

Course Companion

International Baccalaureate · IB Diploma · Biology · HL

Every topic handout in one volume

exercises.lol

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Water

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Scope and prerequisites

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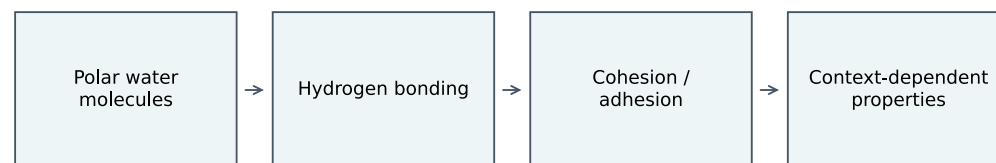
Water: a molecular cause for a biological property

■ What would explain this observation?

- A water droplet holds together on a leaf. Its behaviour comes from interactions between molecules, not a skin made of solid water.

■ Build the model

- Water molecules are polar.
- Attraction between the partially positive hydrogen of one molecule and a partially negative oxygen of another gives hydrogen bonding.
- **Cohesion** is attraction between water molecules; **adhesion** is attraction to another surface.
- cohesion: Attraction between molecules of the same substance.
- adhesion: Attraction between different substances.



Water: a molecular cause for a biological property: original worked-case diagram

■ Choose evidence that can test it

- The same intermolecular interactions help explain surface tension and the energy needed to change temperature.
- Heating changes molecular motion and interactions; it does not normally break the covalent O–H bonds.

In the lab: Compare equal drops on clean surfaces under fixed temperature. Measure contact angle or spreading consistently. A detergent changes the system, so record concentration rather than treating all liquids as equivalent.

■ Work from known quantities

- Known: 0.100 kg of water warms by 5.0 K; specific heat capacity is 4,180 J/(kg K).
- $Q = mc\Delta T = 0.100 \times 4,180 \times 5.0 = 2,090 \text{ J}$.
- This calculation excludes energy absorbed by the container and lost to the surroundings.

Your turn: Use $c = 4,180 \text{ J/(kg K)}$. Calculate Q for 0.200 kg water heated through 5.0 K.

■ Check the conclusion and its limits

- Hydrogen bonds between molecules differ from covalent bonds within a water molecule.
- Polarity alone does not make every substance dissolve well in water.

Not true: Boiling water normally breaks its O–H covalent bonds. Boiling separates molecules from each other, overcoming intermolecular hydrogen bonds. The covalent O-H bonds inside each molecule survive - the steam is still H₂O.

Key:

- Water molecules are polar.
- The same intermolecular interactions help explain surface tension and the energy needed to change temperature.
- Watch for: hydrogen bonds between molecules differ from covalent bonds within a water molecule.

■ Write from a heat transfer of 2508 J

- 0.200 kg of water is heated through 3.0 K. Use 4180 J per kilogram per kelvin.
- Find Q . Boiling separates molecules. It does not break the covalent O-H bonds.

Nucleic acids

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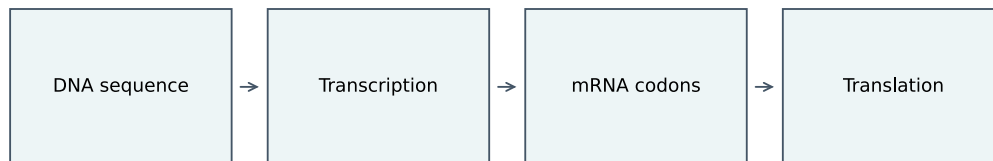
DNA, protein synthesis and evidence

■ What would explain this observation?

- A change in DNA can affect a protein, but not every DNA change changes the amino-acid sequence. The effect depends on the sequence and how it is used.
-

■ Build the model

- DNA stores information in a base sequence.
- Complementary base pairing supports copying.
- During gene expression, **transcription** makes RNA and **translation** uses codons to assemble an amino-acid sequence.
- transcription: Formation of RNA using a DNA template.
- translation: Formation of a polypeptide using an mRNA sequence.



DNA, protein synthesis and evidence: original worked-case diagram

■ Choose evidence that can test it

- A codon comprises three bases.
- The genetic code is degenerate: more than one codon can specify the same amino acid.
- A substitution can therefore be silent, while insertions or deletions can shift the reading frame.

In the lab: Keep DNA template, coding DNA and mRNA distinct. State the strand used and write sequences in the required direction. Use a codon table for mRNA, not an unexplained DNA triplet.

■ Work from known quantities

- Known: an mRNA coding region contains 90 bases, including one stop codon.
- Codons = bases/3 = $90/3 = 30$.
- A stop codon does not encode an amino acid, so the peptide contains 29 amino acids under this stated model.

Your turn: A coding mRNA segment has 63 bases including a stop codon. Find peptide length.

■ Check the conclusion and its limits

- The number of bases is not automatically the number of amino acids.
- Real genes include regulatory regions and, in eukaryotes, often introns; a whole gene length is not a peptide-length calculation.

Not true: Each DNA base encodes one complete amino acid. Amino acids are encoded by triplets of bases (codons), not by single bases. Three bases specify one amino acid, and a stop codon specifies none.

Key:

- DNA stores information in a base sequence.
- A codon comprises three bases.
- Watch for: the number of bases is not automatically the number of amino acids.

■ Write from a peptide of 23 amino acids

- An mRNA coding region has 72 bases, including one stop codon.
- Find the number of amino acids. A substitution can be silent.

Origins of cells

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Origins of cells: evidence and limits

■ What would explain this observation?

- Mitochondria have their own DNA and divide within cells. These features invite an evolutionary explanation that can be tested against other evidence.
-

■ Build the model

- The endosymbiotic model explains mitochondria and chloroplasts as descendants of bacteria living within another cell lineage.
- Double membranes, ribosomes, DNA and division provide several lines of evidence.
- This model is distinct from a complete explanation for the origin of the first life.
- **endosymbiosis** : One organism living within another in an evolutionary association.
- **inference** : An explanation drawn from observations and reasoning.



Origins of cells: evidence and limits: original worked-case diagram

■ Choose evidence that can test it

- Independent observations strengthen a model when they make a consistent prediction.
- Similarity is evidence to evaluate alongside ancestry, sequence comparisons and alternative explanations, rather than proof from one feature.

In the lab: Use attributed micrographs and sequence data. Separate observations from inferences in a table. Check whether each comparison concerns a mitochondrion, chloroplast, bacterial cell or eukaryotic nucleus.

■ Work from known quantities

- Known: 18 of 24 compared sequence sites are identical.
- Identity = $18/24 \times 100 = 75\%$.
- Identity across this short alignment cannot alone date an evolutionary split or establish that one organism is the direct ancestor of another.

Your turn: 21 of 28 compared sites match. Calculate percentage identity.

■ Check the conclusion and its limits

- The endosymbiotic model does not say that every organelle arose from an engulfed bacterium.
- A laboratory model of early chemistry is not a recreation of the whole historical event.

Not true: One matching sequence proves the complete origin of life. One sequence match is one piece of evidence about one locus. Origins models rest on many independent lines - DNA, ribosomes, membranes, biochemistry - not a single comparison.

Key:

- The endosymbiotic model explains mitochondria and chloroplasts as descendants of bacteria living within another cell lineage.
- Independent observations strengthen a model when they make a consistent prediction.
- Watch for: the endosymbiotic model does not say that every organelle arose from an engulfed bacterium.

■ Write from an identity of 80 percent

- 16 of 20 compared sequence sites are identical.
- Find the percentage identity. Say what that percentage does not prove.

Cell structure

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Cell measurements and scale

■ What would explain this observation?

- A cell can look larger on a screen without changing its real size. Two photographs at different zoom settings cannot be compared by eye alone.

■ Build the model

- Eukaryotic cells contain a nucleus.
- Prokaryotic cells have genetic material but no membrane-bound nucleus.
- A bacterial cell is a living cell; a virus depends on a host cell to reproduce.
- **magnification** : Image length divided by actual length.
- **resolution** : Ability to distinguish two close points.

Measured image length = 30 mm

Real cell length = 50 μm

Scale must be stated

Cell measurements and scale: original worked-case diagram

■ Choose evidence that can test it

- A scale bar provides a known real distance in the same image.
- Convert the image length and real length to the same unit before dividing.
- Magnification is a ratio and has no unit.

In the lab: Focus a prepared slide at low power first. Move to a higher power and use fine focus. Make a clear line drawing, label structures with straight lines, and record the scale rather than shading the image.

■ Work from known quantities

- Known: a cell image is 30 mm long and represents a 50 micrometre cell.
- Use magnification = image size / actual size.
- Convert 30 mm to 30,000 micrometres.
- Magnification = $30,000 / 50 = 600$.
- A separate 10 mm scale bar representing 20 micrometres gives $10,000 / 20 = 500$, and that magnification applies to every object in its image.

Your turn: An image is 12 mm long; the cell is 40 micrometres long. Calculate magnification.

■ Check the conclusion and its limits

- A nucleus is not the only cell structure.
- Do not claim bacteria have no DNA, or that more magnification always means better resolution.

Not true: Every bacterial cell has a membrane-bound nucleus. Bacterial cells are prokaryotic: their genetic material lies free in the cytoplasm, not inside a membrane-bound nucleus. Only eukaryotic cells have a true nucleus.

Key:

- Eukaryotic cells contain a nucleus.
- A scale bar provides a known real distance in the same image.
- Watch for: A nucleus is not the only cell structure.

■ Write from a magnification of 750

- An image of a cell is 15 mm long. The cell is 20 micrometres long.
- Find the magnification. A scale bar is a real distance, not a decoration.

Viruses

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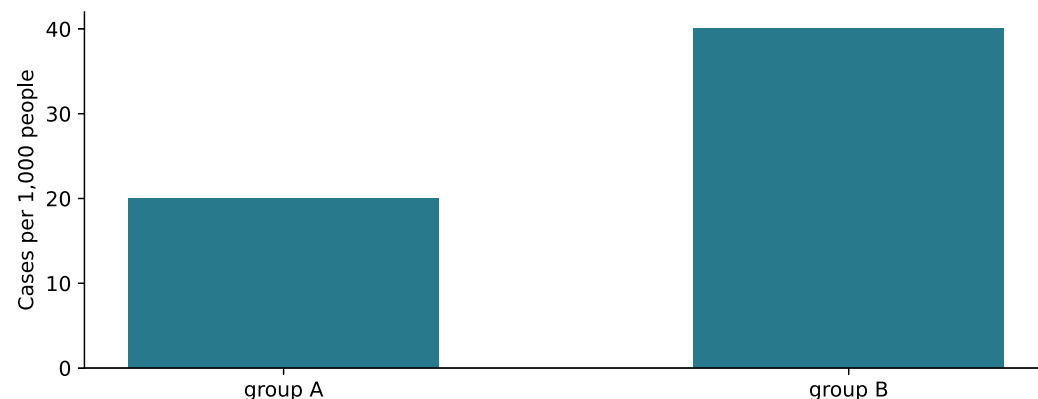
Disease transmission and immune response

■ What would explain this observation?

- An antibiotic may help against a bacterial infection but fail against a viral illness. Treatment depends on the causal organism and the evidence supporting diagnosis.
-

■ Build the model

- **Pathogens** cause infectious disease.
- Physical barriers, phagocytosis and specific immune responses reduce infection.
- Antibodies bind particular **antigens**.
- Vaccination exposes the immune system to antigen safely enough to develop memory.
- pathogen : An agent that causes disease.
- antigen: A structure recognized by a specific immune response.



Disease transmission and immune response: original worked-case diagram

■ Choose evidence that can test it

- After vaccination, memory cells can support a faster secondary response.
- Antibiotic resistance arises through heritable variation and selection; an individual bacterium does not choose to become resistant because it needs to survive.

In the lab: Use published infection data to compare rates per equal population size. Distinguish prevalence at a time from new cases over a period. In school, use safe simulations or approved cultures rather than collecting unknown pathogens.

■ Work from known quantities

- Known: 18 cases occur in 900 people.
- Rate per 1,000 = cases / population $\times$ 1,000.
- Rate = $18/900 \times 1,000 = 20$ cases per 1,000.
- A second group with 10 cases in 250 people has 40 per 1,000, even though it has fewer cases.

Your turn: 12 cases occur among 600 people. Find cases per 1,000 people.

■ Check the conclusion and its limits

- Antibiotics do not act on viruses in the same way they act on bacteria.
- A vaccine is not an immediate cure for an established infection.

Not true: Every antibiotic is effective against every viral infection. Antibiotics act on bacterial structures and processes that viruses do not have, so they cannot cure a viral infection. Using them against viruses adds selection pressure for resistance without benefit.

Key:

- Pathogens cause infectious disease.
- After vaccination, memory cells can support a faster secondary response.
- Watch for: antibiotics do not act on viruses in the same way they act on bacteria.

■ Write from 16 cases per 1000

- 8 cases occur among 500 people.
- Find the rate per 1000. A smaller case count can still be a higher rate.

Diversity of organisms

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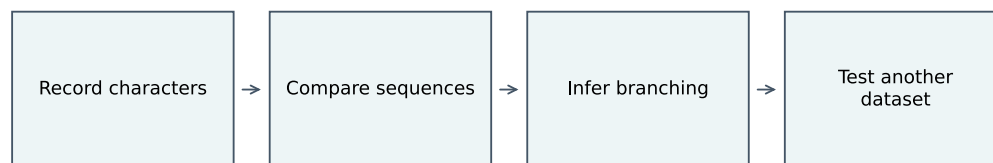
Diversity, classification and a branching model

■ What would explain this observation?

- Two species look similar but their DNA comparison places them in different branches. Classification uses several kinds of evidence rather than appearance alone.
-

■ Build the model

- A species is a biological grouping; a **taxon** is a named classification group.
- A cladogram represents a hypothesis of relationships based on shared derived characteristics or molecular evidence.
- A branch point represents a common ancestor, not an individual alive today.
- **taxon**: A named group in a classification.
- **clade** : A common ancestor and all its descendants.



Diversity, classification and a branching model: original worked-case diagram

■ Choose evidence that can test it

- Read relationships from the branching order.
- Rotating branches at a node does not change ancestry.
- A branch length represents time or change only when the diagram gives a scale.

In the lab: Record character states in a matrix before drawing a tree. Define which state is ancestral using an appropriate comparison. Test whether a new molecular dataset supports the same grouping.

■ Work from known quantities

- Known: an alignment contains 40 sites, with 6 differences.
- Difference proportion = $6/40 = 0.15$, or 15%.
- This is an observed comparison, not a calibrated molecular clock unless rate assumptions and corrections are supplied.

Your turn: There are 8 differences in 50 aligned sites. Calculate percentage difference.

■ Check the conclusion and its limits

- A modern species is not automatically the ancestor of another modern species.
- Similarity caused by convergent evolution can mislead a classification based on one trait.

Not true: Every cladogram branch length is a measurement of elapsed time. Branch lengths mean time only in trees explicitly drawn with a time or change scale. Many cladograms encode relationships only, with arbitrary lengths.

Key:

- A species is a biological grouping; a taxon is a named classification group.
- Read relationships from the branching order.
- Watch for: A modern species is not automatically the ancestor of another modern species.

■ Write from a difference of 28 percent

- An alignment has 7 differences in 25 sites.
- Find the percentage difference. Say what rotating a branch does.

A.3.2 · Classification and cladistics

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Prerequisites: diversity of organisms from A.3.1 and DNA sequences from A.1.2.

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Classification and cladistics

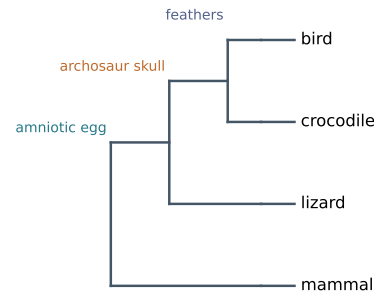
■ What would explain this observation?

- Birds were once classed far from reptiles, yet their DNA and skull bones place them next to crocodiles. Which evidence should decide the grouping?
-

■ Build the model

- **Classification** places every species in the nested hierarchy: domain, kingdom, phylum, class, order, family, genus, species, named by the **binomial system** (genus name + a second word identifying the species, as in *Homo sapiens*).
Cladistics groups organisms by **shared derived characters** – features that appeared in a common ancestor – drawn as a **cladogram** whose branching nodes represent common ancestors.
- Molecular evidence such as DNA sequence differences usually decides between competing trees. Rotating two branches at a node changes nothing: the branching pattern, not the left-right order, records the relationships.
- classification: Placing organisms into nested groups by shared features; binomial system: The naming of a species with its genus name followed by a second identifying word; shared derived character: A feature inherited from the group's most recent common ancestor; cladogram: A branching diagram of relationships built from shared derived characters.

A cladogram: shared derived characters define each clade



Rotating at a node changes nothing about the relationships

Molecular evidence counts differences

8 differences in 50 aligned sites
 $8/50 \times 100 = 16\%$

fewer differences →
a more recent shared ancestor

An observed percentage is not a molecular clock
without rate assumptions

Shared derived characters define each clade; fewer sequence differences suggest a more recent common ancestor

■ Choose evidence that can test it

- Build the tree from a character matrix first, then ask whether a NEW dataset (for example a DNA sequence) reproduces the same groupings; independent agreement is the strongest support.
- A single visible feature can mislead through convergent evolution – distantly related animals evolve similar shapes for similar lives – so one trait alone never defines a clade.

■ Work from known quantities

- Known: two aligned DNA sequences differ at 8 of 50 sites. Percentage difference = differences / sites $\times 100 = 8/50 \times 100 = 16\%$. A third species differing at only 5 of 50 sites (10%) shares a more recent ancestor with the second sequence than the first does.

Example:

Another alignment shows 6 differences in 40 sites. Find the percentage difference using the same sequence: known quantities → model → relation → substitution → unit and interpretation. (Answer: $6/40 \times 100 = 15\%$. The percentage is an observed comparison, not a calibrated molecular clock – dating a split needs rate assumptions.)

■ Check the conclusion and its limits

- A cladogram is a hypothesis of relationships, revisable when better evidence arrives. The observed percentage difference ignores multiple changes at the same site, so it underestimates true divergence for distant pairs.

Warn:

A modern species at one branch tip is the ancestor of the species at another tip. This claim is false: every tip is a modern descendant; the nodes represent shared ancestors that no longer exist. Birds are descended from archosaur ancestors – they are not descended from today's crocodiles.

Key:

Classification and cladistics: nested groups from domain to species, named binomially; cladograms group by shared derived characters, with molecular differences as decisive evidence. Count differences as a percentage, and read the branching – never the tip order – as the relationship.

■ Write from 20 percent difference

- Two aligned DNA sequences differ at 12 of 60 sites.
- Find the percentage difference: $12 \div 60 \times 100 = 20$ percent.

■ Write from the closest pair

- Species C differs from B at 3 of 50 sites and from A at 12 of 50 sites.
- Say which two share the more recent common ancestor: C with B (6 percent against 24 percent – the smaller divergence, the closer the node).

■ Write from a tip-order trap

- A cladogram draws X and Y on adjacent tips, Z further away.
- Does X descend from Y? No – tips are modern cousins; their shared NODE is the ancestor, and rotating branches changes nothing.

Evolution and speciation

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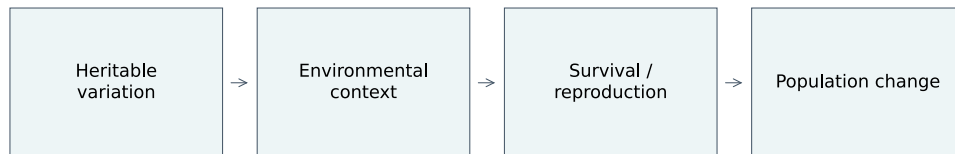
Adaptation : a function in an environment

■ What would explain this observation?

- Leaves in dry environments often have features that reduce water loss. The value of a feature depends on environmental conditions and trade-offs.

■ Build the model

- An **adaptation** is a heritable feature associated with improved survival or reproduction in particular conditions.
- A thick cuticle can reduce evaporation; stomatal control affects gas exchange and water loss.
- Acclimatization** is an individual response during life and is different from evolutionary adaptation.
- adaptation: A heritable feature benefiting survival or reproduction in a context.
- acclimatization: An individual adjustment to changed conditions during life.



Adaptation: a function in an environment: original worked-case diagram

■ Choose evidence that can test it

- Explain both a benefit and a cost.
- Reducing stomatal opening conserves water but can limit carbon dioxide entry.
- A feature cannot be judged as universally best without its ecological context.

In the lab: Compare replicated observations across a measured environmental gradient. Account for relatedness, leaf area and age. Use local permitted plant observations rather than removing protected species.

■ Work from known quantities

- Known: water loss is 12 g from 0.20 square metres of leaf area over 2 h.
- Area-time-normalized rate = $12 / (0.20 \times 2) = 30 \text{ g}/(\text{m}^2 \text{ h})$.
- Comparisons require the same humidity and temperature.

Your turn: Water loss is 8 g from 0.20 m² over 2 h. Calculate rate per area per hour.

■ Check the conclusion and its limits

- An individual organism does not evolve a new inherited trait because it needs it.
- A plausible story about function is a hypothesis requiring evidence.

Not true: Every useful individual response is evidence of a newly evolved inherited trait. Evolution acts on populations over generations through heritable variation and selection. An individual's useful acquired response is not inherited and is not evidence that a new trait evolved.

Key:

- An adaptation is a heritable feature associated with improved survival or reproduction in particular conditions.
- Explain both a benefit and a cost.
- Watch for: an individual organism does not evolve a new inherited trait because it needs it.

■ Write from a water-loss rate of 15 grams per square metre per hour

- Water loss is 15 g from 0.25 square metres over 4 hours.
- Find the rate per area per hour. A smaller stomatal opening saves water and can limit carbon dioxide.

Conservation of biodiversity

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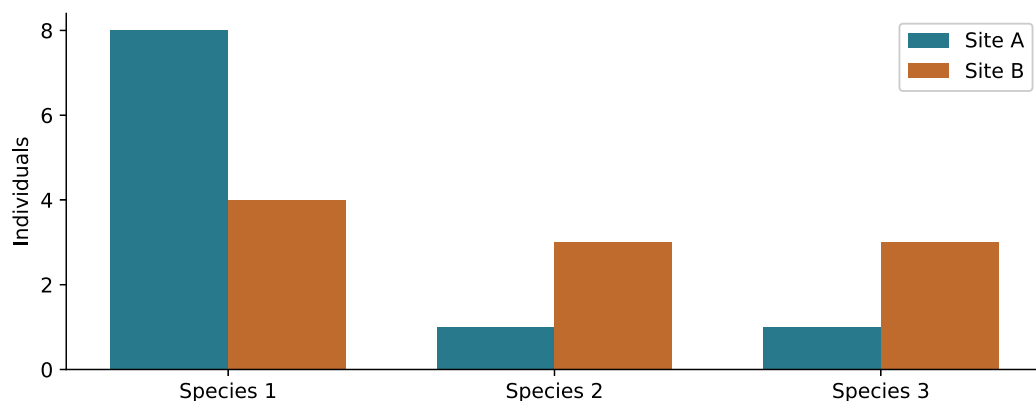
Biodiversity, conservation and sampling evidence

■ What would explain this observation?

- A site with many individuals can still be dominated by one species. Abundance, richness and **evenness** describe different features of biodiversity.

■ Build the model

- **Species richness** counts species.
- Evenness concerns relative abundance.
- Conservation can protect habitats, populations or genetic diversity; a management judgement must state the conservation goal.
- species richness: The number of species recorded.
- evenness: How evenly individuals are distributed among species.



Biodiversity, conservation and sampling evidence: original worked-case diagram

■ Choose evidence that can test it

- Compare surveys with similar area, effort, season and identification rules.
- A diversity index is meaningful only with its formula and conventions specified.
- Habitat fragmentation can affect movement and gene flow even when total area changes little.

In the lab: Use non-destructive field sampling approved by the school. Identify organisms with a suitable key and record uncertain identifications rather than inventing species. Combine ecological evidence with stakeholder perspectives on land use.

■ Work from known quantities

- Known: site A has counts 8, 1 and 1; site B has 4, 3 and 3.
- Both have richness 3 and total abundance 10.
- The most abundant species occupies 80% in A and 40% in B.
- B is more even under these counts.

Your turn: A survey records 6, 5, 3 and 2 individuals in four species. Find species richness.

■ Check the conclusion and its limits

- An index cannot by itself explain the cause of a difference.
- A newly recorded species may reflect improved observation rather than a recent ecological arrival.

Not true: A larger total number of individuals always means greater species richness. Richness counts how many species are present, not how many individuals. Ten thousand individuals of one species give richness 1, while ten species with one individual each give richness 10.

Key:

- Species richness counts species.
- Compare surveys with similar area, effort, season and identification rules.
- Watch for: an index cannot by itself explain the cause of a difference.

■ Write from a richness of 6

- Counts are 5, 2, 2, 1, 1 and 1.
- Find the species richness. Say why the total of 12 is not the richness.

Carbohydrates and lipids

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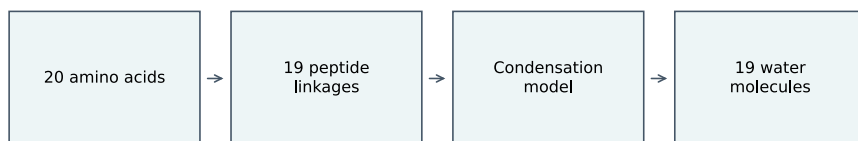
Biomolecule structure: bonds, polarity and function

■ What would explain this observation?

- Starch, a triglyceride and a protein can all contain carbon, hydrogen and oxygen, yet their structures and functions differ. An element list alone does not identify a biomolecule.

■ Build the model

- Carbohydrates include monosaccharides and polymers joined by glycosidic bonds.
- A triglyceride has glycerol joined to three fatty acids by ester bonds.
- Proteins contain amino-acid residues joined by **peptide bonds**; side chains and folding contribute to their properties.
- These structures support storage, membrane or functional roles depending on the molecule.
- peptide bond : A covalent linkage between amino-acid residues.
- hydrolysis** : Breaking a linkage using water.



Biomolecule structure: bonds, polarity and function: original worked-case diagram

■ Choose evidence that can test it

- Condensation forms a linkage with a small molecule such as water released in the simplified model; hydrolysis uses water to break such a linkage.
- Polymer sequence, branching, polarity and three-dimensional shape matter.
- Saturated fatty acids have no carbon-carbon double bond, while unsaturated fatty acids have at least one; this difference can influence packing under stated conditions.

In the lab: Use labelled molecular models and identify the actual linkage rather than memorizing shapes alone. Compare an attributed structure with the proposed function, mark polar and non-polar regions where justified, and distinguish a monomer from a residue within a polymer. Food tests provide evidence of chemical groups under specific conditions, not complete molecular structures.

■ Work from known quantities

- Known: a single unbranched peptide formed from 20 amino acids contains 19 peptide linkages.
- In a simplified condensation accounting model, forming these links releases 19 water molecules.
- A triglyceride formed from one glycerol and three fatty acids has three ester linkages and releases three waters in the corresponding model.
- These are linkage counts, not complete pathways in living cells.

Your turn: A single unbranched peptide contains 35 amino-acid residues. How many peptide bonds join them?

■ Check the conclusion and its limits

- Not every protein is an enzyme, and not every catalyst is a protein.
- Lipids are not all polymers of repeating monomers.
- A protein can lose function when its folding changes without every peptide bond being broken.

Not true: Every protein is an enzyme and every lipid is a repeating-monomer polymer. Enzymes are one functional class of protein; structural and transport proteins are not enzymes. And lipids such as triglycerides are built from unlike parts, not repeating monomers, so they are not polymers.

Key:

- Carbohydrates include monosaccharides and polymers joined by glycosidic bonds.
- Condensation forms a linkage with a small molecule such as water released in the simplified model; hydrolysis uses water to break such a linkage.

- Watch for: not every protein is an enzyme, and not every catalyst is a protein.

■ Write from 27 peptide bonds

- A single unbranched peptide has 28 amino-acid residues.
- Find the number of peptide bonds. Condensation releases water in the simplified model.

■ Write from 23 bonds after cleavage

- A second peptide of 30 residues has its first 6 residues removed as a signal sequence.
- Find the peptide bonds in the mature chain: 24 residues remain, so 23 bonds.

■ Write from 3 waters for full hydrolysis

- A tetrasaccharide of four monosaccharides is completely hydrolysed.
- Say how many water molecules are used: three glycosidic bonds ($n - 1$, the peptide's rule), so three waters – one per bond broken.

B.1.2 · Proteins

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL/SL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: amino-acid structure and condensation reactions from B.1.1 (carbohydrates and lipids), and microscopy units from B.1.

The examples are original and fictional: they are not real measurements or real student investigations.

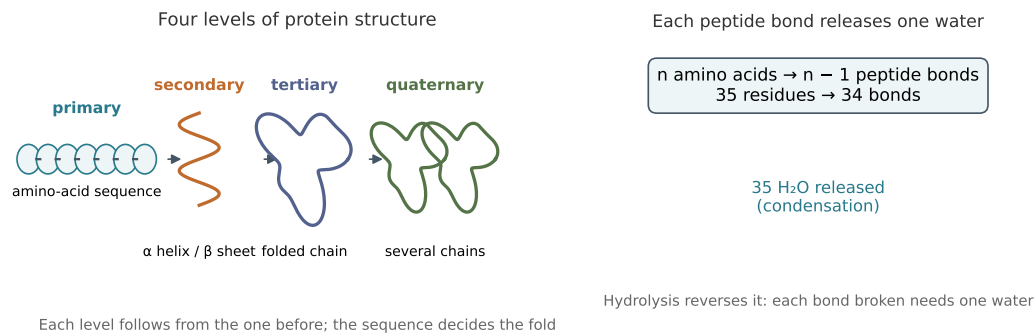
Proteins

■ What would explain this observation?

- An egg white turns from clear runny liquid to firm white solid when heated – and cooling never turns it back. What happened to its proteins?

■ Build the model

- Proteins are chains of amino acids joined by **peptide bonds** in condensation reactions; each bond forms with the loss of one water molecule. The chain order is the **primary structure**, which folds into local helices and sheets (secondary), then into a working three-dimensional shape (tertiary), sometimes with several chains together (quaternary).
- The twenty R groups differ in charge and polarity, so the sequence decides the fold. Heating or extreme pH breaks the weak bonds holding the fold – **denaturation** – while the peptide bonds survive; the protein unravels and loses its function, which is why the egg does not run again on cooling.
- peptide bond: The covalent link between two amino acids, formed with the loss of water; primary structure: The sequence of amino acids in a protein chain; denaturation: The loss of a protein's working shape when its weak structure bonds break.



Proteins: original worked-case diagram

■ Choose evidence that can test it

- The Biuret test identifies peptide bonds: it turns from blue to purple with protein but not with free amino acids. Use it to check whether a sample contains peptide linkages.
- Compare an enzyme's activity before and after heating, keeping substrate and pH constant: a lasting loss of activity after cooling supports permanent denaturation, not just a reversible pause.

■ Work from known quantities

- Known: a peptide chain contains 35 amino-acid residues joined in one unbranched chain. Each link between two neighbours is one peptide bond, so bonds = residues - 1 = 35 - 1 = 34. Each bond formed by condensation releases one water molecule, so 34 water molecules were released when this chain formed.

Example:

A different chain contains 120 amino-acid residues. Find the number of peptide bonds and the number of water molecules released during its formation, using the same sequence: known quantities $\rightarrow$ model $\rightarrow$ relation $\rightarrow$ substitution $\rightarrow$ unit and interpretation. (Answer: bonds = 120 - 1 = 119; waters released = 119. Hydrolysis back to single amino acids would need 119 water molecules.)

■ Check the conclusion and its limits

- The bond count assumes a single unbranched chain; real proteins may be branched or cross-linked by disulfide bridges, which are not peptide bonds. Denaturation is usually irreversible in food but some small proteins can refold under careful laboratory conditions.

Warn:

Heating denatures a protein by breaking its peptide bonds. This claim is false: denaturation breaks the weaker hydrogen bonds and interactions that hold the fold; the peptide bonds of the primary structure survive, which is why the amino-acid sequence is unchanged in a cooked egg.

Key:

Proteins: amino acids join by peptide bonds through condensation, releasing one water per bond (n residues $\rightarrow$ n-1 bonds). The sequence folds through secondary and tertiary structure into the working shape; denaturation destroys the fold, not the chain.

Membranes and membrane transport

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

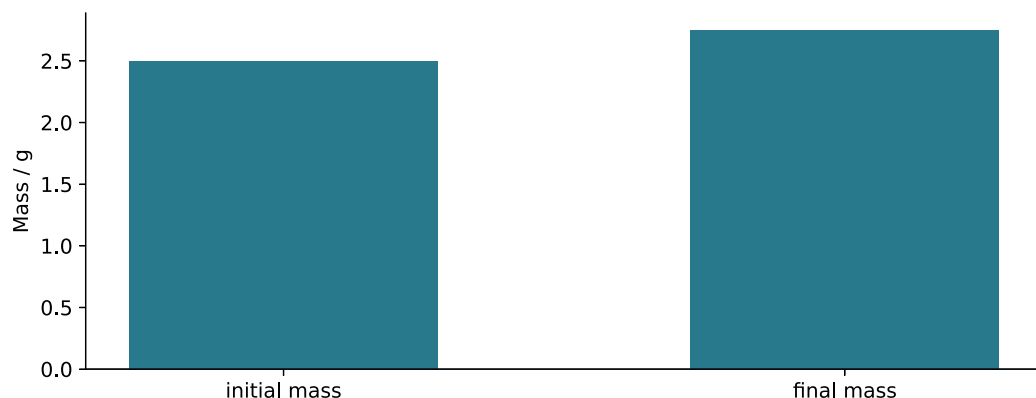
Osmosis and a fair potato experiment

■ What would explain this observation?

- A potato cylinder gains mass in one solution and loses mass in another. Its mass change provides evidence about movement of water, rather than movement of potato tissue.

■ Build the model

- **Osmosis** is the net movement of water through a partially permeable membrane from a more dilute solution to a more concentrated solution.
- Dissolved solutes can change the direction of net water movement.
- osmosis: Net water movement through a partially permeable membrane.
- **control variable** : A factor kept constant for a fair comparison.



Osmosis and a fair potato experiment: original worked-case diagram

■ Choose evidence that can test it

- Use percentage change to compare samples with different initial masses.
- A zero percentage change estimates a solution concentration with no net water movement.
- This is an estimate from a trend, not proof that water molecules stop moving.

In the lab: Use equal-length cylinders from similar tissue, fixed solution volume, temperature and immersion time. Blot each cylinder in the same way before weighing. Repeat each concentration and plot mean percentage change against concentration.

■ Work from known quantities

- Known: initial mass 2.50 g; final mass 2.75 g.
- Use percentage change = $(\text{final} - \text{initial}) / \text{initial} \times 100$.
- Percentage change = $(2.75 - 2.50) / 2.50 \times 100 = +10\%$.
- A positive value means net water entry.
- Interpolate the concentration where the plotted trend crosses zero.

Your turn: A 4.00 g cylinder ends at 3.60 g. Find percentage mass change.

■ Check the conclusion and its limits

- Blotting removes surface solution.
- Weighing a wet cylinder without blotting adds liquid that did not enter the cells.
- Repeats reduce random variation but do not correct a miscalibrated balance.

Not true: At zero net water movement no water molecules cross the membrane. Zero NET movement means water molecules cross the membrane in both directions at equal rates. Molecules never stop moving; only the net transfer is zero.

Key:

- Osmosis is the net movement of water through a partially permeable membrane from a more dilute solution to a more concentrated solution.
- Use percentage change to compare samples with different initial masses.
- Watch for: blotting removes surface solution.

■ Write from a gain of 25 percent

- A potato cylinder starts at 6.40 g and ends at 8.00 g.
- Find the percentage change. Say what a result of 0 percent would estimate.

B.2.2 · Organelles and compartmentalization

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL/SL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: cell structure from A.2.2 and membrane transport from B.2.1.

The examples are original and fictional: they are not real measurements or real student investigations.

Organelles and compartmentalization

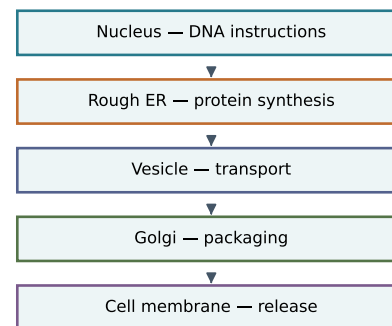
■ What would explain this observation?

- A pancreatic cell that secretes enzymes is packed with rough endoplasmic reticulum and Golgi bodies, while a skin cell has very few. Why should a cell's contents reflect its job?

■ Build the model

- A eukaryotic cell divides its work among membrane-bound **organelles**: the nucleus stores the DNA instructions, the rough endoplasmic reticulum synthesises proteins for export, the Golgi body modifies and packages them, vesicles carry them, and mitochondria release energy by respiration.
- Compartmentalization** keeps each process at its own conditions: enzymes and substrates are concentrated in one place, damaging reactions are contained, and incompatible pH or chemistry can coexist in one cell. Lysosomes, for example, hold digestive enzymes away from the cytoplasm.
- organelle: A specialised structure inside a cell with a specific function; many organelles are enclosed by membranes.
- compartmentalization: The division of a cell into membrane-bound regions, each with its own conditions.

The secretory pathway: one compartment per job



Scale check: image ÷ actual = magnification

image of mitochondrion: 30 mm

actual length: 50 µm

30 mm = 30 000 µm

M = 30 000 / 50 = ×600

Convert both lengths to the same unit before dividing

A secreted protein passes compartment to compartment; magnification = image ÷ actual = ×600

■ Choose evidence that can test it

- Compare electron micrographs of a secretory cell and a non-secretory cell: the model predicts far more rough ER and Golgi in the secretory one. Identify each organelle from its membranes and shape, not from colour – micrographs are greyscale.
- Use a scale bar or the stated magnification to measure an organelle: convert the image length and the real length to the same unit before dividing, so the comparison is of real sizes.

■ Work from known quantities

- Known: a mitochondrion's image is 30 mm long and the scale information says the real length is 50 µm. Use magnification = image size / actual size. Convert: 30 mm = 30,000 µm. Substitution: M = 30,000 / 50 = ×600. The image is 600 times the real organelle; the ratio has no unit.

Example:

On the same micrograph, a vesicle image measures 4 mm. Find its real diameter using the same sequence: known quantities → model → relation → substitution → unit and interpretation. (Answer: actual = image / magnification = 4 mm / 600 = 0.0067 mm ≈ 6.7 µm. Keep the units with every value.)

■ Check the conclusion and its limits

- A static micrograph shows structure, not movement: the vesicle pathway is inferred from many images and labelling experiments, not seen in one frame. Magnification arithmetic assumes the stated scale is accurate; a misread scale bar corrupts every measurement from that image.

Warn:

Every cell contains the same organelles in the same amounts. This claim is false: cells are specialised – a secretory cell invests in rough ER and Golgi while a red blood cell abandons its nucleus entirely to carry more haemoglobin. Organelle content follows the cell’s role.

Key:

Organelles and compartmentalization: organelles divide the cell’s work, and this division lets each process run at its own conditions. The secretory pathway runs nucleus → rough ER → vesicle → Golgi → membrane; measure structures with image ÷ actual in one unit.

■ **Write from a magnification of 200**

- An organelle images at 24 mm; its actual length is 120 micrometres.
- Find the magnification: $24\text{ mm} = 24,000\text{ micrometres}$; $24,000 \div 120 = \times 200$ – one unit before dividing.

■ **Write from a 30 mm image**

- A structure 2 micrometres long is drawn at $\times 15,000$.
- Find the image size: $2 \times 15,000 = 30,000\text{ micrometres} = 30\text{ mm}$.

■ **Write from organelle abundance**

- A pancreas cell exports enzymes; a muscle cell contracts repeatedly.
- Name the dominant organelle in each: rough ER and Golgi in the secretory cell; mitochondria in the muscle – organelle content follows the cell’s role.

Cell specialization

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

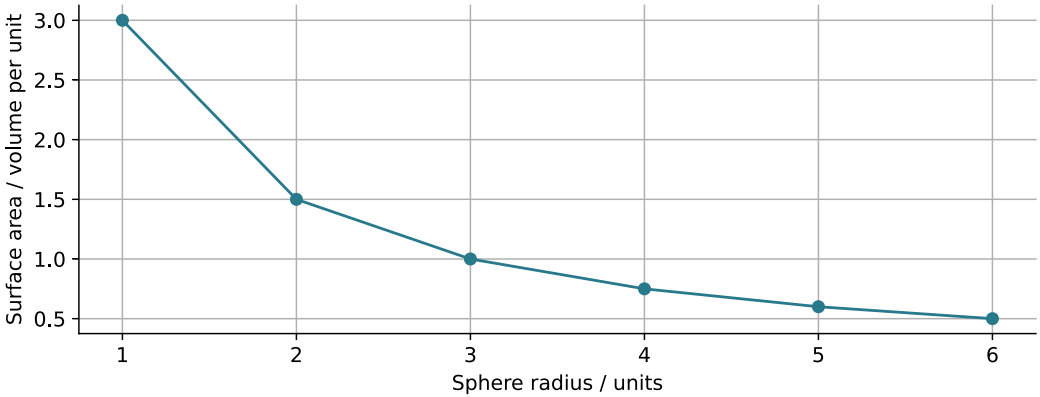
Specialized cells: structure linked to function

■ **What would explain this observation?**

- A root-hair cell and a red blood cell have different shapes because their functions impose different demands.

■ **Build the model**

- **Differentiation** produces specialized cells through different patterns of **gene expression**.
- A root-hair extension increases exchange area.
- A mammalian red blood cell lacks a nucleus at maturity and contains haemoglobin; this is a specific adaptation, not a rule for all animal cells.
- differentiation: Development of specialized cell structure and function.
- gene expression: Use of genetic information to produce a functional product.



Specialized cells: structure linked to function: original worked-case diagram

■ Choose evidence that can test it

- Link a named feature to a mechanism and then to the function.
- Increased area can support exchange, but membrane proteins, gradients and metabolic demand also matter.
- Stem cells retain different degrees of developmental potential.

In the lab: Compare scaled drawings of named cells. Label the structure, state the function and explain the causal link. Use tissue-specific examples rather than saying every specialized cell has every adaptation.

■ Work from known quantities

- Known: a spherical model cell has radius 2 units.
- Surface area/volume = $3/r = 1.5$ per unit.
- A radius of 4 gives 0.75 per unit.
- Doubling radius halves this ratio, even though total area increases.

Your turn: For a sphere, surface area/volume = $3/r$. Find this ratio when $r = 6$ units.

■ Check the conclusion and its limits

- Specialization does not usually require a cell to lose most of its genes.
- The spherical calculation models geometry; it does not describe every actual cell shape.

Not true: All mature animal cells lack a nucleus. Most mature animal cells keep their full genome and nucleus; only a few exceptions, such as mammalian red blood cells, lose the nucleus. Specialization comes from gene expression, not gene loss.

Key:

- Differentiation produces specialized cells through different patterns of gene expression.
- Link a named feature to a mechanism and then to the function.
- Watch for: specialization does not usually require a cell to lose most of its genes.

■ Write from a surface-to-volume ratio of 0.30

- A spherical model cell has radius 10 units. Use surface area over volume = 3 over r .
- Find the ratio. Doubling the radius halves this ratio.

Gas exchange

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

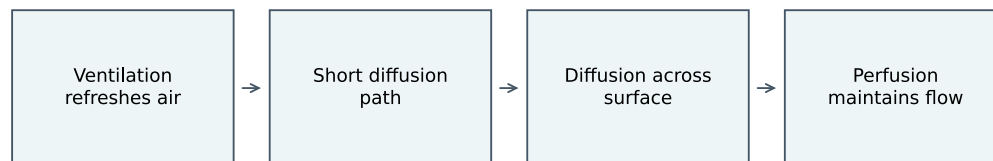
Gas exchange: maintaining diffusion gradients

■ What would explain this observation?

- An exchange surface can be very thin yet fail to deliver enough oxygen when **ventilation** or blood flow falls.

■ Build the model

- Gas exchange occurs by diffusion across a surface.
- Large area, short diffusion distance and maintained concentration gradients support transfer.
- Ventilation refreshes the external medium; **perfusion** carries gases to and from the exchange surface.
- ventilation: Movement of air or water over an exchange surface.
- perfusion: Blood flow through tissue or an exchange surface.



Gas exchange: maintaining diffusion gradients: original worked-case diagram

■ Choose evidence that can test it

- Distinguish movement of the whole medium from diffusion across the membrane.
- Ventilation and perfusion work together, while haemoglobin helps transport oxygen in blood.
- A change in breathing rate alone does not measure oxygen uptake.

In the lab: Use an approved model or published respiratory data. Compare exchange surface area, diffusion path and flow. For human demonstrations use voluntary resting measurements; do not induce breathlessness or hyperventilation.

■ Work from known quantities

- Known: tidal volume is 0.50 L and breathing rate is 12 breaths/min.
- Minute ventilation = $0.50 \times 12 = 6.0$ L/min.
- This includes dead-space ventilation and is not identical to alveolar ventilation.

Your turn: Tidal volume is 0.60 L and breathing rate is 10 breaths/min. Find minute ventilation.

■ Check the conclusion and its limits

- Air entering the lungs is not all exchanged with blood.
- Oxygen and carbon dioxide diffuse in opposite net directions because their own gradients differ.

Not true: Minute ventilation directly equals oxygen uptake. Ventilation moves air into the lungs; oxygen uptake is what crosses into the blood. Dead-space air never reaches the exchange surface, and uptake depends on diffusion and blood flow, so the two quantities differ.

Key:

- Gas exchange occurs by diffusion across a surface.
- Distinguish movement of the whole medium from diffusion across the membrane.
- Watch for: air entering the lungs is not all exchanged with blood.

■ Write from a minute ventilation of 12 litres per minute

- Tidal volume is 0.80 L and the breathing rate is 15 breaths per minute.
- Find minute ventilation. It includes dead space.

Transport

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

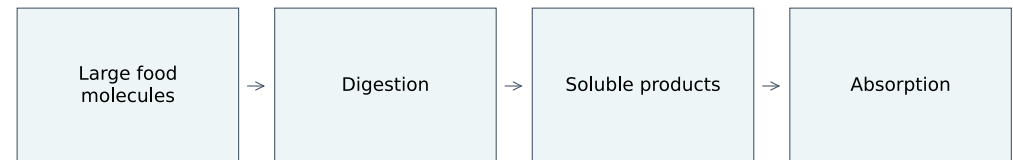
Digestion, transport and health evidence

■ What would explain this observation?

- Two foods can have the same mass but provide different nutrients. A health claim must distinguish the nutrient measured from the health outcome inferred.

■ Build the model

- Large insoluble food molecules are digested into smaller soluble molecules.
- Carbohydrases form sugars, proteases form amino acids, and lipases form fatty acids and glycerol.
- Bile emulsifies lipids and helps neutralize acidic stomach contents.
- **digestion:** Breakdown of large food molecules.
- **absorption**: Movement of soluble products into the body.



Digestion, transport and health evidence: original worked-case diagram

■ Choose evidence that can test it

- Absorption moves soluble products into blood or lymph.
- Thin exchange surfaces and a large surface area shorten diffusion paths and increase transfer.
- Enzyme activity and transport are different processes.

In the lab: Use Benedict reagent with controlled heating for reducing sugars, iodine for starch, Biuret reagent for protein, and the ethanol emulsion test for lipids. Keep ethanol away from flames. Use positive and negative controls.

■ Work from known quantities

- Known: 6 of 24 study participants report a condition.
- Proportion = cases / total.
- Percentage = $6/24 \times 100 = 25\%$.
- The percentage describes this sample.
- It does not establish that one food caused the condition; confounders and how the sample was chosen matter.

Your turn: 9 of 36 participants report an outcome. Calculate the percentage.

■ Check the conclusion and its limits

- Bile is not an enzyme.
- A positive food test identifies a component under the test conditions; it does not show that a food is healthy or unhealthy in every diet.

Not true: A correlation between diet and illness proves causation. A correlation shows that two measurements vary together; it does not prove one causes the other. A confounding variable, reverse causation or chance could explain the link, so a controlled comparison is needed before claiming causation.

Key:

- Large insoluble food molecules are digested into smaller soluble molecules.
- Absorption moves soluble products into blood or lymph.
- Watch for: bile is not an enzyme.

■ Write from 15 percent of a sample

- 6 of 40 participants report an outcome.
- Find the percentage. The sample percentage is not proof that one food caused it.

Muscle and motility

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

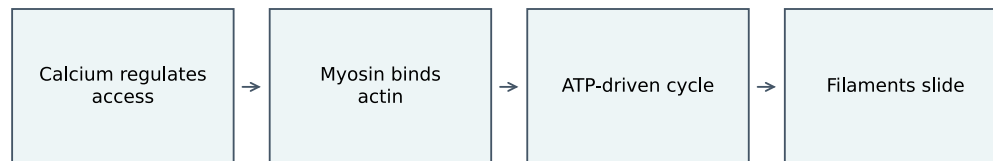
Muscle contraction: filaments slide

■ What would explain this observation?

- A **sarcomere** becomes shorter during contraction although its thick and thin filaments keep approximately the same length.

■ Build the model

- Actin and myosin interact in a sliding-filament mechanism.
- Calcium permits the interaction through regulatory proteins; ATP binding and hydrolysis support the **cross-bridge** cycle.
- Skeletal muscles pull through tendons and work in coordinated groups.
- sarcomere: The repeating contractile unit between two Z lines.
- cross-bridge: A myosin-actin interaction during the contraction cycle.



Muscle contraction: filaments slide: original worked-case diagram

■ Choose evidence that can test it

- During shortening, overlap increases.
- The A-band length stays approximately constant while I bands and the H zone become smaller.
- Movement at a joint also depends on tendon insertion, lever geometry and opposing muscle activity.

In the lab: Annotate two sarcomere diagrams at different lengths using the same scale. Track band widths separately from filament length. Use prepared models or existing images, not painful or maximal-exertion tasks.

■ Work from known quantities

- Known: sarcomere length changes from 2.5 to 2.0 micrometres.
- Percentage shortening = $(2.5 - 2.0)/2.5 \times 100 = 20\%$.
- This does not mean either filament shortened by 20%.

Your turn: A sarcomere shortens from 3.0 to 2.4 micrometres. Calculate percentage shortening.

■ Check the conclusion and its limits

- ATP is required for myosin detachment as well as the continuing cycle.
- A muscle pulling harder does not mean all its fibres become shorter under every load.

Not true: Contracting muscle shortens by shrinking every actin filament. Contraction is sliding, not shrinking: actin and myosin filaments keep their length while their overlap increases. A filament that shortened would contradict the sliding-filament evidence.

Key:

- Actin and myosin interact in a sliding-filament mechanism.
- During shortening, overlap increases.
- Watch for: ATP is required for myosin detachment as well as the continuing cycle.

■ Write from a shortening of 25 percent

- A sarcomere shortens from 2.0 to 1.5 micrometres.
- Find the percentage shortening. The filaments themselves do not shorten by that percentage.

B.4.1 · Adaptation to environment

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL/SL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: transpiration from B.2.3 onwards and natural selection from D.4.1.

The examples are original and fictional: they are not real measurements or real student investigations.

Adaptation to environment

■ What would explain this observation?

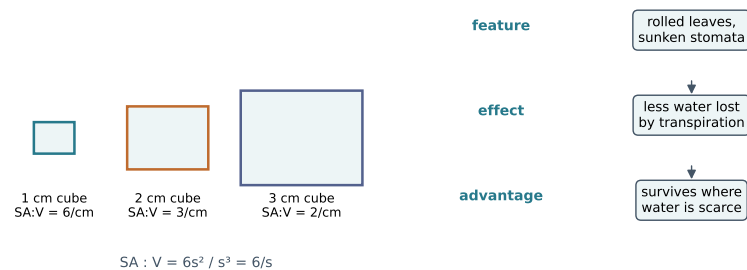
- A cactus survives months without rain while a water lily lives with its leaves flat on the water surface. Both are plants, yet their bodies are nearly opposite. Why?

■ Build the model

- An **adaptation** is an inherited feature that improves survival or reproduction in a particular environment. Adaptations are structural (rolled leaves, sunken stomata in a **xerophyte**), physiological (concentrated urine in a desert mammal) or behavioural (a lizard basking to warm up).
- A useful adaptation explanation links feature → effect → advantage: rolled leaves trap moist air, so less water is lost by transpiration, so the plant survives drought.
Surface area to volume ratio (SA:V) explains many adaptations: a smaller body has a larger SA:V and loses heat or water faster.
- adaptation: An inherited feature improving survival or reproduction in a given environment; xerophyte: A plant adapted to dry conditions; surface area to volume ratio: Surface area divided by volume, controlling exchange rates.

Smaller body → larger surface area per volume

An adaptation links a feature to survival in its environment



Adaptation to environment: original worked-case diagram

■ Choose evidence that can test it

- Compare water loss from a xerophyte leaf and a mesophyte leaf under the same warm, dry, moving air: the adaptation model predicts less loss from the xerophyte. Keep leaf size, temperature and humidity constant, or the comparison proves nothing.
- Measure the SA:V of model cubes or of organisms and compare with their habitats; a claim about surface area must come from measured dimensions, not from looking at the picture.

■ Work from known quantities

- Known: cube side $s = 3$ cm. Surface area $= 6s^2 = 6 \times 9 = 54$ cm²; volume $= s^3 = 27$ cm³. SA:V $= 54/27 = 2$ per cm. For a 1 cm cube: SA:V $= 6/1 = 6$ per cm. Tripling the side cut the ratio to one third – larger bodies have less surface per unit volume, so they lose less heat per unit of tissue.

Example:

A desert mammal model has body surface 400 cm² and volume 2,000 cm³. Find its SA:V and compare it with a small desert mouse at 2 per cm, using the same sequence: known quantities → model → relation → substitution → unit and interpretation. (Answer: SA:V $= 400/2,000 = 0.2$ per cm – one tenth of the mouse's, so the larger animal loses proportionally less water and heat through its surface.)

■ Check the conclusion and its limits

- A plausible story about a feature's use is a hypothesis until evidence supports it; some features are side effects of other traits, not adaptations. The cube model assumes a uniform shape – real organisms extend surface where exchange is needed (lungs, gills, root hairs), breaking the simple scaling.

Warn:

A desert plant adapts during one hot summer by growing thicker cuticle because it needs to. This claim is false: adaptations are INHERITED features shaped by selection over generations; an individual's one-season response is acclimatization, not adaptation, and need never directs the change.

Key:

Adaptation to environment: inherited features link to survival through a feature → effect → advantage chain, testable by controlled comparison. SA:V $= 6/s$ for a cube, and it falls as size rises – exchange surfaces and body plans follow from it.

Ecological niches

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

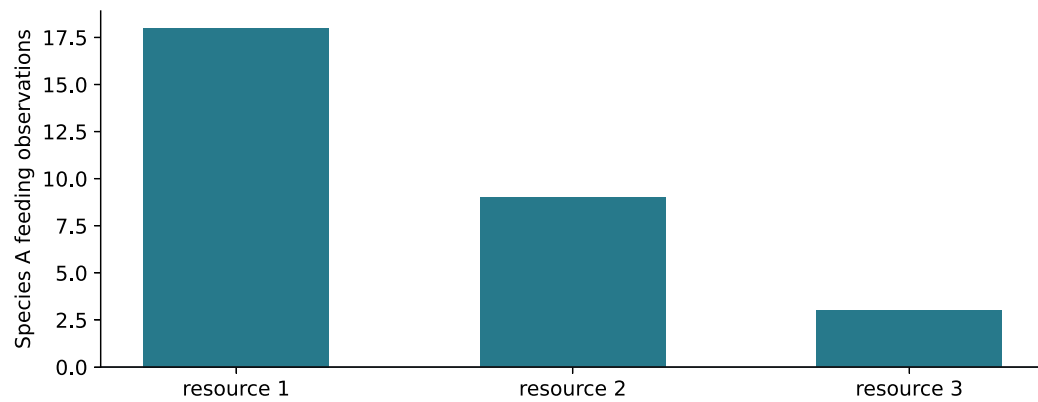
Ecological niches: resources, conditions and interactions

■ What would explain this observation?

- Two species can share a habitat while using different resources or using the same resource at different times. A niche describes more than a location.

■ Build the model

- An **ecological niche** includes how an organism uses resources, responds to conditions and interacts with other organisms.
- A fundamental niche describes potential conditions without restrictive biotic interactions in the model; a realized niche describes the conditions occupied when those interactions operate.
- Competition can restrict resource use or distribution.
- ecological niche: The resource use, conditions and interactions associated with an organism's role.
- **resource partitioning** : Differences in resource use that can reduce overlap among organisms.



Ecological niches: resources, conditions and interactions: original worked-case diagram

■ Choose evidence that can test it

- Separate a habitat observation from a causal claim about a niche boundary.
- Absence from a site can reflect dispersal, detection, abiotic conditions or interactions.
- Resource partitioning can reduce overlap, but an observational difference alone does not prove that competition caused it.
- Compare alternative explanations and the timescale of evidence.

In the lab: Use permitted field observations or an attributed dataset. Record species identification confidence, resource category, time, abiotic conditions and sampling effort. Repeat observations at several locations rather than choosing only patches that fit the hypothesis. Non-destructive comparisons or approved models should be used instead of removing native species or introducing competitors.

■ Work from known quantities

- Known: fictional birds A use resource categories in counts 18, 9 and 3 out of 30 observations; birds B use 3, 9 and 18.
- Their shared middle category is 30% for each, but the preferred categories differ.
- This is evidence of different observed resource use.
- It does not alone establish their full niches or demonstrate the cause of the difference.

Your turn: A species uses one resource in 12 of 40 feeding observations. Calculate the observed percentage.

■ Check the conclusion and its limits

- A niche is not identical to a trophic level or a habitat.
- A realized niche is a context-dependent model, and an incomplete survey cannot establish every tolerance limit or competitive interaction.

Not true: Two species living in the same habitat necessarily have identical ecological niches. Species sharing a habitat can partition it - different foods, times or microsites - so identical location does not mean identical niches. Competition actually pushes coexisting species apart in their resource use.

Key:

- An ecological niche includes how an organism uses resources, responds to conditions and interacts with other organisms.
- Separate a habitat observation from a causal claim about a niche boundary.
- Watch for: A niche is not identical to a trophic level or a habitat.

■ Write from 40 percent of feeding observations

- A species uses one resource in 14 of 35 feeding observations.
- Find the percentage. Absence from a site is not by itself a niche boundary.

■ Write from 10 percent for comparison

- A second species uses the same resource in 5 of 50 feeding observations.
- Find both percentages and say which species is the narrower-niche specialist.

Enzymes and metabolism

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

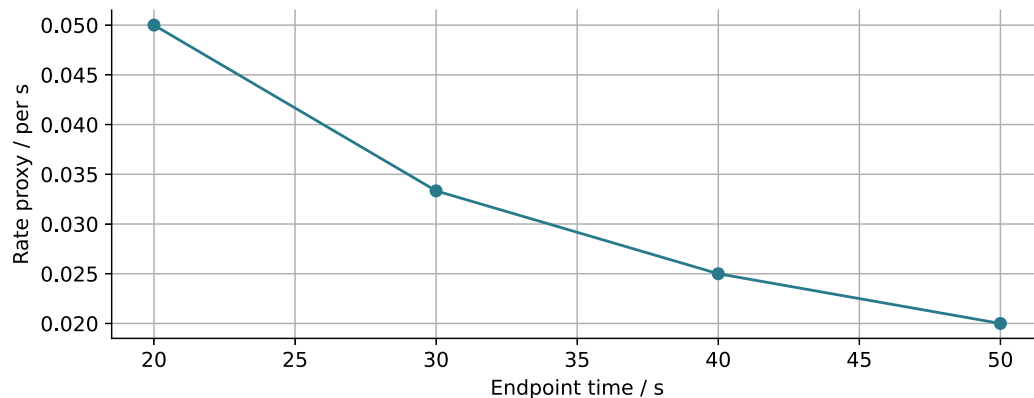
Enzyme rate and controlled measurements

■ What would explain this observation?

- An **enzyme** works quickly at one temperature and slowly at another. Heating can increase successful collisions, but excessive heat can change the active site.

■ Build the model

- An enzyme is a biological catalyst.
- The substrate binds at an active site whose shape and chemical properties support the reaction.
- A catalyst increases rate without being used up overall.
- enzyme: A biological catalyst.
- **denaturation** : A structural change that disrupts function.



Enzyme rate and controlled measurements: original worked-case diagram

■ Choose evidence that can test it

- Measure rate using product formed per unit time or a fixed endpoint.
- For an endpoint test, $1/\text{time}$ is a rate proxy if the same amount of product or substrate change defines the endpoint each time.

In the lab: For starch digestion, equilibrate enzyme and starch in a water bath, control pH with buffer, mix measured volumes, and test samples with iodine at fixed intervals. Use a clean spot for each test. Do not put iodine into the reaction mixture.

■ Work from known quantities

- Known: the endpoint is reached in 40 s.
- Use rate proxy = $1/\text{time}$.
- Rate proxy = $1/40 = 0.025$ per second.
- At 20 s the proxy is 0.050 per second, twice as large.
- This comparison is valid only if the same endpoint and starting concentrations are used.

Your turn: A fixed endpoint takes 50 s. Calculate the rate proxy $1/\text{time}$.

■ Check the conclusion and its limits

- An optimum is specific to the enzyme and conditions.
- Low temperature usually slows the reaction; it does not necessarily denature the enzyme.
- Endpoint intervals limit precision.

Not true: A low temperature always permanently denatures an enzyme. Low temperature usually only slows an enzyme because molecules collide less often; the active site is unchanged and warming restores activity. Denaturation is a structural change from excessive heat or extreme pH, not a guaranteed result of cooling.

Key:

- An enzyme is a biological catalyst.
- Measure rate using product formed per unit time or a fixed endpoint.
- Watch for: an optimum is specific to the enzyme and conditions.

■ Write from a rate proxy of 0.0125 per second

- A fixed endpoint takes 80 s.
- Find the rate proxy 1 over time. The same endpoint must define every trial.

Cell respiration

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

Respiration, ATP and energy transfers

■ What would explain this observation?

- A muscle can use oxygen while you exercise without producing a flame. **Respiration** transfers energy through a controlled series of reactions.

■ Build the model

- Aerobic respiration uses oxygen and releases carbon dioxide and water from organic substrates.
- Energy released can support **ATP** formation.
- ATP hydrolysis can be coupled to processes such as active transport and muscle contraction.
- respiration: Cell reactions that transfer energy from substrates.
- ATP: A molecule that couples energy transfers in cells.



Respiration, ATP and energy transfers: original worked-case diagram

■ Choose evidence that can test it

- Anaerobic processes allow ATP production when oxygen supply cannot support the required aerobic rate, but give less ATP per glucose.
- In humans lactate can accumulate; yeast can produce ethanol and carbon dioxide.

In the lab: A respirometer can measure oxygen uptake when carbon dioxide is absorbed. Control temperature with a water bath and use a comparison containing inert material. Keep absorbent separated from organisms and follow the school risk assessment.

■ Work from known quantities

- Known: oxygen uptake is 0.80 cubic centimetres in 4.0 minutes for 2.0 g of tissue.
- Rate per mass = volume / (time × mass).
- Rate = $0.80 / (4.0 \times 2.0) = 0.10$ cubic centimetres per minute per gram.
- Normalizing allows a fairer comparison of samples of different mass.

Your turn: 0.60 cubic centimetres are used in 3.0 minutes by 2.0 g of tissue. Find the mass-specific rate.

■ Check the conclusion and its limits

- Breathing ventilates the lungs; respiration consists of chemical reactions in cells.
- A moving respirometer marker can also reflect temperature or pressure changes.

Not true: Breathing and cellular respiration are the same process. Breathing is ventilation - moving air in and out of the lungs. Cellular respiration is the set of chemical reactions in cells that transfers energy from glucose. The names overlap but the processes are different.

Key:

- Aerobic respiration uses oxygen and releases carbon dioxide and water from organic substrates.
- Anaerobic processes allow ATP production when oxygen supply cannot support the required aerobic rate, but give less ATP per glucose.
- Watch for: breathing ventilates the lungs; respiration consists of chemical reactions in cells.

■ Write from a respiration rate of 0.16 cubic centimetres per minute per gram

- Tissue uses 0.96 cubic centimetres of oxygen in 4.0 minutes. The tissue mass is 1.5 g.
- Find the mass-specific rate. Anaerobic routes make less ATP per glucose.

Photosynthesis

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

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Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

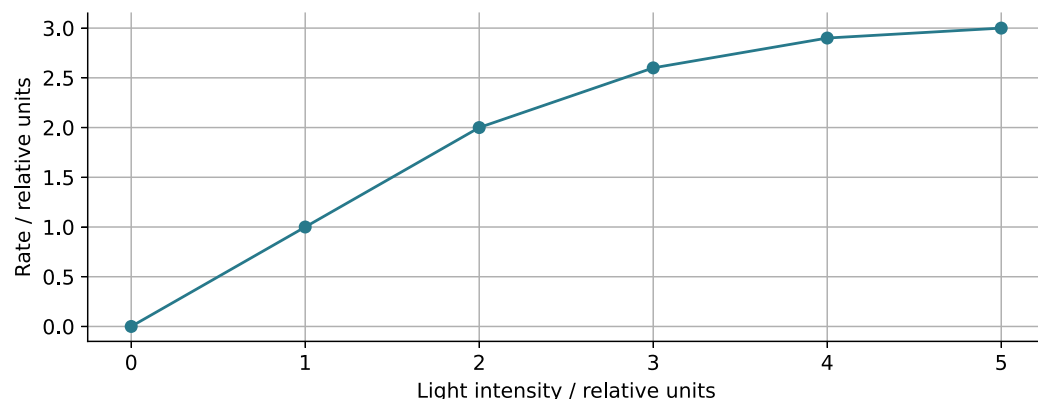
Photosynthesis and limiting factors

■ What would explain this observation?

- A brighter lamp does not always produce more oxygen from pondweed. Another factor may limit the process when light is already sufficient.

■ Build the model

- **Photosynthesis** transfers energy from light into chemical stores.
- Carbon dioxide and water form carbohydrate, releasing oxygen.
- Chlorophyll absorbs light; light intensity, temperature and carbon dioxide supply can affect rate.
- **limiting factor** : A factor whose shortage restricts rate.
- photosynthesis: Light-driven formation of carbohydrate.



Photosynthesis and limiting factors: original worked-case diagram

■ Choose evidence that can test it

- Change only one factor when testing a limiting factor.
- At low light, extra light may increase rate.
- At a plateau, the changed factor is no longer the main limit in that range; the graph alone does not identify which other factor is limiting.

In the lab: Measure collected gas volume over a fixed time instead of assuming all bubbles have the same volume. Control temperature, plant size and carbon dioxide supply. Allow the plant to adjust before each reading and repeat.

■ Work from known quantities

- Known: 6.0 cubic centimetres of gas are collected in 3.0 minutes.
- Use rate = volume/time.
- Rate = $6.0/3.0 = 2.0$ cubic centimetres per minute.
- Bubble counts can be a rough proxy, but bubbles of different size make comparisons less reliable.

Your turn: 9.0 cubic centimetres of gas are collected in 3.0 minutes. Find the rate.

■ Check the conclusion and its limits

- Moving a lamp changes light and may also change temperature.
- A photosynthesis experiment needs control of heating, not just a ruler.

Not true: All oxygen bubbles have exactly the same volume. Bubbles from pondweed vary in size and composition, so a bubble count is only a rough proxy for gas volume. Measuring collected volume, as in the calculation above, is more reliable.

Key:

- Photosynthesis transfers energy from light into chemical stores.
- Change only one factor when testing a limiting factor.
- Watch for: moving a lamp changes light and may also change temperature.

■ Write from a gas rate of 2.5 cubic centimetres per minute

- 10.0 cubic centimetres of gas are collected in 4.0 minutes.
- Find the rate. At a plateau, the factor you changed is no longer the main limit.

Chemical signalling

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

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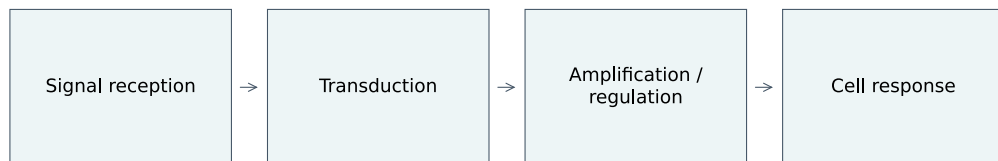
Cell signalling: a receptor selects the response

■ What would explain this observation?

- Two cell types encounter the same signal but respond differently. Their **receptors** and internal pathways determine what follows.

■ Build the model

- A signalling molecule binds a compatible receptor.
- Receptor activation can initiate **signal transduction** through intracellular molecules.
- The resulting response may change enzyme activity, transport or gene expression.
- A signal need not enter the cell to cause an effect.
- receptor: A molecule that binds a compatible signal.
- signal transduction: Conversion of signal reception into intracellular changes.



Cell signalling: a receptor selects the response: original worked-case diagram

■ Choose evidence that can test it

- Distinguish signal reception, transduction and response.
- Amplification can allow a small extracellular change to produce a larger intracellular effect.
- Different receptors or pathways can give different responses to one signal.

In the lab: Use an attributed dataset comparing signal concentration and response. Include an untreated control and, where supplied, receptor-blocking evidence. Do not infer the whole pathway from a concentration-response graph alone.

■ Work from known quantities

- Known: response increases from 20 to 80 units.
- Fold change = $80/20 = 4$.
- Percentage increase = $(80-20)/20 \times 100 = 300\%$.
- A fourfold final value is not a 400% increase.

Your turn: Response rises from 10 to 50 units. Calculate the fold change.

■ Check the conclusion and its limits

- A receptor is not interchangeable with every signalling molecule.
- Greater signal concentration does not imply unlimited response once the system saturates.

Not true: Fourfold final response means a 400% increase from baseline. A fold change is a ratio of final to initial; a percentage increase is the change relative to the initial value. A fourfold final value means a 300% increase, so “fourfold” and “400%” are not interchangeable.

Key:

- A signalling molecule binds a compatible receptor.
- Distinguish signal reception, transduction and response.
- Watch for: A receptor is not interchangeable with every signalling molecule.

■ Write from a threefold rise

- A response rises from 12 units to 36 units.
- Find the fold change and the percentage increase. A threefold value is not a 300 percent increase.

Neural signalling

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

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Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

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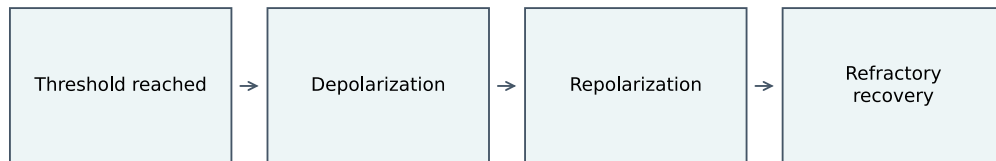
Neural signalling: impulses and synapses

■ What would explain this observation?

- A stronger stimulus can increase impulse frequency while each **action potential** remains a similar size.

■ Build the model

- An action potential is a brief change in membrane potential involving voltage-gated ion channels.
- Depolarization followed by repolarization propagates along a neuron.
- At a chemical **synapse**, transmitter release can alter the next cell membrane potential.
- action potential: A brief propagating change in membrane potential.
- synapse: A junction for communication between cells.



Neural signalling: impulses and synapses: original worked-case diagram

■ Choose evidence that can test it

- The all-or-none principle applies to an individual action potential.
- Stimulus information can be encoded by frequency and recruitment.
- Myelination permits saltatory conduction between nodes rather than making ions move freely through myelin.

In the lab: Interpret supplied voltage-time traces and compare time intervals. Identify threshold, rising phase and recovery before explaining ions. Use classroom models rather than electrical stimulation of people.

■ Work from known quantities

- Known: 30 impulses occur in 0.50 s.
- Frequency = count/time = $30/0.50 = 60$ Hz.
- This is impulse frequency, not an estimate of propagation speed.

Your turn: 24 impulses occur in 0.40 s. Find impulse frequency.

■ Check the conclusion and its limits

- A neurotransmitter diffuses across the synaptic cleft; an action potential does not jump intact through the liquid gap.
- Excitatory input does not guarantee the postsynaptic cell reaches threshold.

Not true: A stronger stimulus always makes each action potential larger. Action potentials are all-or-none: once threshold is reached, the impulse has a fixed size set by the ion gradients. A stronger stimulus raises the frequency of impulses, not their amplitude.

Key:

- An action potential is a brief change in membrane potential involving voltage-gated ion channels.
- The all-or-none principle applies to an individual action potential.
- Watch for: A neurotransmitter diffuses across the synaptic cleft; an action potential does not jump intact through the liquid gap.

■ Write from an impulse frequency of 70 per second

- 21 impulses occur in 0.30 s.
- Find the frequency. This is not the propagation speed.

Integration of body systems

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

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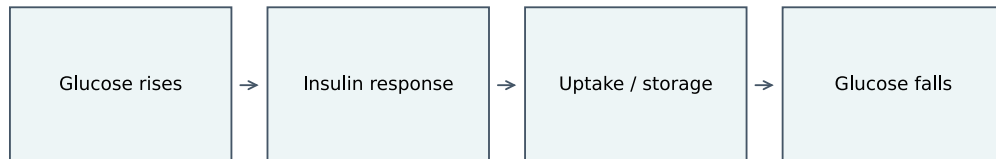
Feedback and internal conditions

■ What would explain this observation?

- Blood glucose rises after a meal, but usually does not keep rising indefinitely. A control system responds to the change in internal conditions.

■ Build the model

- **Homeostasis** maintains internal conditions within suitable limits.
- Receptors detect changes, coordination centres process information, and effectors respond.
- **Negative feedback** opposes the original change.
- homeostasis: Maintenance of suitable internal conditions.
- negative feedback: A response opposing the original change.



Feedback and internal conditions: original worked-case diagram

■ Choose evidence that can test it

- When blood glucose is high, insulin helps increase glucose uptake and storage as glycogen.
- When it is low, glucagon supports release of glucose from stores.
- These responses are coordinated, not identical effects of two hormones.

In the lab: Interpret a time graph by identifying the initial disturbance, the response and the return toward the normal range. Mark the delay before a response. Do not assume a graph shows an instantaneous correction.

■ Work from known quantities

- Known: glucose changes from 5.0 to 7.0 arbitrary concentration units.
- Increase = final - initial.
- Increase = $7.0 - 5.0 = 2.0$ units.
- Percentage increase = $2.0/5.0 \times 100 = 40\%$.
- The numerical change is evidence of a disturbance, not a diagnosis on its own.

Your turn: A value rises from 4.0 to 5.0. Calculate the percentage increase.

■ Check the conclusion and its limits

- Negative feedback does not mean the response is harmful or the measured value becomes negative.
- Diabetes has different mechanisms; do not treat every case as a failure to make insulin.

Not true: Negative feedback always makes the measured value negative. Negative feedback means the response opposes the change - it pushes the value back towards the set point. “Negative” describes the direction of correction, not a harmful effect or a negative measurement.

Key:

- Homeostasis maintains internal conditions within suitable limits.
- When blood glucose is high, insulin helps increase glucose uptake and storage as glycogen.
- Watch for: negative feedback does not mean the response is harmful or the measured value becomes negative.

■ **Write from a rise of 60 percent**

- A glucose value rises from 5.0 to 8.0 units.
- Find the percentage increase. The number is not a diagnosis.

■ **Write from a fall of 37.5 percent**

- A second glucose value falls from 8.0 back to 5.0 units.
- Find the percentage decrease, and say why it is not also 60 percent: the denominator is the new original.
- Both use change over original $\times 100$ – only the original has changed.

■ **Write from a doubling**

- A third value doubles from 2.0 to 4.0 units.
- Find the percentage increase: 2.0 over an original of 2.0 – 100 percent, and every doubling always is.

C.3.2 · Defence against disease

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: cells and membranes from B.2 and enzymes from B.1.

The examples are original and fictional: they are not real measurements or real student investigations.

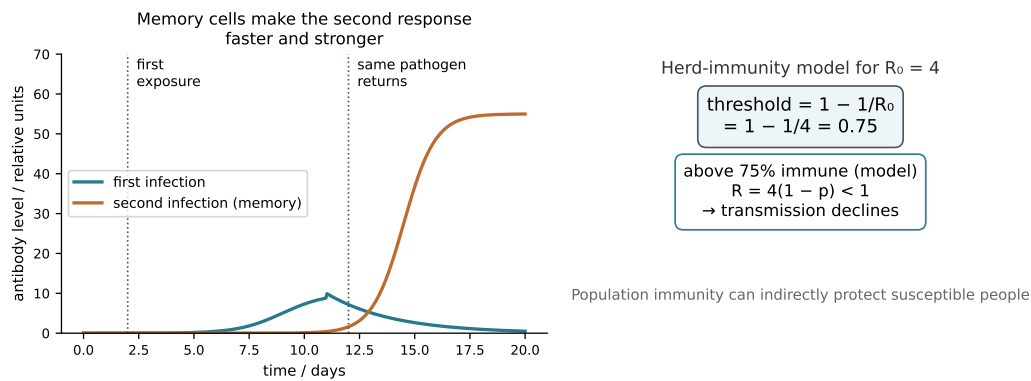
Defence against disease

■ **What would explain this observation?**

- Most people catch chickenpox once and never again, while a cold can return every year. What does the immune system remember, and why does it fail against the cold?

■ **Build the model**

- Pathogens carry **antigens** – molecular structures recognised by specific immune receptors. Phagocytes engulf and digest pathogens, while lymphocytes make **antibodies**, proteins shaped to bind one specific antigen. The first response is slow because the matching lymphocytes must be selected and multiplied.
- After the first infection, **memory cells** remain. On re-exposure they produce a faster, stronger secondary response, often destroying the pathogen before symptoms appear. **Vaccination** can prepare immune memory for later exposure. Immunity in a population can reduce transmission and indirectly protect susceptible people – **herd immunity**. Protection depends on the pathogen, population and vaccine; it does not guarantee that no infection or outbreak can occur.
- antigen: A molecular structure recognised by a specific antibody or immune receptor; antigens can come from the body itself or from outside it; antibody: A protein that binds one specific antigen; memory cell: A long-lived lymphocyte that enables a fast secondary response; vaccination: Giving a vaccine to prepare a specific immune response and memory; herd immunity: Indirect population protection when immunity reduces transmission.



Memory cells make the second response faster and larger; with $R_0 = 4$, herd immunity needs 75% immune

■ Choose evidence that can test it

- Track antibody concentration after a first and a second exposure to the same antigen: the model predicts a faster and larger second peak. A cold can return because many different viruses and strains cause colds; immunity to one need not protect against another.
- Compare outbreak sizes in populations with different vaccination coverage; above the threshold, outbreaks should fail to grow.

■ Work from known quantities

- Known: a pathogen has a basic reproduction number $R_0 = 4$, meaning four secondary cases per case on average in a fully susceptible population under this model. The threshold is $1 - 1/R_0 = 1 - 1/4 = 0.75$. With uniform mixing and complete protection, exactly 75% immune gives $R = 4 \times (1 - 0.75) = 1$. The immune proportion must exceed 75% to give $R < 1$ and declining transmission in the model.

Example:

A different pathogen has $R_0 = 2.5$. Find the herd-immunity threshold as a percentage using the same sequence: known quantities $\rightarrow$ model $\rightarrow$ relation $\rightarrow$ substitution $\rightarrow$ unit and interpretation. (Answer: $1 - 1/2.5 = 1 - 0.4 = 0.6 = 60\%$. A less contagious pathogen needs less coverage.)

■ Check the conclusion and its limits

- The threshold model assumes uniform mixing, equal susceptibility and complete protection against transmission among immune people; real populations cluster and protection can wane. If vaccination gives incomplete protection against transmission, the required vaccination proportion is higher than the immune threshold

in this simplified model.

Warn:

An antibody can bind equally well to any pathogen. This claim is false: antibodies recognise particular antigen shapes. A different antigen can escape an existing response; vaccines target chosen antigens.

Key:

Defence against disease: phagocytes engulf; lymphocytes make antigen-specific antibodies; memory cells give a faster, stronger second response. Vaccination can prepare specific immune memory. When population immunity reduces transmission, herd immunity can provide indirect protection. The simplified threshold $1 - 1/R_0$ is a model boundary, not a guarantee that everyone is protected.

■ Write from a threshold of 80 percent

- A pathogen has $R_0 = 5$.
- Find the herd-immunity threshold: $1 - 1/5 = 0.8$, so 80 percent immune.

■ Write from a threshold of 50 percent

- A milder strain has $R_0 = 2$.
- Find the threshold: $1 - 1/2 = 50$ percent – the threshold tracks $1/R_0$, falling toward zero as R_0 approaches one.

■ Write from coverage that falls short

- $R_0 = 4$ and vaccination covers 60 percent of the population.
- Is the threshold met? $1 - 1/4 = 75$ percent needed, so no – transmission continues in the gap.

Populations and communities

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

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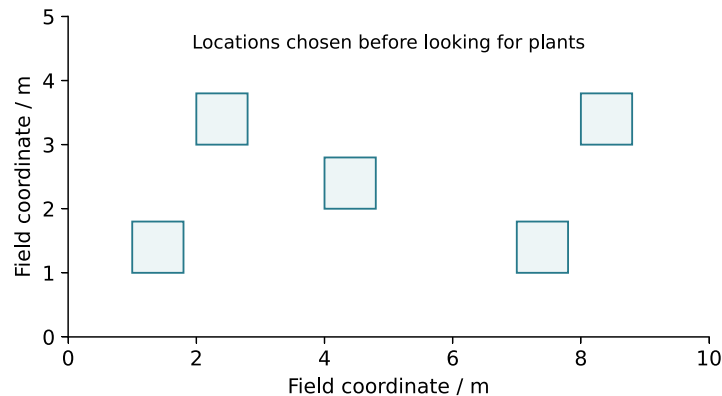
Sampling populations without choosing the answer

■ What would explain this observation?

- A field edge looks richer in plants than its centre. Choosing only the richest patches would build the desired result into the sampling method.

■ Build the model

- A **population** consists of organisms of one species in a defined area.
- Random **quadrats** estimate density without deliberately selecting patches.
- A transect investigates change along an environmental gradient.
- quadrat : A defined area used for sampling.
- population: Organisms of one species in a defined area.



Sampling populations without choosing the answer: original worked-case diagram

■ Choose evidence that can test it

- Estimate total abundance by multiplying mean density by area, with consistent units.
- This assumes sampled areas represent the habitat.
- Patchiness and too few samples widen uncertainty.

In the lab: Choose coordinates with random numbers before visiting the patches. Record quadrat area and counting rules. For a transect, use fixed distances and measure a relevant abiotic variable. Do not damage habitats or sample unsafe locations.

■ Work from known quantities

- Known: five 0.25 square metre quadrats contain 3, 4, 6, 5 and 2 plants.
- Mean count = $20/5 = 4$.
- Density = $4/0.25 = 16$ plants per square metre.
- Estimated abundance in 100 square metres = $16 \times 100 = 1,600$ plants.

Your turn: Mean count is 6 in a 0.5 square metre quadrat. Find density per square metre.

■ Check the conclusion and its limits

- Quadrats suit organisms that do not move quickly.
- A food chain arrow shows the direction of energy transfer, not the direction a predator travels.

Not true: Sampling only the most crowded patches gives an unbiased population estimate. Choosing the most crowded patches overestimates density, because the samples are not representative of the whole area. Unbiased estimation needs random or systematic sampling decided before looking at the plants.

Key:

- A population consists of organisms of one species in a defined area.
- Estimate total abundance by multiplying mean density by area, with consistent units.
- Watch for: quadrats suit organisms that do not move quickly.

■ Write from a density of 20 plants per square metre

- Three quadrats of 0.20 square metres contain 2, 4 and 6 plants.
- Find the mean count and the density. The estimate assumes the quadrats represent the habitat.

Transfer of energy and matter

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

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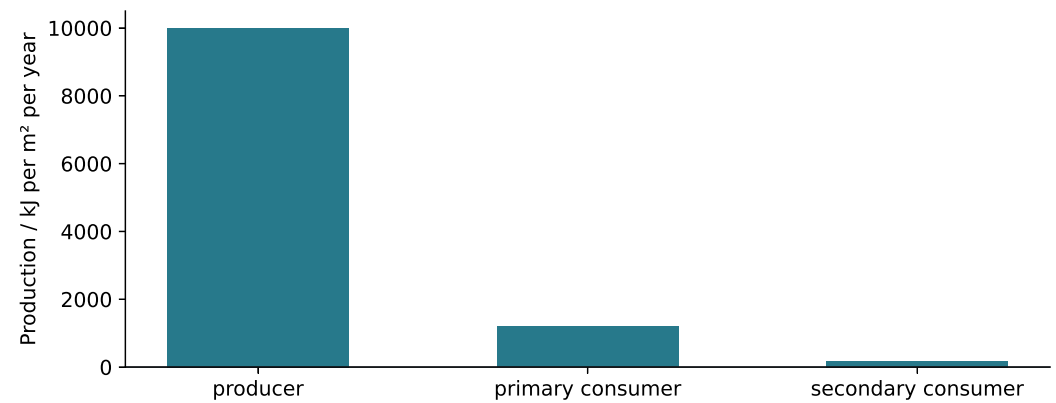
Energy transfer: use production and a stated boundary

■ What would explain this observation?

- Energy available as new biomass usually decreases along a food chain. Energy is conserved overall, but some transferred energy leaves the next-level production pathway.

■ Build the model

- Producers convert an energy input into chemical energy in organic material.
- Consumers obtain material by feeding.
- **Trophic transfer efficiency** compares production available at one level with production at the preceding level over a common area and time.
- Energy can enter detrital pathways, remain in uneaten material, leave in egested waste or be transferred as heat through respiration.
- trophic transfer efficiency: Production at one trophic level divided by production at the preceding level over a common interval.
- **assimilation** : Uptake of digested material into an organism's usable internal pool.



Production falls at each level: 12% then 15% transfer, not a fixed 10%

■ Choose evidence that can test it

- Use the same energy units and period in numerator and denominator.
- Distinguish ingestion, assimilation and production: consumed energy is not all assimilated, and assimilated energy is not all stored as new biomass.
- An energy pyramid records a flow per area per time; a standing biomass snapshot is a different quantity.

In the lab: Analyse attributed or fictional ecosystem budget data. Draw a boundary and arrows for feeding, detritus and heat transfer. Identify which values are measured and which inferred, and check whether the budget includes decomposers. Avoid treating a fixed 10% rule as a universal measurement for every ecosystem.

■ Work from known quantities

- Known: producer production is 10,000 kJ/m²/year and primary-consumer production is 1,200 kJ/m²/year.
- Transfer efficiency is $1,200/10,000 \times 100 = 12\%$.
- Secondary-consumer production of 180 kJ/m²/year gives $180/1,200 \times 100 = 15\%$ for that step.
- These different values show why a universal 10% assumption would misrepresent this dataset.

Your turn: Producer production is 8,000 and primary-consumer production is 800 kJ/m²/year. Calculate transfer efficiency.

■ Check the conclusion and its limits

- Energy is not destroyed when respiration transfers it as heat.
- Material can cycle through an ecosystem, while usable energy flow depends on continuing input.
- A count pyramid or biomass snapshot cannot automatically be substituted into an energy-efficiency calculation.

Not true: Respiration destroys energy instead of transferring it to other forms. Respiration transfers energy to the surroundings as heat - the energy still exists. “Loss” between trophic levels means energy leaves the food chain’s usable flow; conservation is never violated.

Key:

- Producers convert an energy input into chemical energy in organic material.
- Use the same energy units and period in numerator and denominator.
- Watch for: energy is not destroyed when respiration transfers it as heat.

■ Write from a transfer efficiency of 30 percent

- Producer production is 8000 kJ per square metre per year. Primary-consumer production is 2400 in the same units.
- Find the transfer efficiency. Ingestion is not the same as production.

DNA replication

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

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Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

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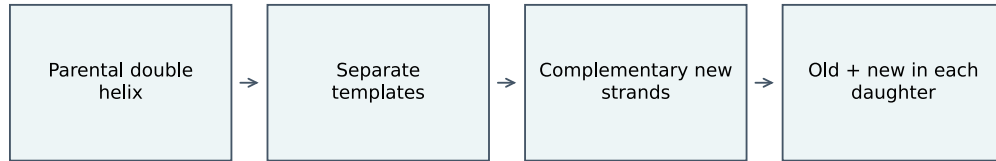
DNA replication: retain one strand in each daughter molecule

■ What would explain this observation?

- After DNA replication, each daughter double helix contains one pre-existing strand and one newly synthesized strand. Copying a molecule is different from expressing its information.

■ Build the model

- DNA replication is semi-conservative.
- Complementary base pairing supports copying of the base sequence: adenine pairs with thymine and cytosine with guanine.
- The strands have opposite orientations.
- Helicase separates paired strands, while **DNA polymerase** DNA DNA builds new DNA using a template and available nucleotides.
- **semi-conservative replication** : DNA copying in which each daughter double helix retains one parental strand.
- DNA polymerase: An enzyme that synthesizes DNA using a template.



DNA replication: retain one strand in each daughter molecule: original worked-case diagram

■ Choose evidence that can test it

- New DNA is synthesized in the 5' to 3' direction.
- In a simplified fork model, one new strand can be synthesized continuously while the other is produced in fragments that are joined.
- Distinguish these molecular mechanisms from the later separation of chromosomes during cell division.
- Copying errors can occur despite proofreading and repair.

In the lab: Use labelled strand models or an attributed experimental diagram. Mark old and new material with both labels and colours so the meaning survives monochrome viewing. Track successive rounds using a stated starting population and assumptions. A classroom model illustrates predictions; it is not direct evidence about enzyme activity or a substitute for experimental results.

■ Work from known quantities

- Known: one double-stranded molecule contains two labelled original strands.
- After one complete round in unlabelled nucleotides, two molecules each contain one labelled strand.
- After two rounds, four molecules exist: two retain one labelled original strand and two contain only unlabelled strands.
- The fraction containing an original strand is $2/4=50\%$.

Your turn: One labelled double helix replicates for three complete rounds in unlabelled nucleotides. What percentage of the eight molecules contain an original strand?

■ Check the conclusion and its limits

- Replication uses DNA as a template to make DNA; transcription uses a DNA template to make RNA.
- A predicted label distribution assumes complete rounds and no degradation or exchange of the labelled material.

Not true: DNA replication and transcription both produce the same type of nucleic-acid product. Replication copies DNA into DNA; transcription copies a DNA template into RNA. The products are different nucleic acids with different roles.

Key:

- DNA replication is semi-conservative.
- New DNA is synthesized in the 5' to 3' direction.
- Watch for: replication uses DNA as a template to make DNA; transcription uses a DNA template to make RNA.

■ Write from 2 labelled molecules out of 32

- One labelled double helix replicates for 5 complete rounds in unlabelled nucleotides.
- Say how many of the 32 molecules still contain an original strand.

■ Write from 3 rounds and 8 molecules

- The same labelling runs for 3 complete rounds instead, giving 8 molecules.
- Say how many molecules retain an original strand, and what fraction of all 16 single strands is original.

D.1.2 · Protein synthesis

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL/SL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: DNA structure and base pairing from A.1.2, and enzymes from B.1.

The examples are original and fictional: they are not real measurements or real student investigations.

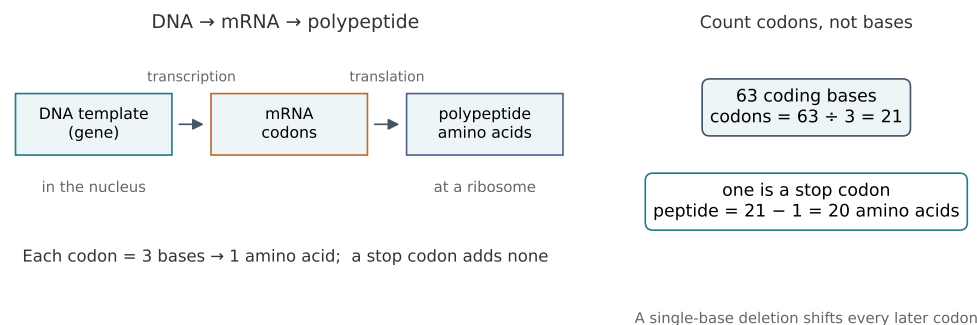
Protein synthesis

■ What would explain this observation?

- A gene hundreds of bases long produces a much shorter protein, and a one-base mutation can destroy the whole product. How does the cell read a base sequence into an amino-acid sequence?

■ Build the model

- In **transcription**, the enzyme RNA polymerase builds an mRNA strand complementary to one DNA template strand. In **translation**, a ribosome reads the mRNA in groups of three bases – **codons** – and joins the matching amino acids into a polypeptide.
- Most codons specify an amino acid. The genetic code is degenerate: several codons can specify the same amino acid. A **stop codon** signals the end of translation and specifies no amino acid. Because the reading frame runs in threes, inserting or deleting one base shifts every later codon – a frameshift.
- transcription: Copying a gene's DNA sequence into a complementary mRNA; translation: Reading mRNA codons at a ribosome to build a polypeptide; codon: A group of three mRNA bases specifying an amino acid or a stop signal; stop codon: A codon that ends the chain without coding for an amino acid.



Count codons, not bases: 63 bases give 21 codons and, with one stop codon, 20 amino acids

■ Choose evidence that can test it

- The base sequence of a gene predicts the amino-acid sequence of its protein through the code table; compare a known gene and its protein to check. Radioactive-labelling experiments placed amino acids in the order the mRNA specified – evidence for the codon reading, not a guess.
- Mutations that change a codon to a stop codon truncate the protein exactly at that point, which can be checked against the sequence.

■ Work from known quantities

- Known: a coding mRNA segment has 63 bases, including one stop codon. Codons = bases / 3 = $63 / 3 = 21$. The stop codon codes for no amino acid, so the peptide has $21 - 1 = 20$ amino acids.

Example:

A coding segment of 90 bases includes one stop codon. Find the peptide length using the same sequence: known quantities → model → relation → substitution → unit and interpretation. (Answer: codons = $90/3 = 30$; peptide = $30 - 1 = 29$ amino acids. Bases are not amino acids – divide by three first.)

■ Check the conclusion and its limits

- This counting model covers the coding sequence only: real genes also carry promoters, untranslated regions and, in eukaryotes, introns that are removed before translation. A gene's total base count is therefore not a peptide-length calculation.

Warn:

Each base in the coding sequence codes for one amino acid. This claim is false: amino

acids are coded by triplets – three bases per codon – and the stop codon adds none, so a 63-base segment gives 20 amino acids, not 63.

Key:

Protein synthesis: transcription copies the gene into mRNA; translation reads codons in threes at the ribosome. Codons = bases $\div$ 3, and the stop codon codes for no amino acid; a one-base insertion or deletion shifts the whole reading frame.

■ Write from 29 amino acids

- An mRNA coding region is 90 bases including the single stop codon.
- Find the amino acids: $(90 - 3) \div 3 = 29$ – the stop codon adds none.

■ Write from 14 amino acids

- A second segment is 45 bases, again with one stop codon at the end.
- Find the amino acids: $45 \div 3 = 15$ codons, one of them stop, so 14.

■ Write from a shifted frame

- Base 4 of a coding region is deleted.
- Say what changes: every codon after the deletion is re-read in a new frame – one deletion is not one change but a whole-sequence change.

D.1.3 · Mutations and gene editing

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL/SL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: DNA structure from A.1.2 and protein synthesis from D.1.2.

The examples are original and fictional: they are not real measurements or real student investigations.

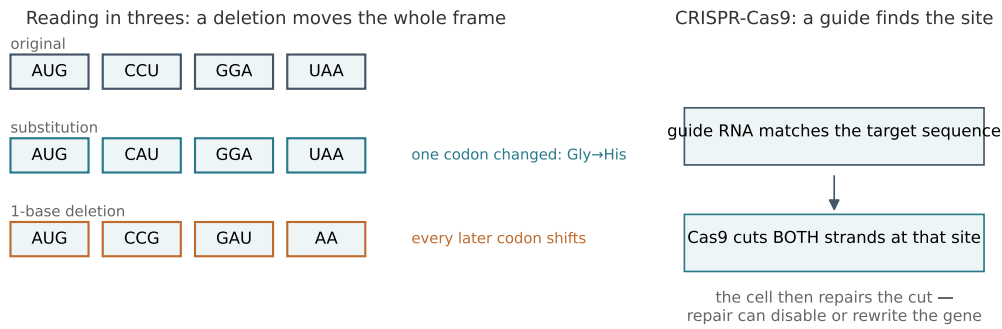
Mutations and gene editing

■ What would explain this observation?

- One changed base in the haemoglobin gene causes sickle cell disease, while a one-base deletion in another gene destroys the entire protein. Why does one small edit matter so much more than the other?

■ Build the model

- A **mutation** is a change in the base sequence of DNA. A **substitution** swaps one base; if the new codon still codes for the same amino acid (a silent change) the protein is unchanged, but a change to a different amino acid can alter the protein's shape, as in sickle cell disease.
- An insertion or deletion within a coding region shifts the **reading frame** when the number of bases added or lost is not a multiple of three. This can change the amino-acid sequence after the edit or introduce an early stop codon, affecting protein function. **Gene editing** with CRISPR-Cas9 uses a guide RNA to find one chosen sequence and the Cas9 enzyme to cut both strands there; the cell's repair then disables or rewrites the gene.
- mutation: A change in the base sequence of DNA; substitution: A mutation swapping one base for another; reading frame: The grouping of bases into codons from a fixed start; gene editing: Deliberately changing a chosen DNA sequence, for example with CRISPR-Cas9.



A coding substitution affects one codon; the one-base deletion shown shifts the frame downstream. Cas9 cuts where the guide RNA matches

■ **Choose evidence that can test it**

- Compare the DNA sequence with the protein produced: a coding substitution may change one amino acid, create a stop codon or leave the amino acid unchanged. A one-base coding deletion shifts the downstream reading frame. Sequence data show which changes actually occur.
- In gene editing, sequencing the target site after repair shows whether the cut disabled the gene or inserted the intended change; an off-target check sequences similar sites elsewhere.

■ **Work from known quantities**

- Known: the coding sequence AUG CCU GGA UAA reads in codons of three. Delete the fourth base (the first C). The sequence becomes AUG CCG GAU AA: the first codon is intact, but every later codon is shifted, and the stop codon is destroyed – the ribosome reads on into wrong codons. A substitution of that same C to A instead gives AUG CAU GGA UAA: only the second codon changes.

Example:

A 30-base coding segment loses its fourth base. Is the first codon changed, and what happens after it? (Answer: the first three bases still form the original first codon. The remaining bases are grouped in a new frame. The final peptide length depends on where a stop codon is encountered.)

■ **Check the conclusion and its limits**

- This simple model covers the coding region; mutations in control regions can change how MUCH protein is made without changing its sequence. Gene editing’s safety depends on off-target rates measured experimentally, not on the guide’s design alone.

Warn:

A mutation is always harmful and always changes the protein. This claim is false: silent substitutions change the DNA but not the amino acid, many mutations fall outside coding regions, and a few mutations are beneficial – variation from mutation is the raw material of evolution.

Key:

Mutations and gene editing: a coding substitution affects one codon, with effects that depend on the new sequence. A coding insertion or deletion shifts the frame only when its length is not a multiple of three; protein function may change. CRISPR-Cas9 edits by guide-RNA targeting plus a two-strand cut, with results checked by sequencing.

■ **Write from a 3-base deletion**

- One complete codon is deleted from a coding region, without crossing a codon boundary.
- Say what happens to the protein: one amino acid is lost and the frame survives – 3 is a whole codon.

■ **Write from a substitution to a stop codon**

- One base changes so a codon becomes a stop codon, 40 codons into the sequence.
- Say what happens: translation ends early – a shortened protein, not a shifted one.

■ **Write from a silent change**

- A substitution in a non-coding region appears in a population.
- Does the protein change? No – and even coding substitutions can be silent under degeneracy.

Cell and nuclear division

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

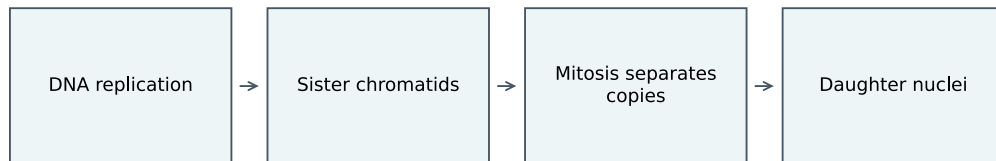
Cell division: count nuclei and chromosomes carefully

■ What would explain this observation?

- A root-tip image contains cells at different stages of mitosis. A snapshot can estimate the fraction of cells dividing, but it does not time one observed cell directly.

■ Build the model

- DNA replication occurs before mitosis.
- Mitosis separates sister **chromatids**, preserving chromosome number in daughter nuclei.
- Meiosis includes homologous chromosome separation and normally halves the chromosome number while generating variation.
- **mitotic index** : Fraction of scored cells undergoing mitosis.
- chromatid : One copy of a replicated chromosome before separation.



Cell division: count nuclei and chromosomes carefully: original worked-case diagram

■ Choose evidence that can test it

- Count chromosomes by centromeres under the stated convention.
- DNA amount and chromosome number are different quantities.
- Crossing over and independent assortment contribute to meiotic variation.

In the lab: Use a prepared root-tip slide or a labelled image. Define a counting rule and field selection before counting. Distinguish dividing cells from damaged or ambiguous cells and report exclusions.

■ Work from known quantities

- Known: 25 dividing cells among 200 scored cells.
- Mitotic index = $25/200 = 0.125$, or 12.5%.
- Estimating phase duration from this proportion requires assumptions about a steady, representative cell population.

Your turn: 18 of 120 scored cells are dividing. Calculate mitotic index as a percentage.

■ Check the conclusion and its limits

- Replication doubles DNA amount without immediately doubling the chromosome count.
- Meiosis does not simply produce two identical diploid cells.

Not true: DNA replication immediately doubles chromosome number under the centromere convention. Under the centromere convention a chromosome with two sister chromatids still counts as one chromosome. Replication doubles DNA content; only sister-chromatid separation later doubles the chromosome count.

Key:

- DNA replication occurs before mitosis.
- Count chromosomes by centromeres under the stated convention.
- Watch for: replication doubles DNA amount without immediately doubling the chromosome count.

■ Write from a mitotic index of 20 percent

- 8 of 40 scored cells are dividing.
- Find the mitotic index as a percentage. Chromosome number is not the same as DNA amount.

Gene expression

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

Gene expression: regulate products, not just genes

■ What would explain this observation?

- Two cells with the same genome make different proteins. Regulation changes which information is used and when.

■ Build the model

- Gene expression can be regulated at transcription and later stages.
- A **transcription factor** can affect transcription through interactions with DNA and other proteins.
- **Epigenetic modifications** can influence expression without changing the underlying DNA sequence.
- transcription factor: A protein that influences transcription.
- epigenetic modification : A change affecting expression without changing the DNA sequence.



Gene expression: regulate products, not just genes: original worked-case diagram

■ Choose evidence that can test it

- Distinguish a measured mRNA change from a protein or functional change.
- Translation, degradation and protein modification can all intervene.
- Regulation is specific to a cell context and environmental conditions.

In the lab: Compare treated and control expression data after checking normalization and replicates. Use evidence from a supplied perturbation to discuss causal models, rather than equating every association with a direct mechanism.

■ Work from known quantities

- Known: normalized transcript abundance is 12 in treatment and 3 in control.
- Fold change = $12/3 = 4$.
- Equal normalized abundance does not require equal absolute cell counts in the two raw samples.

Your turn: Transcript abundance is 15 in treatment and 5 in control. Find fold change.

■ Check the conclusion and its limits

- An epigenetic change is not automatically a DNA-sequence mutation.
- More mRNA does not guarantee proportionally more active protein.

Not true: Every change in gene expression is a mutation. Expression changes are regulatory - the same DNA is read more or less often. A mutation is a change in the DNA sequence itself; most changes in expression involve no mutation at all.

Key:

- Gene expression can be regulated at transcription and later stages.
- Distinguish a measured mRNA change from a protein or functional change.
- Watch for: an epigenetic change is not automatically a DNA-sequence mutation.

■ Write from a transcript fold change of 5

- Normalized transcript abundance is 20 in the treatment and 4 in the control.
- Find the fold change. An mRNA change is not automatically a protein change.

Water potential

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

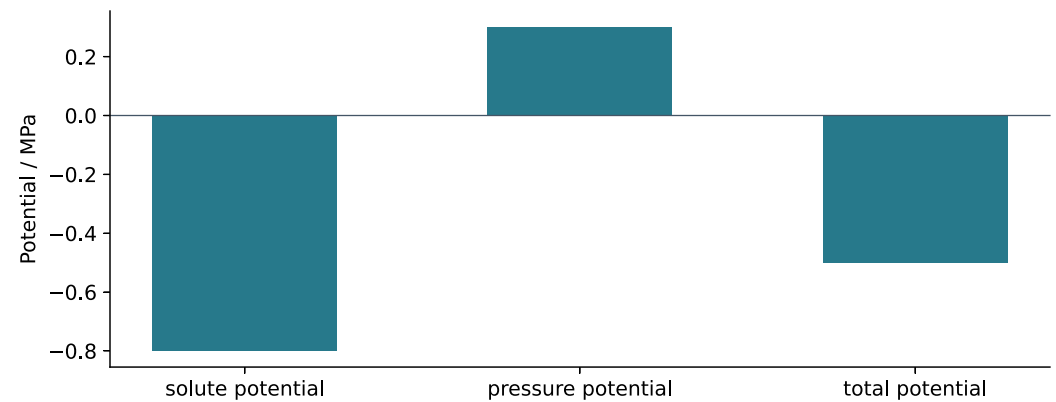
Water potential : include solute and pressure effects

■ What would explain this observation?

- A plant cell can stop gaining net water even while its contents contain solute. The cell wall permits pressure to build, altering the **water-potential** balance.

■ Build the model

- Water potential describes the tendency of water to move relative to a chosen reference, with pressure units.
- In the simplified cell model, water potential equals solute potential plus **pressure potential**.
- Dissolved solute lowers solute potential; positive pressure can raise water potential.
- Net water movement through a water-permeable membrane is from higher to lower water potential.
- water potential: A pressure-equivalent measure of the tendency of water to move relative to a reference.
- pressure potential: The pressure contribution to water potential in the stated model.



Water potential: include solute and pressure effects: original worked-case diagram

■ Choose evidence that can test it

- Compare the complete water potentials of the two sides rather than solute concentrations alone.
- A turgid cell can have the same total water potential as its surroundings despite unequal solute potential.
- At equilibrium there is no net transfer, but water molecules can continue moving in both directions.

In the lab: Use provided potential values and labelled plant-cell models. State the reference and units before adding components. For school tissue investigations, control temperature, tissue dimensions, time and blotting, and estimate a zero-change point from repeated measurements. Do not claim the mass method separately measures cell pressure without further evidence.

■ Work from known quantities

- Known: a cell has solute potential -0.8 MPa and pressure potential $+0.3$ MPa, so total potential is -0.5 MPa.
- Surrounding solution is -0.2 MPa.
- Water tends to enter the cell because -0.2 is higher than -0.5 .
- If the cell components change to -0.8 and $+0.6$ MPa, its total is -0.2 MPa, matching the surroundings in this simplified model.

Your turn: Solute potential is -0.7 MPa and pressure potential is $+0.4$ MPa. Find total water potential.

■ Check the conclusion and its limits

- More negative is lower, not higher.
- The additive cell model has stated boundaries and does not require pretending that every real tissue has one uniform value.
- Loss of turgor and cell-wall support differ from a rigid wall directly controlling solute concentration.

Not true: Solute concentration alone always determines water movement in a turgid plant cell. In a turgid cell the wall pushes back: pressure potential opposes the solute effect, and movement depends on the SUM. Solute concentration alone decides only when pressure potential is zero.

Key:

- Water potential describes the tendency of water to move relative to a chosen reference, with pressure units.
- Compare the complete water potentials of the two sides rather than solute concentrations alone.
- Watch for: more negative is lower, not higher.

■ Write from a water potential of -0.7 megapascals

- Solute potential is -0.9 MPa and pressure potential is +0.2 MPa. The surrounding solution is -0.4 MPa.
- Find the cell's water potential and the direction of net water movement.

Reproduction

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

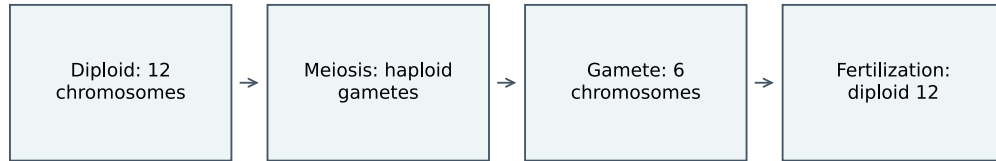
Sexual reproduction: meiosis and fertilization have different roles

■ What would explain this observation?

- Gametes normally contain one set of chromosomes, while **fertilization** joins two sets. Maintaining chromosome number across generations requires both processes.

■ Build the model

- Meiosis reduces chromosome number when producing **haploid** cells from a diploid starting cell.
- Homologous chromosomes separate in meiosis I, while sister chromatids separate in meiosis II.
- Fertilization combines haploid gamete nuclei to form a diploid zygote.
- Sexual reproduction can create new combinations of existing alleles.
- haploid: Having one chromosome set in the stated life cycle.
- fertilization: Fusion of gamete nuclei to form a zygote.



Sexual reproduction: meiosis and fertilization have different roles: original worked-case diagram

■ Choose evidence that can test it

- Distinguish homologous chromosomes from sister chromatids, and chromosome number from DNA quantity.
- Replication before meiosis copies DNA without doubling the number of chromosome sets.
- Crossing over and independent assortment contribute to genetic variation, while random fertilization further changes combinations.
- These processes do not make every offspring genetically distinct under every conceivable condition.

In the lab: Use a labelled model organism with a stated chromosome number. Track chromosome sets through replication, meiosis I, meiosis II and fertilization. Use anonymous model data rather than personal family or reproductive-health information. Compare organism life cycles carefully; flowering-plant and animal reproductive structures require their own additional teaching.

■ Work from known quantities

- Known: a model organism has diploid chromosome number $2n=12$.
- A gamete has $n=6$.
- After fertilization, the zygote has 12 chromosomes.
- With six independently assorting chromosome pairs and ignoring crossing over, there are $2^6=64$ possible maternal/paternal chromosome combinations in a gamete.
- This is a model count, not a probability of an individual phenotype.

Your turn: A model organism has diploid chromosome number 20. How many chromosomes are normally in a gamete?

■ Check the conclusion and its limits

- A gamete is not made by halving the size of an ordinary cell.
- Independent assortment counts assume distinct homologous alternatives and do not include crossing-over outcomes.
- Human and plant reproduction cannot be fully replaced by a monohybrid Punnett grid.

Not true: DNA replication alone changes a diploid cell into a tetraploid cell. Replication doubles the DNA content but the chromosomes still count as one each (two sister chromatids); the cell remains diploid. Tetraploidy needs a failure of division, not replication.

Key:

- Meiosis reduces chromosome number when producing haploid cells from a diploid starting cell.
- Distinguish homologous chromosomes from sister chromatids, and chromosome number from DNA quantity.
- Watch for: A gamete is not made by halving the size of an ordinary cell.

■ Write from a gamete of 4 chromosomes

- A model organism has diploid number 8.
- Find the gamete chromosome number. With 4 pairs and no crossing over, how many maternal-paternal combinations are there?

Inheritance

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

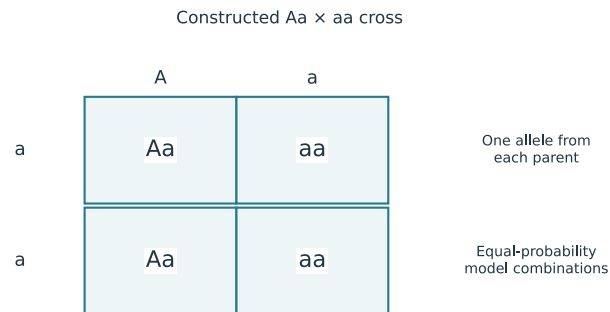
Inheritance, variation and probability

■ What would explain this observation?

- Two parents can carry a recessive **allele** without expressing the associated phenotype. Their children do not have to match the parents phenotypically.

■ Build the model

- An allele is a variant of a gene.
- A **genotype** lists alleles; a phenotype is the expressed characteristic, influenced by genotype and sometimes environment.
- Dominant and recessive describe the relationship between alleles, not how common they are.
- allele: A variant of a gene.
- genotype: The alleles an organism carries.



Boxes show possible outcomes, not a fixed sequence of births.

Inheritance, variation and probability: original worked-case diagram

■ Choose evidence that can test it

- In a simple monohybrid cross $Aa \times Aa$, gametes carry A or a.
- Combining independent gametes gives AA, Aa, Aa and aa.
- The predicted probabilities describe many possible fertilizations, not a fixed order of children.

In the lab: Write parental genotypes and gametes before making the grid. State the inheritance model and phenotype key. Use a pedigree to check consistency with a model; do not infer certainty from a small family alone.

■ Work from known quantities

- Known: $Aa \times Aa$ with complete dominance.
- Probability of $aa = 1/4 = 25\%$.
- Probability of the dominant phenotype = $3/4 = 75\%$.
- If four children are born, there is no guarantee that exactly one has the recessive phenotype.

Your turn: In $Aa \times aa$, what percentage of offspring are predicted to be aa?

■ Check the conclusion and its limits

- A dominant allele can be rare.
- Mutation is a source of new variation; selection changes the relative success of existing variants rather than directing mutations toward a goal.

Not true: A dominant allele must be the most common allele in a population. Dominant describes how an allele is expressed in a heterozygote, not how common it is. A dominant allele can be rare in a population and a recessive allele can be common; frequency depends on inheritance and selection, not dominance.

Key:

- An allele is a variant of a gene.
- In a simple monohybrid cross $Aa \times Aa$, gametes carry A or a.
- Watch for: A dominant allele can be rare.

■ Write from an expected 5 offspring

- Aa crosses with Aa . There are 20 offspring. Complete dominance applies.
- Find the expected number of aa offspring. The count is not a guarantee.

D.3.3 · Homeostasis

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL/SL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: hormones and cell signalling from D.3.1–D.3.2, and percentages from mathematics.

The examples are original and fictional: they are not real measurements or real student investigations.

Homeostasis

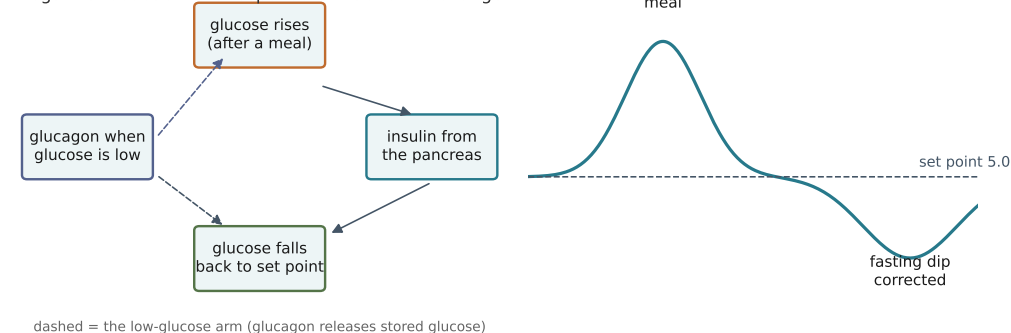
■ What would explain this observation?

- After a large meal your blood glucose jumps, yet within an hour it returns to near where it started – and after a night without food it still does not collapse. What keeps it steady?

■ Build the model

- **Homeostasis** is the maintenance of a nearly constant internal environment around a set point. It runs on **negative feedback**: a detector notices the change, a control centre compares it with the set point, and an effector produces a response that **OPPOSES** the change.
- For blood glucose: when it rises, the pancreas releases **insulin**, which makes liver and muscle cells take up glucose and store it as glycogen, so glucose falls. When glucose falls too low, **glucagon** triggers the liver to convert glycogen back to glucose, so it rises. Hormone secretion adjusts through negative feedback as glucose returns towards its usual range.
- homeostasis: Maintaining a nearly constant internal environment around a set point; negative feedback: A control loop whose response opposes the original change; insulin: The hormone that lowers blood glucose by promoting uptake and storage; glucagon: The hormone that raises blood glucose by releasing stored glucose.

Negative feedback: the **response** OPPOSES the change



Insulin answers a rise and glucagon a fall, so blood glucose returns to the set point

■ Choose evidence that can test it

- Measure blood glucose at intervals after a meal: the model predicts a rise, a peak, and a return towards the set point as insulin acts – and the same record shows insulin rising before glucose falls, the cause arriving before the correction.
- Compare a person whose pancreas cannot make insulin: glucose stays high after a meal, direct evidence that insulin is the link between the detector and the response.

■ Work from known quantities

- Known: a person's blood glucose rises from a set point of 5.0 to 7.0 mmol/L after a meal. Change = final – initial = 7.0 – 5.0 = 2.0 mmol/L. Percentage deviation = $2.0/5.0 \times 100 = 40\%$ above the set point. Negative feedback acts until the value returns close to 5.0 mmol/L.

Example:

During a fast, blood glucose falls from 5.0 to 4.2 mmol/L. Find the percentage deviation from the set point and name the responding hormone, using the same sequence: known quantities → model → relation → substitution → unit and interpretation. (Answer: change = 4.2 – 5.0 = –0.8 mmol/L; deviation = $-0.8/5.0 \times 100 = -16\%$; glucagon responds to raise it.)

■ Check the conclusion and its limits

- Homeostasis is NEAR-constant, not fixed: the value oscillates around the set point because each response takes time. This model covers blood glucose; temperature, water and carbon dioxide each have their own detectors and effectors with the same logic.

Warn:

Negative feedback makes the measured value negative. This claim is false: “negative” means the response OPPOSES the change – a rise triggers a fall and a fall triggers a rise. The measured value stays positive and close to the set point.

Key:

Homeostasis: detector → control centre → effector loops keep internal conditions near a set point by negative feedback. Insulin lowers raised blood glucose; glucagon raises lowered blood glucose; the corrective response decreases as balance returns.

■ **Write from insulin’s moment**

- Blood glucose rises from 4 to 9 mmol per litre after a meal.
- Which hormone acts, and in which direction? Insulin – lowering glucose toward the set point.

■ **Write from glucagon’s moment**

- Hours later glucose falls to 3 mmol per litre.
- Which hormone acts? Glucagon – raising glucose; the loop responds in both directions.

■ **Write from the corrective response decreasing**

- Insulin has worked and glucose returns to the set point.
- What happens to insulin secretion? It declines – negative feedback reduces the corrective response as balance returns.

D.4.1 · Natural selection

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL/SL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: variation and inheritance from D.1 and evolution evidence from A.4.1.

The examples are original and fictional: they are not real measurements or real student investigations.

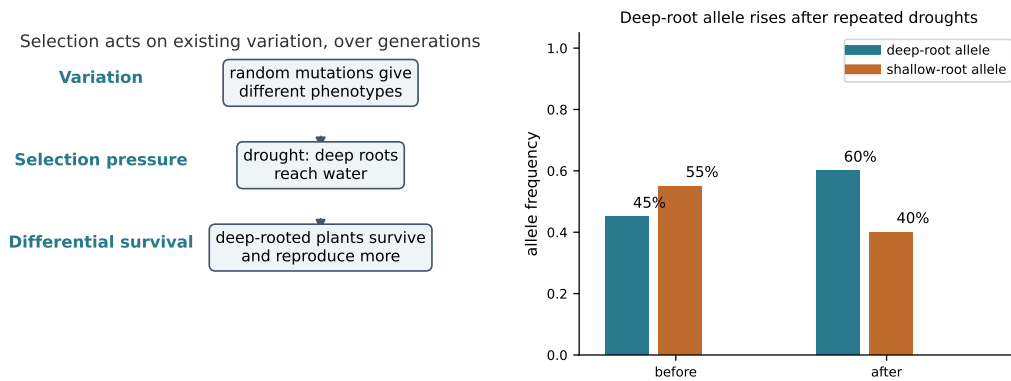
Natural selection

■ **What would explain this observation?**

- After several dry summers, most plants in a population have deeper roots than their grandparents’ generation did. Nobody chose this – how did the population change?

■ **Build the model**

- **Natural selection** needs three ingredients: inherited **variation** exists in the population; a **selection pressure** makes some variants survive and reproduce better than others; and the successful variants’ alleles become commoner in the next generation. Over generations the population’s traits shift.
- Mutation can occur before or during exposure to a selection pressure; it is not directed by an organism’s needs. Selection acts on available heritable variation. Over generations, the population’s **allele frequency** can change.
- natural selection: The process by which heritable variants that fit the environment leave more offspring, changing allele frequencies over generations; variation: Inherited differences among individuals of a population; selection pressure: An environmental factor that affects survival or reproduction; allele frequency: The proportion of one allele among all copies of that gene in a population.



Repeated droughts raise the deep-root allele from 45% to 60%

■ Choose evidence that can test it

- The model predicts the direction of change: after repeated droughts, measure the deep-root allele's frequency in stored seed collections or dated samples – it should rise. If it does not, the explanation fails.
- A fair test compares the SAME population across time or matched populations across a boundary, so that migration or sampling differences cannot fake the shift.

■ Work from known quantities

- Known: before the droughts, 200 gene copies include 90 copies of the deep-root allele; after several generations, 120 of 200. Allele frequency = copies of the allele / total copies. Before: $90/200 = 45\%$. After: $120/200 = 60\%$. The frequency rose by 15 percentage points – evidence of selection acting on the population.

Example:

In a new generation, 140 of 200 copies carry the deep-root allele. Find the frequency and the change from the previous generation using the same sequence: known quantities → model → relation → substitution → unit and interpretation. (Answer: $140/200 = 70\%$; change = $70\% - 60\% = +10$ percentage points. Frequencies of two alleles at one gene sum to 100%.)

■ Check the conclusion and its limits

- A frequency shift shows association between the trait and survival; proving the mechanism needs the variation to be heritable and the survival difference measured. Genetic drift in small populations can shift frequencies with no selection at all.

Warn:

An organism develops a useful adaptation during its lifetime because it needs one.

This claim is false: mutation is random with respect to need – the deep-root alleles existed before the drought. Selection only changes which variants leave more offspring; individuals do not evolve.

Key:

Natural selection: inherited variation + a selection pressure + differential reproduction shifts allele frequencies over generations. Track the shift with allele counts divided by total copies, and remember that the population evolves – never the individual.

■ Write from an a frequency of 0.4

- A population of 100 plants has genotypes AA 36, Aa 48, aa 16.
- Find the a frequency: $(48 + 32) \div 200 = 0.4$ – count alleles, not individuals.

■ Write from a frequency of 0.29 after selection

- A drought kills every shallow-rooted aa plant; the 84 survivors (AA 36 + Aa 48) breed equally.
- Find the new a frequency: $48 \div 168 \approx 0.29$ – selection changed the allele pool, not any single plant.

■ Write from the direction of the shift

- The next generation is grown from the survivors' seeds only.
- Say which alleles rise: a falls toward 0.29 and below; A rises – the population evolves, the individuals never did.

D.4.2 · Sustainability and change

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL/SL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: populations and ecosystems from D.4.1 and energy flow from earlier ecology.

The examples are original and fictional: they are not real measurements or real student investigations.

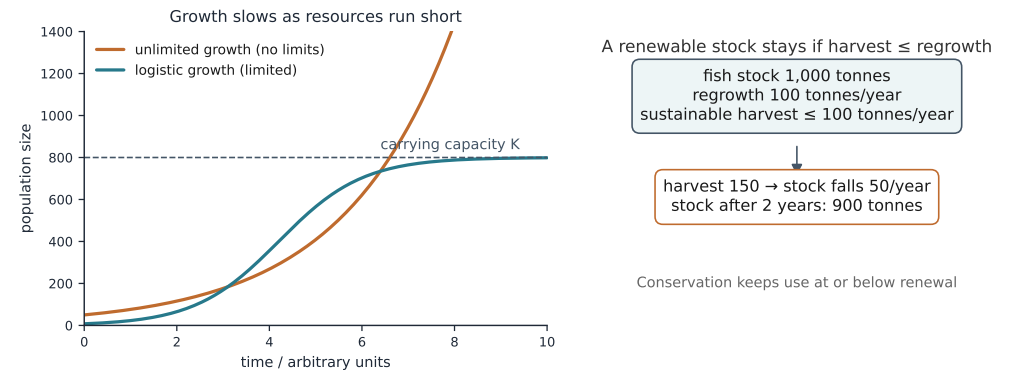
Sustainability and change

■ What would explain this observation?

- A fishery that harvests the same tonnage every year can thrive for decades, while a neighbouring one collapses in five. Both fish the same sea – what separates them?

■ Build the model

- Populations cannot grow without limit. The **logistic model** shows growth slowing as resources run short, levelling at the environment's **carrying capacity** – the largest population the habitat can support. Food, space, disease and predation supply the limits.
- A **renewable resource** is sustainable only when harvest stays at or below regrowth. Change is constant in ecosystems: climate shifts, species arrive, and human activity alters habitats, so management must track stocks and adjust.
- logistic model: Growth that levels at the carrying capacity as resources become limiting; carrying capacity: The largest population an environment can support; renewable resource: A resource that regenerates, such as a fish stock or a forest.



Sustainability and change: original worked-case diagram

■ Choose evidence that can test it

- Compare the stock before and after each harvest season: a sustainable fishery holds the stock near its level, while decline year on year means harvest exceeds regrowth. Distinguish a falling stock from a falling CATCH, which can hide the decline until late.
- Track the same population over several years rather than once; a single count cannot show a trend.

■ Work from known quantities

- Known: a fish stock is 1,000 tonnes and regrows 100 tonnes per year. A harvest of 150 tonnes per year gives net change = regrowth – harvest = 100 – 150 = –50 tonnes per year. After two years the stock is 1,000 – 2 × 50 = 900 tonnes – a sustainable harvest at this regrowth is at most 100 tonnes per year.

Example:

After better management the regrowth is 120 tonnes per year and the harvest quota is set at 80 tonnes per year. Find the yearly change in the stock and the stock after three years from 900 tonnes, using the same sequence: known quantities → model → relation → substitution → unit and interpretation. (Answer: net change = 120 – 80 = +40 tonnes per year; after three years, 900 + 3 × 40 = 1,020 tonnes – the stock recovers.)

■ Check the conclusion and its limits

- The balance model assumes a constant regrowth rate; in reality regrowth depends on the stock size itself, collapsing fastest when the stock is already small. One year's figures cannot establish a trend – management needs the whole time series and honest catch reporting.

Warn:

A renewable resource cannot be used up. This claim is false: renewable means it CAN regenerate, not that it always outpaces use – a stock harvested faster than its regrowth shrinks every year and can collapse entirely, as overfished cod stocks did.

Key:

Sustainability and change: populations level at the carrying capacity, and renewable resources stay only if harvest $\leq$ regrowth. Track stocks over time and set harvests from measured regrowth, because ecosystems never stand still.

Climate change

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

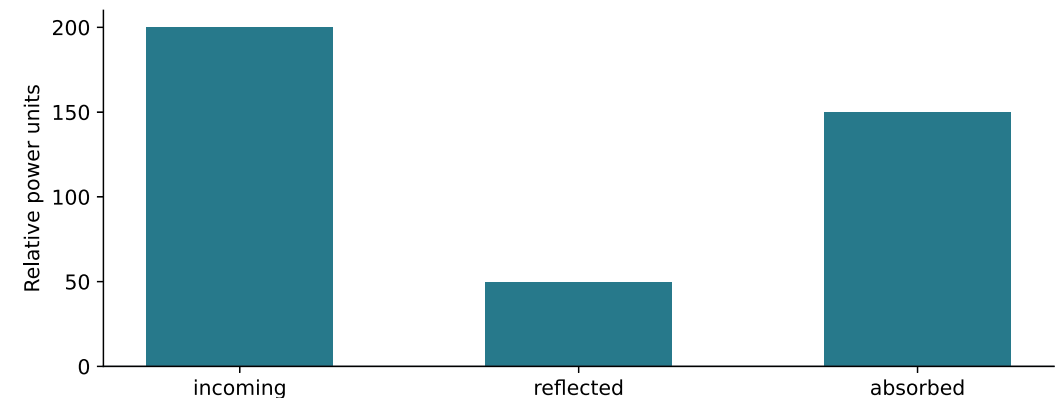
Climate evidence, energy budgets and policy

■ What would explain this observation?

- One cold day does not disprove a warming climate. Weather describes short-term conditions; climate describes distributions over longer times and regions.

■ Build the model

- The Earth energy balance includes incoming solar radiation, reflection, absorption and outgoing infrared radiation.
- Greenhouse gases absorb and emit infrared radiation.
- Feedback can alter the response to an initial forcing.
- **mitigation** : Actions addressing causes of environmental change.
- **adaptation** : Actions reducing harm from environmental impacts.



Climate evidence, energy budgets and policy: original worked-case diagram

■ Choose evidence that can test it

- Distinguish mitigation, which addresses drivers, from adaptation, which reduces harm from impacts.
- A policy assessment needs evidence about effectiveness, cost, equity and uncertainty; one criterion is not the entire decision.

In the lab: Compare multi-year data using consistent baselines. State the region, timescale and uncertainty. At HL, connect a management decision to law, economics and ethics rather than treating these lenses as extra definitions only.

■ Work from known quantities

- Known: a surface receives 200 power units and reflects 50.
- Absorbed input = incoming-reflected = $200 - 50 = 150$.
- Reflected fraction = $50/200 = 0.25 = 25\%$.
- A change in reflectivity alters the absorbed budget under this model.

Your turn: Incoming energy is 240 units and reflected energy 72. Find reflected percentage.

■ Check the conclusion and its limits

- The greenhouse effect is not the same process as ozone depletion.
- A carbon footprint estimate depends on its system boundary.

Not true: One local weather observation establishes a global climate trend. Weather is a short-term local state; climate is the long-term statistical pattern. One cold day in one city cannot confirm or refute a global trend built from decades of worldwide records.

Key:

- The Earth energy balance includes incoming solar radiation, reflection, absorption and outgoing infrared radiation.
- Distinguish mitigation, which addresses drivers, from adaptation, which reduces harm from impacts.
- Watch for: the greenhouse effect is not the same process as ozone depletion.

■ Write from a reflected share of 20 percent

- A surface receives 180 energy units and reflects 36.
- Find the reflected percentage and the absorbed amount.

Experimental programme

International Baccalaureate · IB Diploma · Biology · HL

Scope and prerequisites

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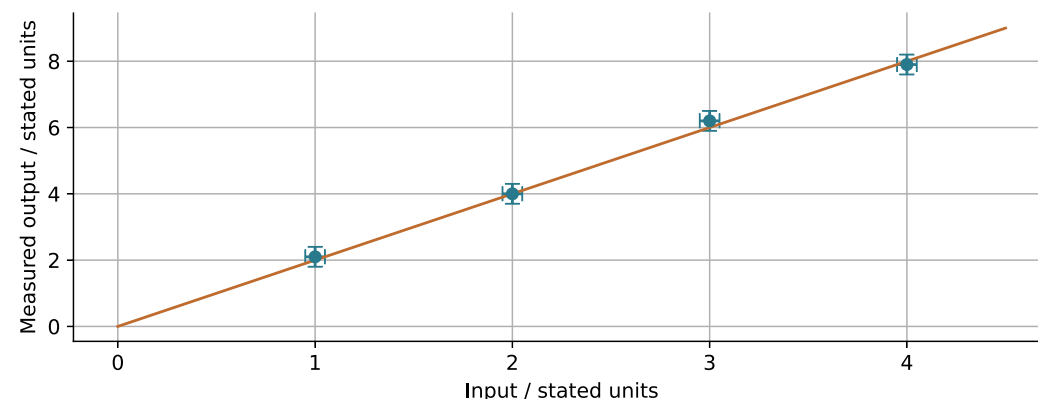
Uncertainty, gradients and model testing

■ What would explain this observation?

- A line passing near every data point is useful, but its gradient can still be uncertain. A graph is evidence for a model within the measurement range.

■ Build the model

- Random variation makes repeated readings differ.
- **Systematic error** shifts results consistently.
- Absolute **uncertainty** has the measured unit; relative or percentage uncertainty compares uncertainty with the measured value.
- uncertainty: A quantified limitation on a measured result.
- systematic error: A consistent measurement bias.



Uncertainty, gradients and model testing: original worked-case diagram

■ Choose evidence that can test it

- For a product or quotient, adding fractional uncertainties is a common maximum-uncertainty approximation.
- For a difference, add absolute uncertainties.
- A nonzero intercept can reveal an offset or an incomplete model.

In the lab: Show units on axes and choose a sensible scale. Plot uncertainty bars where justified, draw a best-fit line rather than joining every point, and estimate steepest and shallowest plausible gradients when the course method calls for them.

■ Work from known quantities

- Known: length = 50.0 mm with uncertainty 1.0 mm.
- Percentage uncertainty = absolute uncertainty/value $\times 100 = 1.0/50.0 \times 100 = 2.0\%$.
- For a quotient of two independently measured quantities with maximum percentage uncertainties 2% and 3%, the summed maximum estimate is 5%.

Your turn: A 40 cm reading has an absolute uncertainty of 1 cm. Find percentage uncertainty.

■ Check the conclusion and its limits

- Repeating readings reduces random uncertainty in a mean but does not automatically remove a zero error.
- Do not quote more decimal places than your measurement can support.

Not true: Repeating a measurement always removes a calibration offset. Repeating and averaging reduces RANDOM scatter in the mean. A calibration offset shifts every reading identically, so repeats land on the same wrong value; only recalibration removes it.

Key:

- Random variation makes repeated readings differ.
- For a product or quotient, adding fractional uncertainties is a common maximum-uncertainty approximation.
- Watch for: repeating readings reduces random uncertainty in a mean but does not automatically remove a zero error.

■ Write from an uncertainty of 15 percent

- A 40 mm reading has an absolute uncertainty of 6 mm.
- Find the percentage uncertainty. For a quotient, add the percentage uncertainties.