.

The base sequence of a short mRNA molecule is shown below, together with part of a table of the genetic code.

5'–AUG UGU CCA GAU UAA–3'

Codon	Amino acid
AUG	methionine (start)
CCA	proline
CCG	proline
GAU	aspartic acid

Codon	Amino acid
UGU	cysteine
UGC	cysteine
UAA	stop

Question 4

The polypeptide assembled from this mRNA molecule is

- A. cysteine–proline–aspartic acid
- B. methionine–cysteine–proline
- C. methionine–cysteine–proline–aspartic acid–stop
- D. methionine–cysteine–proline–aspartic acid

Question 5

A substitution changes the last codon of this mRNA molecule from UAA to UGU. The polypeptide assembled from the altered mRNA is most likely to be

- A. one amino acid shorter than normal.
- B. the same length as normal, but with one different amino acid.
- C. unchanged, because the change is in the last codon.
- D. longer than normal, because the ribosome does not stop at that codon.

Question 6

A protein in solution is exposed to a strongly acidic pH. Its shape changes and it can no longer carry out its function, but no peptide bonds are broken. The level of protein structure that is unchanged is

- A. none — every level of structure is changed.
- B. the primary structure only.
- C. the tertiary structure only.
- D. the primary and the secondary structures.

Question 7

In the polymerase chain reaction, the reaction mixture is heated to about 95 °C at the start of every cycle. This step

- A. activates the DNA polymerase, which works only at high temperatures.
- B. allows the primers to bind to the sequences on either side of the target region.
- C. joins free nucleotides into the growing new strands.
- D. breaks the hydrogen bonds between the base pairs, separating the two strands of each molecule.

Question 8

In a bacterial cell, tryptophan acts on the trp operon as

- A. an enzyme that breaks down the repressor protein.
- B. the product of the regulatory gene.
- C. the molecule to which RNA polymerase binds before transcription begins.
- D. a corepressor, which changes the shape of the repressor protein so that it can bind to the operator.

Question 9

Two lines of farmed abalone have been produced. In line 1, a gene taken from a marine bacterium has been inserted into the abalone genome, giving resistance to a bacterial disease. In line 2, the abalone's own gene for a shell-pigment enzyme has been switched off, so the shell is paler. Which one of the following is correct?

- A. Line 1 is genetically modified but not transgenic; line 2 is transgenic.
- B. Line 1 is transgenic; line 2 is genetically modified but not transgenic.
- C. Both lines are transgenic.
- D. Neither line is genetically modified.

Question 10

A research team is using CRISPR-Cas9 to cut a chosen gene. The component of the system that determines where in the genome the cut is made is

- A. the Cas9 protein.
- B. the vector used to carry the system into the cell.
- C. the guide RNA.
- D. the cell's own repair machinery.

Question 11

In an investigation, tubes of pond water were held at each of five temperatures and the number of a microscopic alga in each tube was counted after five days. Five tubes were set up at each temperature. Setting up five tubes at each temperature, rather than one, has which one of the following effects?

- A. It removes any systematic error in the counting method.
- B. It increases the number of levels of the independent variable.
- C. It allows a mean to be calculated and reduces the effect of random error on that mean.
- D. It shows that the result can be obtained by a different investigator using different equipment.

Question 12

An enzyme increases the rate of a chemical reaction by

- A. supplying energy to the reactants.
- B. lowering the activation energy of the reaction.
- C. raising the temperature of the reaction mixture.
- D. making the products more stable than the reactants.

Question 13

A metal ion in polluted water binds to a site on a bacterial enzyme that is not the active site. The shape of the active site changes and the maximum rate of the reaction falls. The metal ion is acting as

- A. a competitive inhibitor.
- B. a coenzyme.
- C. a second substrate.
- D. a non-competitive inhibitor.

Question 14

The amount of an enzyme is held constant while its substrate is supplied at higher and higher concentrations. Past a certain substrate concentration the rate of reaction climbs no further. This is because

- A. all of the active sites are already occupied, so no further substrate can bind at any one moment.
- B. the substrate has begun to inhibit the enzyme.
- C. the enzyme has been denatured by the high substrate concentration.
- D. the product has begun to break down as fast as it is formed.

Use the following information to answer Questions 15, 16 and 17.

A potted plant was sealed inside a clear chamber. The carbon dioxide concentration of the air inside the chamber was measured over two hours in bright light, and again over two hours in complete darkness. The temperature was the same in both trials.

Condition	Change in the carbon dioxide concentration of the air in the chamber over two hours
bright light	fell
complete darkness	rose

Question 15

The rise in the carbon dioxide concentration in complete darkness occurs because

- A. photosynthesis continues in the dark, but cellular respiration stops.
- B. the light-independent stage of photosynthesis releases carbon dioxide.
- C. the plant's cells carry out cellular respiration but not photosynthesis.
- D. the plant carries out neither photosynthesis nor cellular respiration.

Question 16

The fall in the carbon dioxide concentration in bright light shows that, in bright light,

- A. the plant's cells have stopped respiring.
- B. carbon dioxide is released by photosynthesis and used by cellular respiration.
- C. carbon dioxide is used by photosynthesis faster than it is released by cellular respiration.
- D. the light-dependent stage of photosynthesis fixes carbon dioxide.

Question 17

The plant is returned to bright light and the carbon dioxide concentration in the chamber is now held constant. The temperature of the chamber is raised from 20 °C to 45 °C, and the rate at which carbon dioxide is removed from the air falls almost to zero. The most likely reason is that

- A. light has become the limiting factor.
- B. the enzymes that catalyse the reactions of photosynthesis have been denatured.
- C. all of the carbon dioxide in the chamber has been used up.
- D. the plant has stopped carrying out cellular respiration.

Question 18

In aerobic cellular respiration, the electron transport chain

- A. takes place in the matrix of the mitochondrion and releases carbon dioxide.
- B. yields a small amount of ATP and proceeds whether or not oxygen is present.
- C. takes place on the inner mitochondrial membrane and yields most of the ATP made from each molecule of glucose.
- D. uses ATP to move hydrogen ions across a membrane, and produces no ATP of its own.

Question 19

A human muscle cell and a yeast cell are both respiring without oxygen. Compared with the muscle cell, the yeast cell

- A. produces far more ATP from each molecule of glucose.
- B. produces a different carbon-containing end product, and a gas as well.
- C. stops breaking glucose down as soon as the oxygen runs out.
- D. breaks each molecule of glucose down completely to carbon dioxide and water.

Question 20

After finding that a new coating reduced water loss from cut flowers, a student writes: “This coating could be used by growers to keep cut flowers saleable for longer.” This statement is

- A. an implication of the finding.
- B. the conclusion of the investigation.
- C. the hypothesis of the investigation.
- D. a limitation of the investigation.

Question 21

A macrophage engulfs a bacterium, breaks it down, and displays fragments of the bacterium’s molecules on its own surface. This process

- A. destroys the antigens so that lymphocytes cannot detect them.
- B. converts the non-self antigens into self antigens.
- C. produces antibodies against the bacterium.
- D. presents non-self antigens to lymphocytes, so that a specific response can begin.

Question 22

Which one of the following is a feature of every cellular pathogen, but of no non-cellular pathogen?

- A. the presence of ribosomes
- B. the presence of nucleic acid
- C. the presence of surface molecules that act as antigens
- D. the ability to cause disease in a host

Question 23

Antibiotics are not effective against viral infections because

- A. antibiotics act on structures and processes of bacterial cells, which viruses do not have.
- B. viruses reproduce too quickly for an antibiotic to act on them.
- C. viruses are always enclosed in a membrane taken from the host cell.
- D. antibiotics are broken down by the host cell before they can reach the virus.

Question 24

Within the first line of defence, which one of the following acts chemically rather than physically?

- A. the layer of dead cells at the surface of the skin
- B. the cilia that line the airways
- C. lysozyme in tears and saliva
- D. the waxy cuticle on the surface of a leaf

Question 25

Histamine released at the site of an injury causes

- A. blood vessels near the injury to widen and to become more permeable.
- B. the affected tissue to become cooler and paler.
- C. antibodies to be released into the tissue fluid.
- D. infected body cells to be destroyed by cytotoxic T cells.

Question 26

A body cell infected by a virus releases interferons. Interferons

- A. bind directly to the virus and destroy it.
- B. cause nearby uninfected cells to make proteins that interfere with viral replication.
- C. are antibodies, and are specific to the one virus that triggered their release.
- D. mark the infected cell so that a neutrophil will engulf it.

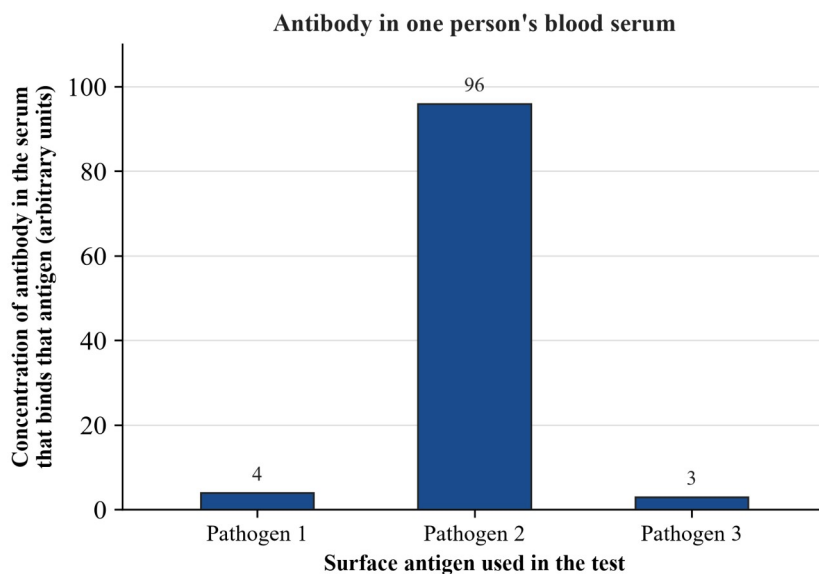
Question 27

Lymph nodes contribute to the immune response mainly because

- A. they filter red blood cells out of the lymph.
- B. they store red blood cells until an infection occurs.
- C. they carry lymph back to the tissues under pressure from the heart.
- D. antigens and antigen-presenting cells carried in the lymph meet very large numbers of lymphocytes there.

Use the following information to answer Questions 28, 29 and 30.

A sample of blood serum was taken from one person, who is well and who has never been vaccinated against any of the three pathogens named below. For each pathogen, the concentration of antibody in the serum that binds to that pathogen's surface antigen was measured.



Question 28

These results indicate that the person has previously been infected by

- A. pathogen 1 only.
- B. pathogen 3 only.
- C. pathogen 2 only.
- D. all three pathogens.

Question 29

The antibodies that bind to the surface antigen of pathogen 2 help to clear that pathogen from the body by

- A. breaking the pathogen down into fragments that are then displayed on a cell surface.
- B. entering the pathogen and destroying its genetic material.
- C. binding to its surface antigens, so that pathogens are clumped together and taken up more readily by phagocytes.
- D. dividing to form further antibodies for as long as the infection lasts.

Question 30

The immunity that this person now has to pathogen 2 is best described as

- A. natural active immunity.
- B. natural passive immunity.
- C. artificial active immunity.
- D. artificial passive immunity.

Question 31

Two populations of a native shrub grow 8 km apart. Each year insects carry pollen from one population to the other, and the seed set from that pollen grows into mature plants that themselves breed. This yearly movement of pollen

- A. has no effect on the gene pool of either population.
- B. is an example of genetic drift.
- C. will make the two populations more different from each other with every generation.
- D. is gene flow, because alleles are being carried from one population into the gene pool of the other.

Question 32

A small proportion of the individuals in an isolated population of a native fish carry an allele that allows them to tolerate low oxygen concentrations in the water. A run of hot summers lowers the oxygen concentration of the pools in which the fish live, and over the following generations the frequency of that allele rises. The rise is best explained by

- A. the fish developing a tolerance to low oxygen during their lifetime and passing it to their offspring.
- B. fish that carry the allele surviving and breeding more often than those that lack it.
- C. the low oxygen concentration causing the allele to arise by mutation.
- D. gene flow from a population that already tolerates low oxygen.

Question 33

An introduced predator reduces a population of a native bird on an island from about 4000 adults to about 25 adults within two years. The predator is removed and the population recovers to about 3000 adults. Compared with the original population, the recovered population is most likely to have

- A. more different alleles, because the survivors bred rapidly.
- B. fewer different alleles, because the survivors carried only part of the variation present before.
- C. the same alleles at the same frequencies as before.
- D. no genetic variation at all.

Question 34

Horses are vaccinated each year against a virus. Small changes accumulate from year to year in the gene coding for the virus's surface antigen, so a vaccine made three years ago protects horses poorly today. The process that has changed the virus's surface antigen is best described as

- A. antigenic shift.
- B. genetic drift.
- C. antigenic drift.
- D. a bottleneck effect.

Question 35

In a breeding program, each generation of sheep is bred only from those animals whose wool yield is highest. After many generations the flock has a much higher mean wool yield, but far fewer different alleles than the flock it was founded from. The fall in the number of different alleles has occurred because

- A. new mutations have been removed from the flock.
- B. alleles held only by the animals that never bred have disappeared from the flock.
- C. selective breeding raises the rate at which mutations occur.
- D. the selected animals are all descended from a wild population.

Use the following information to answer Questions 36 and 37.

The same gene was sequenced in three species of native ant. The number of base positions at which the sequences of each pair of species differ is shown in the table.

Pair of species	Number of base positions at which the two sequences differ
species X and species Y	6
species X and species Z	41
species Y and species Z	43

Question 36

These data indicate that

- A. species X and species Z have been separate for the shortest time of any pair.
- B. the line leading to species Z separated from the other two lines before species X and species Y separated from each other.
- C. all three lines separated from one another at about the same time.
- D. species Y is more closely related to species Z than to species X.

Question 37

The number of base positions at which two of these sequences differ can be used as a measure of how closely two species are related because

- A. base changes accumulate independently in two lines after they separate, so more differences mean a longer time since they last shared an ancestor.
- B. two species that live in the same way come to share the same base sequence.
- C. the number of differences between two species is fixed at the moment their lines separate.
- D. each base position that differs represents one generation since the two lines separated.

Question 38

Two rock layers, one exposed in a coastal cliff and one in a quarry 700 km inland, both contain fossils of the same marine species. That species was short-lived, widespread, abundant and easily identified. A geologist can conclude that

- A. the two layers are made of the same type of rock.
- B. the species evolved at the coast and spread inland.
- C. the two layers were formed at about the same time.
- D. the two layers must lie at about the same depth below the present surface.

Question 39

Compared with earlier hominins, later members of the genus *Homo* show

- A. arms that are longer relative to the legs, and a smaller braincase.
- B. a foramen magnum that has moved towards the back of the skull.
- C. larger canine teeth and a more projecting face.
- D. shorter arms relative to the legs, and a larger braincase.

Question 40

In a set of eight readings, seven lie between 12 and 15 and the eighth is 47. The logbook records nothing unusual about the eighth measurement. The investigator should

- A. report the reading, and give the mean both with and without it.
- B. delete the reading of 47 without comment, because it is clearly wrong.
- C. replace the reading of 47 with the mean of the other seven readings.
- D. report only the mean of all eight readings, without mentioning the unusual value.

End of Section A

Section B — Short answer

Every question in this section must be attempted, in the spaces provided. For any question carrying two or more marks, a response earns full credit only if it reaches the depth that its command term and its mark allocation call for. No diagram in this section is drawn to scale.

Question 1 (6 marks)

An investigation used a line of cultured animal cells that secrete a digestive enzyme. Samples of the cells were treated with one of three drugs. Each drug blocks a different step of the pathway by which a newly made protein leaves the cell.

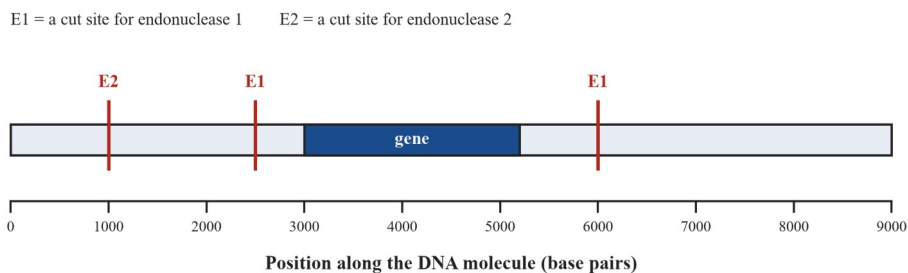
Table 1 Location of the newly made enzyme in the treated cells

Treatment	Where the newly made enzyme collected in the cell	Enzyme released from the cell
no drug	it did not collect anywhere	yes
drug 1	in the rough endoplasmic reticulum	no
drug 2	in the Golgi apparatus	no
drug 3	in vesicles pressed against the plasma membrane	no

- a.** The enzyme is a protein. Name the organelle at which its polypeptide chain is assembled, and state the feature of that organelle that identifies it as a site of protein synthesis. 2 marks
- b.** Drug 3 prevents vesicles fusing with the plasma membrane. Name the process that drug 3 blocks, and describe what normally happens at this step. 2 marks
- c.** In a separate experiment a mutation replaced one amino acid of the enzyme with a different amino acid. The altered enzyme was still assembled and still released from the cell, but it no longer broke down its substrate. Explain how a change to a single amino acid can stop a protein working. 2 marks

Question 2 (9 marks)

A length of DNA 9000 base pairs long has been isolated from a soil bacterium. It carries a gene, of interest to industry, that codes for an enzyme. The map below shows the position of the gene and the positions at which two endonucleases, endonuclease 1 and endonuclease 2, cut this DNA.



Endonuclease 1 cuts double-stranded DNA wherever it meets the sequence below, making a staggered cut within it.

5'–G G A T C C–3'

3'–C C T A G G–5'

- a.** Explain why the ends produced by endonuclease 1 allow the fragment carrying the gene to be joined to a plasmid that has also been cut by endonuclease 1. 2 marks
- b.** State the number of fragments produced when this DNA is cut with endonuclease 1 alone, and give the length of the fragment that contains the whole gene. 2 marks
- c.** The DNA is now cut with endonuclease 1 and endonuclease 2 together, and the fragments are separated by gel electrophoresis. State the number of bands that would appear, identify the fragment that would lie furthest from the wells, and explain why it travels furthest. 3 marks
- d.** The fragment carrying the gene is joined into the cut plasmid. When these recombinant plasmids are added to a culture of bacterial cells, only a minority of the cells take one in. Explain how a gene for antibiotic resistance carried on the plasmid allows those cells to be identified. 2 marks

Question 3 (7 marks)

A soil bacterium produces an enzyme, referred to here as esterase F, that breaks down a polyester plastic film. A team measured the mass of film broken down in 30 minutes by the same amount of enzyme, at each of five pH values. The measurements were then repeated with the same fixed concentration of a substance, R, added to every tube.

Table 2 Mass of plastic film broken down in 30 minutes

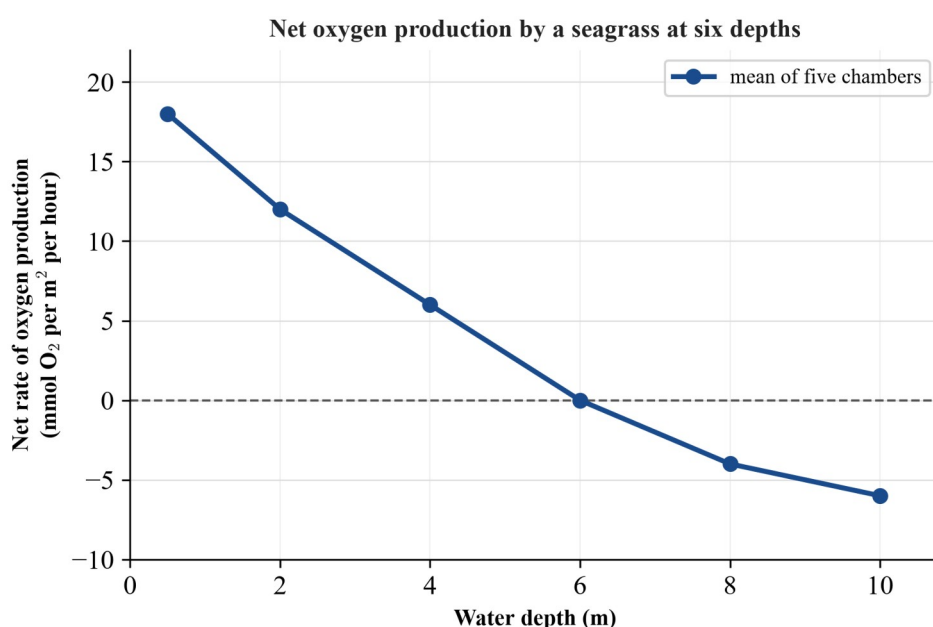
pH	Without substance R (mg)	With substance R (mg)
5.0	4	2
6.0	14	6
7.0	30	13
8.0	18	8

pH	Without substance R (mg)	With substance R (mg)
9.0	3	1

- State the optimum pH of esterase F, and explain, in terms of the structure of the enzyme, why the mass of film broken down falls at pH 9.0. 3 marks
- State the effect that substance R had on esterase F across the range of pH tested, quoting the two values recorded at pH 7.0, and state whether substance R changed the optimum pH. 2 marks
- The team suggests that substance R binds to a site on esterase F other than the active site. Describe one further measurement the team could make to test this suggestion, and state the result they would expect if the suggestion is correct. 2 marks

Question 4 (5 marks)

A seagrass grows on the floor of a coastal bay. Light intensity falls as water depth increases. Divers placed clear chambers over patches of the seagrass at six depths and measured the net rate at which oxygen was produced or taken up inside each chamber over one hour in the middle of a sunny day. A positive value means oxygen was released into the water; a negative value means oxygen was taken up. Each point is the mean of five chambers at that depth. (Adapted from Ellersby & Nakamura, 2024.)



- Describe how the net rate of oxygen production changes with depth. Quote figures from the graph in your answer. 2 marks
- Explain why the seagrass releases less oxygen, and eventually takes oxygen up, as the water becomes deeper. 2 marks
- At a depth of 6 m the net rate is zero. State what this indicates about the rates of photosynthesis and of cellular respiration in the seagrass at that depth. 1 mark

Question 5 (10 marks)

A worm burrows in the sand of an estuary. At high tide its burrow is filled with well-oxygenated sea water. At low tide the burrow is left above the water line, and the oxygen inside it is used up within about 20 minutes. A team measured the oxygen in the burrow, and the concentration of a substance J in the worms' body tissue, at four points in one tidal cycle.

Table 3 Oxygen in the burrow and substance J in the tissue

Time after the burrow was exposed (hours)	Oxygen in the burrow (% of the high-tide value)	Concentration of substance J in the tissue (units)
0	100	2
1	3	21
3	1	48
5 (the tide has returned)	96	9

- Name the stage of cellular respiration that continues in the worm's cells while the burrow is without oxygen, state where in the cell it occurs, and state its net yield of ATP per molecule of glucose. 3 marks
- Substance J is the carbon-containing end product of anaerobic respiration in the worm. Name this substance, and name the different carbon-containing end product that a yeast cell would produce under the same conditions. 2 marks
- Using the data, describe what happens to the concentration of substance J after the tide has returned, and explain why. 2 marks
- Explain why the worm could not rely on anaerobic respiration for a long period. Refer to the ATP yield in your answer. 2 marks
- A company ferments plant waste with yeast in sealed tanks to make a biofuel. State why the tanks are sealed. 1 mark

Question 6 (8 marks)

Antivenom is used to treat people bitten by venomous snakes. To make it, a horse is given an injection of a very small, non-harmful dose of snake venom, and further small doses over several weeks. Blood is then taken from the horse and the antibodies in its plasma are purified. The purified antibodies are injected into a patient who has been bitten.

- Explain what happens in the horse after the injections of venom. Refer to lymphocytes and to the antibodies produced. 3 marks
- State the type of immunity that the injections of venom give the horse, and the type of immunity that the purified antibodies give the patient. Use the terms natural or artificial, and active or passive. 2 marks
- Explain why the patient is given ready-made antibodies rather than being vaccinated against the venom at the time of the bite. 2 marks
- The antibodies injected into the patient are produced in a horse. Suggest one reason why injecting antibodies made in another species could cause a problem for the patient. 1 mark

Question 7 (12 marks)

For decades a virus has been passing from bird to bird within a wild population in one region, and has never made a person ill. Over one summer a change in the virus allows it to infect people who handle the birds, and then to pass directly from person to person. Within three months cases are recorded in several countries. No vaccine exists.

- Explain why this virus is described as an emerging pathogen in the human population, even though it has been present in the bird population for many years. 2 marks
- Explain why the illness caused by this virus is likely to be severe in the first people infected. Refer to the immune response in your answer. 3 marks
- State one measure that would reduce transmission of a virus that passes directly from person to person, and explain how it works. 2 marks
- In the first people infected, before any adaptive immune response has had time to develop, natural killer (NK) cells act against the virus. State what natural killer cells do to virus-infected body cells, and explain why they are described as part of the innate (non-specific) response. 2 marks

A number of infectious diseases that were long established in Europe had never been present in Aboriginal and Torres Strait Islander populations before European arrival from 1788. When these diseases were introduced, they caused severe illness and very high mortality in those populations.

e. Explain why the severe illness these introduced diseases caused in Aboriginal and Torres Strait Islander peoples was a consequence of the populations' exposure history, and not of any difference in the way their immune systems function. 2 marks

f. State one reason why public health programs today are developed in partnership with Aboriginal and Torres Strait Islander communities and community-controlled health organisations. 1 mark

Question 8 (6 marks)

A quarry exposes a thick, undisturbed sequence of sedimentary layers that were laid down in a shallow sea. Fossils of one group of extinct shelled animals occur through the whole sequence. In the deepest layers every shell is tightly coiled and carries no spines. In the shallowest layers every shell is almost straight and carries long spines. In the layers between the two, shells are found that are partly uncoiled and carry short spines. A bed of volcanic ash within the sequence has been dated at about 40 million years old.

a. Name the kind of fossil that the shells from the middle layers are, and explain what the sequence as a whole shows about this group of animals over the time the layers represent. 3 marks

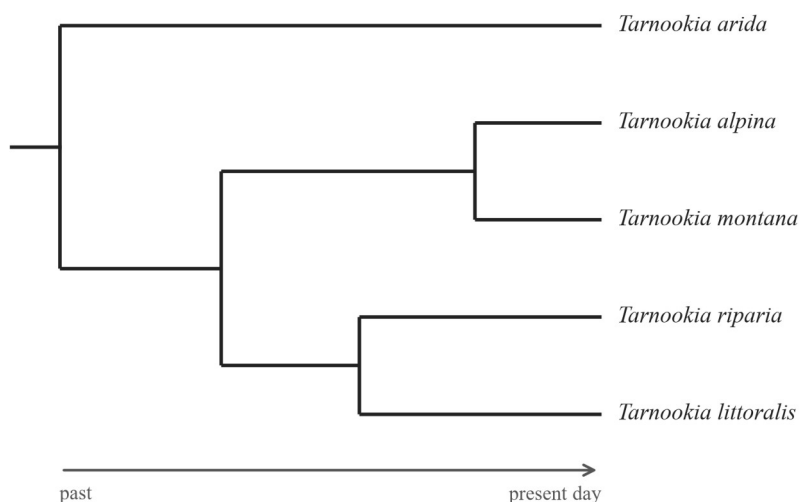
b. Explain why fossils of every stage in the change of shell form are unlikely ever to be found. 2 marks

c. State how the age of the ash bed was most likely determined. 1 mark

Question 9 (9 marks)

The tree below shows the relationships between five living species of the shrub genus *Tarnookia*. It was constructed by comparing, species by species, the base sequence of one gene that all five carry.

Phylogenetic tree of five living species of *Tarnookia*



a. Identify the two species that share the most recent common ancestor, and justify your answer using the tree. 2 marks

b. A student says that *Tarnookia arida* must be the species from which the other four species are descended, because its line is the first to separate on the tree. Explain why the student is wrong. 2 marks

c. *Tarnookia arida* grows at hot, dry inland sites and *Tarnookia littoralis* grows on exposed coastal dunes. Both of these species have thick, waxy leaves; the other three species have thin leaves. Explain whether the thick, waxy leaves are evidence that these two species are closely related. 3 marks

d. *Tarnookia riparia* and *Tarnookia littoralis* are thought to have arisen from one ancestral population that was divided when a long period of drying turned a continuous belt of woodland into two patches, separated by 200 km of

treeless plain that the shrub could not cross. Name the type of speciation this describes, and state the two things that must happen after the population is divided if two species are to result. 2 marks

Question 10 (8 marks)

A virus that infects rabbits and no other animal was released on a large pastoral property in an attempt to reduce the number of introduced rabbits. When it was first released the virus killed almost every rabbit it infected. In each of four later years, rabbits were trapped alive on the property and divided into three samples, and every sample was infected in the laboratory with the original released strain of the virus, which had been kept frozen since the release. The percentage of each sample that died within 14 days was recorded. (Adapted from Meniketti & Rowbotham, 2025.)

Table 4 Percentage of the trapped rabbits killed by the original strain of the virus

Years after the virus was released	Result for each of the three samples (%)
2	95, 92, 92
6	73, 69, 71
12	46, 43, 46
20	33, 31, 32

- a.** Calculate the mean percentage killed at 2 years and at 20 years after the release, showing your working, and state what the comparison shows. 2 marks
- b.** Explain, in terms of mutation and selection, why the rabbit population changed in this way. 3 marks
- c.** Identify the dependent variable in this laboratory testing, and name one variable that had to be held constant every time the testing was carried out. 2 marks
- d.** The team concludes: “Releasing this virus has made rabbits throughout Australia resistant to it.” State one reason this conclusion claims more than the data allow. 1 mark

End of Section B

End of examination questions

Exam 1 — Answers and solutions

Section A — answers

Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	A	11	C	21	D	31	D
2	D	12	B	22	A	32	B
3	A	13	D	23	A	33	B
4	D	14	A	24	C	34	C
5	D	15	C	25	A	35	B
6	B	16	C	26	B	36	B
7	D	17	B	27	D	37	A
8	D	18	C	28	C	38	C
9	B	19	B	29	C	39	D
10	C	20	A	30	A	40	A

Q1. A — guanine pairs with cytosine, so cytosine is also 18% and the two together account for 36%; the remaining 64% is adenine and thymine in equal amounts, giving 32% adenine. D is the trap of halving 82% without first accounting for cytosine.

Q2. D — the anticodon is the triplet on a transfer RNA molecule that pairs with the codon while the tRNA delivers its amino acid. Ribosomal RNA forms part of the ribosome and carries no anticodon.

Q3. A — capping and the addition of the poly-A tail are part of RNA processing, which is completed in the nucleus; only the finished mRNA leaves.

Q4. D — AUG UGU CCA GAU reads as methionine–cysteine–proline–aspartic acid, and UAA is a stop codon that codes for no amino acid, so the chain is four amino acids long. C treats “stop” as an amino acid; A omits the methionine that the start codon specifies.

Q5. D — UGU codes for cysteine, so the ribosome adds a fifth amino acid at the point where it should have stopped. Nothing in the molecule shown now signals it to stop, so translation runs on past the end of the normal chain and the polypeptide is longer than normal.

Q6. B — denaturation disrupts the bonds and interactions that hold the folded chain in shape, so the secondary, tertiary and any quaternary structure are lost; the order of amino acids is held by peptide bonds, which are not broken, so the primary structure survives.

Q7. D — every cycle begins by separating the two strands so that both can act as templates. Only the hydrogen bonds between the paired bases are broken; the sugar–phosphate backbone of each strand is left intact. Primer binding (B) and strand synthesis (C) take place at the lower temperatures later in the cycle, and the polymerase used is one that survives the heating rather than one switched on by it.

Q8. D — tryptophan is the corepressor: on its own the repressor protein cannot bind the operator, and binding tryptophan changes its shape so that it can, switching the operon off when tryptophan is plentiful. C describes the promoter.

Q9. B — a gene taken from a different species makes line 1 transgenic (and therefore also genetically modified); switching off the organism’s own gene changes the genome without introducing foreign DNA, so line 2 is genetically modified but not transgenic.

Q10. C — the guide RNA is complementary to the chosen target sequence and positions the complex; Cas9 makes the cut but does not choose where.

Q11. C — repeats within one investigation allow a mean, and averaging reduces the effect of the small unpredictable variations that fall on either side of the true value. A is wrong because averaging cannot correct an error that pushes every reading the same way, and D describes reproducibility, which requires the conditions of measurement to be changed.

Q12. B — an enzyme provides an alternative route with a lower energy barrier, so a larger proportion of collisions have enough energy to react. It supplies no energy and does not change how much energy the reaction releases overall.

Q13. D — an inhibitor that binds away from the active site and alters its shape is acting non-competitively; a competitive inhibitor binds in the active site itself. A coenzyme assists an enzyme rather than slowing it, and a second substrate would be converted to product.

Q14. A — once substrate is plentiful the enzyme is saturated, an active site being refilled the instant it empties, so the ceiling on rate is set by how quickly the enzyme can turn substrate over rather than by how much substrate surrounds it.

Q15. C — photosynthesis needs light and stops in the dark, but respiration continues day and night, so carbon dioxide is released and none is taken up.

Q16. C — respiration continues in the light as well, so a fall in carbon dioxide shows only that photosynthesis is using it faster than respiration is releasing it. A is the common error of assuming respiration switches off.

Q17. B — carbon dioxide and light are both held constant, so the only variable changed is temperature; well above the optimum the enzymes catalysing photosynthesis lose their shape and the rate collapses. C is excluded because the stem states the carbon dioxide concentration is held constant.

Q18. C — the electron transport chain sits on the inner mitochondrial membrane, and it is where the great majority of the ATP obtained from each molecule of glucose is made. Carbon dioxide is released by the Krebs cycle in the matrix (A), the chain halts without oxygen to accept the electrons at its end (B), and it makes ATP rather than consuming it (D).

Q19. B — without oxygen a yeast cell converts pyruvate to ethanol and releases carbon dioxide, whereas a muscle cell converts pyruvate to lactic acid and releases no gas. Both cells go on breaking glucose down without oxygen (C), for the same small yield of about 2 ATP per glucose (A), and neither can take that breakdown through to carbon dioxide and water without oxygen (D).

Q20. A — the finding itself is the conclusion; a statement about how someone else might use the finding beyond the conditions tested is an implication.

Q21. D — antigen presentation displays fragments of the pathogen on the cell surface where lymphocytes can meet them, which is the step that links the innate response to the specific response.

Q22. A — every cellular pathogen is built of cells and so contains ribosomes, whereas a virus has none and must borrow the host cell's ribosomes, and a prion is a single protein. Nucleic acid (B) is present in viruses too, and surface antigens (C) and the ability to cause disease (D) belong to both groups.

Q23. A — antibiotics target features of bacterial cells such as the cell wall, the bacterial ribosome or bacterial enzymes. A virus has none of these and uses the host cell's machinery, so there is nothing for the antibiotic to act on.

Q24. C — lysozyme is an enzyme that attacks bacterial cell walls, so it acts chemically. The dead skin layer, the cilia and the leaf cuticle are all physical barriers.

Q25. A — histamine from mast cells widens arterioles and makes capillary walls leakier, which produces the redness, heat and swelling of inflammation and lets phagocytes and plasma proteins reach the tissue.

Q26. B — interferons are signalling proteins released by an infected cell that prepare neighbouring cells to resist the virus; they do not attack the virus themselves, and they are not antibodies — unlike an antibody, an interferon is not specific to one virus.

Q27. D — the node concentrates lymphocytes in one place through which the lymph draining the tissues must pass, so the small number of lymphocytes able to recognise a given antigen are very likely to meet it there.

Q28. C — a raised concentration of antibody against pathogen 2 only, in someone never vaccinated, indicates a previous infection by pathogen 2; the low levels against pathogens 1 and 3 give no evidence of past infection.

Q29. C — an antibody carries two binding sites, so one molecule can bind two pathogens at once and cross-link many of them into clumps that cannot spread and that phagocytes take up in bulk. Antibodies are proteins with no digestive or nuclease activity of their own (A, B), and a molecule cannot divide (D).

Q30. A — the person met pathogen 2 in the ordinary course of life rather than through any medical procedure, so the immunity is natural, and their own lymphocytes made the antibody the test detected, so it is active. The stem rules out the artificial options by stating that the person has never been vaccinated.

Q31. D — alleles are carried from one gene pool into the other and, because the seedlings they produce grow up and breed, they enter the next generation there: that is gene flow. Genetic drift (B) is chance change within a single population rather than movement between two, and C reverses the effect, since alleles moving between populations reduce the differences between them.

Q32. B — the allele was already in the population before the hot summers; the falling oxygen then acts as a selection pressure, and carriers leave more offspring than non-carriers, so the allele becomes commoner. A is Lamarckian, C reverses the timing, and D is ruled out because the stem states the population is isolated.

Q33. B — a bottleneck: the 25 survivors carry only a sample of the alleles that were present in 4000 adults, and the alleles they lack cannot be restored by breeding, so diversity stays low even after the numbers recover. D is too strong — variation is reduced, not abolished.

Q34. C — the slow accumulation of small changes in the gene for a surface antigen is antigenic drift. Antigenic shift is the sudden exchange of whole genome segments, and genetic drift is a change in allele frequencies by chance in a small population.

Q35. B — when only a handful of animals breed, whatever alleles the rest of the flock held go with them and vanish from the population, so diversity falls even while the selected trait improves.

Q36. B — differences accumulate steadily after two lines part, so the smallest count marks the shortest separation: species X and species Y differ at just 6 positions, against 41 and 43 for the other pairings. The line leading to species Z must therefore have parted from the other two before those two parted from each other. A and D are contradicted by the table, and C would require the three counts to be about equal.

Q37. A — once two lines are separate, mutations arise and become fixed in each of them independently, so the number of positions at which their sequences differ grows with the time since they parted. B would make sequence similarity a report on habitat rather than on ancestry, C would leave the count frozen and so useless as a measure, and D assumes a fixed one change per generation, which is not how mutations occur.

Q38. C — a short-lived, widespread, abundant, easily identified species is an index fossil, so its presence dates both layers to the interval in which it lived. The rock type says nothing about age, since different sediments form in different places at the same time.

Q39. D — the trends from *Australopithecus* to later *Homo* are increasing braincase size and legs that lengthen relative to the arms, together with smaller teeth and a flatter face. B reverses the foramen magnum trend.

Q40. A — with no recorded cause the value cannot simply be discarded, since it may be genuine variation; reporting it and giving the mean both ways lets a reader see how much rests on that one reading. B, C and D all hide part of the record.

Section B — solutions

Q1. (a) The polypeptide is assembled at the **rough endoplasmic reticulum** — consistent with Table 1, in which the newly made enzyme is the first thing to collect there when drug 1 is applied. The feature that identifies it as a site of protein synthesis is the **ribosomes studding its outer surface**: a ribosome is the structure at which a polypeptide chain is assembled, and here the growing chain passes through the membrane into the space inside the rough endoplasmic reticulum as it is made. (1 mark: rough endoplasmic reticulum; 1 mark: the ribosomes on its surface, identified as the structures at which the polypeptide is assembled.)

(b) The blocked process is **exocytosis**. Normally the secretory vesicle carrying the finished enzyme moves to the plasma membrane; the **vesicle membrane fuses with the plasma membrane**, so that the two become

continuous, and the contents of the vesicle are **released into the fluid outside the cell** without ever having to cross the membrane. (1 mark: exocytosis named; 1 mark: the vesicle membrane fuses with the plasma membrane and the contents are released outside the cell.)

- (c) The sequence of amino acids along the chain is the protein's **primary structure**, and it is that sequence which dictates the way the chain folds up. Each R group takes part in the interactions that hold the folded shape in place — hydrogen bonds, ionic attractions, disulfide bridges and hydrophobic interactions — so replacing one amino acid with another whose R group behaves differently removes or adds one of those interactions and the chain settles into a **different three-dimensional shape**. An enzyme works because the shape of its **active site is complementary to its substrate**; if the folding change alters that shape, the substrate no longer fits, no enzyme–substrate complex forms, and the enzyme cannot catalyse the reaction even though it has been made and secreted normally. (1 mark: a change to the primary structure changes the way the chain folds, so the tertiary shape changes; 1 mark: the active site is then no longer complementary to the substrate, so the enzyme cannot bind it and does not work.)

Q2. (a) The sequence reads the same, 5' to 3', on each of the two strands, and endonuclease 1 cuts the two strands at **different points within it**. Each cut end is therefore left with a **short single-stranded overhang** — a sticky end. Because the plasmid was cut by the **same enzyme**, its ends carry the **same overhang**, which is **complementary** to the overhang on the fragment carrying the gene, so the two ends **pair by hydrogen bonding** when they meet and are held together while DNA ligase seals the backbone. (1 mark: a staggered cut leaves short single-stranded overhangs — sticky ends; 1 mark: the same enzyme leaves complementary overhangs on both molecules, so they base pair with each other.)

- (b) Endonuclease 1 cuts at 2500 bp and at 6000 bp. Two cuts in a **linear** molecule give **three** fragments: 0–2500 (2500 bp), 2500–6000 (**3500 bp**) and 6000–9000 (3000 bp). The gene runs from 3000 bp to 5200 bp, which lies wholly inside 2500–6000, so the fragment carrying the whole gene is the **3500 bp** fragment. (1 mark: three fragments; 1 mark: 3500 bp.)
- (c) With both enzymes there are three cuts (at 1000, 2500 and 6000 bp), so **four** fragments are produced: 1000, 1500, 3000 and 3500 bp. All four lengths are different, so **four bands** appear. The band furthest from the wells is the **1000 bp** fragment. DNA carries a negative charge and moves towards the positive electrode, and the **shorter a fragment is, the more easily it passes through the pores of the gel**, so in a given time the shortest fragment travels furthest. (1 mark: four bands; 1 mark: the 1000 bp fragment; 1 mark: shorter fragments pass more easily through the gel, so they travel furthest.)
- (d) Spread the treated culture across a plate whose growth medium has **that antibiotic mixed through it**. Any cell holding a plasmid also holds the resistance gene, manufactures its product and is protected, so it **survives and divides into a visible colony**; a cell with no plasmid has no such protection and **dies**. Every colony on the plate is therefore a transformed cell, and those cells can be picked off and grown on. (1 mark: plate the cells on a medium with the antibiotic in it; 1 mark: only cells holding a plasmid are protected and form colonies, so every colony is a transformed cell.)

Q3. (a) The optimum pH is **7.0**, at which **30 mg** of film was broken down in 30 minutes — more than at any other pH tested. At pH 9.0 the concentration of hydrogen ions is far lower than at the optimum, so the charges carried by the R groups of the amino acids change. The **ionic attractions and hydrogen bonds that hold the folded chain in place are disrupted** and the enzyme's tertiary structure changes shape. The **active site is then no longer complementary to the polyester substrate**, so far fewer enzyme–substrate complexes form and only 3 mg is broken down in the same time. (1 mark: optimum pH 7.0; 1 mark: the change in pH disrupts the interactions holding the folded shape, so the tertiary structure changes; 1 mark: the active site is no longer complementary to the substrate, so fewer enzyme–substrate complexes form and the rate falls.)

- (b) Substance R **lowered the mass of film broken down at every pH tested**. At the optimum, pH 7.0, the mass fell from **30 mg to 13 mg** — well under half the value recorded without it. The **optimum pH was not shifted**: with substance R present, the greatest mass is still broken down at pH 7.0. (1 mark: R lowered the mass broken down at every pH, with the pH 7.0 figures of 30 mg and 13 mg quoted; 1 mark: the optimum pH remained 7.0.)
- (c) Repeat the measurement at **pH 7.0 with substance R present**, but supply a **large excess of film**, with everything else unchanged. If substance R binds **away from the active site**, extra substrate **cannot displace**

it, the active site stays the wrong shape, and the mass broken down in 30 minutes will **remain well below the uninhibited value of 30 mg** however much film is supplied. (If instead the mass climbed back to about 30 mg, substance R would be competing with the film for the active site itself.) (1 mark: repeat at the same pH with substance R present and a large excess of substrate; 1 mark: the expected result — the mass broken down stays below the uninhibited value, because extra substrate cannot displace an inhibitor that is not bound at the active site.)

Q4. (a) As the water depth increases from 0.5 m to 10 m, the net rate of oxygen production **falls throughout**. It falls from **+18 mmol O₂ per m² per hour at 0.5 m** to **0 at 6 m**, and becomes **negative below that**, reaching **−6 mmol O₂ per m² per hour at 10 m** — that is, the chambers at 8 m and 10 m took oxygen up rather than releasing it. (1 mark: the direction stated in directional language — the net rate falls as depth increases, at every step; 1 mark: values quoted from the graph, including the change of sign.)

- (b) Light does not travel far through sea water, so the **light intensity reaching the seagrass falls as depth increases**. Light supplies the energy for the **light-dependent stage** of photosynthesis, so less light means less ATP and NADPH is made and passed to the light-independent stage, and the **rate of photosynthesis falls** — light is the limiting factor at these depths. Meanwhile the seagrass's cells go on **respiring at much the same rate at every depth**, and respiration uses oxygen up. The *net* figure — oxygen released by photosynthesis minus oxygen consumed by respiration — therefore falls faster still, and once photosynthesis has slowed below the level of respiration it becomes negative, so the chamber loses oxygen overall. (1 mark: light intensity falls with depth, so the rate of photosynthesis falls — light is the limiting factor; 1 mark: respiration continues at all depths and consumes oxygen, so the net figure falls further and turns negative once photosynthesis drops below the rate of respiration.)
- (c) At 6 m the seagrass is **producing oxygen by photosynthesis exactly as fast as its cells are using oxygen in cellular respiration**, so there is no net change in the oxygen in the chamber. (1 mark.)

Q5. (a) The stage is **glycolysis**. It occurs in the **cytosol** of the cell, and its **net yield is 2 ATP** per molecule of glucose. (1 mark: glycolysis; 1 mark: the cytosol; 1 mark: a net yield of 2 ATP per molecule of glucose.)

- (b) Substance J is **lactic acid**. Under the same oxygen-free conditions a yeast cell would produce **ethanol** instead (together with carbon dioxide). (1 mark: lactic acid; 1 mark: ethanol.)
- (c) Once the tide has returned, the concentration of substance J **falls sharply**, from **48 units at 3 hours** to **9 units at 5 hours**. The burrow has refilled and **oxygen is available again** (96% of the high-tide value), so the worm's cells return to **aerobic respiration**: pyruvate is passed into the mitochondria instead of being converted to lactic acid, so **no more lactic acid is produced**, and the lactic acid already in the tissue is **broken down**, taking its concentration back down towards the starting value of 2 units. (1 mark: describes the fall, quoting values from the table; 1 mark: oxygen is available again, so aerobic respiration resumes — production of lactic acid stops and what has accumulated is broken down.)
- (d) Anaerobic respiration yields only about **2 ATP per molecule of glucose**, whereas aerobic respiration yields about **30 or 32**. To make the same amount of ATP the worm must therefore break down roughly **fifteen to sixteen times as much glucose**, so its glucose stores are consumed very rapidly; and the data show that the **lactic acid produced accumulates in the tissue**, rising more than twenty-fold in three hours. Neither the supply of glucose nor the tolerance of the tissue for the accumulating end product could be sustained indefinitely. (1 mark: the yield comparison — about 2 ATP per glucose anaerobically against about 30–32 aerobically; 1 mark: the consequence — glucose is used up very fast and the end product accumulates, as the data show.)
- (e) The tanks are sealed to **exclude oxygen**, so that the yeast must respire **anaerobically**: it is only without oxygen that yeast converts sugars to **ethanol** (and carbon dioxide). With oxygen present the yeast would respire aerobically, and the carbon would leave as carbon dioxide and water rather than as the ethanol that is wanted. (1 mark.)

Q6. (a) The venom contains **proteins that are non-self antigens** to the horse. These are taken up and displayed by antigen-presenting cells, and a **B lymphocyte whose surface receptor is complementary to one of those antigens is selected** and activated. The selected cell **divides repeatedly** to produce a clone of identical cells; some of these become **plasma cells**, which secrete large numbers of **antibodies whose binding sites are complementary to the venom antigens**, and others become **memory B cells**. Each later dose of venom meets those memory cells, so the

response is **faster and larger each time**, and the concentration of anti-venom antibody in the horse's plasma is built up to a high level. (1 mark: the venom proteins act as non-self antigens and select a B lymphocyte with a complementary receptor, which divides to form a clone; 1 mark: plasma cells secrete antibodies specific to the venom antigens; 1 mark: memory cells formed at the first dose give a faster and larger response to the later doses, building a high antibody concentration.)

- (b) In the horse the immunity is **artificial active** immunity — artificial because the antigen was deliberately introduced by injection, and active because the horse's own lymphocytes responded and made the antibodies. In the patient it is **artificial passive** immunity — artificial because the antibodies were injected, and passive because the patient's own immune system did not produce them. (1 mark: artificial active, for the horse; 1 mark: artificial passive, for the patient.)
- (c) A vaccine works by making the patient mount their **own primary response**, and a primary response carries a **lag of several days to a week or more**: the very few B cells with a complementary receptor must first be selected, and must then divide and differentiate before enough antibody is present to be of any use. Snake venom acts within **minutes to hours**. Ready-made antibodies are **already present in the injection**, so they can bind and neutralise the venom **immediately**, inside the time the patient actually has. (1 mark: a vaccine would trigger only a primary response, which takes days to produce useful amounts of antibody; 1 mark: the venom acts far faster than that, whereas injected antibodies act immediately.)
- (d) The horse antibodies are **foreign proteins (non-self antigens)** to the patient, so the patient's **own immune system may recognise and react against them** — producing an allergic (hypersensitivity) reaction — and may **break them down more quickly**, especially if a further dose is given later, which reduces how well they work. (1 mark for any one valid problem.)

Q7. (a) Whether a pathogen is called **emerging** is judged **relative to the population in which it is appearing**, not by how long the pathogen has existed. This virus is appearing in the human population **for the first time**, so no person has met its antigens before and no one has any existing immunity to it; that it is old and well established in the wild birds is beside the point. (1 mark: “emerging” is defined relative to the population, not by the age of the pathogen; 1 mark: it is appearing in people for the first time, so the human population has no previous experience of it.)

- (b) Because nobody in the human population has met these antigens before, no one's immune system holds **memory B cells or memory T cells** able to recognise them. Every person infected can therefore mount only a **primary response**. A primary response has a **lag of several days** while the few lymphocytes carrying a complementary receptor are selected and then divide and differentiate, and it produces **relatively little antibody**. During that lag the virus **multiplies to very high numbers** and damages a great deal of tissue before the response takes effect, so the illness is severe. (1 mark: with no prior exposure nobody holds memory cells able to recognise these antigens; 1 mark: only a primary response is possible, which is slow — a lag of days — and produces relatively little antibody; 1 mark: the virus therefore reaches high numbers and causes extensive damage before the response takes effect.)
- (c) Any **one** measure, with its mechanism. For example, **isolating people who are infected**: a person kept away from others cannot pass the virus to them, so each chain of transmission is broken. Equally acceptable: **wearing a well-fitting mask** (traps the droplets released by coughing, sneezing and talking before they can reach another person); **physical distancing** (droplets fall out of the air over a short distance, so a gap between people stops them landing on another person's airways); **quarantining the well contacts of a known case** (someone may already be shedding the virus while still feeling perfectly well, so keeping exposed people apart stops them handing it on before they realise they are ill). (1 mark: a valid control measure; 1 mark: an explanation of how it interrupts transmission.)
- (d) Natural killer (NK) cells **destroy the body's own cells once those cells have been infected by the virus** (they release chemicals that make the infected cell die), which reduces the number of cells the virus can use to reproduce. They are part of the **innate (non-specific)** response because they act **without having to recognise a particular antigen** and **without any prior exposure or memory** — they respond to cells that are infected or abnormal, whatever the virus. (1 mark: NK cells kill / trigger the death of virus-infected body cells; 1 mark: innate because they act without recognising a specific antigen and without prior exposure or memory.)
- (e) How quickly a person can respond to a pathogen depends on whether their immune system has **met that pathogen's antigens before** and holds memory cells against them. Immunological memory is **built by exposure**, and it is **specific to the antigens that were met** — it is not a general property of a person or of a

population, and it is not inherited. Aboriginal and Torres Strait Islander populations had **not previously encountered these particular pathogens**, so no one held memory cells against them; only a slow primary response was possible, and people of every age were susceptible at the same time. Populations in Europe held memory against them only because **so many of their members had already been infected** at some earlier point. The two populations therefore differed in **which pathogens they happened to have encountered**, and in nothing else: the difference in outcome is a difference of **exposure history**, not of immune function. (1 mark: immunological memory is built by prior exposure and is specific to the antigens met — it is neither a general property of a population nor inherited; 1 mark: the populations differed only in which pathogens they had previously encountered, so the difference in outcome is one of exposure history and not of immune function.)

- (f) Any **one**: Aboriginal and Torres Strait Islander communities hold the knowledge of their own communities' circumstances and priorities, so a program designed with them is far more likely to reach the people it is meant to reach; Aboriginal and Torres Strait Islander community-controlled health organisations are accountable to the communities they serve, and information and services provided through them are more likely to be trusted and acted on; decisions about the health of a community are properly made **with** that community rather than for it; or the health inequities that this history helped create are still being felt, so partnership is needed if programs are to address them rather than repeat the practice of the past. (1 mark.)

Q8. (a) The shells from the middle layers are **transitional fossils** — fossils that carry a combination of features lying between those of an earlier form and those of a later one. The layers of an undisturbed sequence were laid down one on top of another, so the sequence is a **record in time order**: the deepest layers are the oldest and the shallowest the youngest. Read in that order, the fossils show that the **form of these animals changed gradually over the time the layers represent** — from tightly coiled and spineless, through partly uncoiled with short spines, to almost straight with long spines. The later forms are therefore **descended from the earlier ones, with modification**, rather than being unrelated animals that happen to lie above them. (1 mark: transitional fossils; 1 mark: an undisturbed sequence records time order, deepest = oldest; 1 mark: the group's form changed gradually over that time, the later forms descending from the earlier ones.)

- (b) **Fossilisation is a rare event**. An individual has to be buried quickly in sediment, before scavengers, decay or currents destroy it, and it needs hard parts that will survive; only a very small fraction of all the animals that ever lived left a fossil at all. The record is then broken further by **geology and by sampling**: in many intervals no sediment was deposited, other layers have since been eroded away, uplifted or altered, and the fossils that do survive are found only where rock happens to be exposed and searched. What is preserved can therefore only ever be a **sample** of the whole lineage, so stages of the change will be missing. (1 mark: only a tiny fraction of individuals is ever fossilised, because preservation needs particular conditions; 1 mark: the rock record itself is incomplete — layers missing or eroded, and only some rock is exposed and searched — so the fossils recovered are a sample, not the full series.)
- (c) By **radiometric dating** of crystals within the ash. Each crystal formed as the ash was thrown out, locking in parent isotope with none of the daughter product, so the proportion of parent isotope still present gives the time that has passed since the ash fell. (1 mark.)

Q9. (a) *Tarnookia alpina* and *Tarnookia montana*. Their two lines join at the branch point **closest to the present day** — later than the branch point at which any other pair on this tree joins — so the common ancestor they share is the most recent one shown, and less time has passed since their lineages separated than for any other pair. (1 mark: *T. alpina** and *T. montana*; 1 mark: justified by their branch point lying closest to the present day / being more recent than that of any other pair.)*

- (b) All five names on this tree are **species living today** — the stem says so, and every one of them sits at the end of its own line at the present-day edge of the diagram. None of them is drawn as the ancestor of another. The ancestor the student has in mind is the **population at the earliest branch point**, which is not named on the tree and is not any of the five species shown. What the tree records at that point is that the line leading to *T. arida* **separated from** the line leading to the other four — not that *T. arida* itself gave rise to them. Since that separation the *T. arida* line has been changing on its own for **exactly as long** as the line leading to the other four, so *T. arida* is a modern relative of those species, not their ancestral form. (1 mark: every tip is a species living today — the common ancestor is the unnamed population at the branch point, not any species shown on

*the tree; 1 mark: the branch point shows the *T. arida** line separating from the others, and it has been evolving independently for just as long since, so it cannot be the ancestor of them.)**

- (c) **No.** On the tree, *T. arida* separates from all the other species **at the root**, and *T. littoralis* sits with *T. riparia* on the far side of that first split, so these two species join **only at the root** — they are as distantly related as any pair on this tree, and far less closely related than *T. littoralis* is to *T. riparia*, whose leaves are thin. The thick, waxy leaf must therefore have appeared **separately in each of the two lines**, some time after they parted. Both habitats are ones in which a plant loses water rapidly — a hot, dry inland site, and an exposed coastal dune swept by salt-laden wind — and a thick waxy layer cuts water loss from the leaf surface in either. The feature is **analogous**: what it reports is a **shared habitat and habit**, not a shared ancestor. ∴ the leaves are evidence about the conditions in which the two species live, and the sequence data remain the better guide to how closely they are related. (1 mark: *no — the tree sets *T. arida** and *T. littoralis* on opposite sides of the earliest division, meeting only at the root*; 1 mark: *the thick waxy leaf must therefore have appeared separately in each line after they parted*; 1 mark: *it is an analogous feature produced by similar conditions in the two habitats, so it reports a shared habitat and habit rather than relatedness.)**
- (d) **Allopatric speciation** — the ancestral population was divided by a **geographic barrier**. Two things must then happen. **First, gene flow between the two populations must stop and stay stopped**, so that one gene pool becomes two that no longer exchange alleles. **Second, the two gene pools must diverge**: independent mutation, natural selection under the different conditions of the two patches, and genetic drift must accumulate differences until plants of one patch and plants of the other are **no longer able to breed together and leave fertile young**. Separation by itself achieves nothing further: had the woodland rejoined while the two gene pools were still alike, the shrubs would have bred freely across the join and the two populations would have become one again. (1 mark: *allopatric speciation*; 1 mark: *both requirements — gene flow stops, and the separated gene pools then diverge far enough that the two populations can no longer breed together successfully.*)

Q10. (a) **2 years after the release:** $95 + 92 + 92 = 279$; $279 \div 3 = 93.0\%$. **20 years after the release:** $33 + 31 + 32 = 96$; $96 \div 3 = 32.0\%$. Tested with the **same** strain of virus, the proportion of trapped rabbits killed fell from 93.0% to 32.0%, so the rabbit population on the property became **far more resistant to that virus** over the 20 years. (1 mark: *both means, with working*; 1 mark: *the comparison stated — the percentage killed by the same strain fell greatly, so the population became much more resistant.*)

- (b) Before the virus was released the rabbit population already **varied**: a small number of rabbits happened to carry alleles that made them more likely to survive infection. Those alleles arose by **chance mutation** and were present **whether or not the virus was ever released** — the virus did not create them, and no rabbit became resistant because it needed to be. Releasing the virus then applied a severe **selection pressure**: rabbits without such alleles were killed, most of them before they had bred, while rabbits carrying them were far more likely to **survive and reproduce**. The survivors passed those alleles to their offspring, so the **frequency of the resistance alleles rose in the population generation after generation**. Rabbits breed quickly, so many generations passed in 20 years, and by then the same strain killed only 32.0% of those tested. (1 mark: *resistance alleles arose by chance mutation and were already present at low frequency, independently of the virus*; 1 mark: *the virus acted as a selection pressure — rabbits carrying those alleles survived and bred while those without them died*; 1 mark: *the alleles were inherited, so their frequency rose over many generations and the proportion of the population killed by the same strain fell.*)
- (c) The **dependent variable** is the **percentage of the rabbits in a sample that died within 14 days of being infected**. One variable that had to be held constant is the **strain of virus used** — the original frozen strain every time, since the point of the testing is to hold the virus unchanged while the rabbits change. Equally acceptable: the dose of virus given to each rabbit, the 14-day period over which deaths were counted, the age or condition of the rabbits tested, or the conditions in which they were held during the test. (1 mark: *the dependent variable*; 1 mark: *one valid controlled variable.*)
- (d) Any **one**: the rabbits all came from **one property**, so the data support a conclusion about that population only and say nothing about rabbits elsewhere in Australia; or **nothing was manipulated or controlled** — there is no comparable population that the virus never reached, so other changes over the 20 years could have contributed to the fall and the study can establish an association only. (1 mark.)

Exam 2 — Practice examination

Reading time: 15 minutes. Writing time: 2 hours 30 minutes. Section A: 40 questions, 40 marks. Section B: 10 questions, 80 marks. Total 120 marks. This examination covers Units 3 and 4. Answer all questions.

- No calculator may be used.
- No formula sheet, data sheet, dictionary or notes may be used.
- Diagrams in this examination are not drawn to scale.

Section A — Multiple choice

Every question in this section must be attempted. Select the response that is correct or that best answers the question. One mark is awarded for each correct response, and nothing is taken away where a response is wrong. Where two or more responses have been completed for the same question, no mark is awarded for it. No diagram in this section is drawn to scale.

Question 1

In a molecule of double-stranded DNA, one of the two strands contains a high proportion of the base cytosine. The complementary strand must therefore contain an equally high proportion of

- A. adenine.
- B. guanine.
- C. thymine.
- D. uracil.

Question 2

In many eukaryotic organisms, a single gene can give rise to several different mature mRNA molecules, and hence to several different polypeptides. This is possible because

- A. the gene is transcribed in both directions at the same time.
- B. different combinations of exons can be joined together when the introns are removed.
- C. the cap and the poly-A tail are added in a different order each time.
- D. the ribosome reads the mRNA in three different reading frames at once.

Use the following information to answer Questions 3 and 4.

The base sequence of the coding (sense) strand of a short section of a gene is shown below, read in the 5' to 3' direction. Part of the genetic code is given in the table.

5'–ATG ACG GGA TGT TAA–3'

Codon (in the mRNA)	Amino acid
AUG	methionine (start)
ACG	threonine
GGA	glycine
UGU	cysteine
UGA	stop
UAA	stop

Question 3

The polypeptide encoded by this section of the gene is

- A. methionine–threonine–glycine–cysteine–stop
- B. threonine–glycine–cysteine
- C. methionine–threonine–glycine–cysteine
- D. methionine–threonine–glycine

Question 4

A substitution changes the coding-strand triplet TGT to TGA, so that the corresponding codon in the mRNA changes from UGU to UGA. The most likely effect on the polypeptide is that it is

- A. shortened, because translation stops earlier than normal.
- B. lengthened, because translation continues past the normal stop codon.
- C. unchanged, because UGA and UGU specify the same amino acid.
- D. changed at every position after the point of the substitution.

Question 5

A functional protein is made up of four separate polypeptide chains held together as a single unit. The level of protein structure represented by the way these four chains associate is the

- A. primary structure.
- B. secondary structure.
- C. tertiary structure.
- D. quaternary structure.

Question 6

In a bacterium, a mutation in the operator of the trp operon prevents the repressor protein from ever binding to the operator. In this bacterium, the trp structural genes will most likely be

- A. transcribed whether or not tryptophan is present.
- B. transcribed only when tryptophan is present.
- C. never transcribed under any conditions.
- D. removed from the bacterial chromosome.

Question 7

During each cycle of the polymerase chain reaction (PCR), the mixture is first heated to about 95 °C. The purpose of this heating step is to

- A. activate the DNA polymerase so that it can extend the primers.
- B. allow the primers to bind to their target sequences.
- C. join free nucleotides onto the growing DNA strands.
- D. separate the two strands of the DNA by breaking the hydrogen bonds between them.

Question 8

Bacteria can be given the human gene for insulin, and they will then produce functional human insulin. This is possible mainly because

- A. bacteria naturally produce human insulin.
- B. the human gene is converted into a bacterial gene once it is inside the cell.
- C. the genetic code is essentially universal, so a bacterium reads the human gene's codons in the same way that a human cell does.
- D. the human gene turns the bacterium into a human cell.

Question 9

CRISPR-Cas9 is used to make a double-stranded cut within a chosen gene in order to stop that gene from working. The gene most often stops working because

- A. the cell's own repair of the cut is error-prone and often adds or loses a few bases, disrupting the gene.
- B. Cas9 removes the entire gene from the chromosome.
- C. the guide RNA takes the place of the gene.
- D. the cut permanently prevents the chromosome from being copied.

Question 10

A student investigates how the concentration of a sugar solution affects the rate at which yeast produce gas. She tests solutions of 2%, 4%, 6% and 8% sugar, keeping the temperature and the mass of yeast the same in each. Which of the following is the independent variable?

- A. the rate at which gas is produced.
- B. the temperature and the mass of yeast.
- C. the concentration of the sugar solution.
- D. the values 2%, 4%, 6% and 8%.

Question 11

An enzyme catalyses the breakdown of one particular sugar but has no effect on any other sugar. This specificity is best explained by the fact that

- A. the enzyme is used up as it acts on that sugar.
- B. the shape of the enzyme's active site is complementary to that one sugar only.
- C. the enzyme raises the temperature of that sugar only.
- D. the enzyme supplies energy to that sugar only.

Question 12

A molecule slows an enzyme by binding reversibly to the enzyme's active site; it closely resembles the enzyme's normal substrate. Adding a large excess of substrate restores the reaction to its normal maximum rate. This molecule is acting as

- A. a non-competitive inhibitor.
- B. a coenzyme.
- C. a second substrate.
- D. a competitive inhibitor.

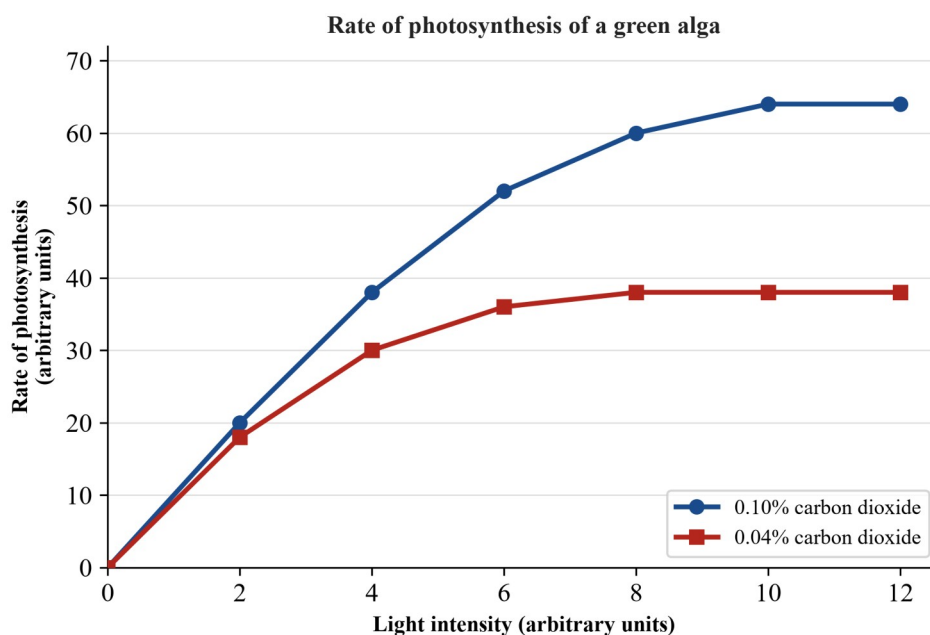
Question 13

The light-independent stage (the Calvin cycle) of photosynthesis takes place in

- A. the thylakoid membranes, and uses light energy directly.
- B. the stroma, and uses the ATP and NADPH made in the light-dependent stage.
- C. the stroma, and releases oxygen as a product.
- D. the thylakoid membranes, and splits water.

Use the following information to answer Questions 14, 15 and 16.

The rate of photosynthesis of a green alga was measured over a range of light intensities, and this was done at two different carbon dioxide concentrations. The graph shows the results.



Question 14

At a light intensity of 2 units, the rate is almost the same at both carbon dioxide concentrations. This is because, at this light intensity,

- A. the carbon dioxide concentration is the main factor limiting the rate.
- B. the temperature is the main factor limiting the rate.
- C. the light intensity is the main factor limiting the rate.
- D. the alga is not photosynthesising at all.

Question 15

On the 0.10% carbon dioxide curve, raising the light intensity beyond 8 units produces almost no further increase in the rate. This indicates that, above 8 units on this curve, the rate is limited by

- A. the light intensity.
- B. a factor other than light, such as the carbon dioxide concentration or the temperature.
- C. the amount of oxygen dissolved in the water.
- D. the amount of water available to the alga.

Question 16

A researcher wishes to raise the maximum rate of photosynthesis that this alga reaches on the 0.04% carbon dioxide curve. The change most likely to achieve this is to

- A. raise the light intensity above 12 units.
- B. supply the alga with a higher concentration of carbon dioxide.
- C. reduce the number of algal cells in the sample.
- D. shade the alga for part of each measurement.

Question 17

In aerobic cellular respiration, the role of oxygen is to

- A. combine with glucose during glycolysis.
- B. supply the carbon that is released as carbon dioxide.
- C. be produced as a waste product of the electron transport chain.
- D. be the final acceptor for the electrons passing down the electron transport chain.

Question 18

During the aerobic respiration of one molecule of glucose, at which stage is carbon dioxide released?

- A. glycolysis only
- B. the electron transport chain only
- C. no stage — carbon dioxide is a product of photosynthesis, not respiration
- D. the Krebs cycle

Question 19

Baker's yeast is added to bread dough to make it rise. The gas that makes the dough rise is produced when the yeast

- A. respire aerobically, releasing oxygen.
- B. photosynthesise, releasing oxygen.
- C. carry out the Krebs cycle, releasing water.
- D. ferment the sugars in the dough, releasing carbon dioxide.

Question 20

After finding that a new fertiliser increased the growth of lettuces in her trial, a student writes: “Market gardeners could use this fertiliser to grow larger lettuces.” This statement is best described as

- A. the conclusion of the investigation.
- B. the hypothesis of the investigation.
- C. an implication of the finding.
- D. the aim of the investigation.

Question 21

A person is given a kidney from a donor who is not related to them. With no medication to hold the immune system back, their immune system attacks and rejects the transplanted kidney. This happens because the transplanted cells carry

- A. no surface antigens at all.
- B. self-antigens identical to the patient’s own.
- C. antibodies directed against the patient’s cells.
- D. surface antigens (MHC markers) that the patient’s immune system recognises as non-self.

Question 22

Malaria is caused by a single-celled eukaryotic parasite that lives and reproduces inside a host’s cells. This pathogen is best classified as

- A. a cellular pathogen, and a protozoan.
- B. a non-cellular pathogen, because it lives inside host cells.
- C. a virus, because it reproduces inside host cells.
- D. a prion, because it has no cell wall.

Question 23

A course of broad-spectrum antibiotics kills many of the harmless bacteria that normally live in a person’s gut, and the person then suffers an overgrowth of a harmful microbe. The harmless gut bacteria had been acting as

- A. antibodies against the harmful microbe.
- B. part of the third line of defence.
- C. a chemical barrier that raises the pH of the gut.
- D. part of the normal microbiota — a first-line defence that competes with pathogens for space and nutrients.

Question 24

Natural killer (NK) cells are part of the innate (non-specific) immune response. They defend the body by

- A. secreting antibodies against one specific antigen.
- B. presenting antigen to B lymphocytes.
- C. destroying virus-infected body cells and cancer cells, without needing to recognise a specific antigen.
- D. producing memory cells after an infection.

Question 25

A neutrophil engulfs a bacterium at the site of a wound. It then destroys the bacterium by

- A. enclosing it in a vesicle that fuses with enzyme-containing lysosomes, which digest it.
- B. displaying the bacterium's antigens and secreting antibodies against it.
- C. injecting interferon into the bacterium.
- D. releasing histamine onto the bacterium.

Question 26

One way in which the lymphatic system contributes to immune defence is by

- A. driving blood around the body under pressure from the heartbeat.
- B. producing red blood cells for the immune response.
- C. collecting tissue fluid and carrying it, along with any pathogens and antigen-presenting cells, through lymph nodes where lymphocytes are concentrated.
- D. secreting acid that kills swallowed pathogens.

Question 27

Antibodies help to defend the body against a bacterium in the blood by

- A. binding to antigens on the bacterium, marking it and clumping bacteria together so that phagocytes destroy them more easily.
- B. digesting the bacterium with enzymes released from the antibody.
- C. entering the bacterium and copying its DNA.
- D. releasing histamine to widen nearby blood vessels.

Use the following information to answer Questions 28, 29 and 30.

Three people are protected against the same disease, each in a different way.

- Person 1 recovered from the disease last year, after being infected by the pathogen.
- Person 2 was given a vaccine containing an inactivated form of the pathogen.
- Person 3, a newborn baby, received antibodies from its mother across the placenta before birth.

Question 28

The immunity of Person 1 is best described as

- A. natural active immunity.
- B. natural passive immunity.
- C. artificial active immunity.
- D. artificial passive immunity.

Question 29

The antibodies that are protecting Person 3 (the newborn baby) against this pathogen were made by

- A. Person 3's own plasma cells.
- B. Person 3's memory B cells.
- C. the mother's immune system, before the antibodies were passed to the baby.
- D. Person 3's own B lymphocytes, in response to the mother's antibodies.

Question 30

Which of the three people would develop long-lasting immunological memory against this pathogen?

- A. Person 3 only
- B. Person 2 only
- C. all three people
- D. Persons 1 and 2, but not Person 3

Question 31

A balance is used to weigh a standard mass of exactly 50.0 g on five separate occasions. The readings obtained are 47.1, 47.3, 47.0, 47.2 and 47.1 g. This set of readings is best described as

- A. accurate but not precise.
- B. both accurate and precise.
- C. precise but not accurate.
- D. neither accurate nor precise.

Question 32

A few individuals of a native plant become established on an isolated rocky outcrop. Over the generations that follow, some alleles are lost from this small population altogether and others become much commoner, simply because of which few plants happen to leave offspring each generation, and not because any of the alleles gives an advantage. This change in allele frequencies is best described as

- A. genetic drift.
- B. natural selection.
- C. gene flow.
- D. an increase in genetic diversity.

Question 33

A population of a native mouse lives on pale, sandy soil; most of the mice are pale and a few are dark. A layer of dark volcanic soil now covers the area, and owls hunt the mice by sight. Over many generations the frequency of the dark-coat allele rises. This rise is best explained by

- A. the mice changing colour during their lives to match the new soil.
- B. dark mice being better camouflaged, so surviving and breeding more often than pale mice.
- C. the dark volcanic soil triggering a mutation that creates the dark-coat allele.
- D. dark mice arriving from a neighbouring population and interbreeding with the local mice.

Question 34

A single population of a flightless insect was divided into two when a new river cut through its range and could not be crossed. Over a very long time the two groups accumulated genetic differences, and when the river later dried up the two groups could no longer interbreed. This is an example of

- A. sympatric speciation, because the two groups later shared the same range.
- B. allopatric speciation, because a geographic barrier separated the two groups while they diverged.
- C. genetic drift, because the size of the population fell.
- D. gene flow, because the two groups later came into contact again.

Use the following information to answer Questions 35 and 36.

In an undisturbed sequence of sedimentary rock, layer 1 lies at the top and layer 4 at the bottom. A bed of volcanic ash between layers 1 and 2 has been radiometrically dated at 15 million years, and a second bed of volcanic ash between layers 3 and 4 has been dated at 40 million years. Fossils of a marine species, species Z, occur in layers 2 and 3 and in no other layer at this site.

Question 35

The best estimate of the age of species Z is that it is

- A. between 15 and 40 million years old.
- B. exactly 15 million years old.
- C. exactly 40 million years old.
- D. older than 40 million years.

Question 36

At a second site, on another continent, fossils of species Z are found in one rock layer. Palaeontologists conclude that this layer formed during the same interval of time as layers 2 and 3 at the first site. Drawing that conclusion depends on the assumption that species Z

- A. existed for only a short interval of geological time, but over a wide geographic area.
- B. was still alive when the youngest ash bed was laid down.
- C. was the only species living in the sea at that time.
- D. arose separately, and at a different time, at each of the two sites.

Question 37

The flipper of a whale, the wing of a bat and the arm of a human all contain the same set of bones arranged in the same basic pattern, although they are used for very different purposes. These forelimbs are an example of

- A. vestigial structures, retained but no longer used.
- B. analogous structures, alike only because they do a similar job.
- C. homologous structures, indicating descent from a common ancestor.
- D. structures that each arose separately, from different origins.

Question 38

Which feature would place a fossil specimen among the hominins, rather than only among the apes (hominoids)?

- A. forward-facing eyes and hands that can grasp
- B. having no tail
- C. a brain that is large in proportion to the body
- D. a skeleton showing that the animal usually stood and moved upright, on two legs

Question 39

In a survey of 40 lakes, lakes with more of a certain water plant tended to have clearer water. The researchers did not alter anything in any lake. These data show that

- A. the water plant causes the water to become clearer.
- B. there is an association between the amount of the plant and the clarity of the water, but the data alone cannot show that one causes the other.
- C. clearer water causes more of the plant to grow.
- D. the association must be due to chance.

Question 40

Mitochondrial DNA is often used to trace ancient human migrations because it is

- A. inherited from both parents and recombined afresh each generation.
- B. inherited only from the mother and not recombined, so it traces a single maternal line back through time.
- C. found only in people living today.
- D. changed so rapidly that it cannot be compared between populations.

End of Section A

Section B — Short answer

Every question in this section must be attempted, in the spaces provided. For any question carrying two or more marks, a response earns full credit only if it reaches the depth that its command term and its mark allocation call for. No diagram in this section is drawn to scale.

Question 1 (6 marks)

A garden plant produces a purple pigment in its flower petals. The pigment is made by an enzyme that is encoded by a gene, referred to here as gene P. Three varieties of the plant were compared: the wild-type variety (purple petals), variety 1 (white petals) and variety 2 (purple petals, like the wild type). Each mutant variety differs from the wild type by a single base substitution in gene P.

- a. Outline how the sequence of bases in gene P leads to the production of the enzyme. Name the two processes involved and state where in a eukaryotic cell each one occurs. 3 marks
- b. In variety 1 the single substitution produces a completely non-functional enzyme, so no pigment is made. Explain how a change to a single base in gene P could stop the enzyme working altogether. 2 marks
- c. In variety 2 the single substitution has no effect on the enzyme at all, and the petals are still purple. Explain how a substitution can leave the protein unchanged. 1 mark

Question 2 (9 marks)

A market stall sells fish fillets labelled as a premium species, species A. An inspector suspects that some fillets are really a cheaper species, species B. DNA was extracted from four fillets and from a reference sample of each species, and the number of repeats at three short tandem repeat (STR) markers was counted for every sample.

Table 1 Number of repeats at three STR markers

Sample	Marker 1	Marker 2	Marker 3
reference species A	8	12	5
reference species B	11	7	9
fillet 1	8	12	5
fillet 2	11	7	9
fillet 3	8	12	5
fillet 4	11	7	9

- a.** The amount of DNA obtained from a fillet is very small. Name the technique used to make many copies of the STR regions before they are counted, and state one thing that technique requires. 2 marks
- b.** Using the data in Table 1, state which fillets were not the species shown on the label, and justify your answer. 2 marks
- c.** The three markers give the same repeat numbers in every genuine species-A fish tested. Explain why markers of this kind are suitable for telling one species from another, whereas the markers used to identify an individual person must instead differ greatly between individuals. 2 marks
- d.** Species A is farmed. To improve its disease resistance, a gene taken from a different species of fish has been introduced into the farmed fish. State whether the farmed fish is transgenic, and give the reason. 1 mark
- e.** Describe how gel electrophoresis could be used to reveal the difference between species A and species B at Marker 1. 2 marks

Question 3 (7 marks)

A juice company uses an enzyme, referred to here as enzyme Z, extracted from a tropical fruit, to break down the pectin that makes fresh juice cloudy. The volume of clarified juice produced in 20 minutes by the same amount of enzyme was measured at a range of temperatures. The juice used at each temperature came from a different batch of fruit.

Table 2 Volume of clarified juice produced in 20 minutes

Temperature (°C)	20	30	40	50	60	70
Clarified juice (mL)	5	11	20	27	12	0

- a.** Using Table 2, state the temperature at which enzyme Z works best. Then explain why the company obtains no clarified juice at all at 70 °C, even though the molecules in the juice are moving faster at 70 °C than at any of the lower temperatures. 3 marks
- b.** The company now doubles the amount of enzyme Z added to the juice at 50 °C, changing nothing else. Predict the effect on the volume of clarified juice produced in 20 minutes, and explain your prediction. 2 marks
- c.** Explain why using juice from a different batch of fruit at each temperature weakens the conclusion that can be drawn from Table 2, and state what should have been done instead. 2 marks

Question 4 (5 marks)

Two grasses grow together on an open plain: grass P and grass Q. One of them is a C3 plant and the other is a C4 plant. On a hot, dry day, with both grasses holding their stomata partly closed, the rate at which each grass fixed carbon was measured at two leaf temperatures.

Table 3 Rate of carbon fixation (arbitrary units)

Grass	Rate at 20 °C	Rate at 40 °C
grass P	20	12
grass Q	18	26

- a. Using the data in Table 3, identify which of the two grasses is the C4 plant, and justify your choice. 2 marks
- b. Explain why holding the stomata partly closed on a hot, dry day lowers the rate of carbon fixation in one of these grasses but not in the other. In your answer, refer to the gas that Rubisco binds in each grass. 3 marks

Question 5 (10 marks)

A food company makes yoghurt by culturing lactic-acid bacteria in warm milk in sealed vats from which the air has been excluded. The bacteria first split the milk sugar, lactose, into the two simple sugars glucose and galactose. In these oxygen-free conditions they then break those simple sugars down and release lactic acid, which slowly sours the milk and thickens it into yoghurt.

- a. Name the energy-releasing process the bacteria are using to obtain ATP from glucose, and state the net number of ATP molecules they gain from each molecule of glucose. 2 marks
- b. As the lactic acid builds up, the pH of the milk falls. Name the change that the milk proteins undergo as the pH falls, and explain, in terms of the bonds that maintain a protein's shape, why a fall in pH brings it about. 3 marks
- c. A batch left to ferment for longer becomes both more sour and firmer. Explain why continued fermentation has both of these effects. 2 marks
- d. These bacteria cannot use oxygen. Name the type of respiration that requires oxygen and the organelle in which most of its ATP is produced, and explain why a cell using oxygen obtains far more ATP from each molecule of glucose than these bacteria do. 3 marks

Question 6 (8 marks)

A person falls on a gravel path and grazes their knee, and soil bacteria enter the tissue through the broken skin. Over the following two weeks the immune system clears the infection and the graze heals.

- a. Soon after the bacteria enter, the area around the graze becomes red, warm and swollen. Name this response, and explain how it helps to defend the body against the bacteria. 3 marks
- b. A macrophage engulfs the bacterium and then displays fragments of it on its own surface. Name this process, and explain how it connects the innate response to the adaptive (specific) response. 2 marks
- c. The bacterium lives in the tissue fluid, outside the body's cells. Name the type of lymphocyte whose activation leads to the production of antibodies against it, and explain why those antibodies will give the person no protection against a different species of bacterium. 2 marks
- d. A year later the same person is infected by the same bacterium but shows no symptoms. Explain why. 1 mark

Question 7 (8 marks)

A vaccine is introduced against a bacterial disease. The vaccine contains a single surface protein (an antigen) taken from the bacterium.

- a. Explain how this vaccine leads to long-lasting protection against the disease. Refer to the cells of the adaptive immune response in your answer. 3 marks

b. A strong antibody response to the vaccine also depends on helper T cells. Describe the role of helper T cells in this response, and predict the effect on the antibody response if the person had no functioning helper T cells. 2 marks

c. People who cannot be vaccinated gain protection from a vaccination program only once a high enough proportion of the community has been vaccinated. Name this effect, and explain why the proportion vaccinated must be high before it works. 2 marks

d. The vaccine contains only a surface protein of the bacterium, not the whole living bacterium. State why this means the vaccine cannot give the person the disease. 1 mark

Question 8 (9 marks)

In one city a poison has been used for 20 years to control a rodent pest. Researchers measured the percentage of the rodents carrying an allele that makes them resistant to the poison, at intervals over that period. (Adapted from Neave & Sultana, 2025.)

Table 4 Percentage of rodents carrying the resistance allele

Year	0	5	10	15	20
Rodents carrying the resistance allele (%)	2	9	28	55	78

a. Between year 0 and year 5 the percentage of rodents carrying the resistance allele rose by only 7 percentage points, but between year 10 and year 15 it rose by 27. Suggest why the rise was so much smaller over the first five years, even though the poison was in use throughout. 2 marks

b. Using the data in Table 4, explain how the use of the poison changed the rodent population over the 20 years, quoting figures from the table. Then state why these percentages are not the same as the frequency of the resistance allele in the population's gene pool. 3 marks

c. The resistance allele also makes a rodent need far more vitamin K in its diet, which is a disadvantage where the poison is absent. Predict what would happen to the frequency of the resistance allele if the poison were withdrawn for many years, and explain your answer. 2 marks

d. The rodents in this city are isolated from those elsewhere. Explain how gene flow, if it occurred, could change the frequency of the resistance allele in a nearby town where the poison has never been used. 2 marks

Question 9 (12 marks)

Occasionally a short piece of DNA becomes inserted into a genome at a position that is otherwise never affected. An insertion of this kind is a useful marker of ancestry: it arises once, in one ancestral population; it is then passed to every descendant of that population; and it is never removed again.

Researchers studying five living species of a group of small Australian marsupials — referred to here as species 1 to 5 — recorded whether each of four such insertions, W, X, Y and Z, is present in the genome of each species. A more distantly related marsupial from outside the group carries none of the four.

Table 5 Presence or absence of four DNA insertions

Species	Insertion W	Insertion X	Insertion Y	Insertion Z
species 1	present	absent	absent	absent
species 2	present	present	absent	absent
species 3	present	present	present	absent
species 4	present	present	present	absent
species 5	present	present	absent	present

- a.** Insertion W is present in all five species but absent from the marsupial outside the group. State what this indicates about the five species. 2 marks
- b.** Using Table 5, identify the two species that are the most closely related to each other, and explain fully how the data lead to that conclusion. 3 marks
- c.** Species 5 is the only one of the five that carries insertion Z. State when insertion Z must have arisen, relative to the separation of the five lineages, and explain your answer. 2 marks
- d.** The researchers then find a fifth insertion, V, which is present in species 1 and species 4 but in none of the other three. Explain why this result cannot be accounted for in the same way as the other four insertions, and describe how the researchers should treat it when they classify these species. 3 marks
- e.** Species 2 and species 5 are alike in size and coat colour, and both feed at night on nectar. Explain why sharing one of these DNA insertions is stronger evidence of common ancestry than sharing a feature such as size, colour or diet. 2 marks

Question 10 (6 marks)

A student investigates whether a detergent that reaches ponds in run-off slows the growth of duckweed, a small plant that floats on the water surface and multiplies quickly. She sets up ten identical containers of pond water, each holding the same number of duckweed plants. To five of the containers she adds a set amount of the detergent; the other five contain pond water only. All ten containers are kept under the same conditions for two weeks, after which she counts the number of duckweed plants in each container.

- a.** Identify the independent variable, the dependent variable, and one variable that must be kept constant in this investigation. 3 marks
- b.** The five containers that received pond water only, with no detergent, act as a control group. Explain the purpose of including this control group in the investigation. 2 marks
- c.** Every container with detergent ended with fewer duckweed plants than every container without it. The student concludes: "This detergent kills all water plants." State one reason why this conclusion goes further than her results can support. 1 mark

End of Section B

End of examination questions

Exam 2 — Answers and solutions

Section A — answers

Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	B	11	B	21	D	31	C
2	B	12	D	22	A	32	A
3	C	13	B	23	D	33	B
4	A	14	C	24	C	34	B
5	D	15	B	25	A	35	A
6	A	16	B	26	C	36	A
7	D	17	D	27	A	37	C
8	C	18	D	28	A	38	D
9	A	19	D	29	C	39	B
10	C	20	C	30	D	40	B

Q1. B — cytosine pairs with guanine, so a strand rich in cytosine is matched, base for base, by a strand equally rich in guanine. Uracil (D) is a base of RNA, not DNA.

Q2. B — one gene can specify several proteins because different combinations of its exons can be joined together when the introns are removed (alternative splicing).

Q3. C — the coding strand reads the same as the mRNA with T replaced by U, so AUG ACG GGA UGU UAA is methionine–threonine–glycine–cysteine, and UAA is a stop codon that adds no amino acid. A counts “stop” as an amino acid, and B drops the methionine specified by the start codon.

Q4. A — UGU codes for cysteine, and the change makes it UGA, a stop codon, so the ribosome stops one codon early and the polypeptide is one amino acid shorter. A substitution changes only one codon, so the reading frame is not shifted (D).

Q5. D — four separate polypeptide chains joined into one functional protein make up the protein’s quaternary structure.

Q6. A — if the repressor can never bind the operator, RNA polymerase is never blocked, so the trp structural genes are transcribed continuously, whether or not tryptophan is present.

Q7. D — heating to about 95 °C splits the two strands apart by breaking the hydrogen bonds between them; the primers bind and the polymerase extends the new strands at lower temperatures.

Q8. C — the genetic code is essentially the same in all organisms, so a bacterium reads the codons of the human gene as the same amino acids and builds functional human insulin.

Q9. A — Cas9 only cuts the DNA; the cell’s own repair rejoins the ends imperfectly, adding or losing a few bases, and it is this that disrupts the gene. Cas9 does not remove the gene (B), and the guide RNA only directs the cut (C).

Q10. C — the independent variable is the factor the student deliberately changes, the sugar concentration. D lists its levels, A is the dependent variable and B names the controlled variables.

Q11. B — an enzyme is specific because its active site has a shape that fits only one substrate, the sole molecule able to bind and be acted on.

Q12. D — resembling the substrate, binding at the active site and being overcome by an excess of substrate are together the signature of a competitive inhibitor.

Q13. B — the Calvin cycle runs in the stroma and is driven by the ATP and NADPH made in the light-dependent stage; it uses no light itself (A), releases no oxygen (C) and does not split water (D).

Q14. C — at low light the two carbon dioxide concentrations give almost the same rate, which shows that at this light intensity it is the light, not the carbon dioxide, that is holding the rate back.

- Q15.** B — once further light no longer raises the rate, light is no longer the limiting factor, so something else (the carbon dioxide concentration or the temperature) has become limiting.
- Q16.** B — the 0.04% curve is already flat from 8 units onwards, so light has stopped being the limiting factor and adding more light cannot lift its ceiling (A); the ceiling is set by the factor that is now limiting, the carbon dioxide supply, which is why the 0.10% curve levels off higher. Fewer cells (C) or less light (D) would lower the rate, not raise it.
- Q17.** D — at the very end of the electron transport chain, it is oxygen that takes up the electrons, acting as the final electron acceptor. Oxygen is not used in glycolysis (A) and is not a product of respiration (C).
- Q18.** D — carbon dioxide is released during the Krebs cycle. Glycolysis produces pyruvate, and the electron transport chain produces water.
- Q19.** D — with little oxygen in the dough the yeast ferment its sugars to ethanol and carbon dioxide, and it is the carbon dioxide that makes the dough rise.
- Q20.** C — a statement about how the finding could be used beyond the conditions actually tested is an implication; the conclusion is the result the trial itself established.
- Q21.** D — the transplanted cells carry MHC surface antigens that differ from the recipient's own, so the recipient's immune system reads them as non-self and attacks the graft.
- Q22.** A — a single-celled eukaryote is built of a cell, so it is a cellular pathogen, and a single-celled animal-like parasite is a protozoan. Living inside host cells does not make it non-cellular (B) or a virus (C).
- Q23.** D — the harmless resident bacteria are the normal microbiota, a first-line defence that competes with pathogens for space and nutrients; removing them lets a harmful microbe take over.
- Q24.** C — NK cells are innate cells that destroy virus-infected and cancerous body cells without recognising a specific antigen; making antibodies (A) and forming memory cells (D) are adaptive functions.
- Q25.** A — a neutrophil kills an engulfed bacterium by enclosing it in a vesicle that fuses with lysosomes, whose digestive enzymes break it down (phagocytosis).
- Q26.** C — the lymphatic system drains tissue fluid and carries it, with any pathogens and antigen-presenting cells, through lymph nodes, where lymphocytes are gathered in large numbers.
- Q27.** A — antibodies bind to antigens on the bacterium, marking it and clumping bacteria together, so that phagocytes engulf and destroy them more easily.
- Q28.** A — Person 1 made their own immune response to a natural infection, so their immunity is natural (not deliberately introduced) and active (their own response).
- Q29.** C — the baby did not make these antibodies itself; they were produced by the mother's immune system and passed to the baby across the placenta, so the baby carries ready-made antibodies it did not produce (the basis of passive immunity). The baby's own plasma cells, memory cells and B lymphocytes (A, B, D) played no part in making them.
- Q30.** D — only Persons 1 and 2 mounted their own active response and so formed memory cells; the newborn received ready-made antibodies and formed no memory, so its protection is temporary.
- Q31.** C — the five readings agree closely with one another (spread of only 0.3 g), so they are precise, but their mean, 47.14 g, is well below the true value of 50.0 g, so they are not accurate.
- Q32.** A — when allele frequencies change purely through chance differences in which individuals happen to leave offspring, rather than because an allele confers any advantage, the process is genetic drift; its effect is largest in a small, isolated population like this one. Natural selection (B) would require the alleles to differ in advantage, gene flow (C) requires movement between populations, and losing alleles altogether reduces, rather than increases, genetic diversity (D).

Q33. B — the dark mice are better camouflaged on the dark soil, so they survive the owls and breed more often than the pale mice, and the dark-coat allele becomes commoner: natural selection acting on variation already present. A is Lamarckian and C reverses the timing.

Q34. B — a geographic barrier, the river, separated the two groups while their gene pools diverged, which is allopatric speciation; that they later shared the same range does not make it sympatric (A).

Q35. A — species Z occurs only in layers 2 and 3, which lie between the ash bed dated at 15 million years and the ash bed dated at 40 million years, so it is between 15 and 40 million years old.

Q36. A — matching layers on different continents by the fossils they contain works only if the species was short-lived in geological terms, so that its presence pins down a narrow interval of time, and widespread, so that it can turn up in both places. A species that was still alive later (B) would not mark any particular interval; being the only species alive (C) is not required and is not the case for any real fossil; and if it had arisen separately at each site (D) the two occurrences would not be the same species, so they could not be used to correlate the layers at all.

Q37. C — the same set of bones put to different purposes is a homologous structure, evidence of descent from a common ancestor; analogous structures (B) share a function but not an underlying plan.

Q38. D — the feature that sets the hominins apart is habitual upright walking on two legs. Forward-facing eyes and grasping hands (A) belong to the primates as a whole, and the loss of the tail (B) to the hominoids — both wider groups than the hominins.

Q39. B — the researchers changed nothing, so the survey can show only an association between the plant and the clarity; it cannot establish that one causes the other, and the association is not necessarily due to chance (D).

Q40. B — mitochondrial DNA is passed only down the maternal line and does not recombine, so it traces a single unbroken lineage back through time.

Section B — solutions

Q1. (a) The base sequence of gene P is expressed in two stages. First, in **transcription**, which takes place in the **nucleus**, the base sequence of the gene is copied into a complementary molecule of messenger RNA. The mRNA then leaves the nucleus. Second, in **translation**, which takes place at a **ribosome in the cytosol**, the sequence of codons in the mRNA is read three bases at a time; each codon is matched by the anticodon of a transfer RNA that carries a particular amino acid, so the amino acids are joined in the order the codons specify, building the enzyme. (1 mark: transcription, in the nucleus; 1 mark: translation, at a ribosome in the cytosol; 1 mark: the base sequence sets the codon sequence, which sets the order of amino acids.)

(b) A single base substitution alters **one codon**. That codon may then code for a **different amino acid** at that point in the chain (a missense change), or it may become a **stop** codon that halts the chain early (a nonsense change). Because the sequence of amino acids determines how the chain folds, swapping one amino acid can disturb the **R-group interactions** that pin the folded shape in place, so the enzyme takes up a **different three-dimensional shape**. If the reshaped **active site** no longer fits the enzyme's substrate, the substrate cannot bind, no reaction is catalysed, and no pigment is produced. (1 mark: the substitution changes a codon and so a single amino acid, or introduces a premature stop; 1 mark: this alters the enzyme's folded shape and active site, so the enzyme no longer works.)

(c) The genetic code is **degenerate** — several different codons can code for one amino acid. In variety 2 the substitution simply swaps one codon for another that stands for the **same amino acid**, so the enzyme's amino acid sequence is not altered and it still works (a silent mutation). (1 mark.)

Q2. (a) The technique is the **polymerase chain reaction (PCR)**. It requires (any **one**): a pair of **primers** that match the ends of each STR region; a **heat-stable DNA polymerase**; a supply of **free nucleotides**; or **cycling between set temperatures** (heating to separate the strands, cooling to let primers bind, and warming for the polymerase to extend them). (1 mark: PCR; 1 mark: one thing it requires.)

(b) **Fillets 2 and 4** were not the labelled species. At all three markers they carry the repeat numbers of **reference species B** (11, 7 and 9), not those of species A (8, 12 and 5), so they are the cheaper species B and have been

mislabelled. Fillets 1 and 3 match species A exactly and are genuine. (1 mark: fillets 2 and 4; 1 mark: justified by their repeat numbers matching species B and differing from species A at all three markers.)

- (c) Markers used to tell **species** apart are chosen because their repeat numbers are **consistent within a species** but **differ between species**, so every genuine species-A fish gives the same profile and any species-B fish gives a different one. Markers used to identify an **individual person** must instead be **highly variable between individuals** — carrying many different possible repeat numbers — so that two different people are very unlikely to share the same profile and a profile can point to one person. (1 mark: species markers are consistent within a species and differ between species; 1 mark: individual-identification markers must vary greatly between individuals so that each person's profile is (almost) unique.)
- (d) **Yes** — the farmed fish is **transgenic**. The gene put into it was taken from **another species** of fish, and moving a gene across the boundary between one species and another is what makes an organism transgenic (rather than only genetically modified, as it would be if its own genome had merely been edited). (1 mark.)
- (e) The Marker 1 regions are first copied by PCR; because species A has **8 repeats** and species B has **11 repeats**, the PCR product from species B is **longer** than that from species A. The products are loaded into a gel and an electric current is applied. Being **negatively charged, the DNA fragments migrate to the positive electrode**, and a **smaller fragment slips through the gel mesh more easily**, so the shorter species-A fragment ends up **further from the well** than the longer species-B fragment. The two species therefore come to rest as **bands in different positions**, which reveals the difference. (1 mark: the different repeat numbers give fragments of different lengths; 1 mark: the smaller fragment travels the further, so the two species form bands in different positions.)

Q3. (a) Enzyme Z works best at **50 °C**, the temperature at which the greatest volume of clarified juice, 27 mL, was produced. Faster-moving molecules do meet more often, but a collision only leads to a reaction if the enzyme still has a working **active site**. At 70 °C the heat has **broken the weak bonds that hold enzyme Z in its folded shape**, so the enzyme has **lost the shape of its active site** and pectin can no longer fit into it — the enzyme has been **denatured**, and that change is **not reversed** on cooling. With no enzyme left able to form an enzyme–substrate complex, no pectin at all is broken down however fast the molecules are moving, so the yield is **0 mL** against 27 mL at 50 °C. (1 mark: 50 °C; 1 mark: at 70 °C the heat breaks the bonds holding the enzyme's folded shape, so the active site loses its shape and pectin can no longer bind — denaturation; 1 mark: with no working active sites left, no enzyme–substrate complexes can form and faster movement cannot compensate, so the yield falls to zero.)

- (b) The volume of clarified juice would be **greater** (up to about double). Doubling the amount of enzyme Z **doubles the number of active sites** available, so at any moment **more enzyme–substrate complexes** can be formed and more pectin is broken down in the 20 minutes — provided there is still plenty of pectin left in the juice for the extra active sites to work on. (1 mark: the volume produced would increase; 1 mark: twice as much enzyme provides twice as many active sites, so more enzyme–substrate complexes form and more pectin is broken down in the fixed time.)
- (c) Different batches of fruit are likely to differ in how much pectin (and what else) their juice contains, so **batch is an uncontrolled variable that changes together with the temperature**. A difference in the volume of clarified juice may therefore have been caused by the batch rather than by the temperature, and the apparent optimum cannot be trusted. All six samples should have been taken from a **single, well-mixed batch of juice**, so that temperature was the only variable that changed. (1 mark: the batches may differ in pectin content, so batch is confounded with temperature and a difference cannot be attributed to temperature alone; 1 mark: all samples should have come from one well-mixed batch.)

Q4. (a) **Grass Q** is the C4 plant. As the leaf temperature rose from 20 °C to 40 °C, grass Q's rate of carbon fixation **rose**, from 18 to 26 units, while grass P's rate **fell**, from 20 to 12 units. Holding up, and even improving, its rate of carbon fixation in hot conditions with the stomata partly closed is the mark of a C4 plant; a C3 plant loses more and more of its fixed carbon as the leaf warms, so its rate falls. (1 mark: grass Q, with both sets of figures and directional language; 1 mark: the C4 plant maintains or raises its rate in hot conditions while the C3 plant's rate falls.)

- (b) Holding the stomata partly closed saves water, but it also **restricts the entry of carbon dioxide** while the **oxygen made by the light-dependent stage builds up** inside the leaf, so the ratio of carbon dioxide to oxygen around Rubisco falls. Rubisco's active site can bind **either** gas. In **grass P** (the C3 plant) Rubisco therefore binds **oxygen** more often as the leaf warms; carbon that has already been fixed is then lost through

photorespiration instead of being built into sugar, so the measured rate of carbon fixation falls (20 to 12 units). **Grass Q** (the C4 plant) captures carbon dioxide in its outer mesophyll cells and delivers it inward to the cells where Rubisco works, keeping the **carbon dioxide concentration around Rubisco high** even when the stomata are almost shut; Rubisco there goes on binding **carbon dioxide**, so little carbon is lost and the rate is maintained (18 to 26 units). (1 mark: partly closing the stomata lowers internal carbon dioxide and raises oxygen, so the ratio around Rubisco falls; 1 mark: in grass P Rubisco binds oxygen more often — photorespiration — so less carbon is fixed and the rate falls; 1 mark: grass Q concentrates carbon dioxide around Rubisco, so Rubisco keeps binding carbon dioxide and the rate is maintained.)

Q5. (a) The process is **anaerobic respiration (lactic acid fermentation)**. From each molecule of **glucose** the bacteria gain a net **2 ATP**. (1 mark: anaerobic respiration / fermentation; 1 mark: a net 2 ATP per glucose.)

- (b) The milk proteins undergo **denaturation**. A protein is held in its particular folded (three-dimensional) shape by bonds between the **R-groups (side chains)** of its amino acids, including **ionic bonds and hydrogen bonds**. A fall in pH is a rise in hydrogen-ion concentration, which **alters the charges carried on those R-groups**, so the ionic and hydrogen bonds that held the folded shape are **broken**. The protein therefore **unfolds**, and the unfolded chains of neighbouring proteins clump together, thickening the milk. (1 mark: denaturation; 1 mark: the folded shape is held by ionic/hydrogen bonds between the R-groups; 1 mark: the lower pH alters the R-group charges and breaks those bonds, so the protein unfolds.)
- (c) The bacteria go on **converting more of the milk sugar into lactic acid**, so the **pH falls further** and the yoghurt **tastes more sour**. Because it is the falling pH that unfolds the milk proteins, the lower pH **denatures and coagulates still more of the protein**, so more of the milk sets and the yoghurt becomes **firmer**. (1 mark: continued fermentation releases more lactic acid, so the pH falls further, giving a more sour taste; 1 mark: the lower pH denatures and coagulates more of the milk protein, so the yoghurt sets firmer.)
- (d) The oxygen-using process is **aerobic respiration**, and most of its ATP is produced in the **mitochondrion** (at the inner mitochondrial membrane). Without oxygen these bacteria can only run **glycolysis**, which breaks glucose down no further than a small three-carbon compound; the lactic acid they release still holds **most of the energy of the original glucose**, so only a net **2 ATP** is captured. A cell supplied with oxygen can go on to break the glucose down **completely, to carbon dioxide and water**, releasing far more of its energy and capturing **30 or 32 ATP** per glucose. (1 mark: aerobic respiration; 1 mark: mitochondrion; 1 mark: without oxygen glucose is only partly broken down and most of its energy stays locked in the lactic acid (2 ATP), whereas with oxygen it is broken down completely to carbon dioxide and water, yielding 30 or 32 ATP.)

Q6. (a) The response is **inflammation**. **Histamine** released by damaged cells and mast cells makes the **blood vessels around the graze widen** and their walls **more permeable**, so more blood reaches the area (making it red and warm) and **plasma and phagocytes leak out into the tissue** (the swelling). The extra phagocytes **engulf and destroy the bacteria**, and the increased flow also delivers clotting factors and other defensive proteins to the site. (1 mark: inflammation named; 1 mark: vasodilation and increased permeability, giving the redness, heat and swelling; 1 mark: this brings phagocytes and defensive proteins to the site to destroy the bacteria.)

- (b) The process is **antigen presentation**. Having engulfed and broken the bacterium down, the macrophage **shows fragments of its antigens, held on MHC markers at the macrophage's surface**, to passing **lymphocytes**. The lymphocyte **whose receptor fits that antigen is switched on**, which sets the specific (adaptive) response going — so antigen presentation is the bridge from the fast, non-specific innate reaction to the targeted adaptive one. (1 mark: antigen presentation named; 1 mark: displaying antigen to a lymphocyte switches on the matching lymphocyte and begins the specific response.)
- (c) The lymphocyte is the **B lymphocyte** (once activated it divides, and its descendants become the **plasma cells** that secrete the antibody). Antibodies are **specific**: the binding sites of each antibody have a shape that is **complementary to one particular antigen** — here, a surface molecule of this species of bacterium — and they will bind that antigen and no other. A different species of bacterium carries **different surface antigens**, whose shapes these binding sites do not fit, so the antibodies cannot attach to it and give the person no protection against it. (1 mark: B lymphocyte; 1 mark: an antibody's binding site fits only the one antigen that is complementary to it, and a different species carries different antigens, so these antibodies cannot bind it.)

- (d) The first infection left behind **memory B cells** (and memory T cells) specific to this bacterium. On the second infection these memory cells recognise the antigen at once and mount a **secondary response** — fast and large — that destroys the bacterium before it can produce any symptoms. (1 mark.)

Q7. (a) The vaccine's antigen is treated as non-self and triggers a **primary response**: the **B lymphocyte whose receptor matches the antigen is selected and divides repeatedly (clonal expansion)**; some of its descendants become **plasma cells** that secrete antibody, and others become long-lived **memory B cells** (helper T cells and memory T cells are also involved). Because the memory cells **persist** long after the antibody has gone, a later infection by the real bacterium meets a **secondary response that is both quicker and larger**, wiping the pathogen out before it causes illness. (1 mark: the antigen triggers selection and clonal expansion of the matching B cell into plasma cells; 1 mark: memory cells are formed and persist; 1 mark: a later infection brings a fast, large secondary response that clears the pathogen.)

- (b) **Helper T cells** are activated when they recognise the vaccine antigen displayed on antigen-presenting cells, and they then release **signalling molecules (cytokines)** that help to **activate the B cells** specific to that antigen, driving them to divide and become antibody-secreting plasma cells. If the person had **no functioning helper T cells**, the antigen-specific B cells would receive little or none of this help, so the **antibody response would be greatly reduced** (weak, or almost absent), and few plasma or memory cells would form. (1 mark: helper T cells release cytokines that activate / help the antigen-specific B cells to produce antibody; 1 mark: without them the antibody response is greatly reduced / weak.)
- (c) The effect is **herd immunity**. It works by **breaking chains of transmission**, so what matters is how many of the people an infectious person meets are already immune. While only a **small proportion** have been vaccinated, an infected person still meets plenty of **susceptible** people, the pathogen keeps finding new hosts, and it goes on circulating — the people who cannot be vaccinated are as exposed as ever. Only once the vaccinated proportion is **high** is almost every contact someone in whom transmission **stops**, so that each round of transmission produces **fewer cases than the one before** and the outbreak shrinks instead of spreading. (1 mark: herd immunity named; 1 mark: below that proportion enough susceptible contacts remain for the pathogen to keep spreading, and only a high proportion leaves so few susceptible contacts that chains of transmission break and case numbers fall.)
- (d) The vaccine contains only a **single surface protein** of the bacterium, not the **whole living bacterium**. A lone protein **cannot reproduce or invade the tissues**, so it cannot establish an infection; it can still act as an **antigen** that the immune system responds to, but with no living pathogen present the vaccine cannot give the person the disease. (1 mark.)

Q8. (a) At the start the resistance allele was very **rare** — only **2%** of the rodents carried it. However strongly the poison favoured those few rodents, they were the only ones able to pass the allele on, so the number of carriers could grow only from a **very small base**, and five years of breeding added just 7 percentage points. By year 10, **28%** of the rodents carried the allele, so a far larger share of each generation's parents were carriers; the **same** survival advantage now acted on many more breeding animals, so it added many more carriers in the same five years — 27 percentage points, to 55% by year 15. (1 mark: at the start almost no rodents carried the allele, so very few survivors were able to pass it on and the increase started from a very small base; 1 mark: once carriers were common a much larger share of the breeding population carried the allele, so the same advantage produced a much larger rise in the same time.)

- (b) The poison acted as a **selection pressure** on the population. Rodents **without** the resistance allele were **killed** by it, while rodents that **carried it survived and bred**, passing it on to their offspring. Generation after generation the proportion of the population carrying the allele therefore **rose steadily**, from **2% in year 0 to 78% in year 20**, so that resistant rodents changed from a rarity into the great majority and the poison became far less effective. Those percentages are **not** the allele's frequency in the gene pool, because they count **individuals that carry** the allele rather than **copies of the allele**. A rodent counted as a carrier may hold only **one** copy, its other copy being the non-resistant allele, and those non-resistant copies are still part of the gene pool — so the frequency of the resistance allele is **lower** than 78%. (1 mark: the poison is a selection pressure — susceptible rodents are killed while carriers survive, breed and pass the allele on; 1 mark: so the proportion carrying it rose steadily over the generations, from 2% to 78%, quoting the data; 1 mark: the table counts individuals carrying the allele, and a carrier may hold only one copy of it, so the allele's frequency in the gene pool is lower than the percentage of carriers.)

- (c) If the poison were withdrawn, the resistance allele would become a **disadvantage**, because resistant rodents need far more vitamin K. Rodents **without** the allele would then survive and breed **more successfully**, so selection would now act **against** the resistance allele and its frequency would **fall** over the generations. (1 mark: the frequency would fall / decrease; 1 mark: without the poison the allele is disadvantageous, so non-resistant rodents breed more successfully and selection acts against it.)
- (d) If resistant rodents from this city **migrated to the nearby town and bred with the rodents there**, they would **introduce the resistance allele into that town's gene pool**, where it had been absent, so its frequency there would **rise**. This movement of alleles between populations by the migration and breeding of individuals is **gene flow**. (1 mark: resistant rodents move to the town and interbreed; 1 mark: this introduces the resistance allele into that gene pool, raising its frequency there.)

Q9. (a) Insertion W must have arisen **once, in a single ancestral population**, and because it is never removed it has been handed on to **every** descendant of that population. All five species carry it and the marsupial from outside the group does not, so all five must be **descended from that one ancestral population** — an ancestor they share with each other but not with the outside marsupial. The five species therefore form a **single natural group (one branch of the marsupial family tree)**. (1 mark: W arose once in an ancestor and is passed to all of its descendants, so every species carrying it descends from that ancestor; 1 mark: the five species share a common ancestor that the outside marsupial does not, so they form one natural group / branch.)

- (b) **Species 3 and species 4**. They are the only two species that carry **insertion Y**, and Y — like the others — arose **once**, in one ancestral population, and was then passed to **all** of that population's descendants and to no one else. Since species 3 and species 4 carry Y and the other three species do not, species 3 and species 4 are the **only** descendants of the population in which Y arose. Their two lineages must therefore have **separated from each other after** they had separated from every other lineage in the group, which makes them each other's closest relatives. (They also match at all four markers, whereas every other pair differs at at least one.) (1 mark: species 3 and species 4; 1 mark: they alone share insertion Y, which arose once in one ancestral population and passes only to its descendants; 1 mark: so they alone descend from that ancestor, meaning their lineages separated from each other more recently than either separated from any other species.)
- (c) Insertion Z must have arisen **after the lineage leading to species 5 had already separated** from the lineages of the other four — that is, on species 5's own branch, after the five lineages had begun to divide. If Z had arisen **before** that separation, it would have been present in the shared ancestor and would therefore have been passed to the other species descended from that ancestor as well; since it is **never removed**, they would all still carry it. Finding it in species 5 alone shows the insertion happened only in that one line of descent. (1 mark: it arose after species 5's lineage had separated from the others / on the branch leading only to species 5; 1 mark: had it arisen earlier, the ancestor would have carried it and — because insertions are never lost — every species descended from that ancestor would still carry it.)
- (d) The other four insertions give groups that fit **inside one another**: W marks all five species, X marks species 2, 3, 4 and 5 within that, Y marks species 3 and 4 within that again, and Z marks species 5 alone. Insertion V marks **species 1 and species 4**, which **cuts across** that pattern — species 4 carries X and Y while species 1 carries neither, so species 1 and species 4 **cannot** be the only descendants of some more recent shared ancestor without contradicting X and Y. V therefore **cannot have arisen once and been inherited by both species**: the same insertion must instead have happened **independently, at the same position, in the two separate lineages** (or the result is a technical error at that site). The researchers should therefore **not** treat V as evidence that species 1 and species 4 are close relatives. They should build the classification on **W, X and Y, which all agree with one another**, and re-check V — for example by sequencing the DNA either side of the insertion in both species to see whether the two are genuinely the same event — setting it aside until that is resolved. (1 mark: V's distribution conflicts with the nested pattern given by W, X and Y — species 1 lacks the insertions that species 4 carries — so it cannot mark a group of common descent; 1 mark: the same insertion must have arisen independently in the two lineages, or the reading is an error, rather than being inherited from a shared ancestor; 1 mark: so V should not be used as evidence of relatedness — the classification should follow the markers that agree, with V checked further / set aside.)
- (e) Size, coat colour and diet are shaped by the **way an animal lives**. Two species that are only distantly related but feed and shelter in the same way can be driven to the **same size, colour or feeding habit independently** by the same selection pressures, so a resemblance of that kind may reflect a **shared way of life rather than shared ancestry**. A DNA insertion of this kind is different: it is a **rare chance event at one particular**

position in a very large genome, it gives the animal **no advantage**, so selection does not favour its appearance, and once present it is copied unchanged into every descendant. The chance of the identical insertion turning up independently at the identical site in two lineages is therefore very small, so two species that share one have almost certainly **inherited it from the ancestor in which it arose**. (1 mark: features such as size, colour and diet can be produced independently in unrelated species by similar selection pressures, so sharing one need not indicate shared ancestry; 1 mark: an insertion is a rare chance event at one site that is not favoured by selection and is inherited unchanged, so sharing one is very unlikely unless both species descend from the ancestor in which it arose.)

Q10. (a) The **independent variable** is **whether the detergent is added to the container** (the treatment the student varies). The **dependent variable** is the **number of duckweed plants in each container after two weeks**. One variable that must be kept constant (any **one**): the **starting number of duckweed plants** in each container, the **volume and source of the pond water**, the **temperature**, the **light** the containers receive, the **size of container**, or the **two-week period**. (1 mark: IV; 1 mark: DV; 1 mark: one valid controlled variable.)

(b) The five detergent-free containers provide a **baseline** — the number of duckweed plants that grow when **everything is the same except that no detergent is added**. Because the two sets of containers are treated **identically apart from the detergent**, the student can **compare** them and attribute any difference in duckweed numbers **to the detergent itself**, rather than to the pond water or the growing conditions. Without the control there would be nothing to compare the treated containers against, so no such conclusion could be drawn. (1 mark: the control gives a baseline / comparison — growth with no detergent, everything else equal; 1 mark: comparing treatment with control lets any difference be attributed to the detergent rather than to other factors.)

(c) Any **one**: only **duckweed** was tested, so the result cannot support a claim about **all** water plants; a lower number of plants shows only that growth was **slowed or reduced**, not that the plants were **killed** (they may simply have multiplied more slowly); or only **one detergent at one amount** was tested, in **containers under set conditions**, not in a real pond. (1 mark.)

Exam 3 — Practice examination

Reading time: 15 minutes. Writing time: 2 hours 30 minutes. Section A: 40 questions, 40 marks. Section B: 10 questions, 80 marks. Total 120 marks. This examination covers Units 3 and 4. Answer all questions.

- No calculator may be used.
- No formula sheet, data sheet, dictionary or notes may be used.
- Diagrams in this examination are not drawn to scale.

Section A — Multiple choice

Every question in this section must be attempted. Select the response that is correct or that best answers the question. One mark is awarded for each correct response, and nothing is taken away where a response is wrong. Where two or more responses have been completed for the same question, no mark is awarded for it. No diagram in this section is drawn to scale.

Question 1

In one of the two strands of a molecule of double-stranded DNA, 20% of the bases are adenine and 30% are guanine. In the other (complementary) strand, the percentage of the bases that are thymine is

- A. 20%
- B. 30%
- C. 25%
- D. 50%

Use the following information to answer Questions 2 and 3.

The base sequence of part of a messenger RNA molecule is given below. A section of the genetic code is provided beside it.

5'–AUG AAA GGU UCA–3'

Codon	Amino acid
AUG	methionine (start)
AAA	lysine
GGU	glycine
UCA	serine
UAA	stop

Question 2

The DNA template strand from which this mRNA molecule was transcribed reads

- A. 5'–TAC TTT CCA AGT–3'
- B. 5'–UAC UUU CCA AGU–3'
- C. 3'–ATG AAA GGT TCA–5'
- D. 3'–TAC TTT CCA AGT–5'

Question 3

A single extra base is inserted into the coding sequence immediately after the start codon. Compared with the original, the polypeptide made using the altered mRNA will most likely be

- A. identical, because only one base has been added.
- B. one amino acid longer, with the rest of the chain unchanged.
- C. changed from the second codon onwards, because the reading frame has shifted.
- D. unchanged, because the extra base lies within an intron.

Question 4

A cell makes two proteins. Protein 1 is secreted from the cell and is assembled on ribosomes attached to the rough endoplasmic reticulum. Protein 2 remains and functions in the cytosol. Protein 2 is most likely assembled on

- A. free ribosomes in the cytosol.
- B. ribosomes attached to the Golgi apparatus.
- C. the smooth endoplasmic reticulum.
- D. ribosomes inside the nucleus.

Question 5

In the polymerase chain reaction (PCR), the number of copies of the target region doubles with every complete cycle. Starting from a single double-stranded target molecule, the number of molecules of that region present after three complete cycles is

- A. 3
- B. 4
- C. 6
- D. 8

Question 6

A fragment of DNA carrying a gene is to be inserted into a plasmid. The two pieces of DNA will pair up and be held together, ready for DNA ligase to seal them, only if the cut ends of both

- A. are blunt, with no unpaired bases.
- B. carry a gene for antibiotic resistance.
- C. have complementary single-stranded overhangs (sticky ends).
- D. were produced by heating the DNA to 95 °C.

Question 7

A variety of maize has had a gene from a soil bacterium inserted into its genome. The bacterial gene codes for a protein that is toxic to a caterpillar pest. This variety of maize is best described as

- A. genetically modified but not transgenic, because only one gene was changed.
- B. transgenic, because it carries a gene from a different species.
- C. not genetically modified, because the change is natural.
- D. a new species, because its genome now differs from that of ordinary maize.

Question 8

Compared with older methods of genetic modification, an advantage of CRISPR-Cas9 is that it can be

- A. used without any enzymes.
- B. directed to cut at a specific chosen DNA sequence by designing the guide RNA.
- C. used only in bacterial cells.
- D. relied upon to change every gene in the genome at once.

Question 9

A liver cell and a muscle cell taken from the same person contain the same genome but have different proteomes. The best explanation is that

- A. the two cells have different DNA base sequences.
- B. the muscle cell has lost some of its genes.
- C. mutations have changed the genome of one of the two cells.
- D. different genes are expressed (transcribed and translated) in the two cell types.

Question 10

An enzyme greatly speeds up a reaction but does not change the amount of energy the reaction releases overall. This is because the enzyme

- A. supplies energy to the reacting molecules.
- B. makes the products more stable than the reactants.
- C. lowers the activation energy without changing the energy of the reactants or the products.
- D. raises the temperature of the reaction mixture.

Question 11

An enzyme is heated to 70 °C, well above its optimum of 37 °C, and is then cooled back to 37 °C. Its activity does not return. The best explanation is that

- A. the enzyme was used up while it was hot.
- B. cooling has now made the enzyme too cold to work.
- C. heating denatured the enzyme, changing the shape of its active site, and cooling does not restore that shape.
- D. the substrate was destroyed by the heat.

Use the following information to answer Questions 12 and 13.

The rate of photosynthesis of an aquatic plant was measured under four conditions: low or high light, each paired with a low or a high carbon dioxide concentration. The temperature was held the same throughout.

Light	Carbon dioxide	Rate of photosynthesis (arbitrary units)
low	low	10
low	high	11
high	low	15
high	high	28

Question 12

At low light, raising the carbon dioxide concentration barely changes the rate of photosynthesis. This is because, at low light, the rate is limited mainly by

- A. the carbon dioxide concentration.
- B. the temperature.
- C. the amount of water available.
- D. the light intensity.

Question 13

At high light, raising the carbon dioxide concentration from low to high increases the rate from 15 to 28 units. This shows that, at high light, the rate is limited mainly by

- A. the light intensity.
- B. the carbon dioxide concentration.
- C. the temperature.
- D. a shortage of chlorophyll.

Question 14

In a cell that is respiring aerobically, the carbon dioxide that the cell gives off is produced

- A. during glycolysis, in the cytosol.
- B. at the end of the electron transport chain.
- C. during the Krebs cycle, in the mitochondrial matrix.
- D. when pyruvate is converted to lactic acid.

Question 15

A plant root cell in waterlogged soil is respiring in the complete absence of oxygen. The pyruvate produced by glycolysis in this cell is then converted to

- A. ethanol and carbon dioxide.
- B. lactic acid only.
- C. glucose and oxygen.
- D. carbon dioxide and water.

Question 16

Anaerobic fermentation releases only a small part of the energy stored in a molecule of glucose. The main reason is that

- A. the glucose molecule is not broken down at all during fermentation.
- B. the glucose is only partly broken down, so most of its energy is still held in the lactic acid or the ethanol that is produced.
- C. all of the energy released is immediately lost from the cell as heat.
- D. the ATP that is made is broken down again as fast as it is formed.

Question 17

A newly discovered infectious agent consists of a single molecule of RNA enclosed in a protein coat. It can reproduce only inside the cells of a host. This agent is best classified as

- A. a bacterium, and a cellular pathogen.
- B. a prion, because it contains no DNA.
- C. a virus, and a non-cellular pathogen.
- D. a fungus, because it has a protein coat.

Question 18

An allergen, such as a pollen protein, differs from a typical pathogen in that an allergen

- A. is a living cell that reproduces inside the body.
- B. is normally harmless, but triggers an exaggerated immune response in some people.
- C. is a self-antigen made by the body's own cells.
- D. cannot be recognised by the immune system at all.

Use the following information to answer Questions 19, 20 and 21.

A virus that reproduces inside the cells lining a person's airways infects someone who has never encountered it before.

Question 19

Before it reached the cells lining the airways, the virus had to get past the mucus and the cilia of the airway lining. Working together, mucus and cilia normally

- A. destroy inhaled pathogens by engulfing and digesting them.
- B. trap inhaled particles and sweep them up and out of the airways, forming a physical barrier.
- C. produce antibodies against any pathogen that is breathed in.
- D. kill inhaled pathogens by lowering the pH of the airway lining.

Question 20

Natural killer (NK) cells also act early in this infection. NK cells belong to the innate response, and they destroy infected body cells

- A. only after being presented with a specific antigen.
- B. without needing to recognise a specific antigen.
- C. by secreting antibodies against the virus.
- D. only after memory cells have formed.

Question 21

Over the following days, the lymph nodes in the person's neck become swollen. This swelling occurs mainly because

- A. the nodes fill with red blood cells filtered out of the lymph.
- B. the virus reproduces inside the lymph nodes themselves.
- C. lymphocytes that recognise the viral antigen multiply rapidly within the nodes.
- D. the heart pumps lymph into the nodes under pressure.

Question 22

When a splinter drives bacteria into the skin, the injured area soon becomes red, warm and swollen. These changes help to clear the infection mainly because they

- A. raise the temperature of the whole body, which kills the bacteria.
- B. allow B cells to secrete antibody at the wound within minutes.
- C. stop all fluid leaving the blood vessels at the wound.
- D. increase the blood flow to the area and make the vessel walls leakier, so more phagocytes reach the tissue.

Question 23

Helper T cells are essential to the adaptive immune response because they

- A. release signalling molecules (cytokines) that activate B cells and cytotoxic T cells.
- B. secrete large amounts of antibody.
- C. engulf and present antigen as the first step of the innate response.
- D. destroy infected cells directly by releasing toxic chemicals.

Question 24

A person given an injection of ready-made antibodies is protected immediately, but only for a few weeks. A person given a vaccine is protected only after a delay, but for years. The key reason for this difference is that

- A. the injected antibodies produce no memory cells, whereas the vaccine causes the person's own immune system to form memory cells.
- B. the injected antibodies are destroyed by the person's own immune system.
- C. the vaccine contains far more antibody than the injection does.
- D. the injected antibodies are not specific to any pathogen.

Question 25

Disease P spreads more easily than disease Q: on average each person with P infects more other people than each person with Q does. To stop outbreaks of these diseases by vaccination, the proportion of the population that must be immune is

- A. lower for P than for Q.
- B. the same for both diseases.
- C. not related to how easily the disease spreads.
- D. higher for P than for Q.

Question 26

In one year, two strains of an influenza virus infect the same host cell and exchange whole segments of their genomes, producing a virus with a combination of surface antigens that no one has met before. This sudden change is best described as

- A. antigenic drift.
- B. genetic drift.
- C. antigenic shift.
- D. a founder effect.

Question 27

A long course of broad-spectrum antibiotics kills much of the normal microbiota living in a person's gut, and the person then develops a gut infection. This happens because the normal microbiota usually

- A. secretes antibodies against gut pathogens.
- B. occupies the available surfaces and uses up the available nutrients, leaving little for an invading pathogen.
- C. forms a layer of dead cells that pathogens are unable to cross.
- D. engulfs and digests any pathogen that reaches the gut wall.

Question 28

Which single change to a gene's coding sequence would you expect to have the *least* effect on the protein it codes for?

- A. the deletion of a single base near the start of the sequence
- B. the insertion of a single base near the start of the sequence
- C. a substitution that changes a codon into a stop codon
- D. a substitution in the third base of a codon

Use the following information to answer Questions 29 and 30.

A small population of a lizard lives on an offshore island. It is separated by sea from a large population of the same species on the mainland.

Question 29

From time to time a few lizards from the mainland are washed onto the island. Their arrival will change the allele frequencies of the island population (that is, cause gene flow) only if the arriving lizards

- A. survive and breed with the island lizards.
- B. are larger than the island lizards.
- C. carry no alleles that are new to the island.
- D. return to the mainland to breed.

Question 30

Within the small island population, a particular allele — one that neither helps nor harms the lizards that carry it — changes markedly in frequency from one generation to the next. The most likely cause is

- A. genetic drift, whose effect is large in a small population.
- B. natural selection favouring the allele.
- C. a high rate of mutation of that allele.
- D. gene flow from the mainland.

Question 31

A population of bacteria that has never been exposed to a particular antibiotic acquires resistance to it within a single generation, without any of the bacteria undergoing a new mutation. This is most likely because the bacteria

- A. were made resistant by the antibiotic itself.
- B. took up a plasmid carrying a resistance gene from other bacteria.
- C. reproduced more slowly than usual.
- D. lost the gene that the antibiotic targets.

Question 32

Two populations of an animal have been separated for a long time. For them to be regarded as two separate species, it is essential that

- A. they look noticeably different from each other.
- B. they live in different places.
- C. they eat different foods.
- D. they can no longer interbreed to produce fertile offspring, even if brought back together.

Question 33

A fossil is discovered that shows a mixture of features of two major animal groups — for example, a jaw like that of a reptile together with limb bones like those of a mammal. Such a fossil is valuable evidence because it

- A. proves that reptiles are still turning into mammals today.
- B. can be used as an index fossil to date the rock precisely.
- C. shows that the two groups are unrelated.
- D. represents a form transitional between the two groups.

Question 34

Radiometric dating of a volcanic rock is based on measuring the ratio of a radioactive parent isotope to the stable daughter isotope it decays into. This ratio is used to find

- A. the age of any fossils lying in the rock, directly.
- B. the temperature at which the rock formed.
- C. the depth at which the rock is now buried.
- D. the time that has passed since the rock crystallised.

Question 35

The wing of a bird and the wing of an insect are both used for flight, but they are built from completely different structures and developed from different origins. These wings are

- A. homologous structures, showing a recent common ancestor.
- B. vestigial structures.
- C. analogous structures, produced by convergent evolution.
- D. evidence that birds evolved directly from insects.

Question 36

A biologist wishes to work out the relationships between three very closely related species. The most informative molecule to compare between them is one whose sequence has changed

- A. so slowly that the three species share an identical sequence.
- B. not at all since they diverged.
- C. quickly enough that even closely related species show clear differences.
- D. only in one of the three species.

Question 37

In a hominin skeleton that indicates habitual upright walking on two legs, the foramen magnum (the opening through which the spinal cord leaves the skull) is positioned

- A. underneath the skull, so that the head is balanced on top of a vertical spine.
- B. at the back of the skull, behind the braincase.
- C. at the front of the face, below the eyes.
- D. on the left-hand side of the skull.

Question 38

A student measures a 40.0 g reference mass five times. The five readings are 34, 46, 38, 44 and 38 g, and their mean is 40.0 g. Taken together, these five readings are

- A. precise but not accurate.
- B. accurate but not precise.
- C. both accurate and precise.
- D. neither accurate nor precise.

Question 39

A thermometer used throughout an investigation reads exactly 2 °C higher than the true temperature every time it is used. Taking many readings with this thermometer and averaging them will

- A. remove the error completely.
- B. reduce the error to about 1 °C.
- C. turn the error into a random error.
- D. not reduce the error, because it affects every reading in the same way.

Question 40

Before beginning an experiment on live animals, a research team designs the procedure so that any harm or distress to the animals is kept to the lowest level possible and never exceeds what is necessary for the study. This care most directly reflects the bioethical concept of

- A. non-maleficence.
- B. beneficence.
- C. justice.
- D. integrity.

Section B — Short answer

Every question in this section must be attempted, in the spaces provided. For any question carrying two or more marks, a response earns full credit only if it reaches the depth that its command term and its mark allocation call for. No diagram in this section is drawn to scale.

Question 1 (6 marks)

In a bacterium, the amino acid tryptophan is made by enzymes coded by the structural genes of the *trp* operon. Transcription of these structural genes is controlled by a repressor protein, which is coded by a separate regulatory gene. The repressor can bind to the operator only when a molecule of tryptophan is bound to the repressor. Three mutant strains of this bacterium were produced.

Table 1 Three mutant strains of the bacterium

Strain	The change carried by the strain
strain 1	the regulatory gene is inactivated, so no functional repressor protein is made
strain 2	the repressor is altered so that it binds the operator even when no tryptophan is present
strain 3	the promoter is deleted

a. In the normal (wild-type) bacterium, explain why the structural genes are transcribed when tryptophan is scarce, but not when it is plentiful. Refer to the repressor and the operator. 3 marks

b. Predict whether the structural genes will be transcribed in strain 1, and in strain 2, when tryptophan is scarce. Justify each prediction. 2 marks

c. Predict whether the structural genes can be transcribed in strain 3 under any conditions, and explain your answer. 1 mark

Question 2 (10 marks)

A captive-breeding program keeps a small number of a rare native parrot. A chick has hatched, and its mother is known, but its father is one of three males — candidate A, candidate B or candidate C. Only a tiny quantity of DNA can be recovered from a shed feather, so the DNA at each of two highly variable (hypervariable) regions was copied and its base sequence read for every bird. Every bird carries two sequences at each region, one on each of its two copies of the chromosome.

Table 2 Base sequence at two hypervariable DNA regions (the two copies carried by each bird)

Bird	Region 1	Region 2
mother	AGGTCA, TCCAGT	CTGATC, AAGCTA
chick	AGGTCA, GACTTG	AAGCTA, TCAGGA
candidate A	GACTTG, CATGCA	TCAGGA, ACGTAC
candidate B	CATGCA, TTGACC	GGAACC, ACGTAC
candidate C	GACTTG, TTGACC	GGAACC, GTTCAG

a. Before a region can be sequenced it is copied many times over by the polymerase chain reaction, which uses two primers to mark out the stretch of DNA that is copied. Explain why the primers must be chosen to match sequences that lie **outside** the hypervariable region rather than within it. 2 marks

b. Using the data in Table 2, identify which candidate is the chick's father. Justify your answer using data from both regions. 3 marks

c. Explain why a match between a candidate and the chick at a single region is not enough to establish parentage, and why testing several regions makes the conclusion reliable. 2 marks

d. The keepers ask whether the test has *proved* that the candidate you identified in part b is the chick's father. Explain why a test of this kind can rule a male out with certainty, but cannot by itself prove that a male who matches is the father. 2 marks

e. In every run, the laboratory also sequences a reference sample whose sequences are already known. State one reason for doing this. 1 mark

Question 3 (7 marks)

In a hot, dry habitat, a CAM succulent opens the stomata of its leaves at night and keeps them closed during the day. A C3 shrub growing nearby opens its stomata during the day. Over one hot, dry day, the water lost and the carbon dioxide fixed by each plant were measured. The sap of the CAM succulent's leaves was also found to be strongly acidic at dawn and almost neutral by dusk; the sap of the C3 shrub showed no such daily change.

Table 3 Water lost and carbon dioxide fixed over one day

Plant	When the stomata are open	Water lost (g)	Carbon dioxide fixed (units)
CAM succulent	at night	3	12
C3 shrub	during the day	24	32

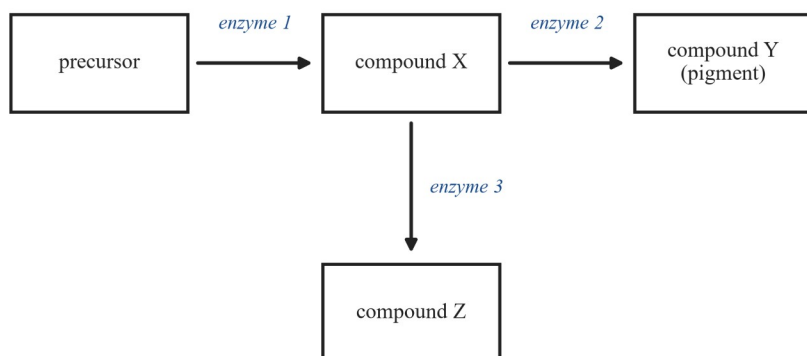
a. Explain what causes the daily change in the acidity of the CAM succulent's leaves, and how that change allows the light-independent stage (the Calvin cycle) to keep running during the day, when the stomata are closed and no carbon dioxide is entering the leaf from the air. 3 marks

b. Using the data in Table 3, calculate the mass of water each plant lost for every unit of carbon dioxide it fixed, and use your two figures to compare how efficiently the two plants use water. 2 marks

c. Using the data, state one advantage and one disadvantage of the CAM strategy compared with the C3 strategy in this habitat. 2 marks

Question 4 (5 marks)

In the cells of a plant, a coloured pigment is made from a precursor by the branched pathway shown below. Each step is catalysed by a different enzyme.



a. Explain why the cell needs a different enzyme to catalyse each step of this pathway. 2 marks

b. A mutation stops the cell making functional enzyme 2. Predict what happens to the amount of compound X, of compound Y and of compound Z in the cell, giving a reason for each prediction. 3 marks

Question 5 (8 marks)

A virus infects and reproduces inside the cells of a person's body. Between infecting one cell and the next, virus particles travel briefly in the blood and tissue fluid.

- a. Explain why antibodies are effective against this virus while it is travelling in the blood between cells, but cannot deal with it once it is inside a body cell. 3 marks
- b. Cytotoxic T cells kill the body's own virus-infected cells. Explain how a cytotoxic T cell is able to pick out an infected cell from among the person's healthy cells. 2 marks
- c. A vaccine is developed that causes the body to make antibodies against the virus, but does not stimulate a strong cytotoxic T cell response. Explain why this vaccine would still be expected to make the illness milder and to reduce spread of the virus from person to person, yet could not clear the infection from a person once their cells were infected. 3 marks

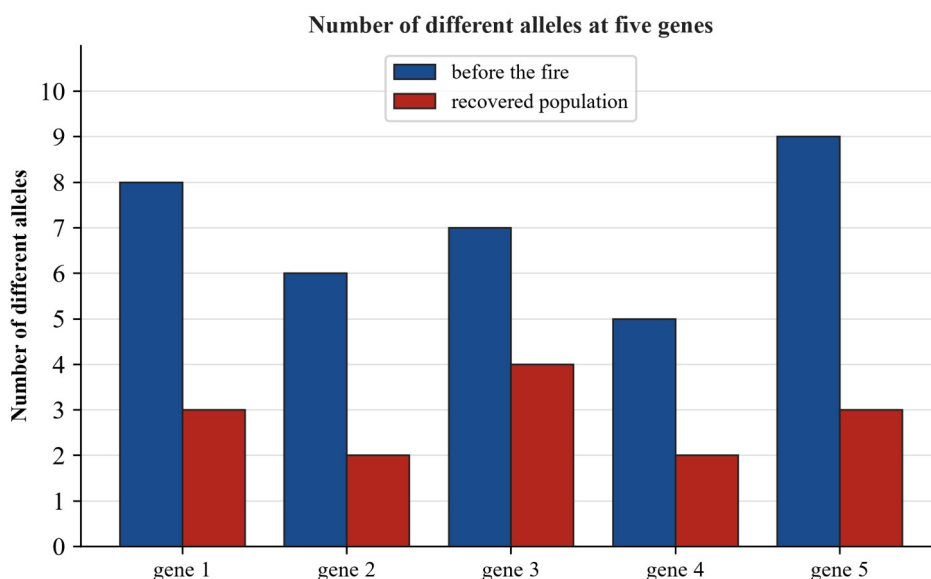
Question 6 (9 marks)

A virus that has long circulated harmlessly in fruit bats changes so that it can infect people and pass from person to person. Cases appear in several countries. At first there is no vaccine, and seriously ill patients are treated with a monoclonal antibody that binds the virus's surface protein.

- a. Explain what is meant by a *monoclonal* antibody and why every antibody molecule in the preparation binds the same target, and describe how binding the virus's surface protein helps a seriously ill patient. 3 marks
- b. Soon after the virus infects a patient's cells, and before any antibody against it has been made, the infected cells release interferons. State what interferons do, and explain how this helps to limit the infection. 2 marks
- c. A new strain of the virus later appears whose surface protein differs slightly in the exact region that the monoclonal antibody binds. Explain why the monoclonal antibody no longer works against this new strain. 2 marks
- d. Doctors then begin treating patients with a mixture of **two** monoclonal antibodies that bind two different regions of the virus's surface protein. Explain why this mixture is much less likely to stop working than a single monoclonal antibody is. 2 marks

Question 7 (6 marks)

A small native marsupial lived in a single patch of forest. An intense bushfire cut the population from about 1200 animals to 40 survivors; over the following fifteen years the numbers built back up to about 1000. The number of different alleles present at each of five genes was recorded before the fire and in the recovered population. (Adapted from Okonkwo & Hartmann, 2025.)



- a.** Name the type of event described by the sharp fall in numbers; using the graph, state the total number of different alleles present across the five genes before the fire and in the recovered population; and explain why that total has not risen along with the number of animals. 3 marks
- b.** Fifteen years after the fire, fewer of the young animals born in this population survive to adulthood than before the fire, even though food and shelter are plentiful. Explain how the change shown in the graph could account for this. 2 marks
- c.** State one reason why a conservation program should record the number of different alleles in this population, and not only the number of animals. 1 mark

Question 8 (14 marks)

At one site, palaeontologists recover a hominin skull from a rock layer. The layer lies just above a bed of volcanic ash dated at 2.5 million years old, and just below a second ash bed dated at 1.9 million years old. At other sites, ancient bones have yielded fragments of DNA, and the complete genomes of many people alive today have been read.

- a.** Describe two trends seen in the skeletons of later hominins compared with earlier ones, and for each trend state what it is associated with. 3 marks
- b.** Hominin fossils are rare. Using the setting in which this skull was found, explain **two** things about that setting that made the preservation of the skull more likely. 2 marks
- c.** DNA recovered from ancient *Homo neanderthalensis* remains shares short segments with the genomes of many people living today. A student concludes from this that *Homo sapiens* is simply descended from *Homo neanderthalensis*. Explain why this shared DNA instead points to interbreeding between two separate species. 2 marks
- d.** The oldest fossils of modern humans occur in Africa, and present-day African populations are more genetically diverse than populations anywhere else. Explain how these two findings together support the view that modern humans arose in Africa and later spread across the world. 2 marks
- e.** Explain why scientists' picture of how modern humans are related to other members of the genus *Homo* has been revised several times as new discoveries have been made. 2 marks
- f.** Two teams examine the same collection of hominin fossils: one team argues that they are all one species, the other that they are two. Explain why disagreements of this kind arise when fossils are classified, and state one kind of additional evidence that could help to settle the question. 3 marks

Question 9 (8 marks)

A pesticide blocks the final step of the electron transport chain in the cells of an insect pest, so that electrons can no longer be passed to oxygen. Plenty of glucose, and plenty of oxygen, are still present in the insect's cells.

- a.** State where in the cell the electron transport chain is located, and name the two energy carriers that deliver electrons to it. 2 marks
- b.** With the electron transport chain blocked, the ATP the cell can obtain from each glucose molecule falls from 30 or 32 to only 2. Explain why the electron transport chain normally accounts for such a large share of the ATP, and name the one stage of respiration that is still able to supply the small amount that remains. 3 marks
- c.** The poisoned cells begin to build up lactic acid. Name the type of respiration now supplying their ATP, and explain why lactic acid is produced from the pyruvate, rather than the pyruvate being broken down further. 3 marks

Question 10 (7 marks)

A team investigated whether warmer water speeds up the development of the eggs of a native frog. Batches of eggs were kept at each of several water temperatures, and the time taken for the eggs to hatch was recorded to the nearest whole day. Five batches were kept at each temperature.

- a.** Explain how recording the hatching time only to the nearest whole day limits what the team can conclude about the effect of temperature, and state one change to the method that would remove that limitation. 2 marks

b. To be confident that any difference in hatching time was caused by the water temperature and not by something else, the team kept all other conditions the same for every batch. Name one such variable they would need to keep constant, and explain how failing to control it could make their conclusion invalid. 2 marks

c. The team writes: “At the temperatures tested, warmer water shortened the mean hatching time of this frog’s eggs.” A magazine reports the work as: “Frogs will hatch faster as the world warms.” Distinguish the team’s conclusion from the magazine’s statement, and give one reason the magazine’s statement is not justified by the data. 3 marks

End of Section B

End of examination questions

Exam 3 — Answers and solutions

Section A — answers

Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	A	11	C	21	C	31	B
2	D	12	D	22	D	32	D
3	C	13	B	23	A	33	D
4	A	14	C	24	A	34	D
5	D	15	A	25	D	35	C
6	C	16	B	26	C	36	C
7	B	17	C	27	B	37	A
8	B	18	B	28	D	38	B
9	D	19	B	29	A	39	D
10	C	20	B	30	A	40	A

Q1. A — a base in one strand pairs with its complement in the other, so the thymine in the complementary strand pairs with, and is equal in amount to, the adenine in this strand: 20%. B applies the guanine figure, and D halves the strand without accounting for the pairing.

Q2. D — the template is complementary to the mRNA and runs antiparallel to it, so 5'–AUG AAA GGU UCA–3' is copied from 3'–TAC TTT CCA AGT–5'. A gives the right bases but the wrong direction; B keeps RNA bases in a DNA strand; C is the coding strand, not the template.

Q3. C — an inserted base shifts the reading frame from that point on, so every codon after the insertion is read in different groups of three and most of the amino acids that follow are changed. A single insertion is not silent (A), does not simply add one amino acid (B), and the sequence shown is coding, not intron (D).

Q4. A — a protein that stays and works in the cytosol is assembled on free ribosomes in the cytosol; ribosomes on the rough endoplasmic reticulum make proteins destined for secretion or membranes. The Golgi and smooth ER carry no ribosomes, and polypeptides are not assembled inside the nucleus.

Q5. D — the number of copies doubles each cycle, so one starting molecule doubles three times over: $1 \rightarrow 2 \rightarrow 4 \rightarrow 8$. A wrongly counts the cycles themselves, B stops after two cycles, and C adds two copies per cycle instead of doubling.

Q6. C — a staggered cut leaves short single-stranded overhangs that base-pair with a complementary overhang, holding the two molecules together for ligase to seal. Blunt ends carry no overhang to pair (A); the resistance gene is for later selection (B); heating separates strands (D).

Q7. B — the inserted gene comes from a different species (a bacterium), which makes the organism transgenic (and therefore also genetically modified). Changing one gene still counts as modification (A); the change was made by people, not naturally (C); and a modified organism is not a new species (D).

Q8. B — CRISPR-Cas9 is aimed at a chosen target by designing a guide RNA complementary to it, giving precise, re-programmable cutting. It still uses the Cas9 enzyme (A), works in many kinds of cell (C), and is directed at one chosen site, not the whole genome (D).

Q9. D — both cells hold the same genes, but different genes are switched on in each, so different sets of proteins are made — different proteomes. The DNA sequence is the same (A); genes are not lost (B); and no mutation is involved (C).

Q10. C — an enzyme provides a route with a lower activation energy, so more collisions succeed, without altering the energy levels of the reactants or products and so without changing the energy released overall. It supplies no energy (A), does not stabilise the products (B) and does not heat the mixture (D).

- Q11. C** — above the optimum the heat breaks the bonds that hold the enzyme's folded shape, so the active site loses its shape (denaturation); this is not reversed by cooling, so activity does not return. The enzyme is not consumed (A), 37 °C is its optimum not "too cold" (B), and the substrate is not what has changed (D).
- Q12. D** — if changing the carbon dioxide concentration makes almost no difference, then carbon dioxide is not what is holding the rate back; at low light it is the light intensity that limits the rate.
- Q13. B** — at high light, raising the carbon dioxide concentration raises the rate, which shows that here it is the carbon dioxide concentration, not the light, that is limiting. Light is now plentiful (A), the temperature was held constant (C), and nothing points to a shortage of chlorophyll (D).
- Q14. C** — the carbon atoms of glucose are finally given off as carbon dioxide during the Krebs cycle, in the mitochondrial matrix. Glycolysis releases no carbon dioxide (A), the electron transport chain's other output is water, not carbon dioxide (B), and converting pyruvate to lactic acid releases none (D).
- Q15. A** — a plant cell deprived of oxygen ferments its pyruvate to ethanol and carbon dioxide (as yeast does), not to lactic acid; lactic acid (B) is the animal product, and carbon dioxide and water (D) are the products of aerobic respiration, which cannot run without oxygen. C names the raw materials of photosynthesis, not a fermentation product.
- Q16. B** — fermentation breaks glucose down only as far as lactic acid or ethanol, molecules that still hold most of the energy of the original glucose, so only a small fraction is released. Glycolysis does break the glucose down in part (A), the little energy released is captured as ATP rather than all lost as heat (C), and that ATP is not destroyed as fast as it is made (D).
- Q17. C** — genetic material (here RNA) inside a protein coat that can reproduce only within a host cell is a virus, which is not built of cells and so is non-cellular. Having a protein coat does not make it a fungus (D); it does contain nucleic acid, so it is not a prion (B); and it is not a cell (A).
- Q18. B** — an allergen is a normally harmless substance that provokes an exaggerated immune response in sensitive people; it is not a living pathogen (A), not a self-antigen (C), and it certainly is recognised by the immune system (D).
- Q19. B** — the mucus traps inhaled particles and the beating cilia sweep the loaded mucus up and out of the airways towards the throat, so the two act together as a physical barrier that removes pathogens before they reach the lungs. Engulfing and digesting is what phagocytes do, not mucus or cilia (A), the lining cells make no antibody (C), and it is the stomach, not the airway lining, that defends by low pH (D).
- Q20. B** — NK cells are innate cells that kill infected or abnormal body cells without having to recognise a specific antigen, which is why they can act within hours; needing to be presented with a specific antigen (A) and waiting on memory cells (D) belong to the adaptive response, and NK cells do not make antibodies (C).
- Q21. C** — a node swells because the few lymphocytes that recognise the antigen are activated and multiply rapidly there. Nodes do not filter or store red cells (A), the virus reproduces in the airway cells not the node (B), and lymph is not driven by the heart (D).
- Q22. D** — in inflammation the vessels near the injury widen and their walls become leakier, so more blood (bringing warmth and redness) and more fluid and phagocytes reach the tissue, and the phagocytes engulf the bacteria. A whole-body temperature rise is fever, a separate response (A); B cells take days, not minutes, and act elsewhere (B); and the swelling shows that more, not less, fluid leaves the vessels (C).
- Q23. A** — helper T cells release cytokines that activate the B cells and cytotoxic T cells of the adaptive response. They do not secrete antibody (B), do not carry out the first innate step (C) and do not kill infected cells directly (D).
- Q24. A** — injected (ready-made) antibodies give passive immunity and leave no memory cells, so the protection is brief; a vaccine drives the person's own active response, which forms long-lived memory cells. B, C and D misstate what happens to the injected antibodies.
- Q25. D** — the more people each case infects, the greater the proportion that must be immune before an outbreak dies out, so the herd-immunity threshold is higher for the more transmissible disease P. A, B and C all deny this relationship.

- Q26. C** — a sudden, large change produced by two strains exchanging whole genome segments is antigenic shift; antigenic drift is the gradual accumulation of small changes (A), genetic drift is a change in allele frequencies by chance (B), and the founder effect describes a new population started by a few individuals (D).
- Q27. B** — the normal microbiota defends by competitive exclusion: it holds the available surfaces and consumes the available nutrients, so an arriving pathogen finds neither space nor food. Removing it leaves both. The microbiota makes no antibody (A), is a living community rather than a layer of dead cells (C), and phagocytosis is carried out by the person's own white blood cells, not by gut microbes (D).
- Q28. D** — because the code is degenerate, a change in the third base of a codon often specifies the same amino acid, so it may have no effect; a single insertion or deletion shifts the reading frame (A, B), and a substitution creating a stop codon truncates the protein (C).
- Q29. A** — gene flow requires the arriving lizards not merely to reach the island but to survive and breed there, adding their alleles to the island gene pool. Their size (B) is irrelevant, carrying no new alleles (C) would add nothing, and returning to the mainland to breed (D) is the opposite of gene flow into the island.
- Q30. A** — a marked, chance change in a neutral allele in a small population is the signature of genetic drift, whose effect is large when few individuals reproduce. Selection is ruled out because the allele is neutral (B), one allele is not driven to a new frequency by mutation (C), and the population is isolated (D).
- Q31. B** — resistance gained in one generation without a new mutation points to a resistance gene taken up on a plasmid from other bacteria. The antibiotic does not create resistance (A), slow growth would not confer it (C), and losing the target gene is not what has happened here (D).
- Q32. D** — two populations are separate species once they can no longer interbreed to produce fertile offspring, even if reunited; looking different (A), living apart (B) or eating different foods (C) does not by itself make them different species.
- Q33. D** — a fossil combining features of two groups is evidence of a form transitional between them. It does not show a living transformation (A), is not necessarily a good index fossil (B), and a shared mixture of features points to relatedness, not to the groups being unrelated (C).
- Q34. D** — the parent-to-daughter ratio measures how much decay has occurred since the mineral crystallised, giving the time since the rock formed; it does not date enclosed fossils directly (A), the temperature of formation (B) or the depth of burial (C).
- Q35. C** — wings built on completely different plans but used for the same job are analogous structures, the result of convergent evolution, not of shared ancestry; they are not homologous (A), not vestigial (B), and do not show that one group came from the other (D).
- Q36. C** — to separate very closely related species you need a molecule that has changed quickly enough to have accumulated differences between them; a molecule that has barely changed (A, B) cannot tell them apart, and one that has changed in only one species (D) gives no comparison.
- Q37. A** — in a habitual biped the foramen magnum sits underneath the skull, so the head balances on top of a vertical spine; a backward-placed opening (B) goes with a four-legged posture, and C and D are anatomically wrong.
- Q38. B** — accuracy is judged of the mean of the set, and the mean (40.0 g) equals the true value, so the set is accurate; but the individual readings are widely spread (34–46 g), so they are not precise. Values scattered about the true value in this way are the mark of random error.
- Q39. D** — an instrument that reads high by the same amount every time produces a systematic error; averaging removes only variation that falls on both sides of the true value, so the mean stays 2 °C too high and repetition does not help.
- Q40. A** — keeping harm to the lowest level necessary is the concept of non-maleficence (avoiding or minimising harm). Beneficence (B) is the duty to do good, justice (C) concerns fair distribution, and integrity (D) concerns honesty in the conduct of the work.

Section B — solutions

Q1. (a) When tryptophan is scarce, there is no tryptophan to bind the repressor, so the repressor cannot take up the shape needed to **bind the operator**; the operator stays free, RNA polymerase transcribes the structural genes, and the enzymes that make tryptophan are produced. **When tryptophan is plentiful**, tryptophan **binds to the repressor** (acting as a corepressor) and changes its shape so that the repressor now **binds the operator**; this **blocks RNA polymerase**, so transcription stops — and the cell avoids wastefully making tryptophan it already has. *(1 mark: when scarce, no tryptophan binds the repressor, so it cannot bind the operator and the genes are transcribed; 1 mark: when plentiful, tryptophan binds the repressor, which then binds the operator; 1 mark: the bound repressor blocks RNA polymerase, so transcription stops.)*

(b) **Strain 1 — transcribed.** With no functional repressor, nothing can ever bind the operator, so the structural genes are transcribed when tryptophan is scarce (and, in fact, at all times). **Strain 2 — not transcribed.** The altered repressor stays bound to the operator whether or not tryptophan is present, so it blocks RNA polymerase even when tryptophan is scarce — so this strain cannot switch the genes on when it actually needs to make tryptophan. *(1 mark: strain 1 transcribed, because there is no repressor to block the operator; 1 mark: strain 2 not transcribed, because the altered repressor stays on the operator even when tryptophan is scarce.)*

(c) **No.** The promoter is the site at which **RNA polymerase binds to begin transcription**; with the promoter deleted, RNA polymerase cannot attach, so the structural genes cannot be transcribed under any conditions. *(1 mark.)*

Q2. (a) A primer can only start the copying if it **base-pairs with (is complementary to) the template**. Inside a hypervariable region the sequence **differs from bird to bird**, so a primer designed to match it would fail to bind in some birds and their DNA would not be copied at all. The sequences **flanking** the region are the **same in every bird of the species**, so one pair of primers binds in every bird — and because only the DNA **between** the two primers is copied, placing them outside the region ensures the whole variable stretch is included in the copy. *(1 mark: the sequence within the region varies between birds, so a primer matching it would not bind in every bird; 1 mark: the flanking sequences are shared by all birds, so the same primers work for every bird and the whole variable region lies between them and is copied.)*

(b) The father is **candidate A**. At each region the chick carries two sequences: one matches a sequence in the mother, and the **other must have come from the father**. At Region 1 the chick's **AGGTCA** is the mother's, so the paternal sequence must be **GACTTG** — carried by candidates A (GACTTG, CATGCA) and C (GACTTG, TTGACC), but not B. At Region 2 the chick's **AAGCTA** is the mother's, so the paternal sequence must be **TCAGGA** — carried only by candidate A (TCAGGA, ACGTAC); neither B nor C carries it. Candidate A is the only male carrying the required paternal sequence at **both** regions. *(1 mark: candidate A; 1 mark: explains that one of the chick's two sequences at each region is maternal and the other must be paternal; 1 mark: supports this with the paternal sequences from both regions, showing A carries them and the others do not.)*

(c) At a single region only a **limited number of sequence variants** exists, so two unrelated birds can quite easily carry the **same sequence by chance**, without one being the parent. A match at one region is therefore weak evidence. The chance of a bird carrying the required paternal sequence at **several independent regions at once** is very small, so agreement across both regions — together with the failure of the other candidates at one region or the other — makes the identification reliable. *(1 mark: a one-region match can easily arise by chance between unrelated birds; 1 mark: agreement across several independent regions is very unlikely by chance, so it is reliable.)*

(d) The test works by **exclusion**. A male who does **not** carry the sequence the chick must have received from its father **cannot** have supplied it, so he is ruled out with **certainty** — that is why candidates B and C can be dismissed. A male who **does** carry the required sequences is only shown to be **consistent with** being the father: another male could carry the same sequences by chance, and only the three birds put forward as candidates were tested, so the true father might be a male that was never sampled. A match therefore makes paternity **very probable**, but it is not proof. *(1 mark: a male lacking a required paternal sequence is excluded with certainty; 1 mark: a match only shows consistency — another, possibly untested, male could carry the same sequences — so it raises the probability rather than proving paternity.)*

- (e) Any **one**: sequencing a sample whose sequences are already known checks that the **method is working correctly** on that run — that the reagents and equipment are performing and that no contamination or error has crept in — so the results for the unknown birds can be trusted. (1 mark.)

Q3. (a) The acidity **builds up overnight** because, while the stomata are open at night, the carbon dioxide taken in is **fixed into an organic acid and stored** in the leaf cells — so by dawn the store, and the acidity, are at their greatest. Through the day the stored acid is **broken down again**, which is why the sap is almost neutral by dusk; breaking it down **releases carbon dioxide inside the leaf**, behind the closed stomata. That internally released carbon dioxide is supplied to the **Calvin cycle**, which continues to turn using the **ATP and NADPH from the light-dependent stage** in the daylight. Capture of carbon dioxide (at night) is thus separated in time from its use (by day). (1 mark: *CO₂ taken in at night is fixed into an organic acid that accumulates, making the sap acidic by dawn; 1 mark: by day the acid is broken down — hence the fall in acidity — releasing CO₂ inside the leaf; 1 mark: this CO₂ feeds the Calvin cycle, which runs on the ATP and NADPH from the light-dependent stage.*)

- (b) CAM succulent: 3 g of water for 12 units of CO₂ fixed, which is **0.25 g of water per unit**. C3 shrub: 24 g for 32 units, which is **0.75 g of water per unit**. The C3 shrub therefore loses **three times as much water for every unit of carbon dioxide it fixes**, so the CAM succulent uses water far more efficiently. (1 mark: *both figures correct — 0.25 and 0.75 g per unit; 1 mark: compares them — the CAM plant uses about a third as much water per unit of carbon fixed / is about three times as water-efficient.*)
- (c) **Advantage:** the CAM succulent conserves water (only 3 g lost against 24 g), so it can survive in a hot, dry habitat where water is scarce. **Disadvantage:** it fixes less carbon dioxide (only 12 units against 32), because it can take carbon dioxide in only at night, so it grows more slowly and is less productive. (1 mark: *a valid advantage with data — much less water lost; 1 mark: a valid disadvantage with data — less carbon fixed, so slower growth.*)

Q4. (a) Each enzyme has an **active site whose shape is complementary to only one particular substrate**, so it can bind and act on that one substrate and no other. Each step of the pathway converts a **different substrate** into a different product, so a **different enzyme** is needed to catalyse each step. (1 mark: *enzymes are specific — the active site fits only one substrate; 1 mark: each step acts on a different substrate, so a different enzyme is required.*)

- (b) Enzyme 2 catalyses the step $X \rightarrow Y$. With no functional enzyme 2:
- **compound Y falls to almost nothing** — its only route of production (from X) is blocked;
 - **compound X builds up (accumulates)** — it is still made from the precursor by enzyme 1, but is no longer being converted into Y;
 - **compound Z is still made, and may even increase** — Z is produced from X by **enzyme 3**, not enzyme 2, so the $X \rightarrow Z$ branch is unaffected, and with more X available more Z can be made.

(1 mark: *Y falls to nothing, its route being blocked; 1 mark: X accumulates, still made but no longer used by enzyme 2; 1 mark: Z is still made / may increase, because the $X \rightarrow Z$ branch uses enzyme 3, which is unaffected.*)

Q5. (a) While the virus is travelling in the **blood or tissue fluid**, its **surface antigens are exposed** and it is in the **same compartment as the antibodies**, so an antibody with a complementary binding site can **reach and bind it**. Antibodies are **proteins that stay in the blood and tissue fluid**: they **cannot cross the plasma membrane** into a cell. So once the virus is **inside a body cell** it is **out of their reach** — the cell goes on making new virus and the antibodies can do nothing about it. (1 mark: *while the virus is free in the blood/tissue fluid its antigens are exposed and antibodies are in the same compartment, so they can reach and bind it; 1 mark: antibodies cannot cross the plasma membrane into a cell; 1 mark: so the intracellular virus is beyond their reach and the infected cell keeps producing virus.*)

- (b) An infected cell **displays fragments of the viral antigen on its surface**, whereas a healthy cell displays only the person's own molecules. A cytotoxic T cell carries a **receptor complementary to that displayed viral antigen**, so it **binds only to cells that are presenting it** and leaves the surrounding healthy cells untouched. (1 mark: *an infected cell displays viral antigen on its surface, a healthy cell does not; 1 mark: the cytotoxic T cell's receptor is complementary to that displayed antigen, so it binds only the cells presenting it.*)
- (c) The antibodies raised by the vaccine can act during the **brief phase the virus spends outside cells**, binding the particles as they travel between one cell and the next. Fewer particles therefore succeed in entering new cells, so **the infection spreads more slowly through the body and less virus is shed**, which makes the

illness **milder** and makes the person **less likely to pass the virus on**. But because there is no strong **cytotoxic T cell (cell-mediated) response**, the **already-infected cells are not destroyed**: they keep making new virus, so the infection is **not cleared** and the protection is only partial. (1 mark: antibodies bind the virus during its brief extracellular phase, so fewer new cells are infected; 1 mark: hence milder illness and less virus shed to others; 1 mark: with no cytotoxic T cell response the infected cells survive and keep producing virus, so the infection is not cleared.)

Q6. (a) A **monoclonal antibody** preparation is made up of **identical antibody molecules**. They are identical because they are all produced by a **single clone of cells descended from one selected B lymphocyte**, so every molecule carries the **same antigen-binding site**, complementary to **one particular region of the virus's surface protein**. By binding that surface protein the antibody **neutralises the virus** (blocks it from entering cells) and **marks it so that phagocytes destroy it**, lowering the number of virus particles in the patient. (1 mark: monoclonal = a preparation of identical antibodies; 1 mark: identical because made by a single clone from one B lymphocyte, so all bind the same target; 1 mark: binding the surface protein neutralises / marks the virus, reducing the infection.)

(b) **Interferons** are **signalling proteins** released by virus-infected cells. They **diffuse to nearby uninfected cells** and cause those cells to **make antiviral proteins that interfere with viral reproduction**, so fewer neighbouring cells become productively infected and the virus **spreads more slowly** — buying time for the adaptive response to develop. (1 mark: interferons signal to nearby uninfected cells; 1 mark: those cells make antiviral proteins that block viral reproduction / slow the spread.)

(c) An antibody binds its target only because its **binding site is complementary in shape to one specific region (epitope)** of the antigen. In the new strain that region of the surface protein has **changed shape**, so the monoclonal antibody's binding site is **no longer complementary** to it and the antibody can **no longer bind** — so it can neither neutralise the new strain nor mark it for destruction. (1 mark: the antibody binds only because its site is complementary to that specific region / epitope; 1 mark: a change in that region means it no longer fits / binds, so the antibody cannot act on the new strain.)

(d) Each of the two antibodies binds a **different region** of the surface protein, so a strain that has changed **one** of those regions is still bound by the **other** antibody and the mixture keeps working. For the mixture to fail, the **same** virus would have to carry a change in **both** regions at once. Each change arises independently by **chance mutation**, so the chance of both occurring in one virus is far smaller than the chance of either alone — the mixture is therefore much harder for the virus to escape. (1 mark: a change in one binding region still leaves the second antibody able to bind, so the mixture continues to work; 1 mark: escape would require changes in both regions in the same virus, which is far less likely than a single change.)

Q7. (a) The event is a **(population) bottleneck**. Reading the graph, the totals across the five genes are **8 + 6 + 7 + 5 + 9 = 35 different alleles before the fire** and **3 + 2 + 4 + 2 + 3 = 14 in the recovered population**. The total has not risen with the numbers because every animal alive today is **descended from the 40 survivors**, and those survivors carried only a **sample** of the original alleles; alleles held only by animals that died were **lost from the gene pool**. Breeding can pass on **only the alleles that are present**, so a lost allele does not return simply because the population has grown. (1 mark: bottleneck; 1 mark: 35 before and 14 after; 1 mark: the recovered animals all descend from the few survivors, which held only a sample of the alleles, so breeding cannot restore the alleles that were lost.)

(b) With only **40 founders** and just **14 different alleles** left across the five genes, nearly all matings in the rebuilt population are between **close relatives**, and there are **few alternative alleles** in circulation. Offspring are therefore far more likely to inherit **two copies of the same allele** (to be homozygous). Harmful **recessive alleles**, which were formerly hidden in carriers, are then **expressed much more often**, and the young that inherit them are **less likely to survive to adulthood** — inbreeding depression. This explains the fall in juvenile survival even where food and shelter are plentiful, because the cause is genetic rather than environmental. (1 mark: the loss of alleles plus breeding among close relatives makes offspring far more likely to be homozygous; 1 mark: harmful recessive alleles are therefore expressed more often, lowering juvenile survival, so the cause is genetic rather than a shortage of food or shelter.)

(c) Any **one**: the number of animals can look healthy while the gene pool stays depleted — as here, where numbers are back to about 1000 but the alleles are not — so a count of animals alone would give a falsely reassuring picture of the population's recovery; or, because the number of different alleles is what determines how much variation natural selection can act on, it is the better guide to whether the population could survive a future change such as a new disease or a hotter climate. (1 mark.)

Q8. (a) Any **two** trends, each with an association. For example: an **increase in brain (cranial) capacity**, associated with greater intelligence, more complex behaviour and tool use; a **reduction in the size of the teeth and jaws** (including smaller canines), associated with changes in diet; a **broad, bowl-shaped pelvis and an inward-angled thigh bone**, associated with habitual upright walking on two legs; **legs that are longer relative to the arms**, associated with striding bipedal walking. *(1 mark for each of two correctly described trends; 1 mark for correctly associating the trends with what they indicate.)*

- (b) Any **two**. The skull is **bone** — a **hard part**, which resists decay and can be mineralised, whereas soft tissue is destroyed long before it could fossilise. The site was **repeatedly blanketed by volcanic ash and sediment**, so the remains were **buried rapidly and deeply**; burial seals them away from **scavengers, and from the oxygen that decomposers need**, before they can be scattered or rotted away. The remains then lay **undisturbed** in a layer that was not eroded or overturned, so what formed survived to be found. *(1 mark each for any two of: hard, mineralisable bone rather than soft tissue; rapid, deep burial by ash/sediment excluding scavengers and oxygen; the layer remaining undisturbed afterwards.)*
- (c) The two species **lived at the same time** and are recognised as **distinct species**, so one cannot be *simply descended* from the other. The shared segments are **patches of *Homo neanderthalensis* DNA scattered through an otherwise *Homo sapiens* genome** — exactly the pattern expected if the two species **interbred where they met**, so that some Neanderthal DNA entered the *Homo sapiens* gene pool and was passed on to people today. Direct descent would have left the *whole* genome derived from Neanderthals, not a scattering of short segments. *(1 mark: the two are distinct, contemporaneous species, so one is not simply descended from the other; 1 mark: the scattered Neanderthal segments within an otherwise *H. sapiens* genome are the signature of interbreeding / gene flow between the two species.)*
- (d) A species that **arises in one region and spreads out** from there will leave its **oldest fossils in that region**, and — because that region has been occupied **longest** — its populations there will have had the **most time to build up genetic variation**. Both findings — the oldest modern-human fossils being African, and African populations being the most diverse — therefore fit an **origin in Africa followed by a spread across the world**. *(1 mark: the oldest fossils mark the region of origin; 1 mark: the longest-occupied region accumulates the most diversity, so together the findings point to an African origin and outward spread.)*
- (e) Each new fossil or ancient-DNA discovery adds evidence that was not available before, and the record is **fragmentary and incomplete**, so any picture built from it is **provisional**. When a find does not fit the current picture — a fossil with an unexpected mix of features, or DNA showing unexpected mixing between groups — scientists **revise** their account to fit the fuller body of evidence. Changing the picture in this way is how science is meant to proceed, not a failure of it. *(1 mark: the fossil / DNA record is incomplete, so any account is provisional and open to revision; 1 mark: new finds that do not fit the current picture lead scientists to revise it — the mark of evidence-based science.)*
- (f) Individuals of a **single species vary** — in age, in sex, and simply from one to the next — so the differences between two fossils may be no more than **variation within one species**; yet comparable differences can also mark **two genuinely different species**, and with only a few, often incomplete, specimens it can be hard to tell which is the case. Where to draw the species boundary is, in the end, a **judgement** on which reasonable experts differ. Additional evidence that could help to settle it (any **one**): **more specimens**, to reveal the full range of variation; **DNA** recovered from the fossils; or **other remains** found together with them. *(2 marks: any two of — individual variation within a species can mimic a difference between species / few and incomplete specimens make it hard to judge / the species boundary is a matter of judgement; 1 mark: one valid kind of further evidence.)*

Q9. (a) The electron transport chain is located on the **inner mitochondrial membrane** (folded into the cristae). The two energy carriers that deliver electrons to it are **NADH and FADH₂**, loaded during the earlier stages of respiration. *(1 mark: inner mitochondrial membrane; 1 mark: NADH and FADH₂ — both required.)*

- (b) The electron transport chain produces **most of the cell's ATP** — **26 or 28 of the 30 or 32 ATP** obtained from a molecule of glucose (glycolysis and the Krebs cycle contribute only 2 each) — because it is the stage at which the **energy carried by the loaded carriers NADH and FADH₂ is used to make the bulk of the ATP**. When it is blocked, that large share is lost. The one stage still able to supply ATP is **glycolysis**, which gives a **net 2 ATP** and needs neither the electron transport chain nor oxygen. *(1 mark: the electron transport chain produces most of the ATP, 26 or 28 of the 30 or 32; 1 mark: because it is where the energy from the*

loaded carriers NADH and FADH₂ is turned into the bulk of the ATP; 1 mark: glycolysis still supplies the remaining 2 ATP.)

- (c) The cells are now relying on **lactic acid fermentation** (anaerobic respiration). With the mitochondrial stages out of action, the **pyruvate made by glycolysis cannot be taken into the mitochondria to be broken down further**, so it is instead **converted to lactic acid**; this conversion is what allows **glycolysis to keep operating** (and keep making its small amount of ATP) without the mitochondrial stages. (1 mark: lactic acid fermentation / anaerobic respiration; 1 mark: the pyruvate cannot enter the blocked mitochondrial stages to be broken down further; 1 mark: so it is converted to lactic acid, which lets glycolysis continue.)

Q10. (a) Recording to the nearest whole day means the measurement **cannot resolve any difference smaller than about a day**. Two temperatures whose true mean hatching times differ by only a few hours would be recorded as **the same number of days**, so a **real but small effect of temperature would be missed** — and a batch that hatched just before or just after a midnight boundary could be recorded a whole day out. The team could therefore only detect fairly large effects. The remedy is to **check the batches far more often — for example every few hours — and record hatching time in hours rather than days**, which gives a much finer resolution. (1 mark: differences smaller than the smallest unit recorded cannot be detected, so a real small effect of temperature could be missed; 1 mark: inspect much more frequently and record in hours instead of days.)

- (b) Any **one** variable, correctly justified. For example, the **oxygen concentration of the water** (equally acceptable: the pH, the light, the source or age of the egg batches, or the volume or depth of water). If a variable like this were **not kept the same** and happened to **change along with the temperature**, then it — not the temperature — could be the real cause of any difference in hatching time. The investigation would then not be measuring the effect of temperature **on its own**, so its conclusion would be **invalid**. (1 mark: names a plausible variable that must be controlled; 1 mark: if left uncontrolled it could vary with temperature and become the real cause, so the conclusion would not validly be about temperature.)
- (c) The team's statement is a **conclusion**: it states what the data actually show, and only **within the range of temperatures tested**. The magazine's statement is an **implication / an extrapolation** that goes well beyond the data. Any **one** reason it is not justified: it extends the finding **beyond the temperatures actually tested** and to conditions in the wild; it assumes faster hatching means the frogs will do better, when only **hatching time was measured, not survival or numbers**; it was a **laboratory study of a single species**, which may not hold generally. (1 mark: the team's statement is a conclusion — what the data show, within the range tested; 1 mark: the magazine's is an implication / extrapolation beyond the data; 1 mark: one valid reason it is not justified.)

Exam 4 — Practice examination

Reading time: 15 minutes. Writing time: 2 hours 30 minutes. Section A: 40 questions, 40 marks. Section B: 10 questions, 80 marks. Total 120 marks. This examination covers Units 3 and 4. Answer all questions.

- No calculator may be used.
- No formula sheet, data sheet, dictionary or notes may be used.
- Diagrams in this examination are not drawn to scale.

Section A — Multiple choice

Every question in this section must be attempted. Select the response that is correct or that best answers the question. One mark is awarded for each correct response, and nothing is taken away where a response is wrong. Where two or more responses have been completed for the same question, no mark is awarded for it. No diagram in this section is drawn to scale.

Question 1

In a molecule of DNA, the base adenine always forms a complementary pair with

- A. cytosine.
- B. guanine.
- C. thymine.
- D. uracil.

Question 2

The process in which the base sequence of a gene is copied into a molecule of messenger RNA, and the place in a eukaryotic cell where it occurs, are

- A. translation; in the cytosol.
- B. replication; in the nucleus.
- C. transcription; on a ribosome.
- D. transcription; in the nucleus.

Question 3

Before a eukaryotic pre-mRNA molecule can be translated, its non-coding regions are removed and its coding regions are joined together. The non-coding regions that are removed are the

- A. exons.
- B. codons.
- C. promoters.
- D. introns.

Use the following information to answer Questions 4 and 5.

A human gene is to be joined into a bacterial plasmid, so that the bacterium will make a useful human protein. The plasmid also carries a gene for resistance to an antibiotic.

Question 4

The human gene and the plasmid are first cut with the same enzyme, so that their cut ends match. This enzyme is

- A. DNA ligase.
- B. DNA polymerase.
- C. a restriction endonuclease.
- D. the Cas9 protein.

Question 5

After the plasmids and bacteria are mixed together, only a fraction of the bacterial cells actually take one up. The antibiotic-resistance gene on the plasmid is used to

- A. cut the human gene out of the chromosome.
- B. join the human gene into the plasmid.
- C. increase the amount of protein each cell makes.
- D. identify which bacteria have taken up a plasmid.

Question 6

The way a polypeptide chain folds into its final three-dimensional shape is determined mainly by

- A. the temperature of the surroundings.
- B. the number of ribosomes that made it.
- C. the sequence of amino acids in the chain.
- D. the amount of DNA in the nucleus.

Question 7

In the trp operon of a bacterium, when tryptophan is plentiful the trp structural genes are switched off. This happens because tryptophan

- A. acts as a corepressor, changing the repressor protein so that it binds the operator and blocks transcription.
- B. binds directly to RNA polymerase and speeds up transcription.
- C. is removed from the operon by an enzyme.
- D. destroys the operator so that it can no longer be read.

Question 8

In genetic engineering, a plasmid is often used as a vector. The role of a vector is to

- A. carry the gene of interest into the host cell.
- B. cut the gene of interest out of the donor DNA.
- C. switch the gene of interest on once it is inside the host cell.
- D. break down any DNA that the host cell does not need.

Question 9

A tobacco plant has had a gene from a firefly inserted into its genome, so that its leaves give off a faint glow. This tobacco plant is best described as

- A. genetically modified only, and not transgenic.
- B. neither genetically modified nor transgenic.
- C. a naturally occurring variety.
- D. transgenic, and therefore also genetically modified.

Question 10

The role of messenger RNA (mRNA) in a cell is to

- A. carry the coded instructions of a gene from the nucleus to a ribosome.
- B. carry amino acids to the ribosome.
- C. form part of the structure of the ribosome.
- D. join amino acids together into a chain.

Question 11

The genetic code is described as being essentially universal. This means that

- A. every organism contains exactly the same genes.
- B. a particular codon specifies the same amino acid in almost all organisms.
- C. the code can never be altered by a mutation.
- D. all organisms make the same proteins.

Question 12

An enzyme speeds up a chemical reaction. At the end of the reaction the enzyme is

- A. used up, and must be replaced.
- B. converted into one of the products.
- C. unchanged, and able to catalyse the reaction again.
- D. broken down into its amino acids.

Use the following information to answer Questions 13 and 14.

The table gives the rate of a reaction catalysed by an enzyme at five different pH values. Every other condition was kept constant.

pH	3	5	7	9	11
Rate (arbitrary units)	2	9	20	8	1

Question 13

The optimum pH of this enzyme is

- A. 3.
- B. 7.
- C. 9.
- D. 11.

Question 14

The rate of reaction is very low at pH 11. This is because, at this pH,

- A. the enzyme's active site has changed shape, so the substrate no longer fits into it.
- B. the substrate has all been used up.
- C. the enzyme is working at its fastest.
- D. the temperature has become too high.

Question 15

The raw materials that a green plant uses to carry out photosynthesis are

- A. glucose and oxygen.
- B. oxygen and water.
- C. glucose and carbon dioxide.
- D. carbon dioxide and water.

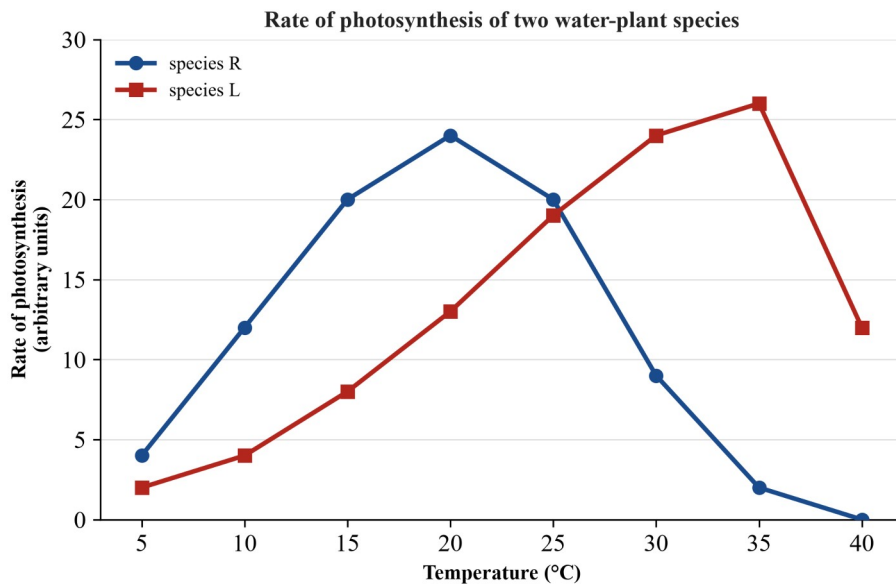
Question 16

During photosynthesis, the energy carried by sunlight is

- A. destroyed as the leaf absorbs it.
- B. turned entirely into heat, which warms the leaf.
- C. converted into chemical energy, which is stored in the glucose that is made.
- D. used to break glucose down into carbon dioxide and water.

Use the following information to answer Questions 17 and 18.

Species R is a water plant of cool mountain streams; species L is a water plant of warm lowland lagoons. The rate of photosynthesis of each species was measured across a range of temperatures. The light intensity and the carbon dioxide concentration were kept constant, and neither was limiting the rate for either species.



Question 17

The rate of species R is greatest at about 20 °C, while the rate of species L is greatest at about 35 °C. The best explanation for this difference is that

- A. species L receives more light than species R.
- B. species R does not rely on enzymes to carry out photosynthesis.
- C. the enzymes of the two species have different optimum temperatures.
- D. species L is able to store more carbon dioxide than species R.

Question 18

Between 20 °C and 30 °C the rate of species R falls while the rate of species L rises. Taken together, these two results show that

- A. the effect of a rise in temperature on the rate depends on the species and on where that species' optimum lies.
- B. temperature affects the rate of photosynthesis in the same way in every plant species.
- C. species R has stopped photosynthesising altogether at 20 °C.
- D. carbon dioxide, and not temperature, is limiting the rate for both species.

Question 19

Glycolysis, the first stage of cellular respiration, takes place in the

- A. matrix of the mitochondrion.
- B. cytosol.
- C. inner membrane of the mitochondrion.
- D. nucleus.

Question 20

Most of the ATP made during aerobic cellular respiration is produced in the

- A. cytosol.
- B. ribosomes.
- C. nucleus.
- D. mitochondria.

Question 21

When a human muscle cell cannot be supplied with enough oxygen, it respire anaerobically and produces

- A. ethanol and carbon dioxide.
- B. lactic acid.
- C. glucose and oxygen.
- D. a large amount of ATP.

Question 22

A brewery ferments sugar using yeast in sealed tanks from which air is excluded. Under these oxygen-free conditions the yeast convert the sugar mainly into

- A. lactic acid.
- B. ethanol and carbon dioxide.
- C. oxygen and water.
- D. proteins.

Question 23

A molecule, often found on the surface of a cell or a pathogen, that the immune system can recognise as either self or non-self, is called a/an

- A. antibody.
- B. interferon.
- C. antigen.
- D. histamine.

Question 24

Which of the following pathogens is non-cellular?

- A. a virus
- B. a bacterium
- C. a protozoan
- D. a fungus

Question 25

Which one of the following is part of the first line of defence against infection?

- A. antibodies made by plasma cells
- B. cytotoxic T cells
- C. memory B cells
- D. the intact skin, acting as a barrier

Question 26

The process by which a macrophage engulfs and digests a pathogen is called

- A. phagocytosis.
- B. antigen presentation.
- C. exocytosis.
- D. inflammation.

Question 27

Complement proteins help to defend the body by

- A. carrying oxygen to infected tissue.
- B. producing antibodies against one specific antigen.
- C. forming pores in the membranes of pathogens and promoting phagocytosis.
- D. storing a memory of past infections.

Use the following information to answer Questions 28, 29 and 30.

A person recovers from an infection by a particular bacterium. Several months later they are exposed to the same bacterium again, but this time they show no symptoms.

Question 28

The immunity that protects the person on the second exposure is best described as

- A. artificially acquired active immunity.
- B. artificially acquired passive immunity.
- C. naturally acquired active immunity.
- D. naturally acquired passive immunity.

Question 29

During the first infection, macrophages in the person's tissues engulfed and digested the bacterium. On the second exposure, those macrophages act

- A. only once memory B cells have been activated.
- B. in the same non-specific way as before, because a macrophage does not develop a memory of a particular pathogen.
- C. against this one bacterium alone, and no longer against any other pathogen.
- D. by secreting antibodies that are specific to the bacterium.

Question 30

If, instead of recovering from the infection, the person had been given an injection of ready-made antibodies against the bacterium, this treatment would have provided

- A. long-lasting immunity, because memory cells would form.
- B. immediate protection, but no lasting memory of the bacterium.
- C. no protection at all.
- D. protection only after several weeks.

Question 31

During an outbreak of a highly contagious disease, health authorities ask everyone who has been in close contact with a confirmed case to stay at home for the length of the incubation period. This measure limits the spread of the disease mainly by

- A. keeping people who may already be infectious away from others before any symptoms appear.
- B. raising the level of herd immunity in the community.
- C. giving those people passive immunity to the pathogen.
- D. preventing the pathogen from mutating.

Question 32

An antibody binds to one particular antigen and not to others. This is because

- A. the antibody can change its shape to fit any antigen it meets.
- B. the antibody engulfs and digests the antigen.
- C. every antibody in the body is identical.
- D. the antibody's binding site has a shape that is complementary to that particular antigen.

Question 33

A pathogen that appears in a human population for the first time, or that rapidly increases in its incidence, is described as

- A. an allergen.
- B. an emerging pathogen.
- C. a first-line defence.
- D. a vestigial pathogen.

Use the following information to answer Questions 34 and 35.

The same gene was sequenced in four species of native possum: W, X, Y and Z. The table below records, for every pairing of the four species, how many positions in the gene differ between them.

Pair of species	Number of positions at which the two sequences differ
W and X	4
W and Y	22
W and Z	24
X and Y	21
X and Z	23

Pair of species	Number of positions at which the two sequences differ
Y and Z	7

Question 34

Of the four species, the pair most closely related to each other is

- A. Y and Z.
- B. W and X.
- C. X and Y.
- D. W and Z.

Question 35

Of the four species, the pair least closely related to each other is

- A. W and X.
- B. Y and Z.
- C. W and Z.
- D. X and Y.

Question 36

In a series of sedimentary rock layers that has not been disturbed since it formed, the layer laid down first, and therefore the oldest, is

- A. the top layer.
- B. the bottom layer.
- C. the middle layer.
- D. impossible to identify from the position of the layers.

Question 37

In a population of a wild plant, individuals vary in how deep their roots grow. After several severe droughts, deep-rooted plants become much more common. The best explanation is that

- A. the drought caused the plants to grow deeper roots, which they then passed to their offspring.
- B. the drought created a new allele for deep roots.
- C. deep-rooted plants moved into the area from elsewhere.
- D. deep-rooted plants were more likely to survive the drought and reproduce, so the allele for deep roots increased.

Question 38

The small, reduced hip bones found in some snakes, which take no part in movement, are best described as

- A. analogous structures.
- B. homologous structures that are still functional.
- C. structures acquired during the snake's lifetime.
- D. vestigial structures.

Question 39

Genetic drift is best described as

- A. a shift in a population's allele frequencies brought about by chance, with a larger effect in small populations.
- B. a change in allele frequencies caused by natural selection.
- C. the movement of alleles from one population to another.
- D. the appearance of new alleles by mutation.

Question 40

An ethics committee approves an investigation only after checking that it is designed to maximise the benefit to the participants and to the wider community. This reflects the ethical concept of

- A. beneficence.
- B. justice.
- C. respect.
- D. integrity.

End of Section A

Section B — Short answer

Every question in this section must be attempted, in the spaces provided. For any question carrying two or more marks, a response earns full credit only if it reaches the depth that its command term and its mark allocation call for. No diagram in this section is drawn to scale.

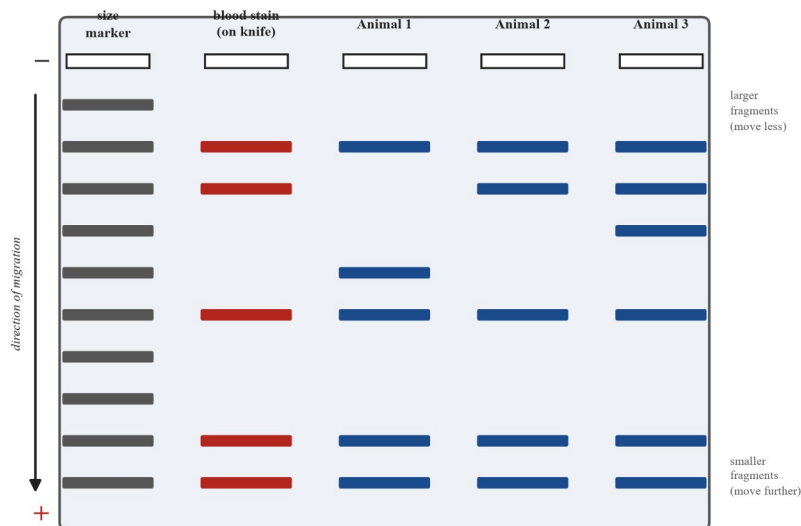
Question 1 (6 marks)

A laboratory keeps a colony of a small native fish. One gene, referred to here as gene D, is thought to control how the fish responds to water that is low in oxygen. To find out what gene D does, a team uses CRISPR-Cas9 to disable gene D in newly fertilised fish eggs, rears the fish that hatch from them, and compares those fish with untreated fish from the same colony.

- a. The Cas9 protein cuts DNA, but on its own it cannot tell one gene from another. Explain how the guide RNA makes sure that the cut is made in gene D and nowhere else in the fish's genome. 2 marks
- b. The team supplies no DNA template to the eggs. Explain why the cell's own repair of the cut is then likely to leave gene D unable to make a working protein. 2 marks
- c. The edited fish behave normally in well-oxygenated water, but unlike the untreated fish they do not survive when the oxygen in the water falls. State what this result allows the team to conclude about gene D, and state one limitation of drawing that conclusion from a disabled gene. 2 marks

Question 2 (9 marks)

Rangers are investigating the illegal killing of a protected animal. A blood stain was found on a knife seized from a suspect. To find out which animal the blood came from, a DNA profile was made from the blood stain and from tissue samples of three protected animals (Animal 1, Animal 2 and Animal 3) that had recently been killed illegally. A size marker was run alongside. The profiles are shown below.



- a. The blood stain yielded only a tiny amount of DNA. Name the technique used to build up the amount of DNA before a profile is made, and explain why this step is needed. 2 marks
- b. Using the gel, state which animal the blood on the knife came from, and justify your answer. 2 marks
- c. Explain why a DNA profile can be used to tell one individual animal apart from another of the same species. 2 marks
- d. The match shows the blood on the knife came from that animal, but on its own it does not prove that the suspect killed the animal. State what the match does establish, and give two reasons why it does not, by itself, prove that the suspect did the killing. 3 marks

Question 3 (7 marks)

Fresh pineapple contains an enzyme, bromelain, that breaks down proteins. A cook finds that a fruit jelly, which sets because it contains the protein gelatine, will not set if fresh pineapple is added, but sets normally if tinned pineapple, which has been heated during canning, is added instead.

- a. Bromelain breaks down the protein gelatine but has no effect on the sugar in the jelly. Explain, in terms of its active site, why bromelain acts on gelatine but not on sugar. 2 marks
- b. Explain why the jelly sets when tinned (heated) pineapple is added, but not when fresh pineapple is added. 3 marks
- c. A student wants to test whether the amount of fresh pineapple added affects how firm the jelly becomes. State the independent variable, and name one variable that would need to be held constant. 2 marks

Question 4 (9 marks)

A variegated geranium leaf has green areas and white (colourless) areas. A student keeps the plant in bright light for several hours, then removes the leaf and tests the whole leaf for starch. Only the green areas of the leaf are found to contain starch.

- a. Explain why only the green areas of the leaf made starch. 2 marks
- b. Photosynthesis occurs in two stages. For **each** stage, name it, state where in the chloroplast it takes place, and give one input and one output. 4 marks
- c. Predict, and explain, the result if a fully green leaf from the same plant were kept in complete darkness for two days and then tested for starch. 3 marks

Question 5 (10 marks)

Two patients arrive at the same clinic with a sore throat and a fever. Tests show that Patient 1's infection is caused by a bacterium, which stays in the fluid outside the cells lining the throat. Patient 2's infection is caused by a virus, which enters those cells and reproduces inside them. Neither patient has met their own pathogen before.

- a. Both pathogens were breathed in. Describe **two** first-line (non-specific) defences of the airways that a pathogen must get past before it can reach the cells of the throat, stating for each how it acts. 2 marks
- b. Explain why the innate (non-specific) response begins in both patients within hours, whereas their adaptive (specific) responses take several days to become effective. 2 marks
- c. Name the cell that secretes antibodies against Patient 1's bacterium, and describe **two** different ways in which those antibodies act on that bacterium. 3 marks
- d. A swab from Patient 1 grows bacteria on a plate of sterile nutrient jelly, but Patient 2's virus will not grow on the same plate — it multiplies only when living cells are supplied. Bacteria are cellular pathogens and viruses are non-cellular pathogens. Using this difference, explain the result on the plate, and explain why a medicine that kills bacteria by damaging their cell walls would be of no use to Patient 2. 3 marks

Question 6 (6 marks)

A person is allergic to a protein found in peanuts. The first time they ate peanuts as a young child, nothing happened; but on later occasions, eating even a trace of peanut causes a rapid and severe allergic reaction. In a skin-prick test, a drop of peanut extract is placed on lightly scratched skin. In this person a raised red lump appears within 15 minutes; in a person who is not allergic to peanuts, nothing appears.

- a. Explain why the reaction is severe on later exposures, but not on the very first exposure to peanut. 2 marks
- b. The same peanut extract is used in both skin-prick tests, yet only the allergic person reacts. Explain what this difference shows about where the cause of an allergy lies. 2 marks
- c. In a severe reaction this person's airways narrow and fluid leaks from their blood vessels into the surrounding tissue, yet the peanut protein itself damages no cells. Explain what produces these symptoms, and why an allergic reaction is described as an exaggerated response. 2 marks

Question 7 (7 marks)

Growers have developed tomato varieties with much larger fruit than the wild tomato they came from. In each generation, only the plants bearing the largest fruit were kept and used to produce the next generation. The table records the mean fruit mass of the crop over 40 generations of this program.

Generation	0	10	20	30	40
Mean fruit mass (g)	12	41	68	79	80

- a. Using the table, describe how the mean fruit mass changed between generation 0 and generation 20, quoting figures, and explain, in terms of which plants were allowed to reproduce, why it changed in this way. 3 marks
- b. Explain, in terms of the alleles present in the crop, why the mean fruit mass had almost stopped rising by generation 40, even though the growers went on choosing the largest-fruited plants in every generation. 2 marks
- c. Selective breeding can work only with variation that is already present in the tomato. Explain what this means for the characteristics a breeding program can produce, and state one way in which genetic engineering is not limited in the same way. 2 marks

Question 8 (10 marks)

A native fly lays its eggs in the fruit of a native shrub. The larvae develop inside the fruit, and the adults that emerge meet and mate on the plant they developed in. About 150 years ago an introduced fruit tree spread through the same district, growing side by side with the native shrub. Some flies began laying their eggs in the fruit of the introduced

tree, and their descendants have gone on doing so. The introduced tree fruits about six weeks earlier than the native shrub, so the flies of the two groups now emerge and mate at different times of the year. Today the two groups differ in body colour and in adult size, and very few matings between them are recorded. (Adapted from Kowalczyk & Bramwell, 2024.)

- a. State which type of speciation is occurring here, and justify your answer using the information given. 2 marks
- b. Explain how two separate species could eventually arise from these two groups of flies. In your answer refer to gene flow and to how the two gene pools would change. 3 marks
- c. Researchers place flies from the two groups together in a cage under identical conditions. The flies mate and produce offspring, and those offspring go on to breed normally. State whether the two groups are yet separate species and justify your answer, and state one result of this trial that would have shown that they are. 3 marks
- d. The introduced tree is now removed from the district, so the flies that had been using it must return to the native shrub. Explain why two species would then be unlikely to form. 2 marks

Question 9 (10 marks)

A university team tests a new medicine intended to lower the level of cholesterol in the blood. Six hundred adult volunteers, all aged between 40 and 65 and all with high blood cholesterol, take part. Each volunteer is allocated at random to one of three groups of 200. Group 1 takes the new medicine each day, group 2 takes a medicine already in use, and group 3 takes an identical-looking tablet that contains no medicine (a placebo). No volunteer is told which tablet they have been given. Each volunteer's blood cholesterol is measured at the start and again after twelve weeks.

Group	1 (new medicine)	2 (existing medicine)	3 (placebo)
Mean fall in blood cholesterol (mmol/L)	1.6	1.1	0.3

- a. It is the fall in each volunteer's blood cholesterol over the twelve weeks, rather than the level each volunteer reaches by the end, that is compared between the groups. Explain why. 2 marks
- b. Explain what group 3 allows the team to find out that group 1 on its own could not, and state what group 2 adds that group 3 does not. 3 marks
- c. Before the trial each volunteer gives informed consent, and an ethics committee has satisfied itself that any harm a volunteer could suffer would not be disproportionate to the benefits the trial could bring. Name the ethical concept shown by the committee's requirement, and state what informed consent requires of the team. 2 marks
- d. Using the results in the table, compare the effect of the new medicine with the effect of the existing medicine and with the effect of the placebo, quoting figures, and state what these results show about the new medicine. 3 marks

Question 10 (6 marks)

From a sequence of sedimentary rock layers, palaeontologists recover an extinct animal, referred to here as specimen F. Specimen F has paired fins supported by a row of strong internal bones with a shoulder joint and an elbow joint, and a flattened skull with the nostrils set on top and a neck that allowed the head to turn — a combination found neither in the fish of the older layers below it nor in the four-legged land animals of the younger layers above it. Specimen F is described as a transitional fossil. It has since been found at several widely separated sites, always in rock of the same narrow age range, and only bones have ever been recovered: no trace of its skin, gills or lungs has been found at any site.

- a. Explain what the combination of features seen in specimen F is evidence of, and explain why that evidence is stronger because specimen F is found in rock lying between the layers that hold only fish and the layers that hold only four-legged land animals. 2 marks
- b. Explain how finding the same combination of features in specimens from several widely separated sites strengthens the case that specimen F represents a real intermediate form, rather than one unusual individual. 2 marks

- c. Explain why the fossil record holds far more information about the hard parts of past animals than about their soft parts. 2 marks

End of Section B

End of examination questions

Exam 4 — Answers and solutions

Section A — answers

Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	C	11	B	21	B	31	A
2	D	12	C	22	B	32	D
3	D	13	B	23	C	33	B
4	C	14	A	24	A	34	B
5	D	15	D	25	D	35	C
6	C	16	C	26	A	36	B
7	A	17	C	27	C	37	D
8	A	18	A	28	C	38	D
9	D	19	B	29	B	39	A
10	A	20	D	30	B	40	A

Q1. C — in DNA, adenine always pairs with thymine (and guanine with cytosine); uracil takes the place of thymine in RNA, not in DNA.

Q2. D — making an mRNA copy of a gene is transcription; in a eukaryotic cell this happens inside the nucleus, which is where the DNA is kept.

Q3. D — the non-coding regions removed from a pre-mRNA are the introns; the coding exons are then joined together.

Q4. C — a restriction endonuclease cuts both the gene and the plasmid at the same recognition sequence, giving matching (complementary) ends; ligase then joins them.

Q5. D — only cells that have taken up the plasmid carry the resistance gene, so growing the cells on the antibiotic lets those transformed cells be identified (they alone survive).

Q6. C — a polypeptide's amino-acid sequence (its primary structure) determines how the chain folds, and so fixes its final three-dimensional shape.

Q7. A — tryptophan is a corepressor: by changing the shape of the repressor it lets the repressor attach to the operator and stop transcription, so the operon is turned off whenever tryptophan is abundant.

Q8. A — a vector is the vehicle that carries the gene of interest into the host cell, where it is then copied along with the plasmid; cutting the gene out is the work of a restriction endonuclease, not of the vector.

Q9. D — a gene taken from a different species (a firefly) makes the tobacco transgenic, and any transgenic organism is also, by definition, genetically modified.

Q10. A — mRNA carries the coded instructions of a gene from the nucleus to a ribosome; tRNA carries amino acids, and rRNA forms part of the ribosome.

Q11. B — “universal” means that a given codon specifies the same amino acid in almost all organisms, which is why a human gene can be read correctly by a bacterium.

Q12. C — an enzyme is a catalyst: it emerges from the reaction unchanged and can be used over and over; it is not a reactant and is not consumed.

Q13. B — the rate is highest at pH 7 (20 units), more than at any other pH tested, so pH 7 is the optimum.

Q14. A — far from the optimum, the pH alters the enzyme's shape so that its active site no longer fits the substrate; the substrate is not used up (B), and no temperature change is involved (D).

Q15. D — photosynthesis uses carbon dioxide and water as its raw materials; glucose and oxygen are its products.

- Q16.** C — photosynthesis converts light energy into chemical energy, which is then held in the bonds of the glucose the plant makes; energy is not destroyed (A), and D describes cellular respiration, the process that releases that stored energy again.
- Q17.** C — light and carbon dioxide were held constant and non-limiting for both species, so the difference must lie in the plants themselves: each species' photosynthetic enzymes have their own optimum temperature, close to the temperature of the water the species lives in.
- Q18.** A — over the same 20–30 °C interval one species' rate falls while the other's rises, so a temperature rise cannot be said to have a single, fixed effect: what it does depends on whether the species is being taken towards its optimum or past it. B is contradicted by the two curves, C is wrong because species R is at its *highest* rate at 20 °C, and D is ruled out by the stem.
- Q19.** B — glycolysis takes place in the cytosol; the later stages occur in the mitochondria.
- Q20.** D — most ATP is produced in the mitochondria (glycolysis in the cytosol yields only a small amount).
- Q21.** B — a human muscle cell short of oxygen ferments glucose to lactic acid; ethanol and carbon dioxide are the products in yeast, not in animals.
- Q22.** B — without oxygen, yeast ferment sugar to ethanol and carbon dioxide; lactic acid is the animal product.
- Q23.** C — a surface molecule that the immune system recognises as self or non-self is an antigen; an antibody binds an antigen but is not one.
- Q24.** A — a virus is non-cellular, being only genetic material inside a protein coat; bacteria, protozoa and fungi are all built of cells.
- Q25.** D — intact skin is a first-line, non-specific barrier; antibodies, cytotoxic T cells and memory B cells all belong to the third line (the adaptive response).
- Q26.** A — engulfing and digesting a pathogen is phagocytosis; antigen presentation, exocytosis and inflammation are different processes.
- Q27.** C — complement proteins can form pores in a pathogen's membrane and coat pathogens to make phagocytosis easier; they are not antibodies and store no memory.
- Q28.** C — the person met the bacterium in the ordinary course of life (natural, not given as a vaccine or an injection) and their own immune system mounted the response (active, not borrowed antibodies), so this is naturally acquired active immunity.
- Q29.** B — a macrophage belongs to the innate (non-specific) response: it engulfs anything the body recognises as non-self and builds no memory of a particular pathogen, so on the second exposure it acts exactly as it did on the first. It does not wait to be switched on by lymphocytes (A), never becomes specific to a single pathogen (C), and secretes no antibodies (D).
- Q30.** B — ready-made antibodies give immediate (passive) protection, but the person's own immune system is not activated, so no memory cells form and the protection is short-lived.
- Q31.** A — a contact may already be carrying and shedding the pathogen before feeling unwell, so separating contacts from other people during the incubation period breaks the chain of transmission. Staying at home confers no immunity of any kind (B, C) and has no effect on mutation (D).
- Q32.** D — an antibody's binding site is shaped to fit one particular antigen, like a lock and key, so it binds that antigen and no other; it cannot change shape to suit any antigen (A), and not all antibodies are identical (C).
- Q33.** B — a pathogen appearing in a population for the first time, or rapidly increasing in incidence, is an emerging pathogen.
- Q34.** B — the fewest differences means the shortest time since two species shared an ancestor; W and X differ at only 4 positions, fewer than any other pair.

Q35. C — the most differences means the most distantly related; W and Z differ at 24 positions, more than any other pair.

Q36. B — by the principle of superposition, in an undisturbed sequence the lowest (bottom) layer was laid down first and is the oldest.

Q37. D — the deep-rooted plants already present survived the droughts and reproduced more than the others, so the allele for deep roots became commoner: natural selection acting on existing variation. A is Lamarckian and B reverses the timing.

Q38. D — a reduced structure that no longer serves its original function, such as a snake's hip bones, is vestigial.

Q39. A — genetic drift shifts allele frequencies through chance alone, and it bites hardest in small populations; B, C and D describe selection, gene flow and mutation.

Q40. A — designing a study to maximise the benefit to participants and the community reflects beneficence.

Section B — solutions

Q1. (a) The guide RNA carries a short base sequence that is **complementary to a sequence within gene D**. Because bases pair only with their complements, the guide RNA **base-pairs only with that matching sequence** and with no other stretch of the fish's DNA, so it positions the Cas9 protein at gene D and the cut is made there and nowhere else. *(1 mark: the guide RNA's sequence is complementary to a sequence in gene D, so it base-pairs there; 1 mark: this positions Cas9 so that the cut is made only at the matching site.)*

(b) The Cas9 protein makes only the cut. **With no DNA template supplied, the cell has nothing correct to copy**, so it must rejoin the broken ends itself — and **this repair is not exact**: it often **adds or removes a few bases** where the ends are joined. That changes the base sequence of gene D (and can shift the reading frame), so when gene D is transcribed and translated a **working protein is no longer made** — the gene has been disabled. *(1 mark: with no template the cell rejoins the ends itself, adding or losing a few bases at the cut; 1 mark: the altered base sequence means gene D can no longer make a working protein.)*

(c) The team can conclude that **gene D is needed for the fish to survive when the oxygen in the water falls**: the edited and untreated fish came from the same colony and differ only in that gene D has been disabled, and the edited fish are normal until the oxygen drops, so gene D must have a part in the response to low oxygen. One limitation: **disabling a gene shows only what goes wrong when the gene is missing, not what the gene normally does**. Losing gene D might block the low-oxygen response directly, or it might disturb some other process that the low-oxygen response depends on, so this result alone does not identify gene D's actual job. *(Also acceptable: the CRISPR-Cas9 edit could have cut somewhere else in the genome as well — an off-target effect — and that change, not the loss of gene D, could be what kills the fish.) (1 mark: gene D is required for survival in / for the response to low oxygen; 1 mark: one valid limitation of inferring a gene's normal function from disabling it.)*

Q2. (a) The DNA is copied using the **polymerase chain reaction (PCR)**. This is needed because the blood stain holds **too little DNA to profile directly**, so many copies must be made first, giving enough to produce a readable band pattern. *(1 mark: PCR; 1 mark: there is too little DNA in the stain to profile directly, so it must be amplified first.)*

(b) The blood came from **Animal 2**. On the gel, the **blood-stain profile is identical to Animal 2** — the same five bands, in the same positions, with **no extra band and none missing**. **Animal 1 is not a match**: it carries a band the stain does not have, and it is missing one of the bands the stain does have. **Animal 3 is not a match either**, even though it carries **every one of the stain's bands**: it also has an **extra band** that the stain lacks. A match requires an **identical** pattern, not merely the presence of all of the stain's bands, so Animal 3 is a different individual. *(1 mark: Animal 2; 1 mark: justified — the pattern is identical to Animal 2, while Animal 1 both adds and misses a band and Animal 3 is excluded by its extra band.)*

(c) A DNA profile is based on **regions of DNA whose length varies from individual to individual** (regions of repeated sequence that are repeated different numbers of times in different individuals). When these regions are copied and separated by size, **different individuals give different patterns of bands**, and the pattern is effectively **unique to each individual**, so one animal can be told apart from another of the same species. *(1*

mark: profiles are based on regions that differ in length between individuals; 1 mark: so each individual gives its own band pattern.)

- (d) What the match **does** establish is that the **blood on the knife came from that particular animal** (Animal 2). It does **not** prove the suspect did the killing, for any **two** of the following reasons: a profile shows **whose blood it is, not who shed it or how it got onto the knife**; the blood could have reached the knife **innocently** — the suspect may have handled an animal already dead, or the knife may have been used or borrowed by someone else; and a match shows only **contact with that animal's blood**, not the act of killing. (1 mark: the match establishes that the blood is Animal 2's; 1 mark each for two valid reasons it does not prove who did the killing.)

Q3. (a) The **active site of bromelain has a shape that is complementary only to its substrate**, the protein gelatine, so gelatine fits into the active site, binds, and is broken down. **Sugar has a different shape and cannot fit or bind the active site**, so bromelain has no effect on it — this is what makes the enzyme specific. (1 mark: the active site is complementary only to gelatine, so gelatine binds and is broken down; 1 mark: sugar has a different shape and cannot bind, so it is not acted on.)

- (b) In **fresh** pineapple the bromelain is **active**: it breaks down the gelatine, and because it is the gelatine that lets the jelly set, the jelly **cannot set**. In **tinned** pineapple the **heat of canning has denatured the bromelain** — the heat has disrupted the interactions that held the enzyme in its folded form, so its **active site has lost its shape** and can no longer bind gelatine. The gelatine is therefore **not broken down**, and the jelly **sets normally**. (1 mark: in fresh pineapple the active enzyme breaks down the gelatine, so the jelly cannot set; 1 mark: heating denatures the enzyme — its active site is altered; 1 mark: the denatured enzyme cannot break down the gelatine, so the jelly sets.)

- (c) The **independent variable** is the **amount (mass or volume) of fresh pineapple added** to the jelly. One variable that should be kept constant (any **one**): the **volume of jelly**, the amount of gelatine, the temperature at which the jelly is set, the setting time, or the type of jelly used. (1 mark: the independent variable; 1 mark: one valid controlled variable.)

Q4. (a) The green areas contain **chloroplasts with the pigment chlorophyll**, which **absorbs light** for photosynthesis; these areas make glucose, which is stored as **starch**. The white areas **have no chloroplasts (no chlorophyll)**, so they **cannot photosynthesise** and make no starch. (1 mark: green areas have chloroplasts/chlorophyll, so they photosynthesise and make starch; 1 mark: white areas have no chloroplasts, so they make no starch.)

- (b) **Light-dependent stage**: it takes place in the **thylakoid membranes**; an input is **water** (and light), and an output is **oxygen** (and the energy carriers ATP and NADPH). **Light-independent stage (the Calvin cycle)**: it takes place in the **stroma**; an input is **carbon dioxide** (and ATP and NADPH), and an output is **glucose** (sugar). (1 mark: light-dependent stage in the thylakoid membranes; 1 mark: one correct input and output for it; 1 mark: light-independent stage in the stroma; 1 mark: one correct input and output for it.)

- (c) The green leaf kept in the dark would contain **no starch** (a negative starch test). The **light-dependent stage needs light**, so in the dark it cannot run and **no ATP or NADPH is made**; without these the **Calvin cycle stops**, so **no glucose (and no starch) is produced**. Any starch that was already in the leaf is **used up in respiration** during the two days. (1 mark: no starch; 1 mark: without light the light-dependent stage stops, so the Calvin cycle cannot make glucose; 1 mark: any existing starch is used up in respiration.)

Q5. (a) Any **two**, each with how it acts. **Mucus** lining the airways **traps** pathogens and dust so that they never reach the cells beneath, and the **cilia** of the airway lining then **sweep the trapped material back up and out** of the airways. **Lysozyme**, an enzyme in saliva and in the fluid lining the airways, **breaks down the cell walls of bacteria**. The **normal microbiota** of the nose, mouth and throat **compete with an incoming pathogen** for space and nutrients, making it harder for it to establish. The **unbroken lining of the airway** is itself a **physical barrier** between the air breathed in and the tissue beneath. (1 mark each for two valid first-line airway defences, each with a correct statement of how it acts.)

- (b) The innate response can begin at once because the **cells and molecules that carry it out are already in place** — the barriers, the phagocytes, the complement proteins — and they act against **anything recognised as non-self**, so nothing has to be recognised in advance. The adaptive response is slow the first time because **only the very few lymphocytes whose receptor happens to fit that pathogen's antigen can respond to it**: the

antigen must be **presented** to them, and those few cells must then be **selected, activated, divide many times (clonal expansion) and differentiate** into effector cells before enough of them exist to have any effect — which takes several days. *(1 mark: the innate cells and barriers are already present and act non-specifically, so no prior recognition is needed; 1 mark: the adaptive response must first select the few matching lymphocytes and let them multiply and differentiate, which takes days.)*

- (c) The antibodies are secreted by **plasma cells** (formed from activated B lymphocytes). Any **two** of the following ways in which they act on the bacterium: they **clump the bacteria together (agglutination)**, so the bacteria cannot spread and are taken up by phagocytes in bulk; they **coat and mark the bacterium (opsonisation)** so that phagocytes engulf it far more readily; they **neutralise the toxins the bacterium releases**, or block the surface molecules it uses to attach to the lining of the throat; or they **activate complement proteins**, which punch pores in the bacterium's membrane. *(1 mark: plasma cell; 1 mark each for two different, correctly described ways in which the antibodies act.)*
- (d) Patient 1's bacterium is a **complete cell**: it has its own cytoplasm, ribosomes and enzymes, so given the nutrients in the jelly it can **make its own proteins, grow and divide unaided**, and a visible colony forms on the plate. Patient 2's virus is **non-cellular** — no more than **genetic material inside a protein coat**, with **no cytoplasm, no ribosomes and no means of making proteins or of dividing**. It can be copied only by **entering a living host cell and using that cell's machinery**, so nutrient jelly on its own offers it nothing and no new virus is made. For the same reason a medicine that acts on **bacterial cell walls** can do nothing for Patient 2: a virus **has no cell wall — indeed no cell at all** — so the medicine has no structure to attack. *(1 mark: a bacterium is a cell with its own machinery, so it grows on the nutrient medium; 1 mark: a virus is non-cellular and can be reproduced only inside a living host cell; 1 mark: a virus has no cell wall, so a cell-wall medicine has no target in it.)*

Q6. (a) The first exposure sensitised the person's immune system. The peanut protein was treated as a non-self antigen, and the person's lymphocytes were activated and produced **antibodies against it (and memory cells)** — but building that response takes days, by which time the peanut had long passed through, so **no symptoms appeared at the time**. Those **antibodies then stayed in the person's tissues, bound to their mast cells**. On every later exposure the peanut protein meets this **ready-made response**, which is triggered **within minutes** — hence the fast, severe reaction. *(1 mark: the first exposure sensitises the immune system, forming antibodies and memory cells against the peanut protein too slowly to cause symptoms then; 1 mark: later exposures meet that ready-made response, so the reaction is immediate and severe.)*

- (b) The **same extract is applied to both people**, so the extract itself cannot be what makes the difference — and it damages neither of them. The difference must therefore lie in **the two people's immune systems, not in the peanut protein**. This person's immune system has been **sensitised** and now treats the peanut protein as though it were a threat, whereas the other person's immune system **tolerates it as harmless** and mounts no response at all. An allergy is thus a property of the person, not of the substance. *(1 mark: the same substance is applied to both, so the peanut protein is not itself the cause and is harmless in itself; 1 mark: the difference lies in the person — one immune system is sensitised and reacts to it, the other tolerates it.)*
- (c) The symptoms are produced by the **person's own immune response**, not by the peanut. When the allergen binds the **antibodies already attached to the person's mast cells**, those cells release chemicals such as **histamine**, which make **blood vessels widen and leak fluid into the surrounding tissue** and make the **muscle around the airways contract**, narrowing them. The response is called **exaggerated (hypersensitive)** because its scale is **out of all proportion to the threat**: the peanut protein is harmless, so a response of this size does **far more damage than the substance it is aimed at**. *(1 mark: the symptoms come from the person's own response — mast cells release histamine, widening and leaking blood vessels and contracting airway muscle; 1 mark: the response is out of proportion to a harmless substance, so the reaction itself does the harm.)*

Q7. (a) Over the first 20 generations the mean fruit mass rose steeply, from 12 g at generation 0 to 41 g at generation 10 and 68 g at generation 20 — more than five times its starting value. It rose because **only the plants bearing the largest fruit were kept as parents, so only their alleles were passed to the next generation** while the alleles of the smaller-fruited plants were not. The **alleles that make for large fruit therefore made up a larger share of the crop's gene pool in each successive generation**, and the mean fruit mass climbed with them. (This is artificial selection.) *(1 mark: describes the steep rise, quoting figures from the table; 1 mark: only the largest-fruited*

plants were allowed to reproduce, so only their alleles were passed on; 1 mark: the large-fruit alleles therefore rose in frequency generation after generation, raising the mean.)

- (b) After many generations in which only large-fruited plants were bred from, the **alleles for large fruit have become very common in the crop — many of them fixed**, that is, carried by every plant. The plants the growers now choose between therefore **differ hardly at all in the alleles that affect fruit size**. With **almost no variation left for selection to act on**, choosing the largest-fruited plants can no longer shift allele frequencies any further, so the mean levels off — 79 g at generation 30 and only 80 g at generation 40. A further increase would need a **new allele**, from a rare mutation or from a plant brought in from outside the program. (1 mark: repeated selection has made the large-fruit alleles very common or fixed, so nearly every plant now carries them; 1 mark: almost no variation is left for the growers to select between, so further selection cannot change allele frequencies and the mean stops rising.)
- (c) Selective breeding can only **change how common the alleles the species already has are**: the breeder chooses which existing plants reproduce, but cannot create an allele that is not there. A characteristic for which **no allele exists anywhere in the tomato's gene pool therefore cannot be produced by breeding**, however many generations the program runs — new alleles arise only through rare, random mutation. **Genetic engineering** is not limited in this way: a **gene taken from a completely different species** can be **inserted directly into the tomato's genome**, giving the plant a characteristic its own gene pool never contained. (1 mark: breeding can only redistribute alleles already present, so a characteristic with no existing allele cannot be produced; 1 mark: genetic engineering can insert a gene from another species, adding a characteristic the species never had.)

Q8. (a) This is **sympatric speciation**. The two groups of flies live in the **same district, side by side, with no geographic barrier of any kind between them** — the native shrub and the introduced tree grow together. What holds them apart is **biological rather than physical**: because the introduced tree fruits about six weeks earlier, the two groups now **emerge and mate at different times of the year**, and each mates on the plant it developed in, so flies of one group seldom meet flies of the other. (1 mark: sympatric speciation; 1 mark: justified — the two groups share the same area with no geographic barrier, and are kept apart instead by the difference in the timing of emergence and mating.)

- (b) Because the two groups emerge and mate at different times, **very few matings occur between them, so gene flow between them has all but stopped** — in effect the one gene pool is becoming **two separate gene pools**. Each then changes **independently of the other**: each acquires its **own new mutations**; **natural selection** acts differently on each, since the two fruits differ in size, in chemistry and in the season at which they are available, so different alleles are favoured in each group; and **genetic drift** adds further change by chance. Over many generations these differences **accumulate**, and once the two groups can **no longer produce fertile offspring together** they are **reproductively isolated** — that is, two species. (1 mark: the difference in timing means the two groups rarely interbreed, so gene flow between them has effectively stopped and there are two gene pools; 1 mark: each gene pool then diverges independently through its own mutations, natural selection under different conditions, and genetic drift; 1 mark: the differences build up until the two groups can no longer produce fertile offspring — reproductive isolation, and therefore two species.)
- (c) **No — they are not yet separate species**. Put together, the flies **mated, produced offspring, and those offspring bred normally**; that is, the offspring were **fertile**. Producing fertile offspring together is exactly the test of belonging to **one species**, so the two groups are **not yet reproductively isolated**. They are one species in the early stages of diverging, kept apart in the field by *when* they breed rather than by any inability to breed. A result that **would** have shown two species is any **one** of: the two groups **refuse to mate** with each other; they mate but **no offspring are produced at all**; or they produce offspring that are **sterile**. (1 mark: not yet separate species / still one species; 1 mark: because they produce fertile offspring, so there is no reproductive isolation; 1 mark: one valid result that would have shown reproductive isolation.)
- (d) With the introduced tree gone, the flies that had been using it must **lay their eggs in the fruit of the native shrub again**, so both groups would once more **emerge and mate at the same time and on the same plant**. The one thing that was keeping them apart would have been removed, so they would **interbreed freely again and gene flow would resume**. The two gene pools would then simply **mix back into one**, and the differences that had begun to accumulate would be **blended away** instead of building up towards reproductive isolation. (1 mark: the two groups would again breed at the same time on the same plant, so they would interbreed and

gene flow would resume; 1 mark: the gene pools would merge back into one, so the divergence needed for two species could not continue.)

Q9. (a) The volunteers **do not all begin at the same blood cholesterol level**. The level a volunteer reaches by the end combines **two separate things** — **the effect of the tablet and the level that volunteer happened to start from** — so a group that by chance began higher would finish higher whatever its tablet had done. Taking the **fall in each individual volunteer** subtracts that person's own starting level out of the comparison and measures **the change the twelve weeks actually produced in them**, so the three group means can be compared fairly. (1 mark: volunteers start at different levels, so final levels would confound the effect of the tablet with the starting level; 1 mark: the fall measures the change produced in each volunteer, so the groups can be compared fairly.)

(b) **Group 3 is the control group**: it is treated exactly as group 1 is, apart from the one thing being tested — its tablet contains no medicine. Blood cholesterol can change over twelve weeks for reasons that have nothing to do with the new medicine (taking part in a trial, taking a tablet each day, or simply the passage of time), and **group 3 measures how much change all of those other influences produce** — here a fall of 0.3 mmol/L. Only then can the **extra fall in group 1 be attributed to the new medicine itself**; group 1 alone could never show this, because there would be nothing to compare it with. **Group 2 answers a different question**: it shows **how the new medicine compares with the treatment patients can already be given**. A medicine can beat a placebo and still be no better than the one already in use, and only group 2 can reveal that. (1 mark: group 3 is a control treated identically apart from the active medicine, showing the change produced by everything other than the medicine; 1 mark: so the extra fall in group 1 can be attributed to the new medicine itself; 1 mark: group 2 shows whether the new medicine is any better than the treatment already in use, which a placebo comparison cannot show.)

(c) The committee's requirement — that any harm to a volunteer must **not be disproportionate to the benefits** the trial could bring — is the ethical concept of **non-maleficence**. **Informed consent** requires the team to **tell every volunteer, in terms they can understand, what taking part involves and what its possible risks and benefits are**, and then to obtain that volunteer's **agreement freely, without pressure** (and to allow them to withdraw). (1 mark: non-maleficence; 1 mark: informed consent — volunteers must be told what is involved and its risks and benefits, and must agree freely.)

(d) The new medicine produced the **largest fall of the three**: a mean fall of **1.6 mmol/L**, against **1.1 mmol/L** for the medicine already in use — about **0.5 mmol/L more** — and against **0.3 mmol/L** for the placebo, **more than five times** the placebo fall. Because the placebo group fell by only 0.3 mmol/L, most of group 1's fall (about **1.3 mmol/L** of it) can be attributed to the new medicine rather than to taking part or to the passage of time. These results therefore show that, **in adults of this age with high blood cholesterol and over twelve weeks, the new medicine lowered blood cholesterol, and lowered it by more than the medicine already in use did**. (1 mark: compares the new medicine with the existing medicine, quoting both figures; 1 mark: compares the new medicine with the placebo, quoting both figures; 1 mark: states what the results show — the new medicine lowered blood cholesterol and did so by more than the existing treatment.)

Q10. (a) The **paired fins** of specimen F are those of a fish, while the **strong internal limb bones with a shoulder and an elbow joint**, the **nostrils set on top of the skull** and the **movable neck** are features of four-legged land animals. A single animal carrying both sets of features is evidence that **four-legged land animals descended, with change, from fish-like ancestors** — the intermediate forms such a change requires did exist, and were not merely supposed. The evidence is stronger because specimen F lies **between the two groups in time as well as in anatomy**: it occurs **after** the layers holding only fish and **before** those holding only four-legged land animals, which is exactly the position an intermediate must occupy if one group gave rise to the other. Had it turned up above or below that interval, the anatomy alone would have counted for far less. (1 mark: combining features of both groups is evidence that the later group descended from the earlier one; 1 mark: being intermediate in time as well as in anatomy is what descent with change predicts, so the stratigraphic position strengthens the anatomical evidence.)

(b) **A single specimen proves very little on its own**: one animal could be **deformed, diseased or simply unusual for its population**, and the shapes preserved in a fossil can also be **distorted while the rock forms**, so one find cannot show that any whole population ever carried this combination of features. Finding the **same combination in specimen after specimen, at several widely separated sites**, rules those explanations out: the combination must have been **characteristic of a widespread population** living in that span of time, so specimen F represents a **real intermediate form** rather than a one-off oddity. (1 mark: one specimen could

be an atypical individual or a fossil distorted during preservation, so it cannot establish what a population was like; 1 mark: the same combination repeated across many specimens at separate sites shows it was characteristic of a real, widespread population.)

- (c) **Hard parts — bones, teeth and shells — resist decay** and are readily **replaced by minerals** once buried, so they last long enough to become fossils. **Soft parts such as skin, gills and lungs decay within days**, or are **eaten by scavengers and broken down by decomposers**, so they are almost always gone before burial can preserve anything; only very unusual conditions, such as rapid burial in fine oxygen-poor sediment, preserve them at all. The fossil record is therefore a **strongly biased sample**: plenty of skeletons, very little soft anatomy, and hardly anything at all of entirely soft-bodied organisms. *(1 mark: hard parts resist decay and become mineralised, so they are preserved; 1 mark: soft parts decay or are eaten before burial, so they are rarely preserved and the record is biased towards hard parts.)*

Exam 5 — Practice examination

Reading time: 15 minutes. Writing time: 2 hours 30 minutes. Section A: 40 questions, 40 marks. Section B: 10 questions, 80 marks. Total 120 marks. This examination covers Units 3 and 4. Answer all questions.

- No calculator may be used.
- No formula sheet, data sheet, dictionary or notes may be used.
- Diagrams in this examination are not drawn to scale.

Section A — Multiple choice

Every question in this section must be attempted. Select the response that is correct or that best answers the question. One mark is awarded for each correct response, and nothing is taken away where a response is wrong. Where two or more responses have been completed for the same question, no mark is awarded for it. No diagram in this section is drawn to scale.

Question 1

Which one of the following is found in a molecule of messenger RNA but not in a molecule of DNA?

- A. a phosphate group
- B. the base uracil
- C. the base adenine
- D. a five-carbon sugar

Question 2

A eukaryotic gene contains five exons and four introns. The mature mRNA that is translated at the ribosome contains

- A. all five exons and all four introns, in the order in which they occur in the gene.
- B. the four introns joined together, with the exons removed and broken down.
- C. one exon only, chosen at random from the five.
- D. the five exons joined together, with the introns removed.

Question 3

The coding region of a mature mRNA molecule is 300 nucleotides long, and the last three of those nucleotides form a stop codon. The number of amino acids in the polypeptide translated from this mRNA is

- A. 99
- B. 100
- C. 150
- D. 300

Question 4

A single base change occurs in the promoter of a gene, so that RNA polymerase can no longer bind there. The coding sequence of the gene itself is unchanged. In this cell the most likely result is that

- A. the protein is still made, but with one amino acid replaced by another.
- B. a longer mRNA than usual is made, because transcription cannot stop.
- C. no mRNA is transcribed from the gene, so its protein is not made.
- D. every gene in the cell is switched off, because RNA polymerase is shared.

Question 5

One complete codon is removed from the middle of the coding region of a gene. Compared with the normal protein, the protein made from the altered gene is most likely to be

- A. the same length as normal, but with three of its amino acids changed.
- B. one amino acid shorter than normal, with the rest of its sequence unchanged.
- C. completely different from that point onwards, because the reading frame has shifted.
- D. impossible to make at all, because translation would halt at the missing codon.

Question 6

In one region a protein chain twists into an α -helix, a coil stabilised by hydrogen bonding along the chain's own backbone. This level of structure is the protein's

- A. primary structure.
- B. quaternary structure.
- C. secondary structure.
- D. denatured form.

Question 7

The trp operon of a bacterium carries the genes for the enzymes that make tryptophan. Switching these genes off when tryptophan is already plentiful benefits the bacterium because it

- A. avoids spending materials and energy on enzymes the cell does not need.
- B. allows the bacterium to absorb ready-made tryptophan from its surroundings instead.
- C. removes the unused structural genes from the bacterial chromosome.
- D. prevents any mutation from occurring in the structural genes.

Question 8

A protein that a cell will export is assembled at ribosomes on the rough endoplasmic reticulum. It then reaches the outside of the cell by being

- A. released directly into the cytosol, from which it diffuses out through the plasma membrane.
- B. passed out through the pores of the nuclear envelope into the surrounding fluid.
- C. broken down into its amino acids, which are joined together again outside the cell.
- D. carried in vesicles to the Golgi apparatus, then in further vesicles to the surface.

Question 9

Bacterial cells are mixed with recombinant plasmids, and a small proportion of the cells take a plasmid in. A cell that has taken in a plasmid in this way is said to have been

- A. transformed.
- B. denatured.
- C. transcribed.
- D. amplified.

Question 10

In a chloroplast, the role of the pigment chlorophyll is to

- A. join carbon dioxide molecules together to build glucose.
- B. break down glucose to release the energy stored in it.
- C. absorb light energy and make it available to photosynthesis.
- D. carry hydrogen from one photosynthetic reaction to another.

Question 11

The complete aerobic respiration of one glucose molecule produces a large amount of ATP, together with

- A. ethanol and lactic acid.
- B. carbon dioxide and water.
- C. glucose and oxygen.
- D. oxygen only.

Question 12

A cell in the root of a plant lies deep in the soil and receives no light at all. This cell obtains the ATP it needs by

- A. photosynthesis, using the light-independent stage only.
- B. absorbing ready-made ATP from the soil water.
- C. taking ATP from the leaf cells through the xylem.
- D. aerobic respiration, in its mitochondria.

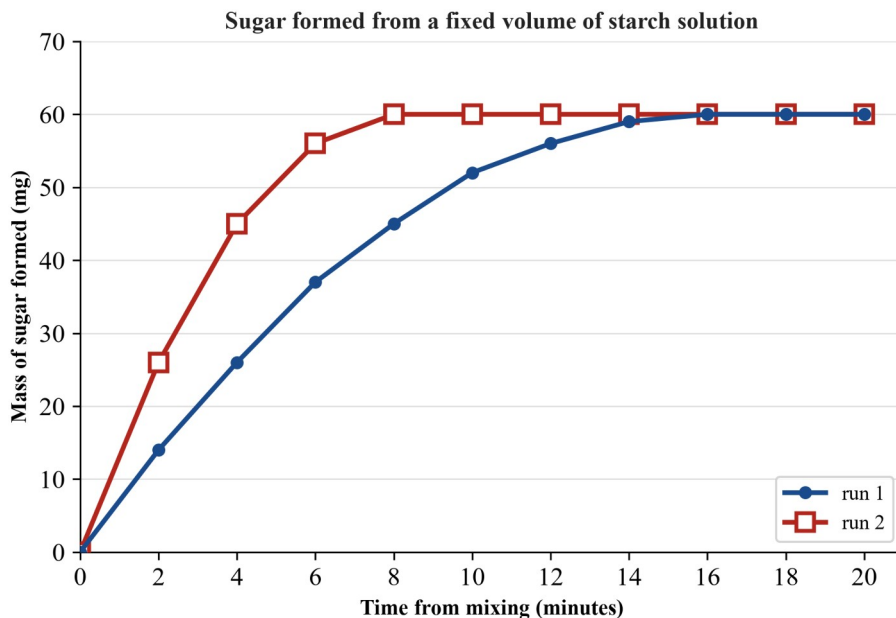
Question 13

Energy is made available to a cell's activities when a molecule of ATP is

- A. built up from ADP and a phosphate group.
- B. joined to a molecule of glucose in the cytosol.
- C. carried out of the cell into the tissue fluid.
- D. broken down to ADP and a phosphate group.

Use the following information to answer Questions 14, 15 and 16.

A fixed volume of a starch solution was mixed with a starch-digesting enzyme, and the mass of sugar formed was measured every two minutes. The whole run was then repeated with everything the same except that twice as much enzyme was added at the start. The results of the two runs are shown below.



Question 14

In both runs the mass of sugar formed stops increasing and then stays constant. The best explanation is that

- A. the enzyme has been denatured by the sugar formed.
- B. all of the starch has been converted to sugar.
- C. every active site is occupied at any one moment.
- D. the temperature of the mixture has fallen steadily.

Question 15

Compared with run 1, run 2 reaches the same final mass of sugar but reaches it sooner. This is because, in run 2,

- A. more starch was supplied at the start, so more product could form.
- B. the sugar formed is a different sugar from the one formed in run 1.
- C. each enzyme molecule is working many times faster than in run 1.
- D. more active sites are available, so starch is converted faster.

Question 16

For the comparison between run 1 and run 2 to be a fair test of the effect of the amount of enzyme, the investigator must hold constant

- A. the temperature, the pH and the amount of enzyme.
- B. only the time at which the first measurement is taken.
- C. the temperature, the pH and the starting mass of starch.
- D. the mass of sugar formed by the end of each run.

Question 17

A mutation replaces one amino acid in the active site of an enzyme with an amino acid of a very different shape. The enzyme is still assembled and is not denatured. The most likely consequence is that

- A. the enzyme now catalyses a completely different reaction in the cell.
- B. its substrate no longer fits the active site, so the reaction is not catalysed.
- C. the enzyme is broken down by the cell as soon as it has been made.
- D. the reaction still proceeds, but releases less energy overall than before.

Question 18

An infectious agent that has just been identified is made up of a single misfolded protein and holds no genetic material at all. It is best classified as

- A. a prion.
- B. a virus.
- C. a bacterium.
- D. a fungus.

Question 19

A parasitic worm, far too large for a phagocyte to take in, becomes established in the tissues of a person. The cells of the innate response that gather around a parasite of this size and release toxic substances onto its surface are

- A. plasma cells.
- B. helper T cells.
- C. eosinophils.
- D. mast cells.

Question 20

The innate (second line) response differs from the adaptive (third line) response in that the innate response

- A. produces antibodies directed against one specific antigen.
- B. must be built up over several days before it can take effect.
- C. is already in place and acts within minutes to hours.
- D. acts only against viruses and has no effect on bacteria.

Question 21

The leaves of a plant are covered by a waxy cuticle, and the wall of every leaf cell contains tough fibres. In the plant's defence against pathogens, these features act as

- A. physical barriers.
- B. antibodies.
- C. memory cells.
- D. an adaptive response.

Question 22

Antibodies against a particular antigen are secreted by

- A. cytotoxic T cells, which arise in the bone marrow.
- B. plasma cells, formed when a B lymphocyte is activated.
- C. macrophages that have engulfed and digested the pathogen.
- D. mast cells in the tissue around the infection.

Question 23

Some vaccines are given as a first injection followed by a booster injection some weeks later. The booster improves protection mainly because it

- A. supplies ready-made antibodies that protect the person immediately.
- B. introduces a second, quite different pathogen to the body's tissues.
- C. replaces the memory cells that were lost after the first injection.
- D. provokes a secondary response, so more memory cells are formed.

Question 24

A bacterial disease that had been well controlled in one country for decades is causing large numbers of cases there again, following a fall in the proportion of children vaccinated against it. The pathogen that causes it is

- A. a re-emerging pathogen, because a known disease is increasing again.
- B. an emerging pathogen, because it has never infected people before.
- C. an allergen, because the immune response to it has become exaggerated.
- D. a pathogen for which no vaccine has yet been developed.

Question 25

A newborn baby is protected for a few months by antibodies that crossed the placenta from its mother. This protection is only temporary because

- A. the baby's skin is not yet an effective barrier against pathogens.
- B. the antibodies are broken down and no memory cells are formed.
- C. the antibodies eventually begin to attack the baby's own body cells.
- D. the mother's antibodies set off an allergic reaction in the baby's tissues.

Question 26

In a community where most individuals are immune, even those who cannot be vaccinated are shielded from the disease. This effect is called

- A. herd immunity.
- B. active immunity.
- C. phagocytosis.
- D. antigenic drift.

Question 27

A virus lives permanently in a population of wild bats, causing them no illness, and occasionally infects people who handle the bats. In the spread of this disease the bat population is best described as

- A. an antigen carried by the pathogen.
- B. a population that has been vaccinated.
- C. the reservoir of the pathogen.
- D. the first line of defence against the pathogen.

Question 28

A disease is said to have been eradicated when

- A. a vaccine against it has been developed and tested.
- B. no cases of it occur anywhere in the world.
- C. it no longer occurs in one particular country.
- D. it can be treated successfully in every case.

Question 29

A mutation occurs in a skin cell of an adult animal. Skin cells do not give rise to gametes. This mutation

- A. will be inherited by all of the offspring the animal later produces.
- B. will change the allele frequencies of the whole population's gene pool.
- C. cannot be passed on to any of the animal's offspring.
- D. is certain to be harmful to the animal that carries it.

Question 30

In a beetle species, one allele produces a thicker, heavier wing case. On islands where a beetle-crushing predator is common, that allele becomes more frequent over the generations; on neighbouring islands, where the predator is absent, the same allele becomes less frequent. Together these observations show that

- A. whether an allele is favoured depends on the environment the population lives in.
- B. the thicker wing case arose because the crushing predator was present.
- C. individual beetles thicken their wing cases to suit the island they are on.
- D. natural selection always increases the frequency of a newly arisen allele.

Question 31

Two populations of the same plant are the same size, but one of them has far fewer different alleles than the other. Compared with the more variable population, the population with fewer alleles is

- A. more likely to contain individuals able to survive a new disease.
- B. certain to become extinct within a few generations.
- C. unaffected, because the number of alleles does not matter to survival.
- D. less likely to contain individuals able to survive a new disease.

Question 32

A change in the frequencies of the alleles in a population's gene pool from one generation to the next is

- A. speciation.
- B. transcription.
- C. evolution.
- D. denaturation.

Question 33

On a phylogenetic tree, the point at which one branch divides into two represents

- A. the extinction of an ancestral species at that time.
- B. the most recent common ancestor of the two branches.
- C. the moment at which a mutation first occurred.
- D. the present-day interbreeding of the two species.

Question 34

The same protein is compared across several species. Biologists treat a smaller number of amino acid differences between two of the species as evidence that

- A. the two species shared a common ancestor more recently.
- B. the two species live in the same kind of habitat.
- C. one of the two species is the ancestor of the other.
- D. the two species have the same number of genes.

Question 35

Animals with shells or bones are far more often preserved as fossils than soft-bodied animals. The main reason is that soft tissue

- A. is never buried deeply enough to be preserved.
- B. contains no carbon compounds that could be preserved.
- C. is always eaten by other animals before burial.
- D. decays before it can be buried and mineralised.

Question 36

Two groups of a fish, living in the same lake with no physical barrier between them, gradually become two separate species. This is an example of

- A. allopatric speciation.
- B. genetic drift.
- C. sympatric speciation.
- D. gene flow.

Question 37

Before collecting soil samples from farmland, a research team asks each landholder's permission, explains how the samples will be used, and agrees to send the landholder the findings. This most clearly shows the bioethical concept of

- A. beneficence.
- B. non-maleficence.
- C. integrity.
- D. respect.

Use the following information to answer Questions 38, 39 and 40.

A research team measured the width of every annual growth ring in timber samples taken from 40 native trees, and obtained the published rainfall records for the district for each of the years in which those rings had formed. The team altered nothing. Rings that had formed in wetter years were, on average, wider.

Question 38

This investigation is best described as

- A. a correlational study.
- B. a controlled experiment.
- C. a simulation.
- D. a classification and identification study.

Question 39

A newspaper reports the finding as: "Higher rainfall causes native trees to grow wider rings." This claim goes beyond what the data show because

- A. only 40 trees were sampled, which is too few for any conclusion at all.
- B. rainfall records kept by other people can never be relied upon.
- C. the width of a ring is not a measurement of how much wood grew.
- D. the team altered nothing, so another factor could explain the pattern.

Question 40

The team now wishes to test whether rainfall does affect ring width. Of the following, the strongest additional evidence would come from

- A. measuring the rings of many more trees in the same district over the same years.
- B. growing young trees under different, controlled watering regimes.
- C. asking local farmers whether they agree with the finding.
- D. repeating the measurements using a ruler with finer divisions.

End of Section A

Section B — Short answer

Every question in this section must be attempted, in the spaces provided. For any question carrying two or more marks, a response earns full credit only if it reaches the depth that its command term and its mark allocation call for. No diagram in this section is drawn to scale.

Question 1 (7 marks)

A researcher examined three tissues taken from the same plant — root, leaf and flower petal — and recorded, for each of four genes, whether that gene was being transcribed in that tissue.

Table 1 Whether each of four genes was being transcribed in three tissues of one plant

Gene	Protein the gene codes for	Root	Leaf	Petal
gene 1	an enzyme of the light-independent stage	not transcribed	transcribed	not transcribed
gene 2	an enzyme that makes a red pigment	not transcribed	not transcribed	transcribed
gene 3	an enzyme of glycolysis	transcribed	transcribed	transcribed
gene 4	a protein of the root-hair surface	transcribed	not transcribed	not transcribed

- a.** Every cell of this plant carries the same four genes. Using Table 1, explain how the three tissues can nevertheless contain different sets of proteins. 3 marks
- b.** Suggest why gene 3 is being transcribed in all three tissues. 1 mark
- c.** A chemical treatment applied to a root causes gene 4 to stop being transcribed and gene 2 to begin being transcribed. Explain what will happen to the proteins present in that root cell over the following days, referring to transcription and to translation. 3 marks

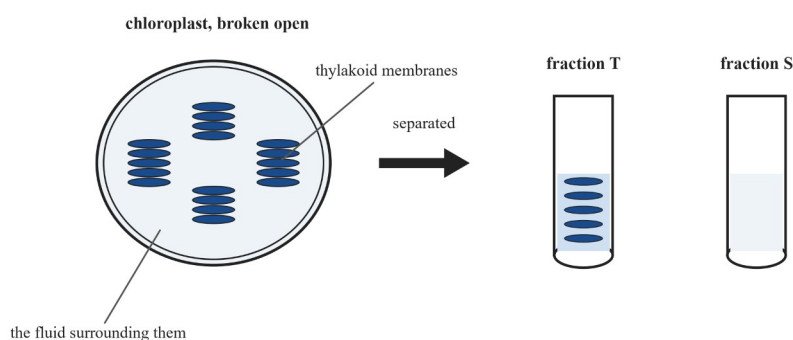
Question 2 (6 marks)

A laboratory tests imported tomato plants for a bacterial pathogen using the polymerase chain reaction (PCR). The two primers are designed to match a DNA sequence that is found only in this pathogen and in no other organism likely to be present in the samples.

- a.** Explain how designing the primers to match a sequence found only in this pathogen allows the test to detect the pathogen specifically, even when many harmless bacteria are also present in a sample. 3 marks
- b.** Each PCR run also includes one tube containing DNA known to be from the pathogen, and one tube containing no DNA. State the purpose of each of these two tubes. 2 marks
- c.** A tested sample gives a PCR product of the expected size. State what this result shows about the sample. 1 mark

Question 3 (8 marks)

Chloroplasts isolated from spinach leaves were broken open and separated into two fractions: fraction T, containing the thylakoid membranes, and fraction S, the fluid that surrounds them.



Four tubes were then set up. Every tube was supplied with water and carbon dioxide, together with the empty carrier molecules that a chloroplast normally uses, and all four were held at the same temperature for 30 minutes.

Table 2 Results obtained from the four tubes

Tube	Fraction(s) present	Lighting	Oxygen released	Sugar detected after 30 minutes
1	T only	bright light	yes	no
2	T only	darkness	no	no
3	S only	bright light	no	no
4	T and S together	bright light	yes	yes

a. Using the results, state which stage of photosynthesis fraction T carries out and which stage fraction S carries out. Justify each answer using data from Table 2. 3 marks

b. Name the substance that is split in tube 1 to release the oxygen, and explain why no oxygen is released in tube 2. 2 marks

c. Sugar was detected in tube 4 only. State what this shows about the two stages of photosynthesis. 2 marks

d. Name the enzyme that fixes carbon dioxide in fraction S. 1 mark

Question 4 (7 marks)

Thirty people who attended the same three-day music festival became ill over the following week with severe diarrhoea and vomiting. Public health officers investigated, in order to find out what was causing the illness and to stop it spreading further.

a. Explain why identifying the pathogen is the first step in controlling an outbreak of this kind, and state one thing that knowing whether the pathogen is a bacterium or a virus would tell the officers about treating the patients. 2 marks

b. The officers find that the pathogen was present in drinking water at the festival that had been contaminated with sewage. Describe **two** measures that would reduce transmission of this pathogen by this route, and explain how each one works. 4 marks

c. Some people who drank the same water did not become ill. Suggest one reason for this. 1 mark

Question 5 (8 marks)

Two children have inherited disorders of the immune system. Child 1 cannot make functional B lymphocytes, and so makes no antibodies at all. Child 2 cannot make functional cytotoxic T cells. In both children every other part of the immune system, including the innate (non-specific) defences, works normally.

a. Predict which of the two children would be more troubled by a bacterium that multiplies in the tissue fluid outside the body's cells, and explain your prediction. 3 marks

b. Predict which of the two children would be more troubled by a virus that multiplies inside the body's own cells, and explain your prediction. 3 marks

c. Both children have normal innate defences. Explain why those defences alone are not enough to keep either child free of infection. 2 marks

Question 6 (7 marks)

A team working in a cave recovers the partial skeletons of several individuals from a single rock layer. The skulls have a cranial capacity of about 520 cm³ — close to that of *Australopithecus* — but the pelvis and the foot bones are shaped like those of much later members of the genus *Homo*, and indicate habitual upright walking on two legs.

a. State **two** features of a skeleton that place a specimen among the hominins rather than among the other hominoids (apes). 2 marks

b. Explain why this combination of a small cranial capacity with an upright-walking pelvis and foot is difficult to fit into the accepted picture of hominin evolution, and state what it suggests about the order in which the two trends appeared. 3 marks

c. A newspaper reports the find under the headline “Missing link found: the direct ancestor of every living person”. State **two** reasons why this headline is not supported by the evidence described. 2 marks

Question 7 (8 marks)

A fruit crop is regularly destroyed by a plant virus that is carried from plant to plant by aphids. A gene taken from the virus itself has been inserted into the crop’s genome, and plants carrying this gene are not damaged when the virus enters them. A two-season field trial compared the new line with the conventional line. Both lines were grown on the same farm, in neighbouring blocks, and received the same water and fertiliser.

Table 3 Results of the two-season field trial

Line	Plants showing virus damage (%)	Mean yield (kg per plant)
conventional	68	4.1
new line	3	11.6

a. State what is meant by a **transgenic** organism, and identify the feature of this crop that makes it transgenic rather than only genetically modified. 2 marks

b. Using Table 3, describe the effect of the inserted gene on virus damage and on yield, quoting figures, and state one feature of the trial that makes the comparison a fair one. 3 marks

c. Before a transgenic food crop of this kind can be approved for sale, regulators require particular questions to be answered. State **three** such questions, and briefly say why each one matters. 3 marks

Question 8 (12 marks)

On an island, a native lizard escapes predators by running fast; lizards with longer hind legs run faster. The island had no predator of the lizard until a predatory bird became established there. The bird became established in the year in which recording began (year 0). Researchers then recorded, over six years, the mean hind-leg length of the lizard population and the percentage of lizards surviving each year. (Adapted from Renton & Adeyemi, 2025.)

Table 4 Hind-leg length and annual survival in the island lizard population

Year	Mean hind-leg length (mm)	Lizards surviving the year (%)
0	18.0	88
2	19.1	71
4	20.3	74
6	21.0	82

a. Using the data, describe how the mean hind-leg length changed over the six years and how the annual survival changed over the same period, quoting figures in each case. 3 marks

b. The bird did not cause longer hind legs to appear. State where the variation in hind-leg length came from, and explain how the arrival of the bird changed the frequency of the alleles for longer legs in the population. 3 marks

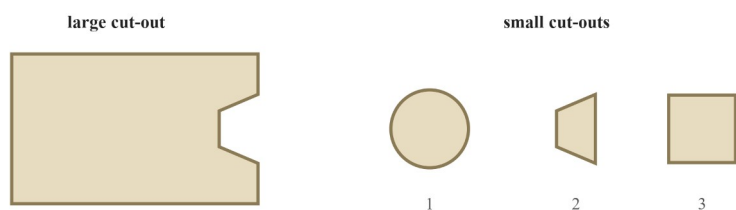
c. Annual survival fell from 88% at year 0 to 71% at year 2, and then rose again to 82% by year 6. Explain this pattern. 2 marks

d. Explain why recording the population for six years, rather than for a single year, makes the researchers’ conclusion about the effect of the bird more reliable. 2 marks

- e. The researchers recorded only the *mean* hind-leg length each year. State one further measurement of hind-leg length that would give a fuller picture of how the population changed, and explain what it would show. 2 marks

Question 9 (8 marks)

To study how an enzyme acts on its substrate, a class used a set of stiff cardboard cut-outs. One large cut-out, representing the enzyme, has a notch cut into one edge. Only one of the small cut-outs fits the notch; when that one is pushed in, it can be snapped into two pieces, which are then lifted out. The large cut-out is then used again with the next small cut-out.



- a. Name the investigation methodology that this activity is an example of, and state what the notch in the large cut-out represents. 2 marks
- b. State **two** ways in which this model does not represent what happens in a living cell, and for each explain why the difference matters. 4 marks
- c. A student writes: "This activity proves that enzymes are specific." Explain why the activity cannot prove this, and state what kind of evidence would be needed instead. 2 marks

Question 10 (9 marks)

A small native mammal hibernates through the winter. During hibernation its body temperature falls close to that of its surroundings and it does not feed. The table shows measurements made on one such animal in summer and in winter.

Table 5 Body temperature and oxygen consumption of one animal

Condition	Body temperature (°C)	Oxygen used (cm ³ per hour)
active, in summer	36	240
hibernating, in winter	5	12

- a. Using the data, calculate how many times greater the animal's rate of oxygen use is when active than when hibernating, showing your working. Then state what a measurement of oxygen use indicates about the rate of aerobic cellular respiration. 2 marks
- b. Explain, in terms of the enzymes that catalyse the reactions of cellular respiration, why the fall in body temperature lowers the animal's rate of respiration. 3 marks
- c. Explain how a greatly reduced rate of respiration helps the animal to survive a winter in which no food is available. 2 marks
- d. As it comes out of hibernation the animal shivers, and its body temperature rises over several hours before it becomes active again. Explain, in terms of respiration, how shivering can raise the animal's body temperature. 2 marks

End of Section B

End of examination questions

Exam 5 — Answers and solutions

Section A — answers

Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	B	11	B	21	A	31	D
2	D	12	D	22	B	32	C
3	A	13	D	23	D	33	B
4	C	14	B	24	A	34	A
5	B	15	D	25	B	35	D
6	C	16	C	26	A	36	C
7	A	17	B	27	C	37	D
8	D	18	A	28	B	38	A
9	A	19	C	29	C	39	D
10	C	20	C	30	A	40	B

Q1. B — RNA carries uracil where DNA carries thymine. Both molecules contain phosphate groups, adenine and a five-carbon sugar (ribose in RNA, deoxyribose in DNA), so those three are shared.

Q2. D — the introns are removed by splicing and the exons are joined together to form the mature mRNA; only the exons carry through to the ribosome.

Q3. A — $300 \div 3 = 100$ codons; the last codon is a stop codon, which adds no amino acid, so the polypeptide is 99 amino acids long. B forgets the stop codon and C halves the nucleotide count instead of taking one third of it.

Q4. C — RNA polymerase must bind the promoter before transcription can begin. With no binding, no mRNA is made from that gene, so no protein is translated from it, even though the coding sequence is intact. The change is outside the coding sequence, so the amino acid sequence is unaffected (A), and a promoter serves one gene, not all of them (D).

Q5. B — removing one whole codon takes out one amino acid and leaves the reading frame of every following codon unchanged, so the rest of the sequence is normal. A frameshift (C) needs a change that is not a multiple of three.

Q6. C — a length of chain coiled into an α -helix and held by hydrogen bonds along the backbone is secondary structure; the primary structure is the amino acid sequence, and the quaternary structure is the joining of several separate chains.

Q7. A — making an enzyme costs the cell amino acids and ATP. When tryptophan is already available the enzymes that make it are not needed, so switching the operon off avoids that waste. Regulation switches transcription on and off; it does not delete genes (C) or affect mutation rate (D).

Q8. D — a protein destined for export leaves the rough endoplasmic reticulum in transport vesicles that carry it to the Golgi apparatus, which modifies, sorts and packages it; secretory vesicles then take it to the plasma membrane and fuse with it, releasing the protein outside. A protein is far too large to diffuse through a membrane (A), the nuclear pores open into the cytosol rather than out of the cell (B), and a finished protein is not dismantled in order to be exported (C).

Q9. A — taking up DNA from the surroundings, so that the cell now carries a gene it did not have before, is transformation; amplification is copying DNA in vitro and transcription is making RNA.

Q10. C — chlorophyll absorbs light energy, which is then used to drive the reactions of photosynthesis. Building glucose from carbon dioxide is the work of enzymes (A), breaking glucose down is respiration (B), and the hydrogen carrier is a coenzyme, not a pigment (D).

Q11. B — the complete aerobic breakdown of glucose releases carbon dioxide and water, together with a large amount of ATP; ethanol and lactic acid are anaerobic products, and glucose and oxygen are the raw materials, not products.

- Q12. D** — plant cells respire just as animal cells do. A root cell in the dark cannot photosynthesise, so it makes its ATP by aerobic respiration in its mitochondria, using glucose transported from the leaves. ATP is not absorbed from outside the cell or moved between cells.
- Q13. D** — energy is released when the bond holding the third phosphate is broken and ATP becomes ADP plus a free phosphate group; building ATP from ADP (A) stores energy rather than releasing it.
- Q14. B** — the amount of enzyme is unchanged and the enzyme is not used up, so the reaction stops only because there is no starch left to convert. Saturation (C) explains a constant *rate*, not a constant *amount* of product, and both runs finish at the same mass of sugar, which is what running out of substrate predicts.
- Q15. D** — doubling the amount of enzyme doubles the number of active sites available at any moment, so starch is converted about twice as fast. The starting mass of starch was unchanged, so the same mass of sugar is finally formed; each individual enzyme molecule works at its usual speed.
- Q16. C** — the amount of enzyme is the variable being changed, so it must not be held constant; everything else that could affect the rate — temperature, pH and the starting mass of starch — must be kept the same. The mass of sugar formed is the measured result, not a controlled variable.
- Q17. B** — the active site's shape is complementary to the substrate. Replacing an amino acid there with one of a very different shape alters that fit, so the substrate can no longer bind and the reaction is no longer catalysed. An enzyme does not change the overall energy released (D).
- Q18. A** — a single misfolded protein with no genetic material and no cell structure is a prion, which is non-cellular; a virus contains nucleic acid, and bacteria and fungi are built of cells.
- Q19. C** — a worm of this size cannot be taken into a phagocyte, so eosinophils instead gather around it and release the toxic contents of their granules onto its surface, damaging it from outside. Plasma cells (A) secrete antibody and helper T cells (B) belong to the adaptive response, while mast cells (D) release histamine in an inflammatory response.
- Q20. C** — the innate defences are already in place before any pathogen arrives, so they begin to act within minutes to hours; it is the adaptive response that must be built up over several days before it takes effect (B). Producing antibodies against one antigen (A) is adaptive, and the innate response is not limited to viruses (D).
- Q21. A** — a waxy cuticle and a reinforced cell wall keep pathogens out by physical means, so they are physical barriers and belong to the plant's first line of defence. Plants have no antibodies, memory cells or adaptive immune response.
- Q22. B** — an activated B lymphocyte divides and differentiates into plasma cells, which secrete antibody. Cytotoxic T cells kill infected cells, macrophages engulf pathogens, and mast cells release histamine; none of them secretes antibody.
- Q23. D** — the booster is met by the memory cells laid down by the first dose, so the response is faster and larger and leaves behind a bigger population of memory cells and a higher antibody level. A vaccine supplies antigen, not ready-made antibody (A), and both doses carry the same antigen (B).
- Q24. A** — the pathogen and the disease it causes were already known in that country and had been brought under control, so a renewed rise in cases makes it a re-emerging pathogen. An emerging pathogen is one meeting a population for the first time (B). A vaccine plainly exists, since the proportion of children receiving it has fallen (D), and a pathogen is not an allergen (C).
- Q25. B** — the mother's antibodies are ready-made, so the baby's own immune system has not responded and forms no memory cells; as the transferred antibodies are gradually broken down, the protection fades.
- Q26. A** — protecting the unvaccinated because most of the community is immune is herd immunity.
- Q27. C** — a reservoir is the population in which a pathogen is maintained between infections of the target species; the bats carry the virus permanently and are the source from which people are infected.
- Q28. B** — eradication means the pathogen no longer causes disease anywhere in the world. Removing a disease from one country (C) is elimination, not eradication, and a vaccine or a treatment on its own does not remove the pathogen.

Q29. C — a mutation in a skin (body) cell is a somatic mutation; because skin cells do not form gametes, it cannot be passed to offspring and it never reaches the gene pool. Most mutations are neither certainly harmful nor certainly helpful (D).

Q30. A — the same allele rises in frequency where the predator is present and falls where it is absent, so the selection pressure — and therefore whether the allele is an advantage — comes from the environment. The allele must have existed before the predator arrived (B) and individuals do not alter their own wing cases (C).

Q31. D — the fewer different alleles a population holds, the smaller the chance that some of its members happen to carry an allele that allows them to survive a new challenge such as a disease. Low diversity raises the risk of extinction but does not make it certain (B).

Q32. C — evolution is a change in the allele frequencies of a population's gene pool over the generations; speciation is the formation of a new species, which is one possible outcome of that change.

Q33. B — each branch point (node) marks the most recent common ancestor of everything on the two branches that leave it. It does not record an extinction, a single mutation, or present-day interbreeding.

Q34. A — differences accumulate in a protein's amino acid sequence over time, so the fewer the differences between two species, the less time has passed since they last shared a common ancestor. Living species are not ancestors of one another (C).

Q35. D — fossilisation requires the remains to be buried and mineralised before they decay. Soft tissue decays quickly, so it is usually gone before that can happen, whereas shells and bones persist long enough to be preserved. Soft tissue does contain carbon compounds (B).

Q36. C — two groups becoming separate species while living in the same place, with no physical barrier between them, is sympatric speciation; allopatric speciation requires a geographic barrier.

Q37. D — seeking permission, explaining the purpose and sharing the findings treats the landholders as people whose interests and decisions count, which is the concept of respect. Beneficence concerns maximising benefit, non-maleficence avoiding harm, and integrity honest reporting.

Q38. A — the team measured two variables that already existed and altered nothing, so it can establish an association only: this is a correlational study. In a controlled experiment the investigator would deliberately change one variable.

Q39. D — because nothing was manipulated, some other factor that varies with rainfall (such as temperature, cloud cover or soil moisture) could be responsible for the wider rings. Forty trees is a reasonable sample (A) and ring width is a fair measure of a year's growth (C).

Q40. B — deliberately varying the water supplied while holding other conditions constant makes it a controlled experiment, which can test whether water itself changes ring width. More trees or a finer ruler improve the existing data but leave the association untested; opinion is not evidence.

Section B — solutions

Q1. (a) Every cell of the plant carries the same genome, but the cells differ in which of those genes are **expressed** — that is, transcribed and then translated. Reading Table 1, the root transcribes genes 3 and 4, the leaf transcribes genes 1 and 3, and the petal transcribes genes 2 and 3, so each tissue is transcribing a different combination. Only the proteins coded by the genes transcribed in a cell are built, so the three tissues end up with different **proteomes** even though their genomes are identical. (1 mark: cells differ in which genes are expressed, not in which genes they carry; 1 mark: the different combinations read correctly from the table; 1 mark: only the expressed genes give rise to protein, so the proteomes differ.)

(b) Gene 3 codes for an enzyme of glycolysis, and **every living cell respire**s, so every tissue needs that enzyme. (1 mark.)

(c) No further mRNA for gene 4 is transcribed, so no new root-hair protein is translated at the ribosomes; the molecules already present are gradually broken down and are not replaced. Gene 2 is now transcribed into mRNA, which is translated at the ribosomes, so the pigment-making enzyme begins to appear and the root cells start to make the red pigment. The cell's **proteome** has therefore changed — it loses one protein and

gains another — although its DNA is unaltered. (1 mark: gene 4's mRNA and protein are no longer made and existing protein is lost; 1 mark: gene 2 is transcribed and its mRNA translated, so its enzyme appears; 1 mark: the proteome changes without any change to the genome.)

Q2. (a) A primer **binds (anneals) only where its base sequence is complementary** to the DNA present. The chosen sequence occurs **only in the target pathogen**, so the primers can bind, and DNA can then be copied, **only if the pathogen's DNA is present** in the sample. The harmless bacteria **lack this sequence**, so their DNA is not amplified — a product is made only when the pathogen is there. (1 mark: primers bind only where complementary; 1 mark: the sequence is unique to the pathogen, so amplification occurs only if the pathogen's DNA is present; 1 mark: other bacteria lack the sequence, so they are not amplified — the test is specific.)

(b) The tube containing **known pathogen DNA is a positive control**: it should give a product, confirming that the reaction and reagents are working (so a negative result on a sample can be trusted). The tube containing **no DNA is a negative control**: it should give no product, showing that there is no contamination that could produce a false positive. (1 mark: positive control — shows the reaction works; 1 mark: negative control — shows there is no contamination / false positive.)

(c) It shows that the **pathogen's DNA is present in that sample** — that plant carries the pathogen. (1 mark.)

Q3. (a) Fraction T carries out the **light-dependent stage**: tube 1 releases oxygen in bright light, but tube 2, which is identical apart from being kept in darkness, releases none — so the reaction taking place in T requires light and gives off oxygen. Fraction S carries out the **light-independent stage (the Calvin cycle)**: sugar is detected only where S is present (tube 4), and never in tubes 1 or 2, which hold T alone. Fraction S on its own releases no oxygen even in bright light (tube 3), so it is not the light-dependent stage. (1 mark: T is the light-dependent stage, with the tube 1 / tube 2 comparison; 1 mark: S is the light-independent stage, with the tube 4 / tube 1 comparison; 1 mark: the tube 3 result rules S out as the oxygen-releasing stage.)

(b) The substance split is **water**. Splitting water requires **light energy absorbed by the pigments of the thylakoid membranes**; in darkness no light energy is absorbed, so no water is split and no oxygen is released. (1 mark: water; 1 mark: the splitting depends on absorbed light energy, which is absent in the dark.)

(c) The two stages are **interdependent**: neither fraction on its own can complete photosynthesis. Sugar is built only when the thylakoid membranes and the surrounding fluid are both present and illuminated, so the products of the light-dependent stage must be passed to the stage that builds sugar. (1 mark: the two stages depend on each other / neither alone is sufficient; 1 mark: the light-dependent stage must supply the sugar-building stage, which is why only tube 4 makes sugar.)

(d) **Rubisco**. (1 mark.)

Q4. (a) Different pathogens are spread by different routes and are controlled in different ways, so the officers cannot choose the right control measures — or identify the host and the mode of transmission — until they know which pathogen is responsible. Knowing whether it is a bacterium or a virus tells them whether an **antibiotic** could help: antibiotics act on bacteria and have no effect on viruses. (1 mark: control measures depend on knowing the pathogen and how it spreads; 1 mark: antibiotics work against a bacterium but not against a virus.)

(b) Any **two** measures, 1 mark for the measure and 1 mark for how it works:

- **treat or boil the water supply, or supply bottled water** — this kills or removes the pathogen, so it is no longer taken in when people drink;
- **keep sewage away from the drinking-water supply (repair or re-site the system)** — this breaks the route by which the pathogen reaches the water in the first place;
- **hand washing after using the toilet and before handling food or drink** — this removes pathogen from the hands, so it is not carried on to food, drink or another person;
- **isolate people who are ill until they have recovered** — an ill person is still shedding the pathogen, so keeping them away from shared water and food prevents further contamination.

(4 marks.)

(c) Any **one**: they had met that pathogen before (or had been vaccinated against it), so memory cells produced a fast secondary response that cleared it before symptoms appeared; **or** they swallowed too small a dose for an

infection to become established; **or** their innate defences (for example stomach acid) destroyed the pathogen. (1 mark.)

Q5. (a) Child 1 would be more troubled. A bacterium multiplying in the tissue fluid is **outside** the body's cells, so it can be reached and bound by the antibodies that circulate in the blood and tissue fluid. Child 1 makes **no antibodies**, so this bacterium is not bound, clumped or marked for the phagocytes and it multiplies far more freely — whereas Child 2's B cells are normal and still produce antibody against it. (1 mark: Child 1; 1 mark: an extracellular bacterium is accessible to antibodies, which is how it is normally dealt with; 1 mark: Child 1 makes none, so it is not cleared, while Child 2's antibody response is intact.)

(b) **Child 2** would be more troubled. Once a virus is **inside** a body cell, antibodies can no longer reach it; the infected cell is dealt with by **cytotoxic T cells**, which recognise the viral antigens displayed on its surface and destroy the cell together with the virus inside it. Child 2 has no functional cytotoxic T cells, so infected cells survive and go on releasing virus — whereas Child 1 still has working cytotoxic T cells. (1 mark: Child 2; 1 mark: an intracellular virus is out of reach of antibody and is dealt with by cytotoxic T cells; 1 mark: Child 2 lacks them, so infected cells are not destroyed, while Child 1's are intact.)

(c) The innate defences act quickly but are **non-specific** — they treat every pathogen in the same general way and are not directed at the particular pathogen present. They also leave **no memory**, so they do not become faster or stronger on a second encounter. Without a working adaptive arm, an infection that the innate response cannot finish off is never cleared efficiently, and the same infections recur. (1 mark: innate defences are non-specific and not targeted; 1 mark: they form no memory and do not improve, so infections are not cleared and recur.)

Q6. (a) Any two (1 mark each): the **foramen magnum** opens underneath the skull rather than towards the back, so the head is balanced on top of an upright spine; the **pelvis** is short and broad (bowl-shaped) rather than long and flat; the **femur angles inwards** from hip to knee, bringing the feet under the body's centre of mass; the **foot is arched** and the big toe lies in line with the others rather than being opposable; the **arms are short relative to the legs**. (2 marks.)

(b) The two long-running trends in hominin evolution — an **increase in brain size** and a **change in limb structure towards habitual upright walking** — are usually met together, so a brain of *Australopithecus* size is expected alongside a more ape-like pelvis and foot. These specimens instead combine a small cranial capacity with *Homo*-like walking anatomy, so they cannot simply be placed at one point along a single line of increasing “advancement”, and it is unclear which known group they belong to. The combination suggests that the change in **limb structure appeared before** the large increase in brain size, rather than the two changing together. (1 mark: the two trends and the expectation that they run together; 1 mark: this specimen mixes them, so it cannot be placed on a simple sequence; 1 mark: upright walking evolved before the large brain.)

(c) Any **two** (1 mark each): a fossil can show that a population existed and what it looked like, but cannot show that it lies on the **direct line of descent** to living people rather than on a side branch that left no descendants; the human fossil record is a classification scheme **open to differing interpretations**, and other researchers may place the same specimens within an already known species; only a few individuals from **one layer at one site** have been recovered, which is far too little evidence to support a claim about the ancestry of everyone alive; the phrase “missing link” wrongly implies a single chain of ancestors, whereas relatedness is **branching**. (2 marks.)

Q7. (a) A transgenic organism is one into whose genome a gene from a **different species** has been inserted. Here the inserted gene came from the **virus**, which is a different species from the crop; an organism in which only one of its **own** genes had been altered or switched off would be genetically modified but not transgenic. (1 mark: transgenic = carries a gene from another species; 1 mark: the gene came from the virus, so this crop qualifies — contrasted with modifying the organism's own gene.)

(b) Virus damage fell from **68% of plants in the conventional line to 3% in the new line**. Mean yield rose from **4.1 kg per plant to 11.6 kg per plant**, close to three times as much. The comparison is fair because both lines were grown **on the same farm, in neighbouring blocks, and given the same water and fertiliser**, so soil, weather and treatment were the same for both and the difference can reasonably be attributed to the inserted gene. (Accept instead: the trial ran over two seasons rather than one.) (1 mark: the damage figures; 1 mark: the yield figures; 1 mark: a valid fair-test feature quoted from the stem.)

(c) Any **three**, 1 mark each (the question and a brief reason together earn the mark):

- **Is the protein made from the inserted gene safe to eat, and could it cause an allergic reaction?** — the crop is eaten by people, and a new protein in a food is the most direct risk to consumers.
- **Can the inserted gene spread in pollen to wild relatives or to other crops, and with what consequence?** — a gene that escapes into wild populations cannot be recalled.
- **Does growing the line affect other organisms, such as the aphids' predators or soil organisms?** — a change to one species in a field can alter the whole community around it.
- **How long will the resistance last, given that the virus can change?** — approval assumes a lasting benefit, and a resistance that fails quickly would not deliver it.
- **How will the transgenic produce be identified and labelled?** — consumers are entitled to know what they are buying.

(3 marks.)

Q8. (a) The mean hind-leg length **increased steadily**, from **18.0 mm at year 0 to 21.0 mm at year 6**. Annual survival **fell from 88% at year 0 to 71% at year 2**, and then **rose again**, to 74% at year 4 and **82% at year 6**, without returning to its year-0 value. (1 mark: leg length increased, 18.0 to 21.0 mm; 1 mark: survival fell, 88% to 71%; 1 mark: survival then recovered to 82% but not to its starting level.)

- (b) The variation in hind-leg length was **already present in the population** before the bird arrived; it had arisen earlier by **mutation** and been passed on through the generations. The bird then acts as a **selection pressure**: longer-legged lizards run faster, escape more often and survive to breed, while shorter-legged lizards are caught more often. The survivors pass their alleles for longer legs to their offspring, so the **frequency of those alleles rises** generation by generation, raising the population's mean hind-leg length. (1 mark: pre-existing variation, ultimately from mutation, not created by the bird; 1 mark: the bird is a selection pressure favouring longer-legged lizards, which survive and reproduce more; 1 mark: the alleles are passed on, so their frequency rises over the generations.)
- (c) When the bird first became established, most of the lizards were poorly equipped to escape a predator the island had never held, so many were caught and annual survival dropped sharply. As the alleles for longer legs became commoner, a larger proportion of each year's population could outrun the bird, so survival recovered — but not to its original level, because the bird is still present and still catching some lizards. (1 mark: survival fell because the population was initially poorly adapted to the new predator; 1 mark: survival recovered as longer legs spread through the population, but stayed below the pre-predator level because the bird remains.)
- (d) A single year's result could be produced by chance, or by some other factor acting in that one year — an unusually dry season, for example. A **consistent trend in the same direction across six years** is much less likely to be a coincidence, so the conclusion that the arrival of the bird caused the change is far better supported. (1 mark: one year could reflect chance or another factor; 1 mark: a consistent multi-year trend makes a coincidence unlikely, so the conclusion is more reliable.)
- (e) A useful further measurement would be the **spread of hind-leg lengths** in the population each year — for example the shortest and longest legs recorded, or the number of lizards in each length class. This would show whether the **whole distribution** had shifted towards longer legs, and whether short-legged lizards were being lost from the population, because a rise in the mean alone could also be produced by a few unusually long-legged individuals. (1 mark: a valid measure of the spread or distribution of leg lengths; 1 mark: it distinguishes a shift of the whole population from a rise in the mean caused by a few extreme individuals.)

Q9. (a) The activity is an example of **modelling** — a physical representation of a system has been built in order to understand how that system works. The notch represents the enzyme's **active site**, the region whose shape is complementary to the substrate. (1 mark: modelling — accept "simulation", since the model is then used to study how the system behaves; 1 mark: the active site.)

(b) Any **two**, 1 mark for the difference and 1 mark for why it matters:

- the cardboard cut-out is **rigid**, whereas a real enzyme is a folded protein whose shape can be changed by heat or by a change in pH — so the model cannot show **denaturation**, which is one of the most important things that happens to a real enzyme;

- the pieces are brought together **by hand**, whereas in a cell an enzyme and its substrate meet by **random collision** — so the model cannot show why the rate of reaction depends on temperature or on the concentration of the reactants;
- the model shows **one** enzyme acting on one substrate molecule at a time, whereas a cell holds vast numbers of both — so it gives no sense of the rate of a real reaction, or of what happens when the substrate runs out;
- the model represents **nothing of the surroundings** — water, pH, or other molecules — so it cannot show inhibition or the effect of conditions on enzyme activity;
- the cut-outs are **two-dimensional**, whereas an enzyme and its substrate are three-dimensional shapes — so the fit between them is far more restrictive in a cell than the model suggests.

(4 marks.)

- (c) The model was **built** to behave in that way: the notch was cut so that only one shape would fit, so the activity can only demonstrate an idea the class already held. How a model behaves is decided by the person who made it, not by nature, so a model can illustrate an explanation but cannot establish that it is true. To establish that a real enzyme is specific, **experimental evidence** is needed — for example measuring whether a purified enzyme catalyses the breakdown of its own substrate but not that of other, similar molecules under the same conditions. (1 mark: the model's behaviour was designed in, so it illustrates rather than tests the idea; 1 mark: experimental evidence on real enzymes and a range of substrates would be required.)

Q10. (a) $240 \div 12 = 20$, so the rate of oxygen use when active is **20 times** the rate when hibernating. Oxygen is a raw material of aerobic respiration, so the rate at which an animal uses oxygen is a measure of its **rate of aerobic cellular respiration** — the hibernating animal is respiring at about one twentieth of its summer rate. (1 mark: 20 times, with the working shown; 1 mark: oxygen consumption measures the rate of aerobic respiration.)

- (b) At a lower temperature the enzyme and substrate molecules carry **less kinetic energy**, so they move more slowly. They therefore **collide less often**, and fewer of the collisions carry enough energy for the substrate to enter the active site and react, so each enzyme forms product more slowly. Every step of glycolysis, the Krebs cycle and the electron transport chain is catalysed by an enzyme, so slowing all of them slows the whole pathway and the rate of respiration falls. (At 5 °C the enzymes are slowed, not denatured — their shape is unaltered.) (1 mark: lower temperature means less kinetic energy and slower movement; 1 mark: fewer and less energetic collisions between enzyme and substrate; 1 mark: every step of respiration is enzyme-catalysed, so the whole pathway slows.)
- (c) A very low rate of respiration means the animal uses up its stored energy reserves — fat and glycogen — very slowly. Its limited reserves therefore last through the whole winter, when it cannot feed, until food is available again in spring. (1 mark: a low rate uses stored reserves slowly; 1 mark: so the limited reserves last through the winter.)
- (d) Shivering is repeated rapid contraction of the muscles, and muscle contraction requires **ATP**, which the muscle cells must supply by greatly increasing their rate of cellular respiration. Respiration does not transfer all of the energy held in glucose to ATP: much of it is released as **heat**. A high rate of respiration in the shivering muscles therefore warms the body, raising the body temperature back towards its active level. (1 mark: shivering means muscle contraction, which demands ATP and so raises the rate of respiration; 1 mark: respiration releases heat as well as ATP, and that heat warms the animal.)

Exam 6 — Practice examination

Reading time: 15 minutes. Writing time: 2 hours 30 minutes. Section A: 40 questions, 40 marks. Section B: 10 questions, 80 marks. Total 120 marks. This examination covers Units 3 and 4. Answer all questions.

- No calculator may be used.
- No formula sheet, data sheet, dictionary or notes may be used.
- Diagrams in this examination are not drawn to scale.

Section A — Multiple choice

Every question in this section must be attempted. Select the response that is correct or that best answers the question. One mark is awarded for each correct response, and nothing is taken away where a response is wrong. Where two or more responses have been completed for the same question, no mark is awarded for it. No diagram in this section is drawn to scale.

Question 1

The role of transfer RNA (tRNA) during translation is to

- A. carry the coded message of a gene from the nucleus to the ribosome.
- B. form part of the structure of the ribosome itself.
- C. remove the introns from a pre-mRNA molecule.
- D. carry a specific amino acid to the ribosome and match it, through its anticodon, to a codon on the mRNA.

Question 2

During translation, a particular codon on a messenger RNA molecule reads 5'–GCA–3'. The anticodon of the transfer RNA that pairs with this codon reads

- A. 5'–CGU–3'
- B. 5'–GCU–3'
- C. 5'–UGC–3'
- D. 5'–TGC–3'

Question 3

In a bacterium, a mutation alters the repressor protein of the *trp* operon so that it can no longer bind a molecule of tryptophan, although the rest of the protein is unchanged. This mutant bacterium is grown in a medium already rich in tryptophan. Compared with a normal bacterium grown in the same medium, the mutant will

- A. make no repressor protein at all.
- B. go on making the enzymes that build tryptophan, wastefully, instead of switching them off.
- C. break down the tryptophan supplied in the medium.
- D. stop making the enzymes that build tryptophan, as a normal bacterium does.

Question 4

Two fragments of DNA have been brought together so that their cut ends are paired. The enzyme that then seals the sugar–phosphate backbones to join them into a single continuous molecule is

- A. a restriction endonuclease.
- B. DNA polymerase.
- C. the Cas9 protein.
- D. DNA ligase.

Question 5

A substitution changes the first codon of an mRNA's coding region from AUG to AUC. The most likely consequence is that

- A. the ribosome will not begin translation at that point, so the normal polypeptide will not be made.
- B. a polypeptide identical to the normal one will be made, because the change is in only one base.
- C. the polypeptide made will be one amino acid shorter than the normal one.
- D. the polypeptide made will carry one different amino acid at its start.

Question 6

The best description of the proteome of a human liver cell is

- A. the complete set of genes carried in the cell's nucleus.
- B. the order of the amino acids in one of the cell's proteins.
- C. the complete set of mRNA molecules the cell is ever able to make.
- D. the complete set of proteins that the cell expresses.

Question 7

In a cell respiring aerobically, the Krebs cycle takes place in the

- A. cytosol.
- B. inner membrane of the mitochondrion.
- C. matrix of the mitochondrion.
- D. ribosomes.

Question 8

When a human muscle cell is deprived of oxygen, the amount of ATP it can obtain from each molecule of glucose falls sharply. This is because, without oxygen,

- A. only glycolysis can continue, and it yields a net of just two ATP per glucose.
- B. glycolysis can no longer take place.
- C. glucose can no longer enter the cell.
- D. the cell stops making ATP altogether.

Question 9

In the light-independent stage (the Calvin cycle) of photosynthesis, the enzyme Rubisco

- A. absorbs the light energy used in photosynthesis.
- B. splits water molecules, releasing oxygen.
- C. joins glucose molecules together to form starch.
- D. attaches carbon dioxide to an acceptor molecule already in the cycle — the first step in building sugar.

Use the following information to answer Questions 10 and 11.

The rate of photosynthesis of a water plant was measured at each of five carbon dioxide concentrations. The light supplied was bright and was held constant, and the water was held at 25 °C. The measurements were then repeated with everything the same except that the water was held at 30 °C.

Carbon dioxide concentration (arbitrary units)	Rate at 25 °C (arbitrary units)	Rate at 30 °C (arbitrary units)
1	8	8
2	15	16
4	25	29
8	33	41
16	34	44

Question 10

At every carbon dioxide concentration above 1 unit, the rate measured at 30 °C is higher than the rate measured at 25 °C. The most likely reason is that, between 25 °C and 30 °C,

- A. the plant absorbs more light at the higher temperature.
- B. carbon dioxide dissolves more readily in the warmer water.
- C. the enzymes that catalyse the reactions of photosynthesis work faster at the higher temperature.
- D. the plant's rate of cellular respiration falls at the higher temperature.

Question 11

Raising the temperature to 30 °C left the rate almost unchanged at 1 unit of carbon dioxide but raised it from 34 to 44 units at 16 units of carbon dioxide. Taken together, these two results are best explained by the fact that

- A. temperature has no effect on the reactions of photosynthesis.
- B. carbon dioxide is not a raw material of photosynthesis.
- C. the plant respire faster at 30 °C, and so photosynthesises more slowly.
- D. at 1 unit the rate is held back by the shortage of carbon dioxide, so relieving a different limiting factor cannot help.

Question 12

Photosynthesis and aerobic cellular respiration are linked, because the main products of one are the raw materials of the other. The products of photosynthesis that a cell then uses in aerobic respiration are

- A. carbon dioxide and water.
- B. ATP and NADPH.
- C. glucose and oxygen.
- D. starch and chlorophyll.

Use the following information to answer Questions 13 and 14.

Two substances, J and K, each slow the same enzyme. The initial rate of the reaction was measured over a range of substrate concentrations: first with no inhibitor, then with a fixed amount of substance J added, and then with a fixed amount of substance K added. The same amount of enzyme was used throughout, and the pH and the temperature were held constant.

Substrate concentration (arbitrary units)	Initial rate, no inhibitor	Initial rate, with J	Initial rate, with K
1	10	3	5
2	18	6	9
5	30	16	15
10	36	30	18
20	38	37	19

Question 13

As the substrate concentration is raised, the rate with substance J present climbs back towards the rate with no inhibitor, reaching 37 against 38 at the highest concentration. This pattern indicates that substance J

- A. binds in the active site itself, so that plenty of substrate can outcompete it.
- B. has been broken down by the enzyme during the reaction.
- C. binds away from the active site and permanently alters its shape.
- D. raises the enzyme's optimum pH.

Question 14

However much substrate is supplied, the rate with substance K present never rises above about 19 — roughly half the rate reached without an inhibitor. The best explanation is that substance K

- A. competes with the substrate for the active site.
- B. has used up all of the substrate before the rate could be measured.
- C. binds at a site other than the active site and changes the shape of the active site, so extra substrate cannot overcome its effect.
- D. has denatured every molecule of the enzyme in the tube.

Question 15

A circular plasmid carries a single site at which a particular restriction endonuclease cuts. A researcher treats a sample of the plasmid with that enzyme and then, without adding any other DNA, adds DNA ligase. The product most likely to form is

- A. two linear fragments of equal length.
- B. a plasmid carrying a second copy of every gene it already had.
- C. a plasmid whose two strands have been separated from each other.
- D. the same circular plasmid, re-sealed at the cut.

Question 16

In a test tube, ribosomes taken from a bacterium are supplied with a mature human mRNA molecule, together with all of the transfer RNAs, amino acids and other factors that translation requires. The polypeptide that the bacterial ribosomes assemble will be

- A. a polypeptide with an entirely different sequence of amino acids.
- B. built from a set of amino acids that human cells never use.
- C. the same polypeptide that human ribosomes would assemble from that mRNA.
- D. no polypeptide at all, because a bacterial ribosome cannot bind a human mRNA.

Question 17

In the expression of a protein-coding gene in a eukaryotic cell, the correct order of the two main processes is

- A. translation, then transcription.
- B. transcription, then translation.
- C. replication, then translation.
- D. transcription, then replication.

Question 18

A cell is treated with a drug that prevents newly made polypeptides from folding into their normal three-dimensional shapes. The polypeptides are still assembled with their normal sequences of amino acids. The immediate consequence for the cell is that the newly made proteins will

- A. carry the wrong sequence of amino acids.
- B. be assembled at the wrong ribosomes.
- C. work normally, because a protein's function depends only on its sequence of amino acids.
- D. be unable to carry out their normal functions.

Question 19

A bacterium and a virus are both infecting the same tissue. Both carry nucleic acid, and both display surface molecules that the person's immune system can recognise. Unlike the bacterium, the virus

- A. can be passed from one person to another.
- B. has no ribosomes or metabolism of its own, so it can make copies of itself only by using the machinery of a host cell.
- C. is able to make a person unwell.
- D. carries no nucleic acid of its own once it is inside a cell.

Question 20

A macrophage at the site of a wound takes in and breaks down invading bacteria. This defence belongs to the

- A. first line of defence (the physical and chemical barriers).
- B. second line of defence (the innate, non-specific response).
- C. third line of defence (the adaptive, specific response).
- D. lymphatic circulation, which plays no part in defence.

Question 21

A cell in the skin takes up material from an invading bacterium, then travels along the lymphatic vessels to a lymph node, where it displays fragments of that material to the lymphocytes gathered there. The cell described is

- A. a plasma cell, which secretes antibody into the lymph.
- B. a memory B cell left behind by an earlier infection.
- C. a dendritic cell, which belongs to the innate response and sets the adaptive response going.
- D. a cytotoxic T cell on its way to find infected cells.

Question 22

A protein found in house-dust-mite droppings is harmless to most people, but in some people it provokes a rapid and exaggerated immune response. In those people this protein is acting as

- A. an allergen.
- B. a self-antigen made by the person's own cells.
- C. an antibody.
- D. an interferon.

Question 23

When a B lymphocyte whose receptor matches a pathogen's antigen binds that antigen and is then triggered to divide many times, producing a large number of identical cells directed against the same antigen, this process is called

- A. clonal selection and expansion.
- B. phagocytosis.
- C. antigen presentation.
- D. passive immunity.

Use the following information to answer Questions 24, 25 and 26.

A fungus attacks the leaves of a crop of a native shrub. Plants have no adaptive immune system and make no antibodies. A plant cell that is attacked can nevertheless respond: it thickens its own cell wall at the point of attack, and it releases into the surrounding tissue substances that are toxic to the fungus. The fungus spreads through the crop when infected leaves release spores that are carried on the wind.

Question 24

The toxic substances released by an attacked plant cell are best described as

- A. antibodies raised against this particular fungus.
- B. part of the plant's adaptive immune response.
- C. a chemical defence, effective against a range of attackers.
- D. memory molecules that will act faster if the fungus returns.

Question 25

A shrub that survives an attack by this fungus is no better protected against a second attack by the same fungus a year later. This is because the plant

- A. breaks down its own memory cells once an attack is over.
- B. makes antibodies but has no way of storing them.
- C. is protected instead by antibodies carried in its sap.
- D. has no adaptive immune response, so it forms neither memory cells nor antibodies specific to the fungus.

Question 26

Of the following, the measure most likely to slow the spread of this disease through the crop is

- A. removing and destroying infected plants before their leaves release spores.
- B. watering the crop more often.
- C. leaving fallen infected leaves on the ground beneath the plants.
- D. planting the crop more densely, so that healthy plants shield the infected ones.

Question 27

A scientist studies a population of wild birds by observing and recording what they do in their natural habitat, without altering anything. This type of investigation is best described as

- A. a controlled experiment.
- B. fieldwork (an observational study).
- C. a simulation.
- D. a literature review.

Question 28

In an autoimmune disease, the immune system

- A. attacks the body's own cells, treating their self-antigens as though they were non-self.
- B. fails to respond to any antigen at all.
- C. responds only to non-self antigens, exactly as it normally should.
- D. is unable to produce any antibodies.

Question 29

Natural selection acts on the variation already present in a population, but it cannot create new alleles. The ultimate source of the new alleles on which selection acts is

- A. natural selection itself.
- B. mutation.
- C. gene flow between populations.
- D. genetic drift.

Question 30

A strain of a bacterium that causes a human infection is now resistant to the antibiotic that was once used to treat it. The most direct consequence of this resistance for the treatment of people infected by this strain is that

- A. the strain can no longer be passed from one person to another.
- B. the infection must now be treated with a different antibiotic, if one that still works can be found.
- C. the person's own immune system can no longer recognise the strain.
- D. the strain has become able to infect a wider range of host species.

Question 31

Speciation requires both isolation and genetic divergence. The part played by isolation is that it

- A. creates the new alleles on which natural selection then acts.
- B. guarantees that the two populations will meet identical selection pressures.
- C. keeps the two populations from exchanging alleles, so that changes arising in one are not shared with the other.
- D. lowers the rate at which mutations occur in both populations.

Question 32

Long-running selective breeding programs leave a crop carrying far fewer different alleles than the population it was bred from. Plant breeders therefore maintain seed banks holding seed of old varieties and of the crop's wild relatives. The chief biological reason for maintaining these seed banks is to

- A. raise the rate at which useful new mutations arise in the modern crop.
- B. make sure that the old varieties can never be grown commercially again.
- C. prevent the modern crop from being affected by natural selection.
- D. keep available the alleles the modern crop no longer carries, so that they can be bred back in if a new pest, disease or climate makes them valuable.

Question 33

Two populations of a native fish were separated when a barrier divided a lake into two. After a very long period apart the barrier was removed. The two populations differ markedly in colour and in body shape, but where they now meet they breed together freely and their offspring are fertile. The two populations are best regarded as

- A. two separate species, because they differ markedly in appearance.
- B. two separate species, because they were kept apart for so long.
- C. one species, because they interbreed and produce fertile offspring.
- D. impossible to classify, because appearance and breeding give opposite answers.

Question 34

In the light-dependent stage of photosynthesis, the coenzyme NADP^+ is

- A. broken down to release carbon dioxide.
- B. reduced to NADPH, which then carries electrons and hydrogen to the Calvin cycle.
- C. used as the final acceptor of electrons, forming water.
- D. joined to glucose to store energy.

Question 35

The particular order of the amino acids along a polypeptide chain is known as the protein's

- A. secondary structure.
- B. primary structure.
- C. tertiary structure.
- D. quaternary structure.

Question 36

Two species of native beetle that look very alike are found to differ at 240 positions in the same protein. Two other beetle species, which look quite unlike each other, differ at only 12 positions in that same protein. Taken together, these results show that

- A. how alike two species look is not a reliable guide to how closely they are related.
- B. the pair that look alike are the more closely related, because appearance is the better guide.
- C. a protein changes more slowly in two species that look alike than in two that do not.
- D. the number of sequence differences cannot be compared between different pairs of species.

Use the following information to answer Questions 37 and 38.

Undisturbed sequences of sedimentary rock are exposed at three sites, hundreds of kilometres apart. Fossils of four extinct marine species — P, Q, R and S — occur in them. At every site at which two of these species are found, they occur in the same order from the deepest layer upwards: P below Q, Q below R, and R below S. No other order is found at any site.

Question 37

The most reasonable conclusion to draw from this repeated order is that the four species

- A. all lived at the same time, and have been sorted by the weight of their shells.
- B. each gave rise directly to the one lying above it.
- C. cannot be compared between sites, because the sites are far apart.
- D. existed one after another in time, in the order P, Q, R, S.

Question 38

A layer at a fourth site contains fossils of species R and of none of the other three. Using the fossil evidence alone, a geologist can establish

- A. the age of this layer in millions of years.
- B. where this layer falls in the sequence of the four species, but not its age in years.
- C. that this layer is the oldest layer at the fourth site.
- D. that species R first appeared at the fourth site and spread from there to the others.

Question 39

An investigator takes the same measurement many times and calculates the mean of the readings. This procedure mainly reduces

- A. the effect of random error on the mean.
- B. the effect of a systematic error in the instrument.
- C. the risk that the method does not measure what it is intended to measure.
- D. the number of variables that must be held constant.

Question 40

A research team plans a study using live animals, and designs the procedure so that the animals share fairly in any benefit the work brings and that no group of animals is made to bear an unfair share of the harm. This concern most directly reflects the bioethical concept of

- A. justice.
- B. beneficence.
- C. integrity.
- D. non-maleficence.

End of Section A

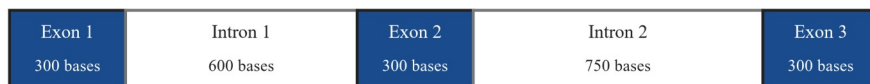
Section B — Short answer

Every question in this section must be attempted, in the spaces provided. For any question carrying two or more marks, a response earns full credit only if it reaches the depth that its command term and its mark allocation call for. No diagram in this section is drawn to scale.

Question 1 (8 marks)

To manufacture a human protein in bacteria, a copy of the human gene is joined into a bacterial plasmid. The copy that is inserted contains only the coding regions of the gene — its non-coding regions have been left out. The diagram shows the structure of the original human gene and of the copy that is inserted into the plasmid.

The human gene



The intron-free copy that is inserted into the plasmid



= exon = intron

- a. Using the diagram, state the number of bases in the copy that is inserted into the plasmid, and state how many bases of the human gene are left out of that copy. 2 marks
- b. Name the process, carried out in the nucleus of a human cell, by which the RNA first transcribed from the complete human gene is converted into the mature mRNA that the cell translates. 1 mark
- c. A bacterium cannot carry out that process. Predict the length, in bases, of the RNA that a bacterium would transcribe from a plasmid carrying the complete human gene, and explain why the protein the bacterium then made from that RNA would not be the human protein, whereas the protein made from the inserted copy is. 4 marks
- d. The inserted copy is joined into the plasmid, but the bacterium still transcribes nothing from it. State what must be added to the plasmid, immediately in front of the inserted copy, before the bacterium's RNA polymerase can transcribe it. 1 mark

Question 2 (7 marks)

A plasma cell, formed from an activated B lymphocyte, secretes many thousands of antibody molecules each second. Antibodies are proteins. The same plasma cell also makes enzymes that work within its own cytosol and are never exported from the cell.

- a. State where in the cell the antibody (a secreted protein) is assembled, and where the cytosolic enzymes are assembled. Explain what determines whether a particular protein is made on the rough endoplasmic reticulum or on free ribosomes. 3 marks
- b. A plasma cell has a very extensive rough endoplasmic reticulum and Golgi apparatus. Describe what the Golgi apparatus does to a protein as it passes through the secretory pathway, and explain why a plasma cell needs so much of both. 2 marks
- c. A drug is applied that blocks the Golgi apparatus of a plasma cell. Predict the effect on the cell's release of antibody, and explain your prediction. 2 marks

Question 3 (8 marks)

In a respiring cell, the coenzyme NAD^+ acts as a carrier: it picks up electrons and hydrogen (becoming NADH) and later releases them again, which regenerates NAD^+ for re-use. A newly discovered substance, referred to here as substance G, locks the coenzyme in its loaded NADH form, so that it can no longer be converted back to NAD^+ .

- a. Using the idea of a carrier that must be re-used, explain why a continuous supply of the empty carrier NAD^+ is needed for glycolysis and the Krebs cycle to keep operating. 2 marks
- b. Predict the effect of substance G on the amount of ATP the cell can produce, and explain your prediction, naming the stages of respiration that would stop. 3 marks
- c. Under normal aerobic conditions, name what regenerates NAD^+ from NADH and state the role of oxygen in this. Then explain why, in a cell with no oxygen, a different process is needed to regenerate NAD^+ so that a small amount of ATP can still be made. 3 marks

Question 4 (6 marks)

A brightly illuminated water plant was suddenly placed in darkness. The rate at which the plant fixed carbon dioxide into sugar did not fall to zero the instant the light went out: it continued at close to its former rate for a few seconds, then fell rapidly away to almost nothing. The enzymes that catalyse the light-independent stage (the Calvin cycle) are not themselves switched off by darkness, and none of them was damaged during the experiment.

- a. Name the two substances that the light-dependent stage supplies to the Calvin cycle, and state where in the chloroplast the light-dependent stage takes place. 2 marks
- b. Explain why carbon fixation continued for a few seconds after the light went out, and why it then stopped, even though the Calvin cycle's own enzymes were undamaged and carbon dioxide was still available. 3 marks
- c. The light is switched back on and carbon fixation returns to its former rate within a few seconds, without the plant having to make any new enzymes. State why no new enzymes are needed. 1 mark

Question 5 (8 marks)

Two people, referred to here as person 1 and person 2, were exposed to the same bacterium on the same day. Person 1 had recovered from an infection by this bacterium five years earlier; person 2 had never encountered it. Blood samples were taken from both people over the fortnight that followed.

Measurement	Person 1	Person 2
Days after exposure at which antibody against the bacterium was first detected in the blood	2	9
Highest concentration of that antibody reached (arbitrary units)	90	12
Days for which the person was unwell	0	6

- a. Explain, in terms of the cells of the adaptive immune response, why antibody appeared so much sooner, and reached so much higher a concentration, in person 1 than in person 2. 3 marks
- b. Using the data in the table, explain why person 2 was unwell for six days while person 1 was not unwell at all. 2 marks
- c. Six months later both people are exposed to a **different** species of bacterium, which neither of them has met before. For each person, predict whether their antibody response to this second bacterium will resemble person 1's response or person 2's response in the table, and explain your prediction. 3 marks

Question 6 (8 marks)

A fungal disease is spreading through a population of a native frog that has never encountered it before. The fungus grows on the frog's skin and kills most of the frogs it infects.

- a. Fungi are living cells. State whether the fungus is a cellular or a non-cellular pathogen, and explain why treating the disease with an antibiotic would be unlikely to help. 2 marks
- b. A small number of frogs survive the disease and breed. Explain, using the ideas of variation and natural selection, how the frog population could become more resistant to the fungus over the following generations. 3 marks
- c. A different frog population had already lost most of its genetic diversity in an earlier population crash. Explain why this population would be much less likely to recover in the same way, and state what this shows about the importance of genetic diversity to a species. 3 marks

Question 7 (13 marks)

Four species of native freshwater turtle — species W, X, Y and Z — were compared. The same short region of the same gene was sequenced in all four species, and the corresponding region of the protein that the gene codes for was

compared as well. The table gives, for each of the other three species, the number of positions at which it differs from species W.

Compared with species W	DNA base differences	Amino-acid differences
species X	6	1
species Y	24	9
species Z	41	17

Two further observations were recorded.

- The shell of species W and the shell of species X are built from the same set of bony plates, fused together in the same arrangement, although species X lives in fast-flowing water and species W in still water.
- Buried within each hind limb of species Y is a row of tiny bones, lying in the position occupied by the toe bones of turtles that walk on land. They bear no claws, carry no muscle used in swimming and take no part in the animal's movement.

a. Name the type of structure that the shells of species W and species X are, and the type of structure that the small bones in the hind limbs of species Y are. State what each of the two types of structure indicates. 3 marks

b. Species Y differs from species W at 24 DNA positions and species Z at 41. Explain what this tells you about when species W last shared a common ancestor with each of them, and state the assumption about the way sequences change on which that reasoning depends. 3 marks

c. For every species the number of amino-acid differences from species W is much smaller than the number of DNA base differences. Explain why, and state which of the two measures would be the more useful for comparing two species that separated from each other only very recently. 3 marks

d. Ten years later the same four species were compared again, this time using their whole genomes rather than this one short region, and the new comparison placed species Y closer to species X than to species W. Explain why a conclusion about relatedness can change in this way, and why the whole-genome comparison is the more reliable of the two. Then state one thing about these turtles that no sequence comparison, on its own, can establish. 4 marks

Question 8 (6 marks)

Researchers test whether a new soil treatment increases the yield of a food crop. They run a controlled field experiment, applying the treatment to some plots and leaving others untreated, and later publish their findings. (Adapted from Okafor & Lindqvist, 2024.)

a. For this experiment, state the independent variable and the dependent variable. 2 marks

b. The treatment is expensive, and only wealthy growers will be able to afford it. One member of the team argues that the work should proceed anyway, because the total extra food produced across the district would far outweigh that drawback. Name the approach to bioethics on which that argument rests, and state one weakness of judging the proposal in that way. 2 marks

c. During the analysis, one researcher is tempted to leave out the results from the plots where the treatment worked poorly, so that the treatment looks better than it is. Name the bioethical concept this would breach, and explain how keeping a complete, dated logbook of all results guards against it. 2 marks

Question 9 (8 marks)

A student investigated whether the leaves of a native shrub growing in full sun are thicker than the leaves of the same species growing in deep shade. Twenty leaves were taken from each of ten plants at each of the two sites, and the thickness of every leaf was measured. The mean leaf thickness was 0.42 mm in full sun and 0.27 mm in deep shade. The student is now preparing a scientific poster.

a. The central panel of a scientific poster carries a short statement communicating the investigation's key finding. Using the results above, write a statement suitable for that panel, and state why a poster carries such a statement. 2 marks

- b.** In preparing the poster the student used a published journal article, was given access to the sites by the landholder, and had the measuring instrument calibrated by a laboratory technician. Distinguish between the references section and the acknowledgements section of a poster, and state in which of the two each of these three belongs. 3 marks
- c.** The Results section of the poster reads: “Mean leaf thickness in full sun was 0.42MM and in deep shade .27 mm.” State two conventions of science communication that have been broken in this sentence, and write the sentence correctly. 3 marks

Question 10 (8 marks)

A small native wildflower grows both on the waste rock left behind by a copper mine, where the soil carries a high concentration of copper, and on the pasture surrounding the mine, where the copper concentration is normal. The mine closed about 60 years ago, and the bare waste rock was colonised by seed blown in from the surrounding pasture. Seed was collected from each population and raised in a glasshouse. Each seedling’s roots were grown first in a normal solution and then in a solution containing copper, and a *tolerance index* was calculated for it: its root growth in the copper solution as a percentage of its root growth in the normal solution. A high index means the plant tolerates copper well. (Adapted from Halloran & Vasquez, 2025.)

Population the seed came from	Mean tolerance index (%)	Range of individual indices (%)
mine waste rock	78	61–92
surrounding pasture	9	2–34

- a.** Using the data, state what the tolerance index shows about the two populations, and identify the feature of the pasture data that shows copper tolerance is not entirely absent from the pasture population. 2 marks
- b.** On normal soil, copper-tolerant plants of this species grow more slowly and set less seed than non-tolerant plants. Insects carry pollen from the mine population to the pasture population every year, yet the pasture population has remained almost entirely non-tolerant. Explain why. 3 marks
- c.** Part of the waste rock has now been covered with a thick layer of clean topsoil, so that the plants rooted in it are no longer exposed to a high copper concentration. Predict what will happen to the frequency of the copper-tolerance alleles among the plants growing on that part of the site over the decades that follow, and explain your prediction. 3 marks

End of Section B

End of examination questions

Exam 6 — Answers and solutions

Section A — answers

Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	D	11	D	21	C	31	C
2	C	12	C	22	A	32	D
3	B	13	A	23	A	33	C
4	D	14	C	24	C	34	B
5	A	15	D	25	D	35	B
6	D	16	C	26	A	36	A
7	C	17	B	27	B	37	D
8	A	18	D	28	A	38	B
9	D	19	B	29	B	39	A
10	C	20	B	30	B	40	A

Q1. D — a tRNA carries a specific amino acid to the ribosome and, through its anticodon, matches it to the codon; carrying a gene's message is the role of mRNA, and forming the ribosome the role of rRNA.

Q2. C — the anticodon is antiparallel and complementary to the codon, so 5'-GCA-3' pairs with 3'-CGU-5', written 5'-UGC-3'; the others have the wrong direction, are not reversed, or use the DNA base thymine.

Q3. B — the *trp* repressor can bind the operator only after a molecule of tryptophan has bound to it, so a repressor that cannot bind tryptophan can never switch the operon off; the mutant keeps transcribing the structural genes and goes on making the tryptophan-building enzymes even in a medium already rich in tryptophan.

Q4. D — DNA ligase seals the sugar-phosphate backbones to join the two fragments; a restriction endonuclease cuts, DNA polymerase extends a strand, and Cas9 makes a guided cut.

Q5. A — AUG is the start codon at which the ribosome begins translation. With it changed to AUC there is no start signal at that point, so the normal polypeptide is not assembled at all; the change is not a simple swap of one amino acid for another, and nothing shortens the chain by one residue.

Q6. D — the proteome is the complete set of proteins a cell expresses; the complete set of genes is the genome, the set of mRNA molecules is the transcriptome, and the order of amino acids in one protein is that protein's primary structure.

Q7. C — the Krebs cycle takes place in the matrix of the mitochondrion; glycolysis is in the cytosol and the electron transport chain on the inner mitochondrial membrane.

Q8. A — without oxygen only glycolysis can operate, giving a net of just two ATP per glucose, so the yield falls sharply; glycolysis still runs, glucose still enters, and some ATP is still made.

Q9. D — Rubisco catalyses carbon fixation: it attaches a molecule of carbon dioxide to an acceptor molecule already turning in the Calvin cycle, and the sugar is built from what that reaction produces. Light is absorbed by chlorophyll, water is split in the light-dependent stage, and glucose is joined into starch by other enzymes altogether.

Q10. C — the reactions of photosynthesis are catalysed by enzymes, and the plant is evidently still below the optimum temperature of those enzymes, since warming the water raises the rate rather than lowering it: at 30 °C the molecules move faster, enzyme and substrate meet more often, and the rate climbs. Temperature does not change how much light a plant absorbs (A); carbon dioxide is in fact less soluble in warmer water, and here its concentration is set by the investigator in any case (B); and respiration speeds up as the temperature rises rather than slowing down (D).

Q11. D — at 1 unit of carbon dioxide it is the shortage of carbon dioxide that sets the rate, so relieving a different limiting factor changes nothing; at 16 units carbon dioxide is plentiful and temperature is limiting, so raising it lifts the rate. Faster respiration could not raise net fixation.

Q12. C — the products of photosynthesis are glucose and oxygen, and these are exactly the raw materials a cell uses in aerobic respiration; carbon dioxide and water are the products of respiration, the ATP and NADPH of the light-dependent stage are spent inside the chloroplast, and chlorophyll is not a product.

Q13. A — an inhibitor whose effect is progressively overcome by adding more substrate is competing with the substrate for the active site: at 20 units the rate with J (37) has almost caught the uninhibited rate (38). An inhibitor binding away from the active site could not be outcompeted in this way.

Q14. C — substance K caps the rate at about half the uninhibited maximum however much substrate is supplied, which is what happens when an inhibitor binds elsewhere on the enzyme and alters the shape of the active site; extra substrate cannot displace it, and enzyme that had been denatured would give no reaction at all.

Q15. D — the enzyme cuts the circle at its one site, giving a single linear molecule whose two ends match each other. With no other DNA present, ligase simply seals those ends back together and the original circular plasmid is restored.

Q16. C — the genetic code is essentially the same in all organisms and the same twenty amino acids are used, so a bacterial ribosome reads each human codon as the same amino acid and assembles the same polypeptide; a mature mRNA needs no further processing before it is translated.

Q17. B — a gene is first transcribed into mRNA and the mRNA is then translated into protein, so the order is transcription then translation.

Q18. D — a protein's function depends on its three-dimensional shape, so polypeptides prevented from folding correctly cannot do their jobs, even though their amino-acid sequences and their ribosomes are normal.

Q19. B — a virus is not built of cells: it has no ribosomes, no enzymes and no metabolism of its own, so new virus particles can be assembled only by the machinery of a host cell. Both pathogens spread from person to person, both cause disease, and a virus keeps its nucleic acid inside the host cell.

Q20. B — a macrophage engulfing and digesting bacteria (phagocytosis) is part of the second (innate) line of defence; the barriers are the first line, and antibodies and memory cells the third.

Q21. C — a dendritic cell takes up antigen in the tissues, travels in the lymph to a lymph node and presents the antigen there; it belongs to the innate response but sets the adaptive response going. Plasma cells secrete antibody, memory B cells are the product of an earlier response, and cytotoxic T cells kill infected cells.

Q22. A — a normally harmless substance that provokes an exaggerated immune response in some people is an allergen; it is not a self-antigen, an antibody or an interferon.

Q23. A — the selection of the B cell whose receptor matches the antigen, and its division into many identical cells, is clonal selection and expansion; it is not phagocytosis, antigen presentation or passive immunity.

Q24. C — substances released to poison an attacker are a chemical defence, and like the plant's other defences they act against a range of attackers rather than one. Plants make no antibodies and have no adaptive response, so nothing here is specific to this fungus or stored as memory.

Q25. D — plants have no adaptive immune system, so neither memory cells nor antibodies specific to the fungus are formed, and a second attack meets exactly the defences the first one met. The plant does not make antibodies at all, so it has none to store or to carry in its sap.

Q26. A — the disease spreads by wind-borne spores released from infected leaves, so removing and destroying infected plants before the spores are shed cuts the supply of spores. Leaving infected leaves beneath the plants, or crowding the crop, would help the fungus spread; watering is irrelevant to it.

Q27. B — observing and recording wild birds in their habitat without altering anything is fieldwork (an observational study), not a controlled experiment, a simulation or a literature review.

Q28. A — in an autoimmune disease self-tolerance breaks down and the immune system attacks the body's own cells, treating their self-antigens as though they were non-self.

Q29. B — mutation is the ultimate source of new alleles; natural selection, gene flow and genetic drift only change the frequencies of alleles that already exist.

Q30. B — a resistant strain is no longer killed or held in check by that antibiotic, so the drug has ceased to be a treatment option and a different one that still works must be found; as resistance spreads, the choice of effective drugs narrows and infections become slower and harder to treat. Resistance to a drug does not change how a bacterium passes between people (A), how the immune system recognises it (C), or which hosts it is able to infect (D).

Q31. C — isolation stops the two populations from exchanging alleles, so that the changes mutation, selection and drift produce in one are not shared with the other and the two gene pools can diverge. New alleles come from mutation, and isolation makes the two environments less alike, not more.

Q32. D — long-running selection leaves the crop carrying only a fraction of the alleles its wild relatives hold; a seed bank keeps the rest available, so an allele can be bred back into the crop when a new pest, disease or climate makes it valuable. Storing seed does not alter mutation rates.

Q33. C — the test of a biological species is whether two populations interbreed to produce fertile offspring. These do, so despite the long separation and the marked difference in colour and body shape they remain one species; a difference in appearance is variation within a species.

Q34. B — in the light-dependent stage NADP^+ is reduced to NADPH, which carries electrons and hydrogen to the Calvin cycle; it is not broken down to release carbon dioxide, nor the final acceptor forming water.

Q35. B — the order of the amino acids along a polypeptide chain is its primary structure; the secondary, tertiary and quaternary levels describe its folding and its assembly from subunits.

Q36. A — the two kinds of evidence point opposite ways: the pair that look alike differ at 240 positions, while the pair that look quite unlike differ at only 12. Outward resemblance therefore cannot be relied on as a guide to relatedness, which is why B, which prefers appearance, is wrong. Nothing in the data supports the invented rule in C, and comparing the number of differences between one pair of species and another is precisely what sequence evidence is used for (D).

Q37. D — finding the same order at site after site shows that the four species followed one another in time, P first and S last: this is faunal succession. It does not show that any species gave rise directly to the next, and it is precisely what makes layers at widely separated sites comparable.

Q38. B — species R places the layer within the interval in which species R lived, and so at a known point in the sequence the other sites establish; that is a relative age. Fossil evidence on its own never yields an age in years (A) — for that, a suitable rock within the sequence must be dated radiometrically. Nothing here shows the layer to be the oldest at its site (C), and the presence of a fossil says nothing about where the species first appeared or how it spread (D).

Q39. A — the scatter of random error falls on both sides of the true value, so averaging many repeated readings lets it largely cancel and brings the mean closer to the true value. A systematic error pushes every reading the same way and survives averaging untouched (B); repeating a measurement says nothing about whether the method measures what it is meant to measure (C); and it does not alter which variables have to be held constant (D).

Q40. A — the concern is the fair distribution of the benefits and the harms, which is the bioethical concept of justice; non-maleficence is minimising harm, beneficence is doing good, and integrity is honesty in the work.

Section B — solutions

Q1. (a) The inserted copy is made up of the three exons: $300 + 300 + 300 = 900$ bases. What is left out is the two introns: $600 + 750 = 1350$ bases. (1 mark: 900 bases; 1 mark: 1350 bases.)

(b) **RNA splicing** — the removal of the introns and the joining of the exons during RNA processing. (1 mark.)

(c) A bacterium transcribes the DNA it is given from end to end, so from the complete human gene it would produce an RNA **2250 bases** long ($900 + 1350$) — every exon and every intron. Because the bacterium cannot splice, **the introns would remain in that RNA**. At the ribosome the intron bases would be read as extra codons, almost certainly shifting the reading frame or bringing in a premature stop codon, so the polypeptide assembled would carry a **wrong sequence of amino acids and be non-functional** — not the human protein. The inserted copy, by contrast, is **exon sequence only, already joined in the correct order**, so the RNA transcribed from it is translated straight through into the correct human protein. (1 mark: 2250 bases; 1 mark:

the introns are retained in the transcript, because the bacterium cannot remove them; 1 mark: those bases are translated, so a wrong / non-functional protein results; 1 mark: the inserted copy is all coding sequence, so it is translated directly into the correct protein.)

(d) A **promoter** that the bacterium's RNA polymerase can bind. (1 mark.)

Q2. (a) The antibody, which is secreted, is assembled on **ribosomes attached to the rough endoplasmic reticulum** (entering the rough ER as it is made); the cytosolic enzymes are assembled on **free ribosomes in the cytosol**. What decides which is used is the protein's **destination**: proteins bound for **secretion (or for membranes)** are made on rough-ER ribosomes, whereas proteins that will **stay and work in the cytosol** are made on free ribosomes. (1 mark: *antibody on rough-ER ribosomes; 1 mark: cytosolic enzymes on free ribosomes; 1 mark: the destination — secretion vs staying in the cytosol — determines which ribosomes are used.*)

(b) In the secretory pathway the **Golgi apparatus modifies, sorts and packages** the protein and buds it off in secretory vesicles for release. A plasma cell secretes protein at a **very high rate**, so it needs extensive **rough ER** to assemble the huge numbers of antibody molecules and an extensive **Golgi** to process and package them all for export. (1 mark: *the Golgi modifies / packages the protein into secretory vesicles; 1 mark: a high rate of secretion requires abundant rough ER and Golgi to make and process so much protein.*)

(c) The cell's **release of antibody would fall or stop**. The antibody would still be assembled in the rough ER, but with the Golgi blocked it **cannot be modified and packaged into secretory vesicles**, so it cannot be carried to the plasma membrane and released; it would **build up inside the cell** instead. (1 mark: *antibody release falls / stops; 1 mark: because the blocked Golgi cannot package it into secretory vesicles for export, so it accumulates in the cell.*)

Q3. (a) NAD^+ works as a **carrier that must be re-used**: at steps of glycolysis and the Krebs cycle it **accepts electrons and hydrogen**, becoming NADH. If there is no supply of the empty carrier NAD^+ to accept them, those steps have nothing to unload their electrons and hydrogen onto, so the reactions **cannot proceed and the stages stall**. (1 mark: *NAD^+ accepts / carries electrons and hydrogen at these stages; 1 mark: without empty NAD^+ available the steps cannot proceed, so the stages stop.*)

(b) The cell's ATP production would **fall drastically, almost to nothing**. With the coenzyme locked as NADH, no NAD^+ is available, so **glycolysis and the Krebs cycle stop** (they cannot pass on their electrons and hydrogen). The **electron transport chain** also stops, because NADH cannot be re-oxidised and no further loaded carriers reach it. With all stages halted, almost no ATP is made. (1 mark: *ATP production collapses / falls sharply; 1 mark: glycolysis and the Krebs cycle stop for want of NAD^+ ; 1 mark: the electron transport chain also stops, so overall ATP production all but ceases.*)

(c) Under aerobic conditions NAD^+ **is regenerated by the electron transport chain**, which takes the electrons carried by NADH and passes them along its carriers; **oxygen** acts as the **final acceptor** of those electrons, and this allows NADH to be re-oxidised to NAD^+ . Without oxygen the chain cannot run, so a **different process — fermentation** — is used: the pyruvate from glycolysis is converted to **lactic acid (in animals), or to ethanol and carbon dioxide (in yeast)**, and this conversion **re-oxidises NADH back to NAD^+** , allowing glycolysis to keep going and yield its small amount of ATP. (1 mark: *the electron transport chain regenerates NAD^+ ; 1 mark: oxygen is the final electron acceptor that lets NADH be re-oxidised; 1 mark: without oxygen, fermentation regenerates NAD^+ so glycolysis can continue.*)

Q4. (a) The light-dependent stage supplies the Calvin cycle with **ATP and NADPH**. It takes place in the **thylakoid membranes** of the chloroplast. (1 mark: *ATP and NADPH; 1 mark: the thylakoid membranes.*)

(b) The Calvin cycle does not use light itself: it runs on the **ATP and NADPH** made by the light-dependent stage. At the instant the light goes out there is still a **small pool of ATP and NADPH already present in the stroma**, and carbon fixation continues at close to its former rate for the few seconds it takes to spend that pool. The light-dependent stage, however, has **stopped**, so nothing replaces them; once the pool is exhausted the Calvin cycle has neither an energy source nor reducing power, and fixation falls away to almost nothing — even though its enzymes are undamaged and carbon dioxide is still available. (1 mark: *the Calvin cycle runs on ATP and NADPH from the light-dependent stage, not on light directly; 1 mark: a small pool of those carriers remains in the stroma and sustains fixation for a few seconds; 1 mark: in darkness the light-dependent stage stops replacing them, so the pool runs out and fixation stops.*)

- (c) The enzymes were never damaged or broken down — what ran out was the supply of ATP and NADPH — so as soon as the light-dependent stage restarts and replenishes those carriers the enzymes already present resume work. (1 mark.)

Q5. (a) Person 1's earlier infection left **long-lived memory B and T cells specific to this bacterium's antigens**. In person 2, meeting the bacterium for the first time, only a very few lymphocytes carry a matching receptor, and it takes about a week for those few to be **selected, activated and multiplied** into antibody-secreting plasma cells — hence antibody only at day 9, and only at 12 units. In person 1 the matching cells are **already present in large numbers**, so they are activated **at once** and divide immediately into very many plasma cells: a **secondary response**, which is why antibody appears by day 2 and reaches 90 units. (1 mark: *person 1's first infection left memory cells specific to that antigen*; 1 mark: *those cells are already numerous and respond immediately, whereas a first exposure must first select and expand a few matching lymphocytes*; 1 mark: *the secondary response therefore gives antibody far sooner and at a far higher concentration*.)

- (b) In person 2 no antibody was present until **day 9**, so the bacterium multiplied unchecked for those nine days, and it was that build-up that produced six days of illness. In person 1 antibody was present by **day 2**, and at a concentration seven times as high, so the bacterium was cleared **before its numbers were great enough to cause symptoms**. (1 mark: *person 2 had no antibody for nine days, so the bacterium multiplied and caused illness*; 1 mark: *person 1's antibody appeared at day 2 and at high concentration, clearing the bacterium before symptoms could develop*.)

- (c) **Both** people will show a response like **person 2's** — antibody appearing only after about a week and reaching a low concentration. Immunological memory is **specific to the antigen that produced it**: person 1's memory cells carry receptors that match the antigens of the *first* bacterium, and those receptors will not recognise the antigens of a different species. Neither person therefore has any head start, so **both must mount a fresh primary response**, and both are likely to become unwell. (1 mark: *both will resemble person 2 — both mount a primary response*; 1 mark: *because memory is specific to the antigen met before, so person 1's memory cells do not recognise the new species*; 1 mark: *a primary response is slow and small, so antibody appears late and at low concentration in both people*.)

Q6. (a) The fungus is a **cellular pathogen** (fungi are living, eukaryotic cells). An **antibiotic** would be unlikely to help because antibiotics act on **structures and processes specific to bacterial cells** (such as the bacterial cell wall or bacterial ribosomes), which a **eukaryotic fungal cell does not have**, so the antibiotic would have nothing to act on. (1 mark: *cellular pathogen*; 1 mark: *antibiotics target bacterial-specific structures / processes that a eukaryotic fungus lacks, so they do not affect it*.)

- (b) The frogs **vary**, and a few happen to carry **allele(s) giving some resistance** to the fungus (having arisen earlier by **mutation**). The fungus acts as a **selection pressure**: it kills susceptible frogs, but the **resistant frogs survive and breed**, passing their resistance allele(s) to their offspring. Over the generations the **frequency of the resistance allele(s) rises**, so the population becomes more resistant. (1 mark: *pre-existing variation in resistance, arising by mutation*; 1 mark: *the fungus selectively kills susceptible frogs but not resistant ones*; 1 mark: *resistant survivors breed and pass the allele on, so its frequency rises over generations*.)

- (c) With very **low genetic diversity**, it is **unlikely that any frog carries a resistance allele** at all. If no resistance allele is present, **natural selection has nothing to act on** — there are no resistant frogs to survive and breed — so the population cannot become resistant and may be wiped out. This shows that **genetic diversity is the raw material a species needs to adapt** to a new threat such as a disease; a species with little diversity is far more vulnerable. (1 mark: *low diversity makes it unlikely any individual carries a resistance allele*; 1 mark: *with no such allele, selection has nothing to act on, so the population cannot adapt / may go extinct*; 1 mark: *genetic diversity provides the variation a species needs to adapt to new pressures*.)

Q7. (a) The shells of species W and species X are **homologous structures**. The small bones in the hind limbs of species Y are a **vestigial structure**. A **homologous** structure is built to the same underlying plan in two species because both **inherited it from a common ancestor**, so it is evidence that they are related, however differently they now live. A **vestigial** structure is a **reduced remnant of a structure that was functional in an ancestor** and no longer performs that job, so it is evidence about the ancestor — here, that species Y descended from an ancestor whose hind limbs bore working toes. (1 mark: *homologous*; 1 mark: *vestigial*; 1 mark: *what each indicates* —

inheritance from a common ancestor and hence relatedness, and descent from an ancestor in which the structure worked.)

- (b) Differences accumulate in a sequence only **after two lineages have separated**, so the more positions at which two species differ, the **longer ago they last shared a common ancestor**. W differs from Y at 24 positions but from Z at 41, so W's most recent common ancestor with **Y is the more recent** of the two, and Y is the closer relative of W. The reasoning depends on the assumption that changes accumulate at a **roughly steady rate** in this region, so that the number of differences can be read as a measure of the time that has passed. (1 mark: more differences means a longer time since the common ancestor; 1 mark: W shared a more recent common ancestor with Y than with Z; 1 mark: the reasoning assumes a roughly constant rate of sequence change over time.)
- (c) The genetic code is **degenerate**: several codons specify the same amino acid, so a base substitution — particularly in the third base of a codon — often leaves the amino acid unchanged. A change of that kind is counted as a **DNA difference but not as an amino-acid difference**, so the DNA figure is always the larger of the two. For two species that separated only very recently the **DNA comparison** is the more useful, because differences register in the DNA first: two such species may still have identical proteins while their DNA already differs. (1 mark: the code is degenerate, so some base changes do not change the amino acid; 1 mark: such changes are counted in the DNA total but not the protein total, so the DNA figure is the larger; 1 mark: the DNA comparison, because it registers differences sooner.)
- (d) A conclusion about relatedness is **provisional**: it is the best interpretation of the evidence available at the time, and is **refined or replaced when better evidence is obtained** — here because a **technological advance**, whole-genome sequencing, made far more of the genome available for comparison than the original study could reach. The whole-genome comparison is the more reliable because **one short region is a very small, and possibly unrepresentative, sample** of the genome, whereas a whole genome compares an enormous number of positions and so is far less affected by any single atypical region. What no sequence comparison can establish on its own is **when, in years, the lineages separated**: sequences give relative relatedness only, and an age in years requires calibration against independently dated evidence such as radiometrically dated fossils. (1 mark: scientific conclusions are provisional and are revised when new evidence appears; 1 mark: the new evidence came from a technological advance giving access to far more sequence; 1 mark: one short region is a small, possibly unrepresentative sample, whereas a whole genome compares far more positions; 1 mark: sequence data give relative relatedness only, not an age in years, which needs calibration against dated fossils.)

Q8. (a) The **independent variable** is **whether the soil treatment is applied** (treated versus untreated plots). The **dependent variable** is the **yield of the crop**. (1 mark: IV; 1 mark: DV.)

- (b) The argument rests on the **consequences-based approach**, which judges an action by its **outcomes** (the ends) and would let the work proceed provided the expected benefits outweigh the expected harms. Its weakness here is that it weighs only the **overall balance**: a large net gain can be approved even though the benefit goes to one group — the wealthy growers who can afford the treatment — while the drawback falls on another, so who gains and who loses is never itself put on the scales. (1 mark: the consequences-based approach; 1 mark: a weakness — judging only the total outcome can approve a course of action in which the benefits and the burdens fall on different people.)
- (c) This would breach **integrity**, which requires the **honest and complete reporting of all results**. Keeping a **complete, dated logbook** of every result as it is generated means the data are **authenticated and cannot be quietly altered or dropped**: the poorly performing plots are on the record, so leaving them out would be exposed, and the reported conclusion must reflect **all** of the evidence. (1 mark: integrity; 1 mark: a complete, dated logbook authenticates all results, so favourable-only reporting is prevented.)

Q9. (a) A suitable statement: **“Leaves of this shrub grown in full sun were thicker than those grown in deep shade (mean 0.42 mm against 0.27 mm).”** A poster carries such a statement so that a reader can take away the **investigation's main finding in a few seconds**, without having to work through the tables and graphs first. (1 mark: a statement giving the direction of the finding and supported by the figures; 1 mark: it communicates the key finding briefly, so that a reader grasps it at once.)

- (b) The **references** section lists the **sources of information and ideas** the student drew on, given in enough detail for a reader to find them and so that credit goes to their authors. The **acknowledgements** section names the **people who helped with the work itself**, whose published ideas are not being used. The journal article therefore belongs in the **references**; the landholder who gave access to the sites and the technician who calibrated the instrument belong in the **acknowledgements**. (1 mark: references = the sources of information and ideas used, given so that a reader can find them; 1 mark: acknowledgements = the people who assisted with the work; 1 mark: article to references, landholder and technician to acknowledgements.)
- (c) Two conventions broken (any two): a **space is left between a number and its unit symbol**, so “0.42MM” should read “0.42 mm”; the **symbol for the millimetre is the lower-case mm** — “MM” is not a recognised symbol for it; and a **zero is written before the decimal point**, so “.27” should read “0.27”. Written correctly: **“Mean leaf thickness in full sun was 0.42 mm and in deep shade 0.27 mm.”** (1 mark for each of two conventions correctly identified; 1 mark for the corrected sentence.)

Q10. (a) The plants from the mine tolerate copper far better than those from the pasture: their mean tolerance index is **78%** against **9%**, so mine plants grow nearly as well in copper as in a normal solution while pasture plants manage less than a tenth of their normal root growth. Tolerance is not entirely absent from the pasture population, because the **range of individual pasture indices reaches 34%** — a few pasture plants are already appreciably tolerant. (1 mark: the mine population is far more tolerant, with the two means quoted; 1 mark: the top of the pasture range, 34%, shows that a few pasture plants are already tolerant.)

- (b) Pollen does carry tolerance alleles into the pasture population every year, so **gene flow adds them continually**. On normal soil, however, a tolerant plant **grows more slowly and sets less seed** than a non-tolerant one, so **natural selection acts against the tolerance alleles there**: the plants carrying them leave fewer offspring in each generation. Selection therefore removes those alleles about as fast as gene flow brings them in, so their frequency stays low and the pasture population remains almost entirely non-tolerant. (1 mark: gene flow does carry the tolerance alleles in each year; 1 mark: on normal soil tolerance is a disadvantage, so selection acts against those alleles; 1 mark: selection removes them as fast as gene flow supplies them, so their frequency stays low.)
- (c) The frequency of the tolerance alleles among the plants on the topsoiled ground will **fall**. Once the high copper concentration is gone the **selection pressure that favoured tolerance has been removed**, so tolerance brings no advantage there. It still carries its cost — tolerant plants grow more slowly and set less seed on normal soil — so **selection now acts against the tolerance alleles**, and the plants carrying them leave fewer offspring each generation. Non-tolerant alleles will also keep arriving in **pollen from the surrounding pasture**, so over the decades the plants on that ground will come to resemble the pasture population. (1 mark: the frequency of the tolerance alleles falls; 1 mark: the copper selection pressure has gone and tolerance carries a cost on normal soil, so selection now acts against it; 1 mark: gene flow from the pasture also adds non-tolerant alleles, so the population comes to resemble the pasture one.)