Biology HL

IB HL — Question Bank

Q1.

Worked Example — Scale Bar Calculation

A photograph shows a mitochondrion with a scale bar of 1 μm that measures 20 mm on the printed image. The mitochondrion image length is 48 mm. What is the actual length of the mitochondrion?

Step 1 — find magnification from the scale bar:

$\text{Magnification} = \frac{\text{scale bar image length}}{\text{scale bar actual length}} = \frac{20\text{ mm}}{0.001\text{ mm}} = \times 20{,}000$

(Note: $1\ \mu\text{m} = 0.001\text{ mm}$)

Step 2 — find actual mitochondrion length:

$\text{Actual size} = \frac{48\text{ mm}}{20{,}000} = 0.0024\text{ mm} = 2.4\ \mu\text{m}$

Q2.

Worked Example — Bohr Effect at Respiring Tissues

A muscle cell is producing CO_2 rapidly during exercise. Explain how the Bohr effect enables oxygen delivery:

1. CO_2 from respiration diffuses into the plasma and combines with water: $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$
2. Increased $[H^+]$ (decreased pH) causes a conformational change in haemoglobin, reducing its affinity for O_2.
3. The oxygen dissociation curve shifts to the **right** — at any given O_2 partial pressure, less O_2 is bound.
4. Haemoglobin releases O_2 to the tissues.

Conclusion: The Bohr effect is a self-regulating mechanism — tissues that produce the most CO_2 (i.e., respire fastest) automatically receive the most O_2 from the blood.

Q3.

Worked Example: Chromosome Counting

A human somatic cell has 46 chromosomes ($2n = 46$).

- After S **phase**: still 46 chromosomes, but each now consists of 2 sister chromatids (92 chromatids total, but still counted as 46 chromosomes because they are joined at the centromere)
- After **anaphase**: 92 chromatids are separated → become 92 individual chromosomes (46 moving to each pole)
- After **telophase + cytokinesis**: each daughter cell has 46 chromosomes (back to normal)

Key rule: A chromosome is counted by its centromere. As long as two chromatids share one centromere, they are ONE chromosome.

Q4.

Question 1 [Michaelis-Menten Kinetics] [~7 marks]

The enzyme lactase catalyses the hydrolysis of lactose into glucose and galactose. An experiment measures the initial reaction rate (v) at different substrate concentrations ($[\mathrm{S}]$) with a fixed enzyme concentration.

(a) Sketch a Michaelis-Menten curve for this reaction. Label $V_{\max}$ and K_m on your graph.

(b) Define K_m and explain its biological significance.

(c) A second experiment uses half the original enzyme concentration. On the same axes, sketch the expected curve and explain the changes to $V_{\max}$ and K_m.

▶ Show Solution

Q5.

Question 2 [Enzyme Inhibition] [~7 marks]

The diagram below shows the effect of two different inhibitors (X and Y) on the rate of an enzyme-catalysed reaction at varying substrate concentrations. Without any inhibitor, the enzyme has $V_{\max} = 120\,\mu\text{mol min}^{-1}$ and $K_m = 4\,\text{mM}$.

- **Inhibitor X:** $V_{\max}$ remains 120, but the apparent K_m increases to 8 mM.
- **Inhibitor Y:** $V_{\max}$ decreases to 60, and K_m remains 4 mM.

(a) Identify the type of inhibition caused by Inhibitor X and Inhibitor Y.

(b) Explain the molecular mechanism of each type of inhibition.

(c) For Inhibitor X, explain why increasing substrate concentration can overcome the inhibition.

▶ Show Solution

Q6.

Question 3 [Denaturation] [~6 marks]

An experiment measures the activity of the enzyme catalase at temperatures ranging from 10 $^{\circ}C$ to 80 $^{\circ}C$.

(a) Sketch a graph of enzyme activity against temperature for catalase. Label the optimum temperature.

(b) Explain the shape of the graph above the optimum temperature in terms of protein structure.

(c) Distinguish between denaturation and competitive inhibition in terms of their reversibility and effect on enzyme structure.

▶ Show Solution

Q7.

Question 1 [Light Reactions vs Calvin Cycle] [~8 marks]

Compare and contrast the light-dependent reactions and the light-independent reactions (Calvin cycle) of photosynthesis. In your answer, include:

(a) The precise location of each set of reactions within the chloroplast.

(b) The role of $NADP^+$ and ATP in linking the two stages.

(c) Explain what would happen to the rate of the Calvin cycle if the light-dependent reactions were suddenly inhibited.

▶ Show Solution

Q8.

Question 2 [Limiting Factors] [~6 marks]

A student investigates the rate of photosynthesis in an aquatic plant (Elodea) by counting oxygen bubbles produced per minute at different light intensities. The temperature is kept constant at 25 $^{\circ}C$ and CO_2 concentration is 0.04%.

(a) Sketch a graph showing the expected relationship between light intensity and rate of photosynthesis. Label the axes and indicate the plateau region.

(b) Explain why the rate of photosynthesis reaches a plateau even though light intensity continues to increase.

(c) Suggest how the student could increase the maximum rate of photosynthesis beyond the plateau.

▶ Show Solution

Q9.

Question 3 [Respirometer] [~6 marks]

A simple respirometer is used to measure the rate of aerobic respiration in germinating seeds. The apparatus contains a sealed tube with seeds, a KOH pellet to absorb $\mathrm{CO_2}$, and a coloured liquid in a capillary tube.

(a) Explain why the coloured liquid moves toward the seeds during the experiment.

(b) Explain the purpose of the KOH pellet in the respirometer.

(c) The experiment is repeated at 35 $^\circ\mathrm{C}$ instead of 20 $^\circ\mathrm{C}$. Predict and explain the effect on the rate of movement of the liquid.

▶ Show Solution

Q10.

Worked Example: Chargaff's Rules Calculation

A DNA sample contains 22% guanine. Calculate the percentage of each of the other three bases.

Step 1: By Chargaff's rules, $[\mathrm{G}] = [\mathrm{C}]$, so C = 22%.

Step 2: G + C = 22 + 22 = 44%, so A + T = 100 - 44 = 56%.

Step 3: By Chargaff's rules, $[\mathrm{A}] = [\mathrm{T}]$, so A = T = 56 / 2 = **28%**.

Q11.

Worked Example: IB-Style Replication Question

A circular bacterial chromosome is 4.6 million base pairs long. It replicates from a single origin of replication. Identify two enzymes active at the replication fork and state the function of each. (4 marks)

Model answer:

1. **Helicase** — breaks hydrogen bonds between complementary base pairs, unwinding the double helix to expose the template strands. (2 marks)

2. **DNA polymerase III** — adds deoxyribonucleotides to the $3'$-OH end of the growing strand in a $5' \to 3'$ direction, using the template strand as a guide by complementary base pairing. (2 marks)

Note: You could also name primase (synthesises RNA primer to provide $3'$-OH start point) or DNA ligase (joins Okazaki fragments on lagging strand). Always state both the enzyme name AND its specific function.

Q12.

Worked Example: Decoding a Codon Table

A segment of the template DNA strand reads: `3'-TAC-CGT-ATT-ACT-5'`

(a) Write the sequence of the corresponding mRNA. (b) Using the codon table below, determine the amino acid sequence produced.

Codon	Amino Acid
AUG	Methionine (Met) — Start
GCA	Alanine (Ala)
UAA	Stop
UGA	Stop
GUG	Valine (Val)
UAU	Tyrosine (Tyr)

Step 1 (a): The template DNA strand is $3' \to 5'$, so transcription produces mRNA in the $5' \to 3'$ direction. Replace T with U and write the complementary bases:

Template (DNA): $3'$-TAC-CGT-ATT-ACT-$5'$

mRNA: $5'$-AUG-GCA-UAA-UGA-$3'$

Step 2 (b): Decode each codon:

- AUG = Methionine (start)
- GCA = Alanine
- UAA = Stop

Q13.

Worked Example: Epigenetics Question

Explain why two genetically identical twins may develop different diseases later in life. (3 marks)

Model answer:

Although identical twins have the same DNA sequence (same genotype), their epigenomes can diverge over time due to differences in environment (1). DNA methylation patterns may differ — for example, genes involved in disease susceptibility may be methylated (silenced) in one twin but not the other (1). Histone acetylation patterns may also differ, altering chromatin accessibility and changing which genes are actively transcribed (1).

Key principle: Same genotype, different epigenome → different phenotype (including disease risk).

Q14.

Question 1 [Gene Expression Regulation] [~8 marks]

In prokaryotes, the lac operon is a well-studied model of gene regulation.

(a) Outline the structure of the lac operon, identifying the role of the promoter, operator, and structural genes.

(b) Explain how the lac operon is regulated when lactose is absent and when lactose is present.

(c) Suggest why regulation of gene expression is important for a bacterium's survival, with reference to energy efficiency.

▶ Show Solution

Q15.

Question 2 [Translation] [~7 marks]

Describe the process of translation in eukaryotic cells.

(a) Outline the roles of mRNA, tRNA, and ribosomes during translation.

(b) Describe the events that occur during the elongation phase of translation.

(c) Explain how a single mRNA molecule can be translated by multiple ribosomes simultaneously, and state the term for this structure.

▶ Show Solution

Q16.

Question 3 [Mutations] [~6 marks]

A gene has the following mRNA sequence for the first six codons:

$\mathrm{AUG\text{-}GAA\text{-}UUU\text{-}CGG\text{-}UAC\text{-}AAG}$

A point mutation changes the third codon from UUU to UAU.

(a) State the type of point mutation this represents and explain your reasoning.

(b) Using the genetic code, determine the amino acid change caused by this mutation and predict its likely effect on protein function.

(c) Distinguish between a missense mutation and a nonsense mutation, giving an example codon change for each.

▶ Show Solution

Q17.

Example: Pea seed colour (yellow Y dominant over green y)

Cross: heterozygous yellow (Yy) × heterozygous yellow (Yy)

Step 1 — Parental genotypes:

$P : Yy \times Yy$

Step 2 — Gametes produced by each parent:

Parent 1 gametes: Y or y

Parent 2 gametes: Y or y

Step 3 — Punnett square:

	Y	y
Y	YY	Yy
y	Yy	yy

Step 4 — Genotype ratio: $YY : Yy : yy = 1 : 2 : 1$

Step 5 — Phenotype ratio: yellow : green = 3 : 1

(Both YY and Yy produce yellow phenotype; only yy produces green phenotype.)

Q18.

Example: Pea seed colour (Y/y) and seed shape (R round dominant over r wrinkled)

Cross: double heterozygote × double heterozygote ($YyRr \times YyRr$)

Gametes for each parent (using FOIL or a 4×4 Punnett square):

Each $YyRr$ parent produces four gamete types: YR, Yr, yR, yr in equal proportions.

Expected phenotype ratio from $YyRr \times YyRr$:

9 yellow round : 3 yellow wrinkled : 3 green round : 1 green wrinkled

This **9:3:3:1 ratio** is the hallmark of a dihybrid cross with two independently assorting genes, each showing simple dominance.

Punnett square (4×4):

	YR	Yr	yR	yr
YR	$YYRR$	$YYRr$	$YyRR$	$YyRr$
Yr	$YYRr$	$YYrr$	$YyRr$	$Yyrr$
yR	$YyRR$	$YyRr$	$yyRR$	$yyRr$
yr	$YyRr$	$Yyrr$	$yyRr$	$yyrr$

Count the phenotypes: 9 with at least one Y and one R (yellow round), 3 with Y but rr (yellow wrinkled), 3 with yy but at least one R (green round), 1 with yy and rr (green wrinkled).

Q19.

ABO Cross Example

A mother has blood type A (genotype $I^A i$) and a father has blood type B (genotype $I^B i$). What blood types are possible in their children?

Punnett square:

	I^A	i
I^B	$I^A I^B$ (AB)	$I^B i$ (B)
i	$I^A i$ (A)	ii (O)

Possible offspring blood types: A, B, AB, and O — all four types are possible (each with probability 1/4).

Q20.

X-linked Haemophilia Cross

A carrier female ($X^H X^h$) × normal male ($X^H Y$)

Gametes: Female produces X^H and X^h; Male produces X^H and Y

Punnett square:

	X^H	X^h
X^H	$X^H X^H$ (normal female)	$X^H X^h$ (carrier female)
Y	$X^H Y$ (normal male)	$X^h Y$ (haemophiliac male)

Phenotype ratio: 1 normal female : 1 carrier female : 1 normal male : 1 haemophiliac male

Key point: 1/2 of all sons will be affected; 0 daughters will be affected (but 1/2 will be carriers). Haemophilia is more common in males because males only need one copy of the recessive allele.

Q21.

Worked Example: Blood glucose regulation after a meal

After eating a carbohydrate-rich meal, blood glucose rises above the set point.

1. **Receptor:** Beta cells in the islets of Langerhans detect the rise in blood glucose.
2. **Coordinator/Effector:** Beta cells secrete **insulin** into the blood.
3. **Response:** Insulin binds to receptors on target cells (liver, muscle, adipose). This causes:
    - Increased uptake of glucose via GLUT4 transporters (in muscle and adipose)
    - Increased **glycogenesis** in the liver and muscle (glucose $\rightarrow$ glycogen)
    - Increased conversion of glucose to fat (lipogenesis) in adipose tissue

4. **Result:** Blood glucose falls back toward the set point (~5 mmol/L).
5. **Feedback:** As glucose returns to normal, the stimulus for insulin secretion diminishes (negative feedback).

Q22.

Worked Example: Blood glucose regulation during fasting

Between meals or during exercise, blood glucose falls below the set point.

1. **Receptor:** Alpha cells in the islets of Langerhans detect the fall in blood glucose.
2. **Coordinator/Effector:** Alpha cells secrete **glucagon** into the blood.
3. **Response:** Glucagon binds to receptors on liver cells. This causes:
    - **Glycogenolysis** — breakdown of stored glycogen to glucose
    - **Gluconeogenesis** — production of new glucose from amino acids and glycerol
4. **Result:** Blood glucose rises back toward the set point.
5. **Feedback:** As glucose returns to normal, the stimulus for glucagon secretion diminishes (negative feedback).

Q23.

Worked Example: Explain how the body integrates multiple systems to respond to a sudden drop in blood pressure (e.g. after blood loss). (6 marks)

1. **Detection:** Baroreceptors in the **aortic arch and carotid sinus** detect the fall in blood pressure and send fewer nerve impulses to the **medulla oblongata**. [1]
2. **Neural response (immediate):** The medulla increases **sympathetic** nerve activity and decreases **parasympathetic** (vagus nerve) activity. This causes: increased heart rate and force of contraction, vasoconstriction of arterioles (raising peripheral resistance), and stimulation of the adrenal medulla. [1]
3. **Short-term hormonal response:** The **adrenal medulla** releases **adrenaline** into the blood, reinforcing the sympathetic effects — increased cardiac output and vasoconstriction. [1]
4. **Medium-term hormonal response:** The **hypothalamus** stimulates ADH release from the posterior pituitary. ADH increases water reabsorption in the collecting ducts of the kidneys, conserving blood volume. ADH also causes vasoconstriction at high concentrations. [1]
5. **Longer-term hormonal response:** The kidneys release **renin**, triggering the **renin-angiotensin-aldosterone system (RAAS)**. Angiotensin II causes vasoconstriction; **aldosterone** from the adrenal cortex increases Na^+ reabsorption in the kidneys, which draws water back into the blood by osmosis. [1]
6. **Negative feedback:** As blood pressure returns toward normal, baroreceptors detect the increase and the medulla reduces sympathetic output. ADH and aldosterone secretion decrease as blood volume and osmolarity normalise. [1]

Q24.

(a) Outline the sequence of events that occurs at a cholinergic synapse when an action potential arrives at the presynaptic terminal. [4 marks]

(b) Organophosphate nerve agents inhibit acetylcholinesterase, the enzyme that breaks down acetylcholine in the synaptic cleft. Predict and explain the effects on the postsynaptic neuron and on the organism. [3 marks]

(c) State one other way in which a drug could modify synaptic transmission, giving an example. [1 mark]

Model Answer:

(a) Action potential arrives at presynaptic terminal (1); calcium ion channels open and Ca^{2+} enters the terminal (1); vesicles containing acetylcholine fuse with the presynaptic membrane by exocytosis (1); acetylcholine diffuses across the synaptic cleft and binds to receptors on the postsynaptic membrane, triggering an EPSP (1).

(b) Acetylcholine accumulates in the cleft (1); the postsynaptic neuron is continuously stimulated — the EPSP is prolonged and repeated (1); at the organism level, this causes uncontrolled muscle contraction (convulsions), paralysis of respiratory muscles, and potentially death due to respiratory failure (1).

(c) A drug could block postsynaptic receptors (antagonist), e.g. curare blocks nicotinic acetylcholine receptors at the neuromuscular junction, causing muscle paralysis. Accept any valid example: SSRIs blocking serotonin reuptake; beta-blockers blocking adrenaline receptors. (1)

Q25.

(a) Explain how blood glucose is regulated after a high-carbohydrate meal, naming the hormones and target organs involved. [4 marks]

(b) Compare Type 1 and Type 2 diabetes mellitus in terms of cause, insulin levels, and treatment. [3 marks]

Model Answer:

(a) Blood glucose rises after a meal (1); beta cells in the islets of Langerhans detect the rise and secrete insulin (1); insulin stimulates glucose uptake by liver and muscle cells (via GLUT4 transporters) and promotes glycogenesis (glycogen synthesis) in the liver (1); blood glucose returns to the set point (approximately 5 mmol/L), completing the negative feedback loop (1).

(b)

	Type 1	Type 2
Cause	Autoimmune destruction of beta cells	Insulin resistance (cells don't respond to insulin) / reduced insulin secretion
Insulin level	Very low / absent	Normal or elevated initially, may fall over time
Treatment	Daily insulin injections (cannot be managed by diet alone)	Diet, exercise, oral hypoglycaemics (e.g. metformin); insulin in later stages

Award 1 mark per correctly compared row, maximum 3.

Q26.

(a) Explain the role of antidiuretic hormone (ADH) in regulating blood osmolarity when a person is dehydrated. [3 marks]

(b) A patient with diabetes insipidus cannot produce ADH. Predict the effect on urine volume and osmolarity, and explain the consequences for blood osmolarity. [3 marks]

Model Answer:

(a) Dehydration causes blood osmolarity to rise above the set point (1); osmoreceptors in the hypothalamus detect this and trigger the posterior pituitary to release more ADH into the blood (1); ADH increases the permeability of the collecting duct of the kidney tubule (by inserting aquaporins), so more water is reabsorbed by osmosis back into the blood, reducing osmolarity and producing small volumes of concentrated urine (1).

(b) Without ADH, the collecting duct remains relatively impermeable to water (1); very large volumes of dilute urine are produced (polyuria) because water is not reabsorbed (1); blood osmolarity rises above normal (hyperosmolarity/hypernatraemia), which — if untreated — can cause dehydration, cellular damage, and neurological symptoms (1).

Q27.

Worked Example: Lincoln Index

A researcher captures 40 snails in a garden, marks them with non-toxic paint, and releases them. One week later, they capture 50 snails, of which 10 are marked.

$N = \frac{n_1 \times n_2}{m_2} = \frac{40 \times 50}{10} = \frac{2000}{10} = 200$

Estimated population size = 200 snails

Q28.

Worked Example: Calculating NPP

A grassland ecosystem has a GPP of $20{,}000 \text{ kJ m}^{-2}\text{yr}^{-1}$. Producers use $12{,}000 \text{ kJ m}^{-2}\text{yr}^{-1}$ for respiration.

$$\text{NPP} = \text{GPP} - R = 20{,}000 - 12{,}000 = 8{,}000 \text{ kJ m}^{-2}\text{yr}^{-1}$$

Therefore, 8,000 $\mathrm{kJ\ m^{-2}yr^{-1}}$ of energy is stored in plant biomass and available to herbivores.

If primary consumers assimilate 10% of this: $8{,}000 \times 0.10 = 800\ \mathrm{kJ\ m^{-2}yr^{-1}}$ is transferred to the secondary consumer level.

Q29.

Classic Example: DDT and Biomagnification

DDT (dichlorodiphenyltrichloroethane) was widely used as a pesticide. It is fat-soluble, persistent, and does not break down easily:

- Water: 0.000003 ppm
- Phytoplankton: 0.04 ppm
- Zooplankton: 0.5 ppm
- Small fish: 2 ppm
- Large fish: 25 ppm
- Fish-eating birds (e.g. osprey): $250+$ ppm

At high concentrations, DDT caused eggshell thinning in birds of prey (e.g. peregrine falcon, bald eagle), leading to population crashes. This led to the ban of DDT in many countries.

Q30.

Worked Example: Simpson's Diversity Index

A meadow survey finds the following:

Species	Number of individuals (n)	$\frac{n}{N}$	$\left(\frac{n}{N}\right)^2$
Daisy	30	0.300	0.0900
Buttercup	25	0.250	0.0625
Clover	20	0.200	0.0400
Dandelion	15	0.150	0.0225
Thistle	10	0.100	0.0100

Total (N) = 100

$\sum\left(\frac{n}{N}\right)^2 = 0.0900 + 0.0625 + 0.0400 + 0.0225 + 0.0100 = 0.2250$

$D = 1 - 0.2250 = 0.775$

Interpretation: $D = 0.775$ indicates relatively high diversity. A value close to 1 means high diversity (many species, evenly distributed); a value close to 0 means low diversity (dominated by one species).

For comparison, if one species had 96 individuals and four others had 1 each: $D = 1 - (0.96^2 + 4 \times 0.01^2) = 1 - 0.9220 = 0.078$ — very low diversity.

Q31.

Worked Example: Chi-Squared Test

A student investigates whether the distribution of a moss species is associated with the direction a wall faces (north vs south). They sample 100 quadrats:

	Moss present	Moss absent	Row total
North-facing	35	15	50
South-facing	20	30	50
Column total	55	45	100

Step 1: Calculate expected values

$E = \frac{\text{row total} \times \text{column total}}{\text{grand total}}$

	Moss present (E)	Moss absent (E)
North-facing	$\frac{50 \times 55}{100} = 27.5$	$\frac{50 \times 45}{100} = 22.5$
South-facing	$\frac{50 \times 55}{100} = 27.5$	$\frac{50 \times 45}{100} = 22.5$

Step 2: Calculate χ^2

$\chi^2 = \frac{(35-27.5)^2}{27.5} + \frac{(15-22.5)^2}{22.5} + \frac{(20-27.5)^2}{27.5} + \frac{(30-22.5)^2}{22.5}$

$= \frac{56.25}{27.5} + \frac{56.25}{22.5} + \frac{56.25}{27.5} + \frac{56.25}{22.5}$

$= 2.045 + 2.500 + 2.045 + 2.500 = 9.09$

Step 3: Determine significance

Degrees of freedom = $(r-1)(c-1) = (2-1)(2-1) = 1$

Critical value at $p = 0.05$ with 1 degree of freedom = 3.841

Since $\chi^2 = 9.09 > 3.841$, we **reject the null hypothesis**. There is a statistically significant association between wall direction and moss distribution at the 5% significance level.

Q32.

The table shows the energy content (kJ m^{-2} yr^{-1}) at each trophic level in a grassland ecosystem.

Trophic Level	Energy (kJ m^{-2} yr^{-1})
Producers	40,000
Primary consumers	4,000
Secondary consumers	480
Tertiary consumers	52

(a) Calculate the trophic efficiency between producers and primary consumers. Show your working. [2 marks]

(b) Trophic efficiency between primary and secondary consumers differs from your answer in (a). Suggest two reasons why energy transfer efficiency varies between trophic levels. [2 marks]

(c) Explain why food chains rarely exceed five trophic levels. [2 marks]

(d) Evaluate the claim that "eating lower on the food chain is always more energy-efficient for humans." [2 marks]

Model Answer:

(a) Trophic efficiency = (energy at next level / energy at current level) x 100 = (4000 / 40000) x 100 = **10%**. (2)

(b) Any two from: different respiratory losses at each level (ectotherms vs. endotherms); different proportions of biomass that are indigestible (e.g. more cellulose in plants than in animal prey); different feeding efficiency or foraging behaviours; differences in reproductive strategy affecting proportion of energy used for growth. (1 mark each, max 2)

(c) Energy is lost at each trophic level — approximately 90% is lost as heat (respiration), waste, and indigestible material (1); so by the time you reach a fifth or sixth trophic level, the available energy is too low to support a viable population of predators (1).

(d) In favour: consuming plants directly (first trophic level) avoids the 90% energy loss at each trophic step, so theoretically more people can be fed from the same land area (1). However, not all land is suitable for crop production — some is only suitable for grazing, so livestock can convert non-human-edible plant matter into food; also, human nutritional requirements include specific amino acids and micronutrients that may not all be efficiently obtained from plants alone (1). Accept any well-reasoned balanced evaluation.

Q33.

(a) Draw and annotate a diagram of the nitrogen cycle, including the following processes: nitrogen fixation, nitrification, denitrification, decomposition/ammonification, and assimilation by plants. [4 marks]

(b) Excessive use of nitrogen fertiliser in agriculture can lead to eutrophication in nearby water bodies. Outline the sequence of events by which this occurs and its ecological consequences. [3 marks]

Model Answer:

(a) Award 1 mark each for any four of: Nitrogen fixation — N_2 in atmosphere converted to NH_3 / NH_4^+ by *Rhizobium* bacteria in root nodules or free-living bacteria like *Azotobacter* / by lightning (1); Nitrification — NH_4^+ converted to NO_2^- then NO_3^- by nitrifying bacteria (1); Assimilation — plants absorb NO_3^- / NH_4^+ through roots and incorporate nitrogen into amino acids and nucleotides (1); Decomposition/ammonification — decomposers break down organic nitrogen in dead organisms into NH_4^+ (1); Denitrification — NO_3^- converted to N_2 by denitrifying bacteria in anaerobic conditions, returning N_2 to the atmosphere (1). Max 4.

(b) Nitrates leach from fields into waterways (1); algae and cyanobacteria grow rapidly in response to the nutrient influx (algal bloom) (1); algal bloom reduces light penetration, causing submerged plants to die; decomposers break down dead organic matter using aerobic respiration, depleting dissolved oxygen (BOD increases); fish and invertebrates die from oxygen depletion (1).

Q34.

(a) Define biodiversity, distinguishing between species richness and species evenness. [2 marks]

(b) Explain how the introduction of an invasive species can reduce native biodiversity, using a named example. [2 marks]

(c) A researcher uses Simpson's Diversity Index (D) to compare two habitats before and after the introduction of an invasive species. Predict how D would change and explain your reasoning. [2 marks]

Model Answer:

(a) Biodiversity is the variety of life in an area (1). Species richness is the total number of different species present. Species evenness refers to how equally individuals are distributed among those species — a community where all species are equally abundant has greater evenness (1).

(b) Any named invasive species with correct explanation, e.g. cane toads (*Rhinella marina*) introduced to Australia killed native predators (quolls, goannas) that attempted to eat them because the toads are toxic — native predators lacked evolutionary adaptations to recognise or tolerate the toxin (1, 1). Accept: grey squirrels outcompeting red squirrels in the UK for food and nest sites, also spreading squirrelpox virus; water hyacinth (*Eichhornia crassipes*) blocking light and oxygen in waterways. Must name the species and explain the mechanism (2).

(c) D would decrease (become closer to 0) (1); because the invasive species typically dominates numerically (reducing evenness) and may cause local extinction of native species (reducing richness) — both of which lower the D value in Simpson's index (1).

Q35.

Worked Example: Calculating R_f

A student uses paper chromatography to separate amino acids. The solvent front travels 12.0 cm from the origin. An amino acid spot is found 7.2 cm from the origin.

$R_f = \frac{7.2}{12.0} = 0.60$

By comparing this R_f value to a table of known amino acid R_f values under the same conditions, the amino acid can be identified.

Important: R_f values are specific to the solvent system and conditions (temperature, paper type) used. They are always between 0 and 1.

Q36.

(a) Distinguish between the primary, secondary, tertiary, and quaternary structures of proteins, including the bonds or interactions responsible for each level. [4 marks]

(b) Explain how the tertiary structure of an enzyme determines its specificity for its substrate. [2 marks]

(c) A student heats an enzyme to 80 degrees C and observes that activity falls to zero. Explain this result in terms of protein structure. [2 marks]

Model Answer:

(a) Primary structure: the sequence of amino acids in the polypeptide chain, held together by peptide bonds formed by condensation reactions (1). Secondary structure: local regular folding into alpha-helices or beta-pleated sheets, stabilised by hydrogen bonds between backbone C=O and N-H groups (1). Tertiary structure: overall 3D shape of a single polypeptide, determined by interactions between R groups — hydrogen bonds, ionic bonds, disulfide bridges, hydrophobic interactions (1). Quaternary structure: two or more polypeptide subunits held together by the same types of interactions as tertiary structure, e.g. haemoglobin (four subunits) (1).

(b) The tertiary structure creates a uniquely shaped active site (1); only a substrate with a complementary shape (and complementary charge distribution) can form an enzyme-substrate complex — this is the basis of enzyme specificity (induced fit model: the active site may adjust slightly on substrate binding) (1).

(c) At 80 degrees C, thermal energy breaks the hydrogen bonds and other weak interactions that maintain tertiary structure (1); the enzyme denatures — the active site changes shape and can no longer bind the substrate, so no enzyme-substrate complexes form and activity falls to zero (1).

Q37.

(a) Compare the structures of starch (amylose), glycogen, and cellulose in terms of the monomer, glycosidic bond type, and degree of branching. [3 marks]

(b) Relate the structural differences in (a) to the different functions of each polysaccharide. [3 marks]

(c) Iodine solution turns blue-black in the presence of starch but not cellulose. Suggest a reason for this. [1 mark]

Model Answer:

(a)

	Starch (amylose)	Glycogen	Cellulose
Monomer	α-glucose	α-glucose	β-glucose
Bond type	α-1,4 glycosidic	α-1,4 and α-1,6	β-1,4 glycosidic
Branching	Unbranched (coiled helix)	Highly branched	Unbranched (straight chains)

Award 1 mark per correctly completed comparison row, max 3.

(b) Starch: stored in plant cells in a coiled, compact form that is insoluble and does not affect osmosis; gradual hydrolysis releases glucose for energy (1). Glycogen: highly branched structure in animal liver and muscle cells provides many chain ends for rapid glucose release during exercise or between meals (1). Cellulose: straight, unbranched chains form hydrogen bonds between parallel strands, creating strong microfibrils that provide structural support in plant cell walls (1).

(c) Iodine molecules are trapped inside the helical coil structure of amylose, forming a blue-black complex (1). Cellulose is straight and does not form a helix, so iodine cannot be trapped and no colour change occurs.

Q38.

(a) Explain why water is described as a polar molecule and how this gives rise to hydrogen bonding between water molecules. [2 marks]

(b) Describe and explain three properties of water that are important to living organisms, linking each property to its biological significance. [4 marks]

Model Answer:

(a) Oxygen is more electronegative than hydrogen; electrons are pulled towards oxygen, creating a partial negative charge (δ^-) on the oxygen and partial positive charges (δ^+) on the hydrogen atoms — this makes the molecule polar (1). The δ^+ hydrogen of one water molecule is attracted to the δ^- oxygen of a neighbouring molecule, forming a hydrogen bond; each water molecule can form up to four hydrogen bonds (1).

(b) Any three of the following, with correct explanation and biological significance (1 + 1 each, maximum 4 marks):

- **High specific heat capacity:** Many hydrogen bonds must be broken to raise temperature; water resists temperature changes (1), buffering aquatic organisms against rapid temperature fluctuations and helping mammals maintain a stable core body temperature (1).
- **High latent heat of vaporisation:** Significant energy is needed to convert liquid water to vapour (1); sweat evaporation absorbs large amounts of heat from the skin, providing effective cooling in endotherms (1).

- **Cohesion and surface tension:** Hydrogen bonds between water molecules create cohesive forces (1); this allows water to form a continuous column in xylem vessels (cohesion-tension mechanism) for transport in tall plants, and provides a surface for small organisms to walk on (1).
- **Excellent solvent:** The polar water molecule surrounds and separates ions and polar molecules (1); metabolites, hormones, and nutrients dissolve in water, allowing blood plasma and cytoplasm to transport substances throughout the organism (1).
- **Maximum density at 4 degrees C / ice less dense than liquid water:** Ice floats on water due to the open lattice structure of hydrogen bonds in ice (1); this insulates bodies of water in winter, allowing aquatic life to survive beneath the ice layer (1).

Q39.

Worked Example: Comparing Diversity

Two forest plots are surveyed:

Plot A:

Species	Individuals (n)	$(n/N)^2$
Oak	40	0.1600
Birch	30	0.0900
Pine	20	0.0400
Elm	10	0.0100
Total	**100**	

$D_A = 1 - (0.1600 + 0.0900 + 0.0400 + 0.0100) = 1 - 0.3000 = 0.700$

Plot B:

Species	Individuals (n)	$(n/N)^2$
Oak	85	0.7225
Birch	5	0.0025
Pine	5	0.0025
Elm	5	0.0025
Total	**100**	

$D_B = 1 - (0.7225 + 0.0025 + 0.0025 + 0.0025) = 1 - 0.7300 = 0.270$

Conclusion: Plot A ($D = 0.700$) has much greater species diversity than Plot B ($D = 0.270$) despite having the same species richness (4 species each). The difference is due to **evenness** — Plot A has a more even distribution of individuals.

Q40.

Question 1 [Classification & Molecular Evidence] [~8 marks]

Scientists compared amino acid sequences of a protein found in five species. The table shows the number of amino acid differences between each pair.

	Species A	Species B	Species C	Species D	Species E
Species A	—	5	12	30	45
Species B	5	—	10	28	43
Species C	12	10	—	25	40
Species D	30	28	25	—	42
Species E	45	43	40	42	—

(a) Using the data, identify which two species are most closely related. Justify your answer. [2]

(b) Explain why molecular evidence is considered more reliable than morphological evidence for determining evolutionary relationships. [3]

(c) Outline how a molecular clock could be used to estimate the time of divergence between Species A and Species D. [3]

▶ Show Solution

Q41.

Question 2 [Natural Selection & Speciation] [~8 marks]

A population of beetles living on a grassland is separated into two groups when a new river forms. The northern group lives on light-coloured sandy soil; the southern group lives on dark volcanic soil. Both groups are preyed upon by birds that hunt by sight.

(a) Using the theory of natural selection, explain how the two populations might develop different body colours over many generations. [4]

(b) Explain the type of speciation that could result from this scenario and the conditions required for speciation to be complete. [2]

(c) Suggest how scientists could test whether the two populations have become separate species. [2]

▶ Show Solution

Q42.

Question 3 [Conservation] [~7 marks]

A tropical island has experienced rapid deforestation for palm oil plantations. Several endemic bird species are now confined to small, isolated forest fragments.

(a) Explain why small, isolated populations are at greater risk of extinction than large, connected populations. [3]

(b) Evaluate the use of in situ and ex situ conservation strategies for protecting the endemic bird species. [4]

▶ Show Solution

Q43.

Worked Example: Explain how the counter-current flow in fish gills maximises oxygen absorption. (4 marks)

1. Water flows over the gill lamellae in one direction while blood flows through capillaries in the **opposite direction**. [1]
2. At every point along the lamella, the O_2 concentration in the water is higher than in the adjacent blood. [1]
3. This maintains a **concentration gradient** along the entire length of the exchange surface. [1]
4. As a result, fish can extract up to **80%** of dissolved oxygen from water — far more than would be possible with concurrent flow, where equilibrium would be reached and net diffusion would stop. [1]

Q44.

Worked Example: Anole lizards in the Caribbean

Five species of *Anolis* lizard coexist on the same Caribbean islands by partitioning their habitat:

- *A. carolinensis* — perches on high branches in the canopy
- *A. distichus* — occupies tree trunks
- *A. sagrei* — forages on lower branches and ground level
- *A. cybotes* — rocky ground habitats
- *A. valencienni* — thin twigs

Each species has evolved different limb proportions and toe pad sizes suited to its microhabitat. This is spatial resource partitioning driven by interspecific competition.

Q45.

Question 1 [Sliding Filament Theory] [~8 marks]

(a) Draw a labelled diagram of a sarcomere in relaxed and contracted states. Identify the I-band, A-band, H-zone, Z-lines, and M-line in both states. (4 marks)

(b) Outline the role of calcium ions, tropomyosin, and troponin in the initiation of muscle contraction. (4 marks)

▶ Show Solution

Q46.

Question 2 [Xerophyte Adaptations] [~6 marks]

A student observes a cross-section of a leaf from a desert plant under the microscope. The leaf has a thick waxy cuticle, sunken stomata with hair-like trichomes, and a tightly rolled structure.

(a) Explain how each of these three features reduces water loss by transpiration. (3 marks)

(b) Distinguish between adaptation and acclimatization, using a named example for each. (3 marks)

▶ Show Solution

Q47.

Question 3 [Ecological Niches and Competition] [~8 marks]

Two species of seed-eating birds, Species A and Species B, live on an island. Species A eats seeds 2—5 mm in diameter; Species B eats seeds 4—7 mm in diameter.

(a) Define the terms *fundamental niche* and *realized niche*. (2 marks)

(b) Identify the region of niche overlap between the two species and predict the outcome according to the competitive exclusion principle. (2 marks)

(c) Explain how resource partitioning and character displacement could allow the two species to coexist. (4 marks)

▶ Show Solution

Q48.

Question 4 [Muscle Contraction and Energy] [~6 marks]

During a 400 m sprint, an athlete's leg muscles initially use aerobic respiration but switch to anaerobic respiration partway through the race.

(a) Explain why the switch to anaerobic respiration occurs. (2 marks)

(b) Describe the lactate pathway and explain why it is essential for continued muscle contraction under anaerobic conditions. (2 marks)

(c) After the race, the athlete continues to breathe heavily. Explain the concept of oxygen debt (excess post-exercise oxygen consumption). (2 marks)

▶ Show Solution

Q49.

Worked Example: CRISPR mechanism steps

A scientist wants to correct the mutation in the *CFTR* gene that causes cystic fibrosis (a single-nucleotide deletion in exon 10, ΔF508).

(a) Describe the role of the guide RNA in CRISPR-Cas9 editing. [2]

(b) Explain which DNA repair pathway the scientist would want to exploit and why. [2]

Part (a) [2 marks]:

- The guide RNA is complementary to the target DNA sequence at the *CFTR* mutation site.
- It directs the Cas9 endonuclease to the correct location in the genome by base-pairing with the target sequence, enabling site-specific cutting.

Part (b) [2 marks]:

- The scientist would use **homology-directed repair (HDR)** by supplying a correct template containing the wild-type *CFTR* sequence.
- NHEJ is error-prone and would likely introduce further disruptive mutations rather than restoring the correct sequence; HDR uses the template to accurately replace the deleted nucleotide.

Q50.

Worked Example: Calculating net water movement

A plant cell has $\Psi_s = -1200\ \mathrm{kPa}$ and $\Psi_p = +400\ \mathrm{kPa}$.

It is placed in a solution with $\Psi = -600\ \mathrm{kPa}$.

(a) Calculate the water potential of the cell. [1]

(b) State the direction of net water movement. [1]

(c) Predict what will happen to Ψ_p as water moves. [2]

Part (a):

$$\Psi_{\text{cell}} = \Psi_s + \Psi_p = -1200 + 400 = -800\ \mathrm{kPa}$$

Part (b): Water moves from the solution ($\Psi = -600\ \mathrm{kPa}$) INTO the cell ($\Psi = -800\ \mathrm{kPa}$) because the solution has higher (less negative) water potential.

Part (c): As water enters the cell, the cell swells and the cell wall exerts greater resistance. Ψ_p (turgor pressure) will **increase** (become more positive). This raises the cell's overall Ψ until equilibrium is reached when $\Psi_{\text{cell}} = \Psi_{\text{solution}}$.

Q51.

Worked Example: miRNA silencing

A researcher identifies a miRNA that targets the mRNA of a growth-promoting protein. When the miRNA is overexpressed in cells, proliferation decreases.

(a) Explain how the miRNA reduces production of the growth-promoting protein. [3]

(b) Suggest what might happen to cell proliferation if the gene encoding this miRNA were mutated and non-functional. [2]

Part (a) [3 marks]:

- The mature miRNA is incorporated into the RISC complex.
- The miRNA is complementary to a sequence in the **3' UTR** of the growth-promoting protein's mRNA.
- RISC binds the target mRNA, leading to either mRNA cleavage and degradation (if perfectly complementary) or blockage of ribosome activity / inhibition of translation (if partially complementary), preventing production of the growth-promoting protein.

Part (b) [2 marks]:

- If the miRNA is non-functional, the target mRNA would be translated at a higher rate (the post-transcriptional silencing mechanism would be lost).
- Increased production of the growth-promoting protein would stimulate cell proliferation, potentially contributing to uncontrolled cell growth/cancer.

Q52.

Question 1 [Mutations and Gene Editing] [~9 marks]

A research group is using CRISPR-Cas9 to correct a missense mutation in the gene *HTT*, which causes Huntington's disease. The mutation is a single nucleotide substitution in exon 36 that introduces a premature stop codon, truncating the huntingtin protein.

(a) Distinguish between a missense mutation and a nonsense mutation. [2]

(b) Outline the mechanism by which CRISPR-Cas9 would be used to correct the mutation in somatic cells. Include the roles of the guide RNA and the Cas9 protein. [4]

(c) Evaluate the ethical considerations of using germline gene editing rather than somatic gene editing to treat Huntington's disease. [3]

▶ Show Solution

Q53.

Question 2 [Water Potential] [~7 marks]

A student places five identical potato cylinders in sucrose solutions of different concentrations. After 30 minutes, the percentage change in mass of each cylinder is measured. The results are shown below.

Sucrose concentration ($\mathrm{mol\ dm^{-3}}$)	% change in mass
0.0	+8.2
0.2	+3.1
0.4	0.0
0.6	-4.5
0.8	-9.2

(a) Identify the water potential of the potato tissue. Explain your reasoning. [2]

(b) A cylinder in the $0.2\ \mathrm{mol\ dm^{-3}}$ solution gained mass. Explain, using the concept of water potential, why water entered the cylinder. [3]

(c) Explain why the student measured percentage change in mass rather than absolute change in mass. [1]

(d) Predict the state of the potato cells in the $0.8\ \mathrm{mol\ dm^{-3}}$ solution. [1]

▶ Show Solution

Q54.

Question 3 [Reproduction and Gene Expression] [~8 marks]

(a) Describe the stages of oogenesis from oogonium to the point of ovulation, including the meiotic stage at which the oocyte is released. [4]

(b) HL Explain how histone acetylation and DNA methylation coordinate to control whether a gene involved in early embryonic development is expressed or silenced. [4]

▶ Show Solution