The whole course, *two pages* a topic.

IB Biology revision guide: every subtopic boiled down to the core you need to know, with the diagrams to draw and the mistakes to dodge.

40 SUBTOPICS · SL AND HL · HL PARTS MARKED · 83 PAGES

What is *inside*

CONTENTS

One sheet a subtopic
Front: the ideas. Back: the detail, the mistakes and exam practice.

HL is marked
A pink HL tag sits on anything standard level students can skip.

Then test yourself
Cover the sheet, write what you remember, check, repeat tomorrow.

A Unity and diversity

What living things share, and how they came to differ.

A1.1	Water	SL + HL	4
A1.2	Nucleic acids	SL + HL	6
A2.1	Origins of cells	HL	8
A2.2	Cell structure	SL + HL	10
A2.3	Viruses	HL	12
A3.1	Diversity of organisms	SL + HL	14
A3.2	Classification and cladistics	HL	16
A4.1	Evolution and speciation	SL + HL	18
A4.2	Conservation of biodiversity	SL	20

B Form and function

How structure fits the job, from molecules to ecosystems.

B1.1	Carbohydrates and lipids	SL	22
B1.2	Proteins	SL + HL	24
B2.1	Membranes and membrane transport	SL + HL	26
B2.2	Organelles and compartmentalization	SL + HL	28
B2.3	Cell specialization	SL + HL	30
B3.1	Gas exchange	SL + HL	32
B3.2	Transport	SL + HL	34
B3.3	Muscle and motility	HL	36
B4.1	Adaptation to environment	SL	38
B4.2	Ecological niches	SL	40

What is *inside*

C Interaction and interdependence

How the parts of a living system work on each other.

C1.1	Enzymes and metabolism	SL + HL	42
C1.2	Cell respiration	SL + HL	44
C1.3	Photosynthesis	SL + HL	46
C2.1	Chemical signalling	HL	48
C2.2	Neural signalling	SL + HL	50
C3.1	Integration of body systems	SL + HL	52
C3.2	Defence against disease	SL	54
C4.1	Populations and communities	SL	56
C4.2	Transfers of energy and matter	SL	58

D Continuity and change

How life copies itself, and how it changes over time.

D1.1	DNA replication	SL + HL	60
D1.2	Protein synthesis	SL + HL	62
D1.3	Mutation and gene editing	SL + HL	64
D2.1	Cell and nuclear division	SL + HL	66
D2.2	Gene expression	HL	68
D2.3	Water potential	SL + HL	70
D3.1	Reproduction	SL + HL	72
D3.2	Inheritance	SL + HL	74
D3.3	Homeostasis	SL + HL	76
D4.1	Natural selection	SL + HL	78
D4.2	Stability and change	SL + HL	80
D4.3	Climate change	SL + HL	82

IB BIOLOGY · A1.1 · SL AND HL

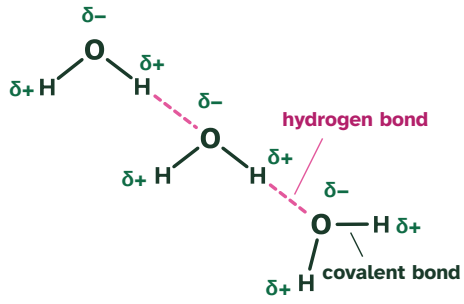
REVISION ON TWO PAGES

Why life runs on *water*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Water molecules are polar, so they form hydrogen bonds. Everything else on this sheet follows from that.



Draw it like this. Solid lines for covalent bonds, dashed for hydrogen bonds, δ+ and δ– on the atoms.

A1.1.2 START HERE

Polar bonds make *hydrogen bonds*

- Oxygen pulls the shared electrons harder than hydrogen does. This **unequal sharing** makes each O–H bond a **polar covalent bond**: the oxygen is slightly negative (δ–) and each hydrogen slightly positive (δ+).
- The δ+ hydrogen of one molecule is attracted to the δ– oxygen of the next. That attraction is a **hydrogen bond**. It forms **between** molecules, never inside one.
- Each hydrogen bond is weak, but there are vast numbers of them. Breaking them takes energy, so water needs a lot of heat to evaporate: that is why sweating cools you.

WHAT HYDROGEN BONDS GIVE WATER — *Cats Avoid Taking Showers*

C	**Cohesion**	water sticks to water
A	**Adhesion**	water sticks to polar surfaces
T	**Thermal**	slow to warm and cool
S	**Solvent**	dissolves ions and polar molecules

A1.1.1

The *medium* for life

- The **first cells arose in water**, more than 3.5 billion years ago.
- Substances dissolve in water, so they can move about, meet and react.
- Water is still the medium in which **most processes of life** happen. Cytoplasm is an aqueous solution, and a cell is about 70% water.
- Land organisms carry their water inside them, in cells, blood and tissue fluid.

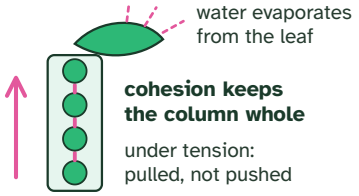
70% of a cell is water

90% of blood plasma is water

A1.1.3 WATER TO WATER

Cohesion

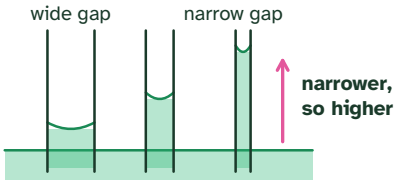
- **Cohesion**: hydrogen bonds hold water molecules to one another.
- **In xylem:** evaporation from leaves pulls water up. Cohesion keeps the column unbroken, so it is pulled up **under tension**.
- **At the surface:** molecules are pulled sideways and inwards, so the surface acts like a stretched film: **surface tension**. Pond skaters use it as a habitat.



A1.1.4 WATER TO OTHER THINGS

Adhesion

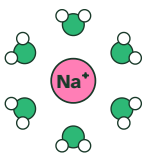
- **Adhesion**: water is attracted to materials that are **polar or charged**.
- **Capillary action**: water adheres to the sides of a narrow space and creeps along; cohesion drags the rest behind.
- **In soil:** water is held between the particles and creeps towards roots.
- **In plant cell walls:** water soaks between the cellulose fibres, keeping the walls wet.



A1.1.5

The *solvent* cells run in

- Water surrounds ions and hydrogen-bonds with polar molecules, so a **wide variety of hydrophilic substances dissolve**.
- **Metabolism:** most **enzymes catalyse reactions in aqueous solution**, where enzyme and substrate can meet.
- **Transport:** blood plasma, xylem sap and phloem sap carry dissolved substances.
- Some molecules work **because they are hydrophobic** and insoluble.



The δ– oxygens face the positive ion

Hydrophilic polar or charged

Ions (Na^+, Cl^-), glucose, amino acids, urea. They dissolve, so they can react and be carried.

Hydrophobic non-polar, insoluble

Wax on a leaf keeps water in. **Fat** stores energy without dissolving. **Phospholipid tails** make a membrane a barrier.

Water as a *habitat*, and water beyond Earth

A1.1.6 COMPARE WATER WITH AIR, AND SAY WHAT IT MEANS FOR AN ANIMAL

Life in water, life in *air*

PROPERTY	WATER AGAINST AIR	BLACK-THROATED LOON *Gavia arctica*	RINGED SEAL *Pusa hispida*
B **Buoyancy** the upward push of a fluid	**Over 800 times as dense.** Water holds a body up; air gives almost no support.	Floats so well that it must work to dive: its bones are dense and it squeezes the air from its feathers.	Water carries its weight, so its flippers are free to drive and steer. On the ice it must haul itself along.
V **Viscosity** resistance to flow	**About 55 times as viscous.** Moving through water meets far more drag.	A streamlined body, with webbed feet set far back to drive it after fish.	A smooth torpedo shape with no ear flaps cuts the drag; hind flippers push it along.
T **Thermal conductivity** how fast heat passes through	**About 23 times as fast.** A warm body loses heat far faster in water.	Dense, oiled feathers trap a layer of air, which conducts heat poorly.	Wet fur traps no air, so thick **blubber** under the skin keeps its heat in.
S **Specific heat capacity** energy to warm 1 g by 1 °C	**About 4 times as high.** Water warms and cools slowly, so it is a stable habitat.	Its lake changes temperature only slowly, from day to night and from week to week.	The sea under the ice stays near −1.8 °C all year. The air above swings from −30 °C to above 0 °C.

Values at 20 °C. In an exam, either the common name or the scientific name is accepted.

Remember the four: *Big Vessels Turn Slowly*

A1.1.7 HIGHER LEVEL

Where Earth's water *came from*

- **Origin: asteroids** carrying water struck the young Earth. This is the one hypothesis you need.

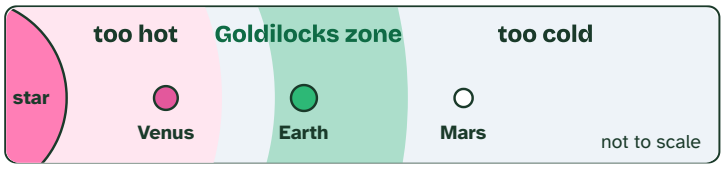
KEPT BY 1
Gravity
Earth is massive enough to hold on to its water.

KEPT BY 2
Temperature
Low enough for water vapour to condense into liquid oceans.

- Water has been abundant for billions of years, which gave **life the time to evolve**.
- **Evidence:** water in some meteorites has almost the same ratio of heavy to light hydrogen as the oceans.

A1.1.8 HIGHER LEVEL

The search for life *elsewhere*



- All known life needs liquid water, so the search for extraterrestrial life **looks for liquid water** first.
- The **Goldilocks zone** is the range of distances from a star where a planet's surface could keep water liquid.
- In the zone, water **could** be liquid. That does not show there is water, or life.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Hydrogen bonds are between molecules.** The O–H bonds inside a molecule are covalent.
- ✕ **Write δ+ and δ−, never a bare + or −.** Water is neutral.
- ✕ **Cohesion is water to water; adhesion is water to something else.** Capillary action needs both.
- ✕ **Capillary action does not lift water up a tree.** Evaporation from leaves pulls; cohesion holds the column.
- ✕ **Conductivity is not heat capacity.** One is how fast heat passes through water; the other, how much energy warms it.
- ✕ **Hydrophilic does not always mean soluble.** Cellulose attracts water but does not dissolve.

COVER THE SHEET

Can you *answer these?*

1. State why water is called the medium for life.
2. Draw two water molecules joined by a hydrogen bond.
3. Explain how water reaches the top of a tall tree.
4. Outline capillary action and two places it matters.
5. Name three solutes in blood plasma, and one molecule that is useful because it is hydrophobic.
6. Explain why a ringed seal needs blubber in the sea.
7. State two reasons why Earth kept its water. HL
8. Explain why the search for life looks in a star's Goldilocks zone. HL

IN THE EXAM

Name the bond ("hydrogen bonds between water molecules"), then **link the property to its consequence** for the organism.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY · A1.2 · SL AND HL

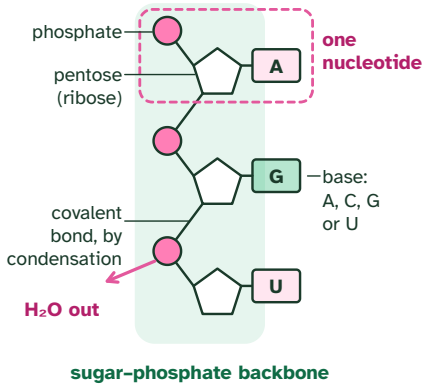
REVISION ON TWO PAGES

Four letters, two *strands*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Nucleotides link into a covalent backbone. Their bases pair, A with T and C with G, so the sequence stores information and can be copied.



Draw it like this. Circle, pentagon, rectangle. Each phosphate joins the lower left corner of the sugar above.

A1.2.2 to 5 START HERE

Nucleotides build a *strand*

- A **nucleotide** is a phosphate, a pentose sugar and a nitrogenous base, joined by covalent bonds. The sugar is in the middle: the base bonds to it, never to the phosphate.
- **Condensation:** the phosphate of each new nucleotide bonds to the sugar of the last one, and water is released. Ten nucleotides make nine bonds and release nine waters.
- Every link is covalent, so each strand is one continuous chain: a strong **sugar–phosphate backbone**. The bases stick out to one side.
- **RNA** is one such strand, a polymer made by condensation. The order of bases, the **base sequence**, is the code: like letters spelling words.

THE BASES: KNOW THE NAMES

Apples in the Tree, Cars in the Garage

A Adenine with T or U	**T** Thymine DNA only	**C** Cytosine with G	**G** Guanine with C	**U** Uracil RNA only

A1.2.1

DNA, the *genetic material*

- The genetic material holds the instructions an organism inherits. In **every living organism** it is **DNA**: bacteria, archaea, protists, fungi, plants and animals.
- DNA and RNA are the **nucleic acids**: polymers of nucleotides.
- A gene is one stretch of the base sequence; one DNA molecule carries many genes.

Living organisms made of cells
The genetic material is always DNA.

Some viruses not living
Genes can be RNA (influenza, measles). **Viruses are not living**, so the rule stands.

A1.2.8

Copied and *read*

- Complementarity rests on **hydrogen bonds**, which line up only in the pairs A–T and C–G.

COPY
Replication
The strands part and each is a template, so each new molecule has the same base sequence.

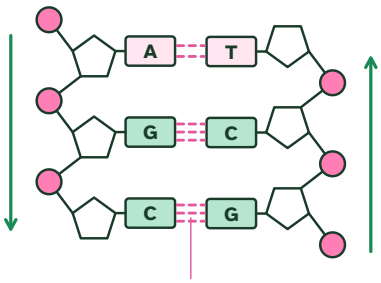
READ
Transcription
A DNA strand is the template for an RNA copy, U opposite A.

READ
Translation
Three mRNA bases pair with three tRNA bases.

A1.2.6

Two *antiparallel* strands

- Two strands, joined by **hydrogen bonds between complementary bases**: A with T, G with C.
- Bases inside, backbones outside. The strands are **antiparallel**: they run in opposite directions.
- They wind into a **double helix**; you need not draw the twist.

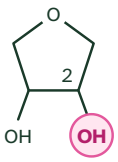


A1.2.7

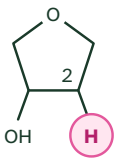
DNA and *RNA* compared

DIFFERENCE	DNA	RNA
Sugar	deoxyribose	ribose
Bases	A, C, G and **T**	A, C, G and **U**
Strands	two	usually one

Remember the three: *Some Bananas Split*



ribose in RNA



deoxyribose in DNA

- **DNA:** the chromosomes, and in mitochondria and chloroplasts.
- **mRNA**: a copy of a gene, taken to a ribosome.
- **tRNA**: brings amino acids; it folds and pairs with itself.
- **rRNA**: part of every ribosome.

One code for all life, and the *evidence*

A1.2.9 and 10

Endless *sequences*

- Any base can follow any other, at any length, so **any sequence is possible**: the capacity is limitless, stored with **great economy**.
- The **genetic code**, a codon of three bases for each amino acid, is **shared by almost all life**.
- The code is arbitrary, so sharing it is evidence of **universal common ancestry**.

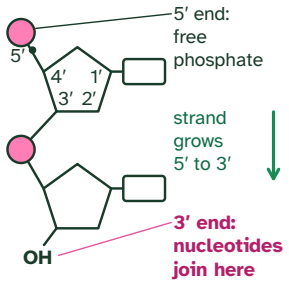
4^{10}
over a million sequences of 10 bases

2 m
of DNA in each human nucleus

A1.2.11 HIGHER LEVEL

5′ and 3′ *ends*

- Sugar carbons are 1′ to 5′. Each 5′ phosphate bonds to the **3′ carbon** before it: a **5′ end** and a **3′ end**.
- Nucleotides join only at the 3′ end, so replication and transcription **build 5′ to 3′**; ribosomes read mRNA 5′ to 3′.



A1.2.12 HIGHER LEVEL

Big base, *small base*

- **Purines** (A, G) have two rings; **pyrimidines** (C, T, U) have one.
- Every pair is **a purine with a pyrimidine**, so A–T and C–G are the same length.
- So the helix has the **same 3D shape** whatever the sequence: stable, and any sequence fits.

TWO SHAPES — *Pure As Gold, CUT*

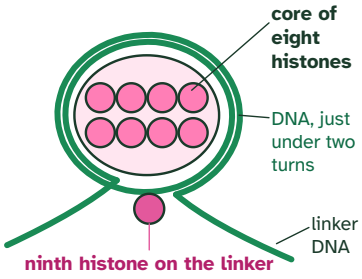
P Purines — two rings

C CUT — one ring each

A1.2.13 HIGHER LEVEL

A *nucleosome*

- DNA wraps just under two turns round a **core of eight histones**.
- A **ninth histone**, on the **linker DNA**, holds it in place.
- **Skill:** study a nucleosome in molecular visualisation software.



A1.2.14 HIGHER LEVEL

Hershey and *Chase*

- Phage T2 is only a protein coat and DNA; what it injects into *E. coli* carries the genes.
- A blender shook coats off; a centrifuge spun bacteria into a **pellet**; coats stayed in the supernatant.
- It became possible once **radioisotopes** were available.

^{35}**S** labels protein	Found in the supernatant: the coats stayed outside.
^{32}**P** labels DNA	Found in the pellet: **DNA entered**, so DNA carries the genes of T2.

A1.2.15 HIGHER LEVEL

Chargaff's *data*

- In every species **A = T and G = C**; the proportions differ between species.
- This **falsified** the tetranucleotide hypothesis (25% of each base).
- Many observations never prove a claim (the problem of **induction**); one reliable contradiction rejects it with certainty.

%	A	T	G	C
Human	30.9	29.4	19.9	19.8
Wheat	27.3	27.1	22.7	22.8
E. coli	24.7	23.6	26.0	25.7

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Hydrogen bonds join the two strands, not a strand.** Inside a strand every link is covalent.
- ✕ **A nucleotide is not a base.** It is base, sugar and phosphate; the base bonds to the sugar.
- ✕ **Complementary is not identical.** The two strands differ; the two molecules made by copying are identical.
- ✕ **Deoxyribose keeps its ring oxygen.** It lacks the oxygen on carbon 2.
- ✕ **Sulfur labels protein, phosphorus labels DNA.** The pellet is the bacteria, not the phages.
- ✕ **Chargaff's rule is A = T and G = C.** Not A = G, and only in double-stranded DNA.

COVER THE SHEET

Can you *answer these?*

1. State why RNA viruses do not break the DNA rule.
2. Draw an RNA strand of three nucleotides.
3. Draw two antiparallel strands, three base pairs long.
4. Distinguish between DNA and RNA in three ways.
5. Explain how base pairing lets DNA be copied.
6. Explain why a shared code suggests a common ancestor.
7. Outline what the 5′ and 3′ ends are. HL
8. Explain why the helix is the same width throughout. HL
9. Describe the structure of a nucleosome. HL
10. Explain what the Hershey–Chase results show. HL
11. Explain how Chargaff falsified a hypothesis. HL

IN THE EXAM

Draw the second strand **upside down**, bases paired A–T and G–C, and write **"hydrogen bonds between complementary bases"**, never just "bonds".

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY | A2.1 | HL

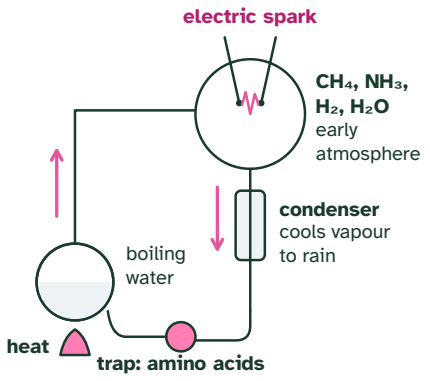
REVISION ON TWO PAGES

From chemistry to *cells*

What to know, what to draw and what to say. All nine statements are higher level.

THE ONE IDEA

Energy acting on simple molecules could make the compounds of life. A membrane and self-copying RNA could then make the first cells.



Draw it like this. Boil, spark, condense, collect: the loop runs for a week.

A2.1.4 START HERE

Miller and Urey: life's molecules *without life*

- **Set-up (1952):** water and a model early atmosphere of **methane, ammonia and hydrogen** were cycled past an **electric spark** (lightning) for a week.
- **Result:** the water turned brown and held **amino acids**, glycine and alanine most of all.
- **Evaluate** means weigh both sides: give a strength and a limit, each with its reason.

Strength what it showed
Organic compounds of life can form from simple molecules and energy, with **no life present**.

Limit the gases
The early air was probably mostly **CO_2 and N_2**, which give far fewer amino acids.

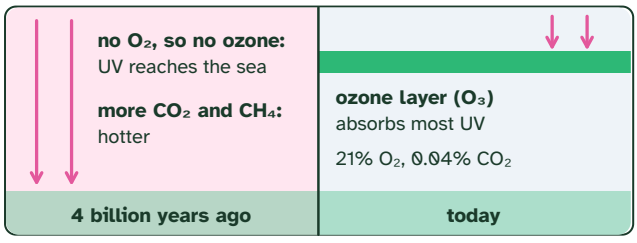
Strength later work
Miller's stored samples, reanalysed, held **more than 20** amino acids.

Limit far from a cell
It made **no proteins, nucleic acids or membranes**.

A2.1.1 CONDITIONS BEFORE LIFE

Early Earth: a world *without oxygen*

- **No free oxygen**, so **no ozone layer**: ultraviolet light reached the surface and the sea.
- Far more **carbon dioxide and methane**, greenhouse gases, so Earth was **hotter**.
- UV, lightning and heat could break simple molecules; the fragments joined into amino acids and sugars.
- Carbon compounds **formed spontaneously**, by chemistry that no longer happens: today oxygen breaks them down and organisms eat them.



A2.1.2 LIVING OR NON-LIVING

The cell: smallest unit of *life*

- A cell is the **smallest unit of self-sustaining life**: the smallest thing that carries out all the functions of life by itself.
- The functions: nutrition, respiration, excretion, growth, response, homeostasis and reproduction. DNA or an enzyme taken out of a cell does none of them.
- **The test is all of them, by itself.** One alone is not enough: a crystal grows and a flame feeds, but neither is alive.

Cell living
Has its own cytoplasm, ribosomes and metabolism. It grows and divides by itself.

Virus usually counted non-living
No metabolism, no cytoplasm, no ribosomes. Inert outside a host; **copied only by a host cell**. It has genes and evolves, but that is not enough.

A2.1.3

Why the first cell is *hard to explain*

- Today cells arise **only by division of pre-existing cells**. A cell is far too complex to assemble by chance in one step, so four things had to arise first.
- **Nature of science:** a hypothesis must be **testable**. This one is hard to test: early Earth cannot be recreated exactly and the first protocells did not fossilise, so scientists test the parts.

NEED 1
Catalysis
So that reactions happen fast enough.

NEED 2
Self-replication
Of molecules, so information can be copied.

NEED 3
Self-assembly
Of structures, such as membranes, by themselves.

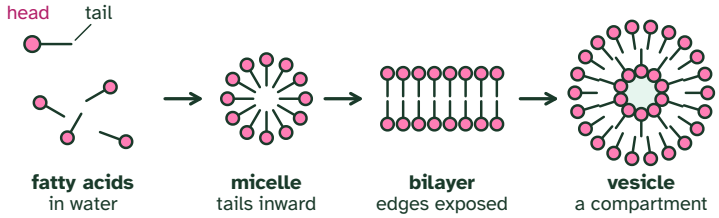
NEED 4
Compartmentalisation
So the chemistry inside differs from outside.

Compartments, the RNA world and *LUCA*

A2.1.5 VESICLES FROM FATTY ACIDS

The first *compartments*

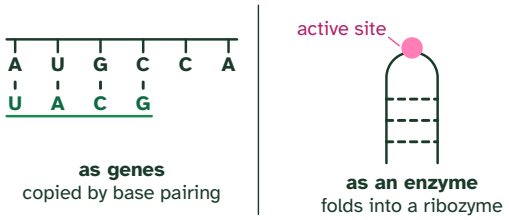
- A **membrane-bound compartment** lets the **chemistry inside differ** from outside. Without one, useful molecules drift away.
- Fatty acids are **amphipathic**: a hydrophilic head and one hydrophobic tail. In water they form micelles, then **coalesce into bilayers**.
- A flat bilayer exposes tails at its edges, so it **closes into a sphere**: a vesicle. In the lab these vesicles hold RNA, grow and divide.
- **Self-assembly:** no gene or enzyme is needed; the shape comes from the molecules alone.



A2.1.6 THE FIRST GENETIC MATERIAL

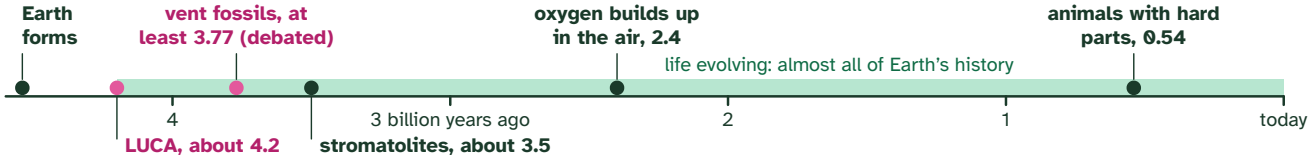
The *RNA world*

- **As genes:** RNA stores information in its base sequence and is **copied by complementary base pairing**.
- **As enzymes:** RNA folds into catalysts, **ribozymes**. So RNA may have been **both genes and enzymes** in the first cells.
- **Still in every cell:** in the ribosome, **RNA catalyses peptide bonds** in protein synthesis.



A2.1.7 to 9

LUCA, the *last universal common ancestor*



A2.1.7 EVIDENCE FOR LUCA

- A **universal genetic code**: the same codons give the same amino acids in all organisms.
- **Shared genes**, and DNA, RNA, ribosomes and ATP, in all life.
- Other early life probably **went extinct**, outcompeted by LUCA and its descendants.

A2.1.8 DATING IT

- **Fossils:** rock is dated by **radioactive isotopes**; stromatolites go back about 3.5 billion years.
- **Molecular clock: differences in shared genes**, with a rate calibrated on dated fossils, put LUCA near 4.2 billion years ago.

A2.1.9 NEAR HYDROTHERMAL VENTS

- **Genes: conserved sequences** traced to LUCA suit life with no oxygen, at high temperature, on H_2 and CO_2.
- **Fossils:** iron mineral threads and tubes in **ancient sea-floor vent precipitates**.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **No ozone because no oxygen.** Ozone (O_3) is made from oxygen: one cause, not two separate facts.
- ✕ **Genes and evolution are not enough to be alive.** A virus has both, yet does nothing outside a host cell.
- ✕ **Miller and Urey did not make life.** They made amino acids: no proteins, nucleic acids or membranes.
- ✕ **A fatty acid vesicle is not a cell.** It has a boundary but no genes, no enzymes and no metabolism.
- ✕ **The RNA world is a hypothesis.** The evidence is what RNA can do today, not RNA from early Earth.
- ✕ **LUCA was not the first life.** It is the last ancestor that everything alive today shares.

COVER THE SHEET

Can you *answer these?*

1. Outline how early Earth let carbon compounds form.
2. Explain why viruses are usually considered non-living.
3. State four requirements for the evolution of the first cells.
4. Evaluate the Miller–Urey experiment.
5. Explain how and why fatty acids form vesicles.
6. Outline why RNA may have been the first genes.
7. Describe two pieces of evidence for LUCA.
8. Outline two approaches used to date LUCA.
9. State two pieces of evidence that LUCA lived near hydrothermal vents.

IN THE EXAM

Evaluate Miller–Urey with a strength and a limit, each with its reason: "amino acids formed with no life present, but the gases were probably not the real early atmosphere."

GO FURTHER

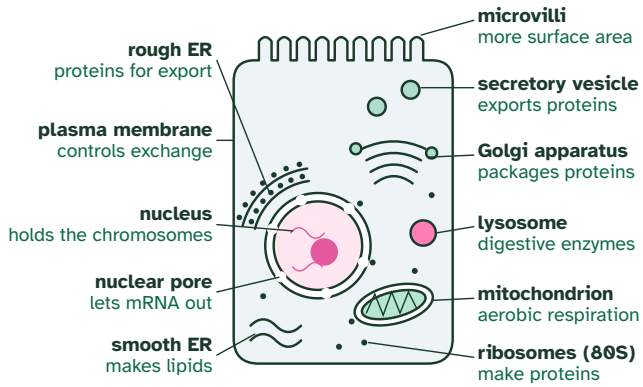
The Miller–Urey film, step-through figures and a marked Check are in the full guide online.

What every *cell* is built from

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Every cell is DNA in watery cytoplasm inside a lipid membrane. Eukaryotes add a nucleus and compartments.



Annotate like this. Each part named, with its function under it.

A2.2.6 START HERE

The *eukaryote*: a cell of compartments

- Membranes **divide the cytoplasm into compartments**, so reactions that would clash are kept apart. Eukaryote ribosomes are **80S**.
- **Nucleus:** chromosomes of DNA wound round **histones**, inside a **double membrane with pores**.
- **Membrane-bound organelles:** mitochondria, rough and smooth ER, the Golgi apparatus, and vesicles and vacuoles, including lysosomes.
- **Cytoskeleton:** microtubules and microfilaments hold the shape and move things about.

A2.2.1

Cells, the unit of *life*

- **Cell theory:** all living things are made of **one or more cells**; the cell is the smallest unit that is alive; cells come only from cells.
- **Deduction:** a new organism is predicted to be **made of cells**.

A2.2.4

What *every* cell has

- **DNA:** the genetic material, copied when the cell divides.
- **Cytoplasm: mostly water**, so substances dissolve and react.
- **Plasma membrane: lipids** do not dissolve, so it holds the inside apart.

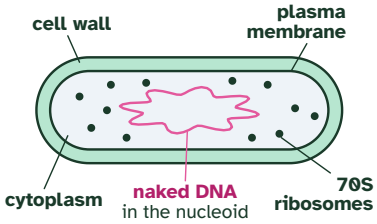
A2.2.5

The *prokaryote*

- **No nucleus**. Learn a Gram-positive bacterium: *Bacillus* or *Staphylococcus*.
- A thick **cell wall** of peptidoglycan keeps the shape and stops bursting; inside it, the membrane and cytoplasm.
- **Naked DNA** in a loop; **70S ribosomes**; no membrane-bound organelles.
- Prokaryote structure varies, but you need no details of how.

1 to 5 µm long, for most

70S smaller ribosomes



A2.2.5 and 6 COMPARE IN PAIRS

Prokaryote against *eukaryote*

FEATURE	PROKARYOTE	EUKARYOTE
Nucleus	None: DNA in the nucleoid	One, in a double membrane
Ribosomes	70S	80S
DNA	Naked loop	Chromosomes with histones
Organelles	No membrane-bound ones	Many membrane-bound
Size	1 to 5 µm	10 to 100 µm

Pink letters: the order to learn them in.

Remember: *Never Ride Dragons Over Seas*

A2.2.2 SKILLS

Mount, focus, *measure*

- **Mount:** thin cells in water or a stain (iodine for plant, methylene blue for cheek cells); coverslip lowered at an angle.
- **Focus: coarse focus** first; at high power **fine focus** only.
- **Measure:** calibrate the **eyepiece graticule** on a stage micrometer for each objective; photograph, add a **scale bar**.

QUANTITATIVE OBSERVATION — *I Am Magnified*

I Image what you measure	**A** Actual image ÷ magnification	**M** Magnification image ÷ actual

A2.2.3

Seeing *smaller*

LIVING CELLS, COLOUR
Light microscope
Resolves about 0.2 µm.

DEAD, THIN SPECIMENS
Electron microscope
Resolves about 1 nm: far finer detail.

- **Freeze fracture:** frozen cells split along the middle of membranes, showing their proteins.
- **Cryo-EM:** frozen protein copies, imaged from all angles, give its **3D structure**.
- **Fluorescent stains** light up one part of a living cell; **immunofluorescence** puts the dye on an antibody.

How cells *differ*, and where eukaryotes came from

A2.2.8 SPOT THE DIFFERENCE

Plant, fungus, *animal*

FEATURE	PLANT	FUNGUS	ANIMAL
Cell wall	**Cellulose**	**Chitin**	**None**
Vacuole	Large **sap vacuole** keeps it firm	Often large.	Small and temporary.
Plastids	**Chloroplasts**, amyloplasts	None: fungi feed on others.	None.
Centrioles, cilia, flagella	None in flowering plants.	None in most fungi.	Centrioles; cilia or a flagellum.

A2.2.7

One cell, *every* job

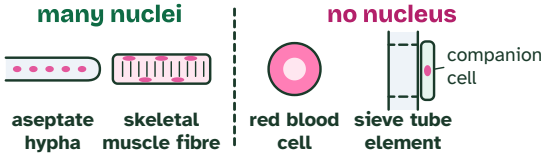
- One cell does every job of life: know *Paramecium* and *Chlamydomonas*.

MANY **Metabolism** All its reactions.	HUNGRY **Homeostasis** Expels water.	NEWTS **Nutrition** Eats or makes food.	MUNCH **Movement** Cilia or flagella.
EGGS **Excretion** Loses CO_2.	GRUBS **Growth** Gets bigger.	ROOTS **Response** Swims to light.	RICE **Reproduction** Divides in two.

A2.2.9

Cells that break the *rules*

- **Many nuclei: aseptate fungal hyphae** (no cross walls) and **skeletal muscle fibres** (fused cells).
- **No nucleus:** mammalian **red blood cells** and phloem **sieve tube elements**.



A2.2.10 and 11 SKILLS

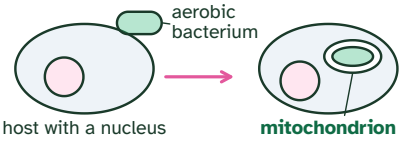
Reading *micrographs*

- **Identify:** no nucleus, a **prokaryote**; a wall and a large vacuole, a plant; neither, an animal.
- **Know by shape** in grey EMs: nucleoid, walls, nucleus, chromosomes, mitochondria, chloroplasts, sap vacuole, Golgi, both ERs, ribosomes, microvilli.
- **Draw:** pencil, clean lines, no shading, ruled labels; **annotate with functions**.

A2.2.12 HIGHER LEVEL

Origin by *endosymbiosis*

- The first eukaryote had a **nucleus** and reproduced sexually. An engulfed aerobic bacterium became the **mitochondrion**; later a cyanobacterium, the **chloroplast**.
- **Evidence: 70S ribosomes**, naked circular DNA, two membranes, own division.



A2.2.13 and 14 HIGHER LEVEL

Many-celled *life*

- **Differentiation**: different **patterns of gene expression**, often set off by the surroundings.
- Multicellularity **evolved many times**: plants, animals, many fungi and algae.
- Gains: a **larger body**, **specialised cells**.



WATCH OUT

Six mistakes that *cost marks*

- ✕ **The nucleoid is not a nucleus.** It is the region where the DNA lies, with no membrane round it.
- ✕ **Prokaryotes do have ribosomes.** What they lack are membrane-bound organelles.
- ✕ **Electron microscopes win on resolution, not magnification.** A blur made bigger is still a blur.
- ✕ **Convert units before you divide:** 1 mm = 1000 µm. Magnification has no units.
- ✕ **Excretion is not egestion.** Excretion removes waste made by metabolism, such as CO_2.
- ✕ **Not every cell has a wall.** Animal cells have none.

COVER THE SHEET

Can you *answer these?*

1. State cell theory and the three structures every cell has.
2. Calculate the magnification: 5 µm drawn as 25 mm.
3. Outline one advantage of immunofluorescence.
4. Draw a Gram-positive bacterium and label five parts.
5. Distinguish prokaryote from eukaryote cells in five ways.
6. List the eight functions of life.
7. Compare the cell walls of plants, fungi and animals.
8. State two cells with many nuclei and two with none.
9. Annotate a drawn mitochondrion with its function.
10. Outline the evidence for endosymbiosis. HL
11. Explain how cells with the same genes differentiate. HL

IN THE EXAM

Compare in matched pairs ("70S in prokaryotes, 80S in eukaryotes"), never two lists; in a magnification sum, **convert units first**.

GO FURTHER

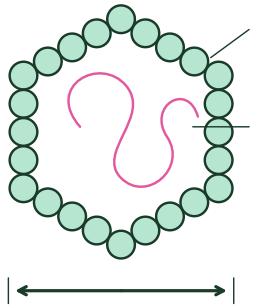
Animated figures, a dry lab and a marked Check are in the full guide online.

How a virus *borrows* a cell

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

A virus is a few genes in a protein coat with no metabolism, so only a host cell can make more of it.



fixed size, most 20 to 300 nm

Draw it like this. A capsid of protein units round DNA or RNA, and nothing else.

A2.3.1 COMMON TO ALL VIRUSES

A virus is genes in a *protein box*

- Viruses are so varied that only **a few features** are shared by every one of them.
- A virus has **no cytoplasm**, no ribosomes and few or no enzymes, so it cannot release energy, make proteins or copy its own genes.
- It is an **obligate parasite**: only the host cell it infects can reproduce it. It is grown in living cells, never in a nutrient broth.

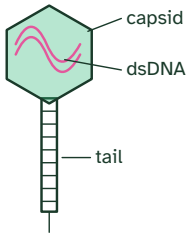
SHARED BY EVERY VIRUS

S Small a fixed size	**G** Genes DNA or RNA	**C** Capsid a protein coat	**N** No cytoplasm or ribosomes	**E** Enzymes few or none

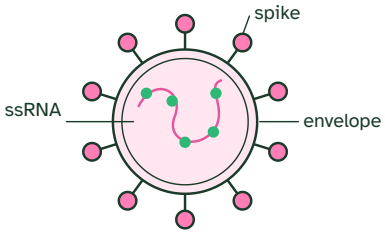
A2.3.2 DIVERSITY OF STRUCTURE

No two *alike*

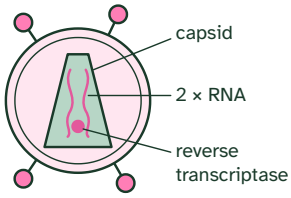
- Genes may be **DNA or RNA**, and either may be **single- or double-stranded**.
- Some have only a capsid. Others are **enveloped** in membrane taken from the host cell.
- Shapes range from many-sided capsids to helical rods and heads with tails.



Phage lambda



Coronavirus



HIV

	PHAGE LAMBDA	CORONAVIRUS	HIV
G **Genes** the nucleic acid	**dsDNA**	**ssRNA**	**ssRNA, two copies**
C **Capsid** the protein coat	Many-sided head on a long tail	Helical: the RNA is wound with protein	Cone-shaped, holding **reverse transcriptase**
E **Envelope** host membrane	**None**	**Yes**, studded with **spike proteins**	**Yes**, with a few protein knobs
H **Host** the cell it infects	The bacterium *E. coli*: its tail binds receptors on the wall	Human and other animal cells: spikes bind their receptors. One causes COVID-19.	Helper T cells: reverse transcriptase copies its RNA into DNA

A2.3.3 TAKE OVER, BURST OUT

The *lytic* cycle of phage lambda

- A virus relies on its host for **energy, nutrition and protein synthesis**: the cell supplies ATP, nucleotides, amino acids, enzymes and ribosomes.

STEP 1
Attach
The tail binds to **receptor proteins** on *E. coli*.

STEP 2
Inject
The DNA goes in; the empty capsid stays out. The DNA forms a circle.

STEP 3
Copy
Host enzymes copy the phage DNA many times.

STEP 4
Make proteins
Host ribosomes make capsids, tails and phage enzymes.

STEP 5
Assemble
Parts join into new phages, each head packed with DNA.

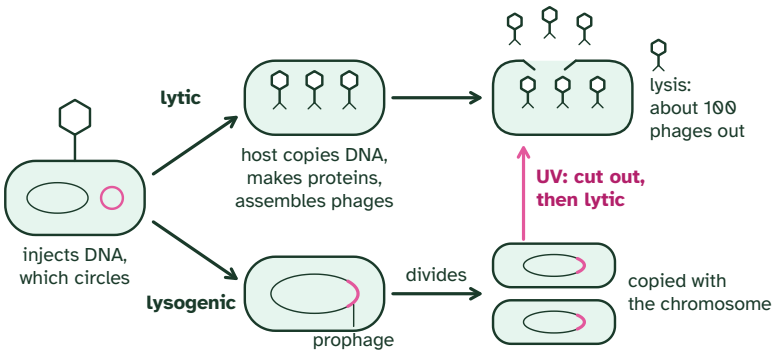
STEP 6
Lyse
A phage enzyme breaks the wall; the cell bursts and about 100 phages leave.

- One cycle takes **under an hour**, and **the host cell is destroyed**.

A2.3.4 PHAGE LAMBDA AGAIN

Lying low: the *lysogenic* cycle

- Once its DNA has circled, lambda may take the **lysogenic cycle** instead.
- A phage enzyme **inserts the DNA into the host chromosome** at one site: it is now a **prophage**.
- A **repressor protein** keeps the phage genes off, so the cell lives. The prophage is **copied with the chromosome** at each division.
- **Induction:** stress such as UV destroys the repressor; the prophage is cut out and the lytic cycle runs.



A2.3.5 ORIGINS OF VIRUSES

Many *beginnings*

- Viruses vary so much that they probably **arose several times**, not from one ancestor. Three hypotheses, not exclusive:

IDEA 1
Escaped genes
Genes that moved about in a cell escaped and gained a coat.

IDEA 2
Reduced cells
Parasitic cells lost parts until only genes and a coat were left.

IDEA 3
Virus first
Replicators existed before cells, then lived on as their parasites.

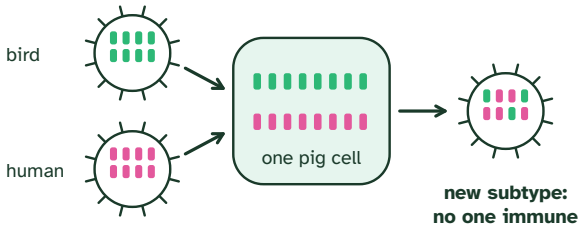
- Shared features may be **convergent evolution**: the same **obligate parasitism** shaped unrelated starts alike.
- Viruses **share the genetic code** with cells, so they likely arose from cells that used it.

A2.3.6 RAPID EVOLUTION: A MOVING TARGET

Why some viruses evolve *so fast*

M Mutation RNA copied without proofreading	**G** Generations a new one in hours	**N** Numbers huge, in each host	**S** Selection by immunity and drugs

- **Influenza, drift:** mutations in the genes for its surface proteins build up, so old antibodies fit less well. **A new vaccine every year.**
- **Influenza, shift:** two strains in one cell swap some of their **eight RNA segments**: a new subtype and a pandemic risk.
- **HIV:** many variants arise in one patient and one drug soon selects resistance, so it is given **three or more drugs at once**. No vaccine works.



WATCH OUT

Five mistakes that *cost marks*

- ✕ **Antibiotics do not work on viruses.** They act on cell walls and bacterial ribosomes, which viruses lack.
- ✕ **An envelope is host membrane.** The virus takes it as it leaves.
- ✕ **The phage makes nothing itself.** After injection, host enzymes and ribosomes do every step, following the phage's genes.
- ✕ **A prophage is not a virus waiting outside.** Its DNA is part of the chromosome in every daughter cell.
- ✕ **Viruses do not change to escape a drug.** Mutations are random; the drug selects the resistant variants.

COVER THE SHEET

Can you *answer these?*

1. State five structural features that all viruses share.
2. Compare the structure of phage lambda and HIV.
3. Outline the phases of the lytic cycle of phage lambda.
4. Distinguish between the lytic and lysogenic cycles.
5. Outline the evidence that viruses have several origins.
6. Explain why the influenza vaccine is changed every year.
7. Explain why HIV is treated with three drugs at once.

IN THE EXAM

Name the host's part in each lytic step ("host ribosomes make the capsid proteins"). For lysogeny write **inserted into the host chromosome as a prophage**, not "hides".

GO FURTHER

An animated phage film, interactive figures and quick checks are in the full guide online.

IB BIOLOGY | A3.1 | SL AND HL

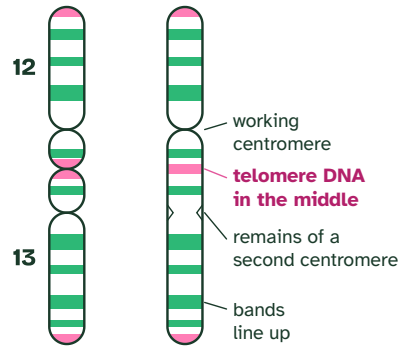
REVISION ON TWO PAGES

No two alike, yet still *species*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

No two organisms are alike, yet they fall into species. Traits, breeding, chromosomes and DNA each help to draw the line.



Draw it like this. The two ape chromosomes end to end beside human 2: the same bands, and telomere DNA (pink) at the join.

A3.1.7 SKILL: CLASSIFY AND EVALUATE

Reading a *karyogram*

- A cell's chromosomes, photographed and arranged in pairs, make a **karyogram**. Pair them by **length, banding and centromere position**, longest first.
- **Hypothesis:** human chromosome 2 formed when two ape chromosomes, **12 and 13**, fused end to end in an ancestor shared with chimpanzees.

EVIDENCE 1	EVIDENCE 2	EVIDENCE 3
Bands match	**Telomere inside**	**Spare centromere**
End to end, the ape pair matches 2 in length and banding.	Chromosome-end DNA sits in the middle of 2.	The switched-off remains of a second one.

- **Testable:** it predicted telomere DNA mid-chromosome, which could have been absent. "It fused so humans could think" predicts nothing: **not testable**.
- Three lines of evidence agree, but no one saw the fusion: they **support it, not prove it**.

A3.1.1 and 2 VARIATION AND SPECIES

No two *alike*

- No two individuals are identical in every trait, not even identical twins. **Variation** is a defining feature of life.
- Its **patterns**, in steps (blood group) or smooth (height), are the basis for **naming and classifying**.
- **Linnaeus** grouped similar, never identical, organisms by shared body form: the **morphological species concept**.

A3.1.3 BINOMIAL NAMES

A name in *two parts*

- The **genus** comes first, then the **species**. Species in one genus have similar traits: *Panthera leo* (lion), *Panthera tigris* (tiger).

THE FOUR RULES — *Green Sloths Inch Along*

G Genus first, capital: *Homo*	**S** Species next, lower case	**I** Italics or underlined	**A** Abbreviate later: *E. coli*

A3.1.4 and 5 BREEDING TEST

Can they *breed*?

- **Biological species concept:** a group that can **breed and produce fertile offspring**.
- **Competing species definitions exist** (by DNA, or by way of life).
- **Speciation**, one species splitting into two or more, is usually **gradual**, so calling two populations one species or two can be arbitrary.

WHERE IT STRUGGLES — *Five Apes Hug Grumpy (Aunts Happily)*

F Fossils cannot be bred	**A** Apart never meet	**H** Hybrids fertile in oaks	**G** Gradual no split day

A3.1.6 CHROMOSOME NUMBERS

Counting *chromosomes*

- Each species has its own chromosome number, and **numbers vary widely**.
- Diploid cells have an **even number**: chromosomes come in homologous pairs, one from each parent.
- Chromosome number is not the number of genes, nor the amount of DNA.

46 human body cell	**48** chimpanzee body cell

A3.1.8 and 9 GENOMES WITHIN AND BETWEEN SPECIES

One genome, *many versions*

- The **genome** is all the genetic information of an organism.
- One species shares most of its genome (two people about 99.9%); **single nucleotide polymorphisms** (SNPs) give diversity.
- Between species, genomes differ in **size** (total DNA) and **base sequence**: **far more than within a species**.

person 1	A	T	G	C	C	G	T	A	A	G	C	T	T	A	C	G
person 2	A	T	G	C	C	**A**	T	A	A	G	C	T	T	A	C	G
person 3	A	T	G	C	C	G	T	A	A	G	C	**C**	T	A	C	G
chimpanzee	A	T	**C**	C	C	G	T	**G**	A	G	C	T	**A**	A	C	**A**

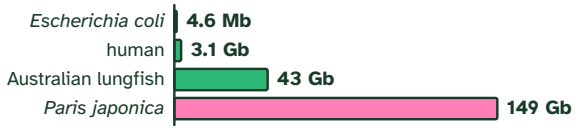
differs from person 1 (between people, a SNP)

Genomes, and where the species idea *breaks*

A3.1.10 SKILL: USE A DATABASE

Big genome, *small* organism

- Genome size, in base pairs (Mb millions, Gb billions), **varies enormously** and is **not a measure of complexity**: much DNA is non-coding or repeated.
- **The skill:** compare genome sizes from a database with complexity.



A3.1.11 USES NOW AND TO COME

Reading a *whole genome*

- Sequencing reads every base of a genome, ever **faster and cheaper**: the first human genome took over ten years and billions of dollars; now days.
- **Current use:** comparing genomes shows how closely species are related: **evolutionary relationships**.
- **Future use: personalised medicine**, the drug and dose chosen from a patient's own genome.
- A genome can also show SNPs that raise the risk of a disease, so it can be watched for.

A3.1.12 TWO MORE PLACES IT STRUGGLES

When the breeding test *fails*

- **Asexual species (Aunts):** bacteria and other **asexual** organisms make clones, so "fertile offspring?" has no answer.
- **Horizontal gene transfer (Happily):** genes pass between living cells, **even between species** (plasmids in conjugation).
- Gene pools are not closed, so the concept fits poorly. Bacteria are grouped by structure, metabolism and DNA instead.

A3.1.13 HIGHER LEVEL

The number that *has to match*

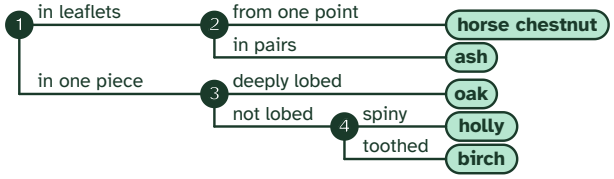
- Chromosome number is a **shared trait** within a species.
- At meiosis each chromosome needs a partner. If parent numbers differ, a hybrid's cannot all pair, so it is **unlikely to be fertile**.

32 + 31	63
horse plus donkey gamete	mule: odd, so sterile

A3.1.14 SKILL: BUILD A KEY

Building a *dichotomous key*

- Each step offers **two choices**, until one name is left. Use features that **do not change**; avoid size, colour, behaviour.
- Key out six to ten **local species**, then test it on others.



A3.1.15 HIGHER LEVEL

Species from *environmental DNA*

- **eDNA** is DNA from water, soil or air. A **DNA barcode** is a short stretch, alike within a species but different between species.
- It surveys a habitat's biodiversity **rapidly**, unseen species too.

THE STEPS — *Cats Eat Any Sausage Mostly*

C	E	A	S	M
Collect a sample	**Extract** the DNA	**Amplify** by PCR	**Sequence** the copies	**Match** to a library

WATCH OUT

Six mistakes that *cost marks*

- ✕ **The capital is for the genus only:** *Homo sapiens*, never *Homo Sapiens*.
- ✕ **Say "fertile offspring", not "can mate".** The mule is sterile.
- ✕ **Humans did not come from chimpanzees.** Both come from a shared ancestor.
- ✕ **A bigger genome is not a more complex organism.** The extra DNA is mostly non-coding.
- ✕ **A SNP is a place where genomes differ, not a disease.** Everyone carries thousands.
- ✕ **eDNA shows who left DNA, not how many.** It names only species in the reference library.

COVER THE SHEET

Can you *answer these?*

1. Outline the morphological species concept.
2. State the rules for writing a binomial name.
3. State two problems with the biological species concept.
4. Explain why diploid chromosome numbers are even.
5. Evaluate the evidence that chromosome 2 is a fusion.
6. Compare genome variation within and between species.
7. Explain why genome size does not show complexity.
8. Outline two uses of whole genome sequencing.
9. Explain why the species concept fits bacteria poorly. HL
10. Explain why a mule is sterile. HL
11. Describe two features of a good dichotomous key. HL
12. Outline how eDNA barcoding surveys a pond. HL

IN THE EXAM

For "evaluate" on chromosome 2, **name each piece of evidence**, then say it **supports the hypothesis but cannot prove it**.

GO FURTHER

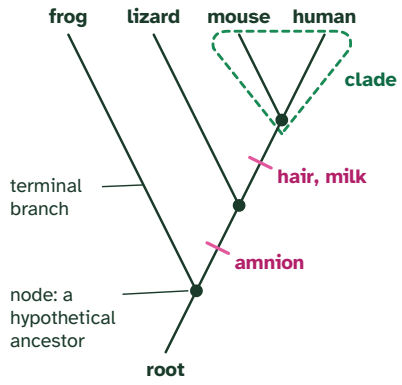
Animated figures, a dry lab and a marked Check are in the full guide online.

THE ONE IDEA

Group organisms by descent. A clade is one common ancestor and all its descendants, found most objectively from sequences.

Sorting life by *descent*

What to know, what to draw and what to say. Higher level only.



Draw it like this. A pink bar marks where a feature arose; every descendant inherits it.

A3.2.7 START HERE

Reading a *cladogram*

- The **root** is the base: the ancestor of everything on the tree. Each line out to a tip is a **terminal branch**.
- Each fork is a **node**: a **hypothetical common ancestor**. It must have existed to explain the split, but need not be a known fossil.
- To deduce how close two organisms are, trace both back until their lines meet. The **more recent that node**, the closer the relatives.
- A node and everything beyond it is a **clade**. Two groups from one node are **sister groups**. Only the branching order carries meaning.

THE PARTS OF A CLADOGRAM

Rabbits Nibble Tasty Carrots Slowly

R Root the base of the tree	**N** Node a hypothetical ancestor	**T** Terminal branch out to a tip	**C** Clade ancestor plus all descendants	**S** Sister groups share one node

A3.2.1

Why *classify*

- There are **too many species** to study one at a time: well over a million have been named.
- A group tells you where to look an organism up and what it is probably like.
- Once classified, a **broad range of further study** opens up: a new species' relatives say what to ask about it.
- Different rules give different groups, so the rule matters: the best one follows descent.

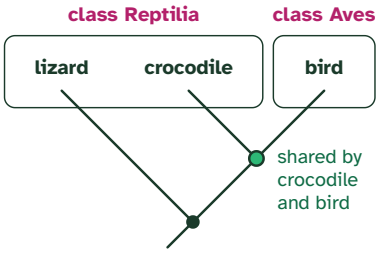
1m+ species named, many still unfound

3 domains hold all of life

A3.2.2 RANKS

When the *boxes* do not fit

- Traditional ranks: kingdom, phylum, class, order, family, genus, species (*King Philip Came Over For Good Soup*).
- Evolution makes branches, not boxes, so ranks **do not always match divergence**.
- **Nature of science:** ranks are **arbitrary**, as variation is gradual. Unranked clades replaced them: a **paradigm shift**.



A3.2.3 WHY DESCENT

Groups that *predict*

- The ideal classification **follows evolutionary relationships**: every member descends from one common ancestor.
- A feature that arose in that ancestor is shared across the clade, so **features can be predicted**: a newly found mammal will have hair and milk.
- Predictions reach biochemistry too: a useful plant chemical is first looked for in its relatives.
- A prediction is a good bet, not a promise: snakes lost the legs of their four-limbed ancestors.

A3.2.4

A *clade*: one ancestor, all its descendants

- A clade is a common ancestor and **all of its descendants**. Clades nest: birds are a clade, and so are birds with crocodiles.
- Leave out one descendant, or add one that is not a descendant, and the group is not a clade.

TEST 1
One ancestor
Do all the members share one common ancestor?

TEST 2
None left out
Are all of that ancestor's descendants in the group?

Sequences the most objective evidence
Base sequences of genes or **amino acid sequences of proteins**, compared position by position: anyone counting gets the same answer.

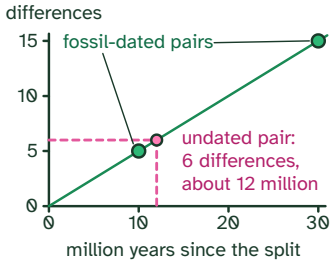
Morphology can also be used
Body structures can assign organisms to clades, but need a judgement on which traits count, and mislead when unrelated lines look alike.

Dating splits, building trees and the *three domains*

A3.2.5 DATING A SPLIT

The *molecular clock*

- After a split, each line gathers its own mutations, so **sequence differences accumulate gradually**.
- **Calibrate:** plot differences against time for pairs whose split is **dated by fossils**, then read an undated pair off the line.
- It gives **only an estimate** of when clades diverged, because the rate of change varies.



WHAT SHIFTS IT

Gerbils Play Sports

- **G** **Generation time** — more copies a year
- **P** **Population size** — chance spreads changes
- **S** **Selection** — removes some changes

A3.2.6 MADE-UP DATA

Building a cladogram by *parsimony*

- Line up the same gene, or protein, from each species and compare it **position by position**.
- An **outgroup**, which split off earlier, shows the older state. A difference from it is a change.
- **Parsimony**: choose the tree that explains the differences with the **fewest changes**, since mutations are rare.
- **Nature of science:** different criteria can give different trees, so a cladogram is a hypothesis.

site	1	2	3	4	5	6
orangutan (out)	T	A	C	G	G	A
human	C	G	T	A	G	A
chimpanzee	C	G	T	G	T	A
gorilla	T	A	C	G	T	C

tree joins	changes
human, chimp	**7**
chimp, gorilla	9
human, gorilla	10

Sites 4 and 6 differ in one species only: they cost one change on every tree, so they cannot decide.

A3.2.8 CASE STUDY

Testing a *classification*

- If a group is real, its members should form a clade. Cladistics can test it.

By flower structure the old view
The figwort family (Scrophulariaceae) was a large family, grouped mostly by look-alike flowers.

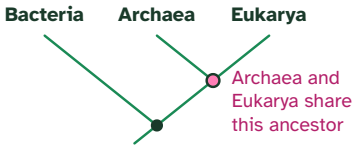
By chloroplast DNA the test
Its members fell into several clades. Many moved to other families, leaving a much smaller figwort family.

- The flowers were alike by **convergent evolution**, not common ancestry, so the old grouping was false.
- **Nature of science:** knowledge claims can be **falsified** by new evidence, so a classification stays open to testing.
- Learn the story, not the plant names. Either the common or the scientific name is accepted.

A3.2.9 RRNA EVIDENCE

The *three domains*

- In 1977, Woese and Fox compared **rRNA base sequences**. Every cell has ribosomes, so rRNA can be compared across all life.
- Prokaryotes were not one group. Life falls into three **domains**: Bacteria, Archaea and Eukarya.
- Archaea look like bacteria, but share a **more recent ancestor with Eukarya**.
- A new level **above the kingdoms**: animals, plants and fungi all sit in Eukarya.



WATCH OUT

Five mistakes that *cost marks*

- ✕ **A node is a hypothetical ancestor, not a living species.** Humans did not evolve from chimpanzees.
- ✕ **Tip order and height mean nothing.** Nodes can be spun; only the branching order counts.
- ✕ **A clade holds every descendant.** Reptilia leaves out the birds, so it is not a clade.
- ✕ **The clock gives estimates, not dates.** Its rate varies with generation time, population size and selection.
- ✕ **"Prokaryote" is not a clade.** Archaea are closer to Eukarya than to Bacteria.

COVER THE SHEET

Can you *answer these?*

1. Outline two reasons for classifying organisms.
2. Explain why the class Reptilia is not a clade.
3. Explain how clades let features be predicted.
4. State the most objective evidence for a clade.
5. Outline why the molecular clock is only an estimate.
6. Describe how parsimony selects a cladogram.
7. Draw a cladogram; label a root, node and terminal branch.
8. Explain what the figwort family case shows.
9. Outline the evidence for three domains.

IN THE EXAM

To deduce a relationship, **trace both tips back to the node where they meet**, then say they "share a more recent common ancestor", never that one evolved from the other.

GO FURTHER

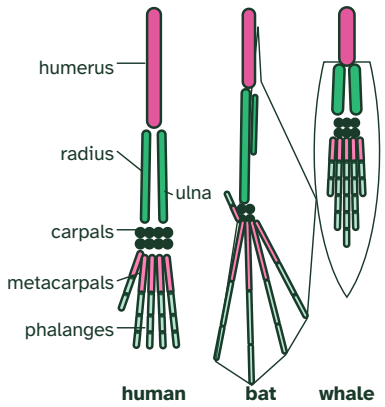
Animated figures, a dry lab and a marked Check are in the full guide online.

How life *evolves*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Populations change in what they inherit. A new species forms only when one population splits and the parts stop sharing alleles.



Same colour, same bone. One plan, reshaped for each job.

A4.1.4 START HERE

One bone plan: *homologous* structures

- Homologous structures are built on a **plan inherited from a common ancestor**, even when they now do very different jobs.
- The **pentadactyl limb**: one upper arm bone, two forearm bones, a block of wrist bones, a row of palm bones, then the digits.
- A human arm, a bat wing, a whale flipper and a horse leg have the **same bones in the same order**, each modified for its own way of life.
- "Pentadactyl" names the plan, not a count: a horse keeps only one digit.

SHOULDER TO FINGERTIP — *Hungry Rats Chew My Pencils*

H	**Humerus** upper arm	**R**	**Radius, ulna** forearm	**C**	**Carpals** wrist	**M**	**Metacarpals** palm	**P**	**Phalanges** digits

A4.1.1

What *evolution* is

- Evolution: a change, over generations, in the **heritable characteristics of a population**.
- **Not evolution: acquired changes** (a weightlifter's muscles) never reach the gametes. Lamarck wrongly thought they were inherited.
- **Example:** after a 1977 drought, deep-beaked finches survived; the next generation's beaks were about 4% deeper.

NATURE OF SCIENCE

Why a "theory"

It explains so much that it is unlikely ever to be falsified, but it cannot be formally proved: a pragmatic truth.

A4.1.2

Evidence in *sequences*

- Compare one gene or protein: **fewer differences, more recent common ancestor**.
- After a split, **mutations build up** separately in each line, so differences grow with time.
- Bases change faster than amino acids (most have several codons): bases sort close relatives, amino acids reach further back.

Cytochrome c: amino acids that differ from the human one

0	chimpanzee	**1**	rhesus monkey	**40+**	yeast

A4.1.5

Analogous structures

- Analogous structures have the **same function but different evolutionary origins**.
- They arise by **convergent evolution**: unrelated lines meet similar demands with similar solutions.
- Another pair: the camera eyes of octopuses and of vertebrates.

Bird wing a forelimb
Bones inside, humerus to digits, carrying feathers.

Insect wing no bones
A thin fold of the body wall, with no bones at all.

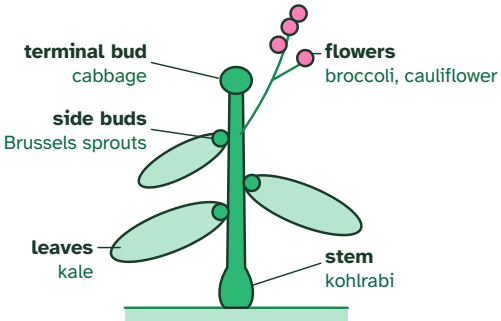
A4.1.3

Evidence from *selective breeding*

- **Selective breeding:** people choose which plants or animals breed, generation after generation.
- Kale, cabbage, Brussels sprouts, kohlrabi, broccoli and cauliflower were all bred from **wild cabbage**, and all are still *Brassica oleracea*.
- They differ far more than the wild species varies, and the changes are **heritable**. Most dog breeds, all from wolves, arose in a few centuries: **evolution can be rapid**.

THREE LINES OF EVIDENCE — *Darwin's Big Hunch*

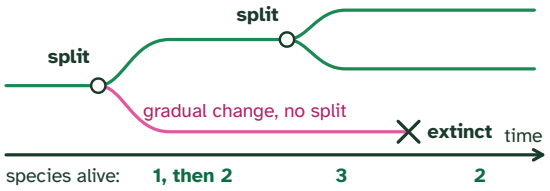
D	**DNA, proteins** fewer differences, closer kin	**B**	**Breeding** big heritable changes, fast	**H**	**Homologous** one bone plan, many jobs



A4.1.6

New species only by *splitting*

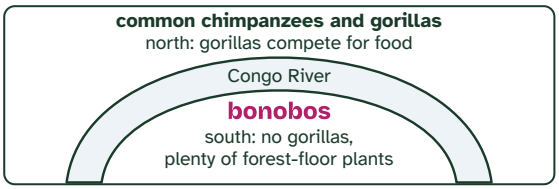
- Speciation: a species **splits** into populations that stop interbreeding and diverge. It is **the only way new species appear**.
- **Speciation adds** species to the Earth; **extinction removes** them.
- **Gradual change** without a split is evolution, **not speciation**.



A4.1.7

Isolation, then *differential* selection

- **Reproductive isolation** stops alleles passing between populations. A river, sea or mountains cause **geographical isolation**.
- **Differential selection**: each side favours different traits.
- **Congo River:** neither ape swims. It split chimpanzees from bonobos 1 to 2 million years ago.



A4.1.8 HIGHER LEVEL

Two routes: *allopatric* and *sympatric*

	ALLOPATRIC *other homeland*	SYMPATRIC *same homeland*
Gene flow stops by	A **geographical barrier**: **geographic** isolation.	In one place: **behavioural** or **temporal** isolation.
Example	Bonobos and chimpanzees, either side of the Congo.	Apple maggot flies: apple flies mate earlier, on apples.

Alike: gene flow stops, then the groups diverge.

Isolation: *Grumpy Birds Tweet*

A4.1.9 HIGHER LEVEL

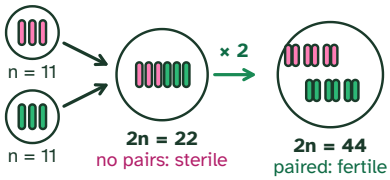
Adaptive *radiation*

- One ancestor's descendants split again and again, each adapting to a **different niche**.
- It needs **vacant niches**: about 18 Darwin's finch species came from one seed-eater, each beak suited to its food.
- Different foods let related species **coexist without competing**, so **biodiversity rises**.

A4.1.10, A4.1.11 HIGHER LEVEL

Sterile *hybrids*, fertile polyploids

- **Before fertilisation: courtship behaviour** usually prevents hybridisation.
- **After it:** a hybrid may be **sterile**. A **mule** (horse × donkey) has 63 chromosomes that **cannot all pair at meiosis**.
- **Plants:** a sterile hybrid's **chromosome number doubles**, so it is fertile but cannot breed with either parent: **a new species at once**.
- **Example:** smartweeds, *Persicaria*, such as redshank (2n = 44). Either name is accepted.



WATCH OUT

Six mistakes that *cost marks*

- ✕ **Acquired changes are not evolution.** Only alleles in gametes are inherited.
- ✕ **Humans did not evolve from chimpanzees.** Both came from a common ancestor.
- ✕ **Flippers are homologous as limbs.** Whale and penguin flippers share pentadactyl bones; only the shape converged.
- ✕ **No split, no speciation.** Gradual change adds no species.
- ✕ **The river did not change the apes.** It stopped gene flow; selection did the changing.
- ✕ **A hybrid adds gametes.** A mule has 32 + 31 = 63 chromosomes, not 64 + 62.

COVER THE SHEET

Can you *answer these?*

1. Distinguish evolution from an acquired change.
2. Explain how protein sequences show common ancestry.
3. Outline how selective breeding is evidence for evolution.
4. Draw a pentadactyl limb and label its bones.
5. Distinguish homologous from analogous structures.
6. State the only way new species arise.
7. Explain how bonobos and chimpanzees diverged.
8. Compare allopatric and sympatric speciation. HL
9. Explain how adaptive radiation raises biodiversity. HL
10. Explain why a mule is sterile but a polyploid is not. HL

IN THE EXAM

For any speciation answer, give three steps: what isolates the populations ("the Congo River"), that **gene flow stops**, and how **differential selection** then acts on each side.

GO FURTHER

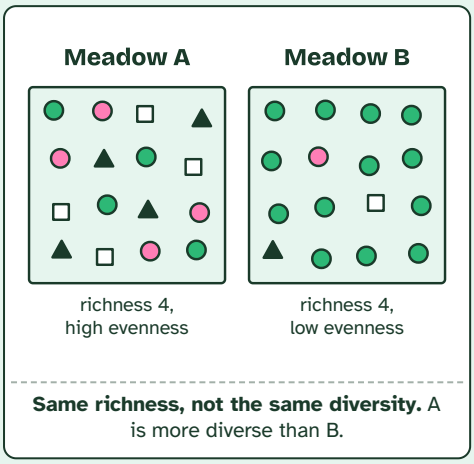
Animated figures, a dry lab and a marked Check are in the full guide online.

Saving the *variety* of life

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Humans are causing a sixth mass extinction. No single method can stop it, so conservation combines several and puts EDGE species first.



Same richness, not the same diversity. A is more diverse than B.

A4.2.1 START HERE

Biodiversity at three *levels*

- **Biodiversity** is the variety of life in all its forms, at three levels: ecosystem, species and genetic.
- Species diversity has two parts: **richness** (how many species) and **evenness** (how equally the individuals are shared among them).
- Two places with the same richness need not be equally diverse: if one species makes up nearly all the individuals, diversity is lower.

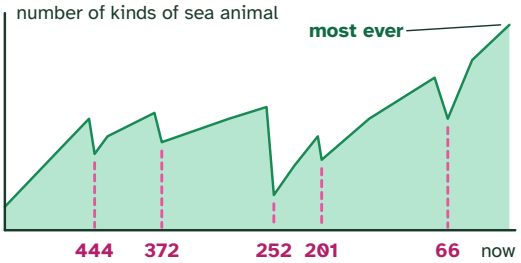
THE THREE LEVELS

E Ecosystem	**S** Species	**G** Genetic
the range of habitats and communities in an area	how many species, and how evenly shared	variety of alleles in a species, so it can adapt

A4.2.2

More species than *ever*

- About **2 million species** are named and described; millions more await discovery (one estimate: 8.7 million eukaryotes).
- Fossils suggest **more species are alive today** than at any time in the past.
- Five mass extinctions broke the rise; after each, recovery took millions of years.
- **Nature of science:** classifying is pattern recognition. From the same data, **splitters** name more species than **lumpers** (giraffes: one species or four).



millions of years ago; pink: mass extinctions

A4.2.3

Extinctions *we caused*

- The **sixth mass extinction** is happening now, and it is **anthropogenic**: caused by humans. The five before it had natural causes.

CASE STUDY	HOW HUMANS DROVE IT OUT
North Island giant moa *Dinornis novaezealandiae*	**Megafauna lost on land.** A giant flightless bird, slow to breed, with no fear of people. Settlers from about 1300 **hunted** it and burned its forest; gone within about 150 years.
Caribbean monk seal *Neomonachus tropicalis*	**A marine species lost.** Basked on beaches and did not flee. Killed for **oil and meat** from the 1500s, and its food fish overfished. Last seen 1952; declared extinct 2008.
One from your area for example	**Great auk, 1844.** A flightless North Atlantic seabird, hunted until the last known pair was killed on Eldey, Iceland.

Either the common or the scientific name is accepted.

A4.2.4

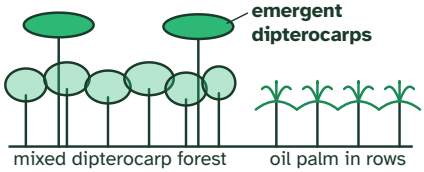
Losing a whole *ecosystem*

- Lose an ecosystem and you lose **every species that depends on it**. Every cause here is human, directly or indirectly.
- **Case 1: mixed dipterocarp forest**, the lowland rainforest of Southeast Asia, named after its tall hardwood trees. On Borneo it is home to orangutans and hornbills.
- **Case 2, near you:** for example the **Aral Sea**. Its rivers were diverted to irrigate cotton; the lake shrank and its fishery and wetlands collapsed.

STEP 1
Logging
Dipterocarp timber taken first, near coasts and rivers.

STEP 2
Roads, clearance
Roads open the forest to **oil palm** and farms.

STEP 3
Fire, drainage
Drained peat and logged forest burn in droughts.



A plantation is green from the air, but it is not forest: one species in rows.

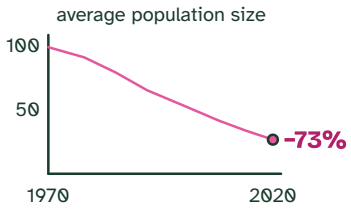
76% of Borneo was forest in 1973

53% by 2010: about half

A4.2.5 and 6

The biodiversity *crisis*: evidence and causes

- A crisis is a change, so a survey must be **repeated the same way** over years to show a change in **richness and evenness**.
- **Living Planet Index:** almost 35,000 monitored vertebrate populations fell by 73% on average, 1970 to 2020.
- **IPBES** (the UN biodiversity panel), 2019: about **1 million species** threatened with extinction.



Peer-reviewed by experts
Published with its method, so others can **check and verify** it.

Citizen science by the public
Data on a huge scale, but skill varies and people record where they go, not a random sample.

A4.2.6 · CAUSES: HUMAN POPULATION GROWTH DRIVES THE REST

HIPPO

H **Habitat loss** deforestation, land cleared for farms, urbanisation

I **Invasive species** and pests and diseases, spread by global transport

P **Pollution** pesticides, fertiliser run-off, plastics, CO_2

P **Population** human growth: the overarching cause

O **Overexploitation** hunting, overfishing, poaching, wildlife trade

A4.2.7

No single *approach* is enough

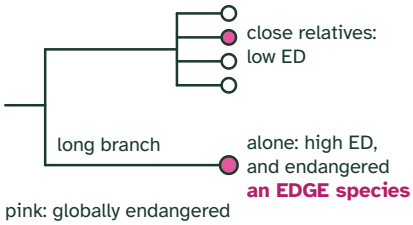
- Different species need different measures, so conservation **combines several approaches**.

APPROACH	WHAT IT DOES
In situ in its habitat	Protects species where they live, in **managed nature reserves**: patrols against poaching, invasive species removed.
Rewilding, reclamation	Restores degraded land: lost species reintroduced (**beavers**, wolves), drains blocked, mines reclaimed.
Ex situ away from it	**Zoos and botanic gardens** breed species for later release.
Seed and tissue banks	Store **germ plasm**: dried, frozen seeds or cells, a reserve of genetic diversity.

A4.2.8

Choosing species: *EDGE*

- Money is limited, so the **EDGE of Existence** programme puts first species that are **Evolutionarily Distinct and Globally Endangered**.
- Distinct means few or no close relatives. Lose one and a **whole branch** of the tree of life goes.
- **Nature of science:** which species to save has ethical, political, economic, social and cultural sides, so it must be debated.



WATCH OUT

Six mistakes that *cost marks*

- ✕ **Richness is not diversity.** Two places with four species each differ if one is uneven.
- ✕ **One survey shows no crisis.** Only repeated surveys, done the same way, show change.
- ✕ **The sixth extinction is caused by humans.** Volcanoes and the asteroid caused earlier ones; do not use them here.
- ✕ **An oil palm plantation is not forest.** One species in rows supports a small fraction of the species.
- ✕ ***Ex situ* backs up *in situ*, never replaces it.** A captive-bred animal needs a habitat to return to.
- ✕ **Evolutionarily distinct is not rare.** It means few close relatives on the tree of life.

COVER THE SHEET

Can you *answer these?*

1. Distinguish between species richness and evenness.
2. Compare the number of species today with the past.
3. Outline how humans drove the North Island giant moa and the Caribbean monk seal extinct.
4. Describe how dipterocarp forest is being lost.
5. Explain why a single survey cannot show a biodiversity crisis, and what can.
6. State the overarching cause and four specific causes.
7. Outline one *in situ* and one *ex situ* approach.
8. Explain why EDGE species are given priority.

IN THE EXAM

Name the case study (species, place, date) and **link each human cause to the loss**: "hunted faster than it could breed", not just "humans".

GO FURTHER

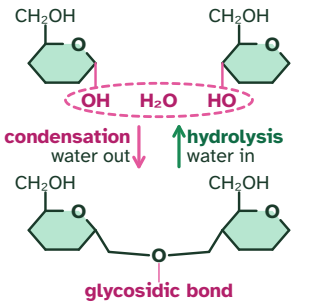
Animated figures, a dry lab and a marked Check are in the full guide online.

How sugars and fats *fuel* and build cells

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Monomers join by condensation and split by hydrolysis. How they join, and how polar they are, decides each molecule's job.



Draw it like this. Other OH groups are left out.

B1.1.2 and 3 START HERE

Water out to *build*, water in to break

- Small **monomers** join into long chains, **polymers**: very large molecules, or macromolecules.
- **Condensation:** an OH from one monomer and an H from the other **leave as water**, and a covalent bond forms. One water per bond.
- **Hydrolysis:** a water molecule is **split**; its H joins one monomer, its OH the other, and the bond breaks. Digestion is hydrolysis.

MONOSACCHARIDES	AMINO ACIDS	NUCLEOTIDES
Polysaccharides	**Polypeptides**	**Nucleic acids**
Joined by glycosidic bonds.	Protein chains (B1.2).	DNA and RNA (A1.2).

B1.1.1

Carbon, the *builder*

- A **covalent bond**: a pair of shared electrons.
- Carbon makes **four covalent bonds**; a double bond counts as two. It bonds to C, H, O, N, P and S.
- Skeletons: an **unbranched or branched chain**, a **single ring** (glucose) or **fused rings** (a steroid).
- **Nature of science:** SI prefixes (kilo, centi, milli, micro, nano) were **agreed internationally**.

B1.1.7

Sugar *name tags* on the cell

- **Glycoprotein**: a protein with sugar chains that **face outwards**.
- Chains vary in sugars, order and branching: **cell-cell recognition**.
- A and B are **antigens**: a body lacking one treats it as foreign.

GROUP O	GROUP A	GROUP B	GROUP AB
Base chain	**+ sugar A**	**+ sugar B**	**Both**

B1.1.4

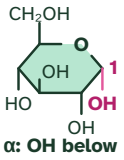
Glucose: small, *soluble*, stable

- **Monosaccharide**: one sugar unit. **Pentose** 5 C (ribose, deoxyribose); **hexose** 6 C (glucose, fructose), CH_2OH included.
- α- and β-glucose are **isomers**, both $C_6H_{12}O_6$: only the OH on carbon 1 differs. *ABBA: Alpha Below, Beta Above.*

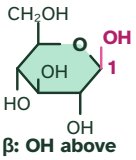
WHY GLUCOSE SUITS ITS JOB

Sweet Treats Stay Energetic

S Soluble: OH groups bond with water	**T** Transportable: in blood plasma	**S** Stable: keeps until an enzyme acts	**E** Energy: oxidised in respiration



α: OH below



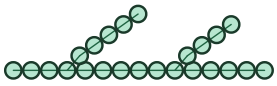
β: OH above

B1.1.5 and 6

Starch and glycogen *store*; cellulose builds



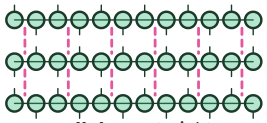
amylose: coiled



amylopectin: branched



glycogen: far more branched



cellulose: straight

- **Starch** (plants) and **glycogen** (animals) are α-glucose polymers, **compact** as they **coil and branch**.
- **Insoluble:** huge molecules stay put and **draw in no water** by osmosis.
- **Easy to use:** glucose is added (condensation) or taken off (hydrolysis) at chain ends; glycogen has many.
- **Cellulose:** an unbranched polymer of **β-glucose**, the main material of plant cell walls.
- Each unit is **turned over** from the last: the chain runs straight.
- Chains lie side by side, **cross-linked by hydrogen bonds** into microfibrils of **high tensile strength**.

Lipids: the molecules that *avoid* water

B1.1.8 and 9

Lipids keep *away* from water

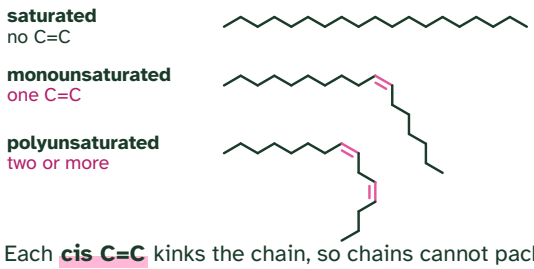
- Lipids **dissolve in non-polar solvents** (hexane) but only sparingly in water: fats, oils, waxes and steroids.
- Mostly C and H, and **C–H bonds are non-polar**, so water pushes them out: **hydrophobic**.
- **Wax:** a fatty acid joined to a long-chain alcohol; it waterproofs a leaf surface.
- **Condensation:** a fatty acid's carboxyl OH and an H from glycerol leave as water: an **ester bond**.

Triglyceride fats and oils
One glycerol, **three fatty acids**: three ester bonds, three waters.

Phospholipid membranes
One glycerol, **two fatty acids** and one **phosphate group**.

B1.1.10

Every double bond *kinks* the tail



- Each **cis C=C** kinks the chain, so chains cannot pack closely: the more C=C, the **lower the melting point**.
- **Plants** store **unsaturated oils**, liquid when cold. **Endotherms** store more saturated fat, soft at body temperature.

Remember it: *Double Kinks Leave Liquids*

B1.1.11

Fat: the *long-term* store and insulator

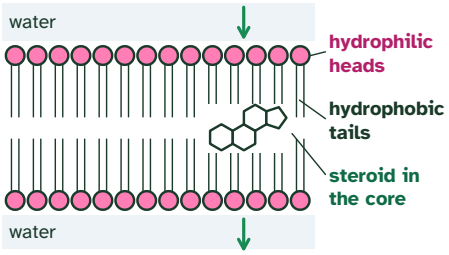
- **Adipose tissue:** cells each holding a large droplet of triglyceride, under the skin and round organs.
- Fat is **energy dense**, stored **without water**, insoluble and stable: a **long-term** store; glycogen, short-term.
- **Insulation:** fat conducts heat about half as well as muscle. Endotherms in polar seas have thick **blubber**; tropical mammals, thin layers.

STORE	GLYCOGEN	TRIGLYCERIDE
Energy	**about 17 kJ g⁻¹**	**about 37 kJ g⁻¹**
Water	about 3 g per gram	none
Release	quick	slower
No oxygen	respired, as glucose	not respired

B1.1.12 and 13

The *bilayer*, and what crosses it

- A phospholipid is **amphipathic**: one part is attracted to water, one is not.
- **Head:** charged phosphate and glycerol, **hydrophilic**. **Tails:** two fatty acids, **hydrophobic**.
- In water they form a **bilayer**: tails in, heads to the water on both sides.



- **Steroid: four fused rings**, three of six carbons, one of five.
- Cholesterol, **oestradiol** and **testosterone** are steroids.
- Non-polar, so they **diffuse through the core** with no protein. Polar glucose and ions cannot.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Condensation releases water; hydrolysis uses it.** In hydrolysis the water is split.
- ✕ **α- and β-glucose have the same formula.** Only the OH on carbon 1 differs.
- ✕ **Insoluble is not hydrophobic.** Starch is covered in OH groups; it is just huge.
- ✕ **A triglyceride is not a polymer:** one glycerol, three fatty acids.
- ✕ **Melting breaks no covalent bonds:** it separates molecules.
- ✕ **Saturated means saturated with hydrogen,** not with fat.

COVER THE SHEET

Can you *answer these?*

1. State how many bonds a carbon atom forms.
2. Distinguish condensation from hydrolysis.
3. Draw α-glucose and state how β-glucose differs.
4. Compare the structures of glycogen and cellulose.
5. Outline how group A and B red blood cells differ.
6. Describe how a triglyceride is formed.
7. Explain why plant oils are liquid when cold.
8. Compare triglycerides and glycogen as stores.
9. Explain how a bilayer forms and why steroids cross it.

IN THE EXAM

Say where the water goes (OH from one monomer, H from the other), then **link each structure to its job**: branched, so many ends, so glucose comes off fast.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY | B1.2 | SL AND HL

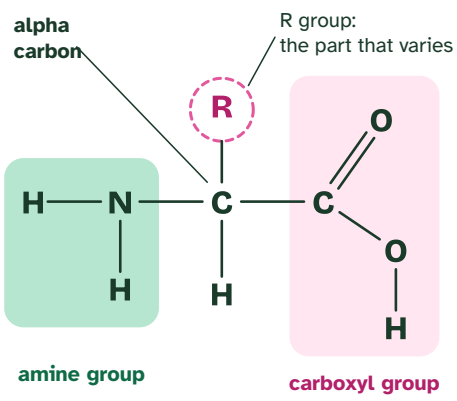
REVISION ON TWO PAGES

Proteins: *endless* chains

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

The sequence of amino acids sets how a protein folds, and its shape sets its job. Lose the shape and the job goes.



Draw it like this. Every atom and bond, the un-ionised form ($-NH_2$ and $-COOH$).

B1.2.1 START HERE

One core: the *amino acid*

- Proteins are polymers; their monomer is the **amino acid**.
- A central **alpha carbon** makes four bonds: to an **amine group** ($-NH_2$), a **carboxyl group** ($-COOH$), **one hydrogen** and an **R group**.
- The **R group is the only part that varies**: twenty R groups, so twenty amino acids. You need not name any at SL.
- **Check your drawing:** four bonds on carbon, three on nitrogen, two on oxygen, one on hydrogen.

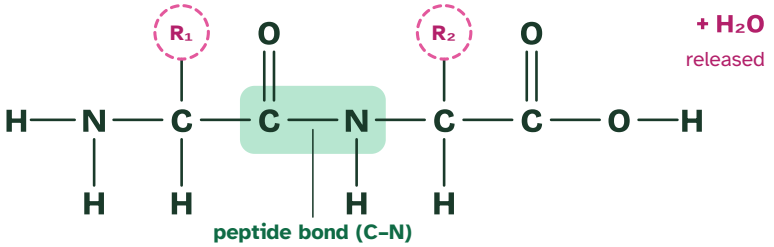
FOUR GROUPS ON THE ALPHA CARBON — *A Cat Has Rhythm*

A Amine $-NH_2$, one side	**C** Carboxyl $-COOH$, other side	**H** Hydrogen one H atom	**R** R group the part that varies

B1.2.2

Condensation makes peptide bonds

- The **OH** of one carboxyl group and an **H** of the next amine group leave as **water**.
- The C–N bond left is a **peptide bond**, a strong covalent bond.
- **Word equation: amino acid + amino acid → dipeptide + water**. Keep adding: a polypeptide.
- A chain of *n* amino acids has ***n* – 1 peptide bonds**; forming it releases *n* – 1 waters.



B1.2.3

Amino acids to *eat*

- All twenty are needed to build your proteins. The body **stores no spare** amino acids.
- Short of one essential amino acid, every protein that needs it **cannot be finished**.
- **Vegan diets need attention: a variety of plant proteins** (rice with lentils) supplies all of them.

Essential nine, for an adult
Cannot be made by the body: must come from food.

Non-essential eleven
Made in the body **from other amino acids**.

B1.2.4

Endless possible chains

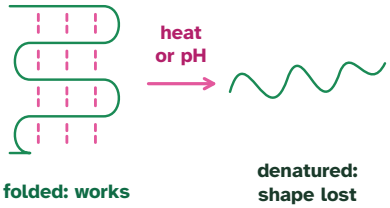
- The genetic code codes for **20 amino acids**. A chain can be **any length**, a few to thousands, in **any order**.
- **Examples:** glucagon 29 amino acids, insulin 51, lysozyme 129, titin about 34,000.
- Twenty amino acids do not mean twenty proteins: **the order is the identity**.

400 dipeptides	**8,000** tripeptides	**20^n** *n* long

B1.2.5

Heat and pH *denature*

- A protein works by its precise 3D shape, held by **many weak bonds**.
- **Heat:** atoms vibrate until the weak bonds break. **pH:** H^+ joins or leaves R groups, **changing their charges**.
- The shape and job are lost: **denaturation**, usually permanent. **Peptide bonds stay intact**.



How a chain folds into a *shape*

B1.2.6 HIGHER LEVEL

The *R groups* set the properties

- R groups **decide the properties of the polypeptide**.
- **Hydrophobic:** non-polar. **Hydrophilic:** **polar or charged**.

FOUR KINDS OF R GROUP

Hungry Pandas Ate Bamboo

H Hydrophobic non-polar	**P** Polar δ+, δ–	**A** Acidic $-COO^-$	**B** Basic $-NH_3^+$

B1.2.7 HIGHER LEVEL

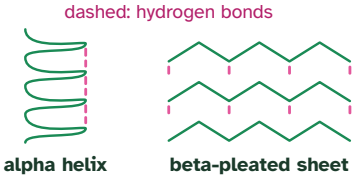
The *sequence* sets the shape

- Primary structure: the **amino acid sequence**.
- The **exact position of each amino acid** sets the shape.
- So proteins are **precise, predictable and repeatable**: one sequence, one shape.
- Change one key amino acid and the shape can change.

B1.2.8 HIGHER LEVEL

Coils and pleats

- **Hydrogen bonds** between backbone **C=O and N–H groups**, in regular positions.
- **Alpha helix:** each C=O bonds to the N–H **four amino acids along**.
- **Beta-pleated sheet:** stretches lie side by side, bonded across.



B1.2.9 HIGHER LEVEL

Four bonds hold the *fold*

- Tertiary structure: the 3D fold of the whole chain, held by **bonds between R groups**.
- Amine and carboxyl R groups **gain or lose H^+** to become charged.

BOND	BETWEEN
Hydrogen	polar R groups
Hydrophobic	non-polar R groups
Ionic	+ to – R groups
Disulfide	**two cysteines** (S–S)

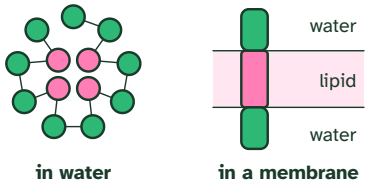
Happy Hippos Ignore Dentists

B1.2.10 HIGHER LEVEL

Oily in, *watery* out

- **Soluble proteins: hydrophobic amino acids cluster in the core**; hydrophilic ones face the water.
- **Integral proteins: hydrophobic regions** sit among the phospholipid tails, in the membrane.

Pink: hydrophobic. **Green:** hydrophilic.



B1.2.11, B1.2.12 HIGHER LEVEL

Three named proteins: *quaternary* structure, form and function

PROTEIN	QUATERNARY STRUCTURE	SHAPE	FORM SUITS FUNCTION
I **Insulin** non-conjugated	**2 chains, 21 and 30.** Joined by disulfide bonds.	**Globular**	Small and soluble, so carried in plasma; its precise shape fits the insulin receptor.
C **Collagen** non-conjugated	**3 chains: a triple helix.** Each about 1,000 amino acids.	**Fibrous**	Insoluble ropes, cross-linked into fibres: **tensile strength** in skin and tendons.
H **Haemoglobin** conjugated	**4 chains, each with haem.** Haem is a **prosthetic group**.	**Globular**	Soluble; each haem binds one O_2, so up to four.

Conjugated: has a non-polypeptide part. **Nature of science:** cryogenic electron microscopy images single protein molecules.

I See Him

WATCH OUT

Six mistakes that *cost marks*

- ✕ **The peptide bond is C–N.** Not between the alpha carbons, not through an oxygen, never an R group.
- ✕ **Denaturing keeps the sequence.** Weak bonds break; peptide bonds hold. Cold does not denature.
- ✕ **Non-essential still matters.** It just need not be eaten.
- ✕ **Secondary structure bonds are in the backbone** (C=O to N–H), not R groups.
- ✕ **A disulfide bond is covalent,** between two cysteines only.
- ✕ **Quaternary means more than one chain, not four.** Conjugated means a non-protein part.

COVER THE SHEET

Can you *answer these?*

1. Draw an amino acid, then a dipeptide made from two.
2. Distinguish essential and non-essential amino acids.
3. Explain why possible polypeptides are endless.
4. Explain how heat or pH denatures a protein.
5. Outline how R groups are classified. HL
6. Explain why proteins have repeatable shapes. HL
7. Describe the bonds that hold an alpha helix. HL
8. State four bonds that hold a tertiary structure. HL
9. Explain how integral proteins embed in membranes. HL
10. Compare insulin, collagen and haemoglobin. HL

IN THE EXAM

Name the weak bonds that break, say **peptide bonds stay**, then link **shape to job**.

GO FURTHER

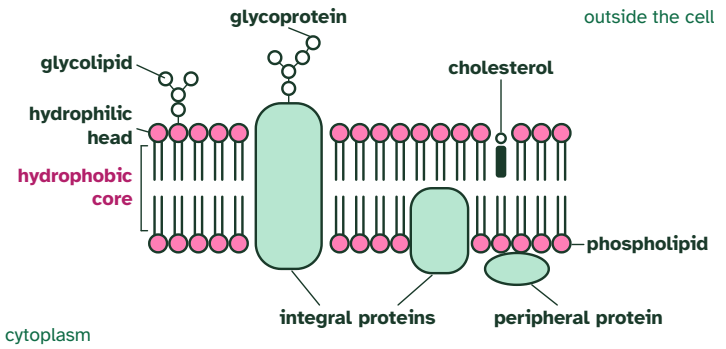
Animated figures and a game online.

A *barrier* with doors

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

The lipid bilayer keeps out ions and polar molecules. Its proteins decide what else crosses, and whether that costs ATP.



Draw it like this. Sugars on the outside only; cholesterol among the tails (animal cells).

B2.1.9 and 10 START HERE

The *fluid mosaic* model

- **Fluid:** phospholipids and many proteins **drift sideways** within their layer. **Mosaic:** proteins are scattered through the bilayer like tiles.
- **Glycoproteins** and **glycolipids** carry short, branched sugar chains, always on the **outer side** of the plasma membrane.
- The sugars are identity tags, for **cell recognition** (the ABO blood groups; immune cells telling self from non-self) and **cell adhesion**.
- **Draw it with** the bilayer, integral and peripheral proteins, a glycoprotein and cholesterol; label the **hydrophilic** and **hydrophobic** regions.

B2.1.1

A bilayer that *builds itself*

- A phospholipid is **amphipathic**: it has a hydrophilic part and a hydrophobic part.
- In water they form a **bilayer** by themselves: heads face the water, tails face each other.
- The sheet closes on itself, so it is **continuous**: no tails are left touching water.

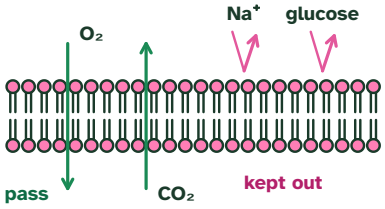
Head hydrophilic
A phosphate group, attracted to water.

Two tails hydrophobic
Fatty acids, squeezed together by the water round them, not by a bond.

B2.1.2 and 3

A barrier with gaps for *small* things

- The hydrophobic core of hydrocarbon tails has **low permeability** to ions, polar molecules and large molecules: a barrier between two watery solutions.
- **Simple diffusion:** small, uncharged O_2 and CO_2 slip **between the phospholipids**, down their gradient, with no energy spent.



B2.1.4

Proteins *in* it and *on* it

- Membrane proteins vary in **structure, position and function**: channels, pumps, enzymes, receptors, anchors for the cytoskeleton.
- Only a detergent that breaks up the bilayer frees an integral protein.

Integral embedded
In **one or both** layers, held by a hydrophobic part among the tails. Channels and pumps cross both.

Peripheral attached
On the inner or outer **surface**, to the heads or to an integral protein.

B2.1.5

Osmosis and *aquaporins*

- **Osmosis:** the net movement of water **towards the higher solute concentration**.
- **Why:** water moves **at random**, both ways, but the membrane holds back solutes. On the concentrated side more water is held round solute particles, so fewer cross back.
- **Aquaporins:** integral proteins with a **narrow hydrophilic pore**. Water passes in single file; ions are kept out by size and charge.

Through the bilayer slow
Small, but polar: few squeeze between the phospholipids.

Through aquaporins fast
Billions a second through each. Many in kidney collecting ducts and plant roots.

B2.1.6 to 8

Channels open, *pumps* push

- **Channel protein:** a hydrophilic pore whose width and charges fit **one kind of ion**. Gate open, ions diffuse through; shut, none pass.
- **Pump protein:** binds a specific particle and uses **energy from ATP** to change shape, moving it **against the gradient**.

	SIMPLE DIFFUSION	FACILITATED DIFFUSION	ACTIVE TRANSPORT
Route	Through the bilayer	Channel protein	Pump protein
Energy	None: passive	None: passive	**ATP**
Direction	Down the gradient	Down the gradient	Can go against it
Selective	No: size and polarity only	Yes: one kind of ion	Yes: specific particles
Example	O_2 in, CO_2 out	Na^+ channel	Na^+ pumped out

Proteins make a membrane **selectively permeable**.

Remember: *Down needs no ATP*

Fluid membranes, *gates* and pumps

B2.1.11 and 12 HIGHER LEVEL

Not too stiff, not too *runny*

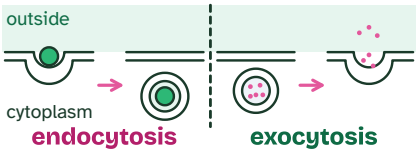
- **Saturated** tails are straight and pack tightly: **higher melting points**, so stronger at high temperatures.
- **Unsaturated** tails kink and pack loosely: **lower melting points**, so fluid at the cell's temperature.
- **Habitat:** Antarctic icefish (water at about −2 °C) have many unsaturated fatty acids.
- **Cholesterol** (animal cells) sits among the tails, its OH by the heads. A **modulator**: less fluid when warm, less stiff when cold.



B2.1.13 HIGHER LEVEL

Vesicles form and fuse

- Fluidity lets a membrane **pinch off a vesicle** or fuse with one, leaving no hole. Both use ATP.
- **Endocytosis:** the membrane folds in round material. Phagocytes take in bacteria; a newborn calf's gut cells, antibodies from milk.
- **Exocytosis:** a vesicle **fuses with the plasma membrane**, releasing digestive enzymes from gland cells or neurotransmitters from neurons.



B2.1.17 HIGHER LEVEL

Cells held in *tissues*

- **Cell-adhesion molecules** (CAMs) are membrane proteins that bind CAMs on the next cell. **Different forms** make different junctions.

SEAL
Gut lining
Nothing leaks between cells.

ANCHOR
Skin, heart muscle
Holds when stretched.

SIGNAL
Other junctions
Cells pass signals.

B2.1.14 and 15 HIGHER LEVEL

Gates and a *pump* in neurons

- **Neurotransmitter-gated:** acetylcholine binds the **nicotinic acetylcholine receptor**; it opens and Na^+ diffuses in.
- **Voltage-gated:** **Na^+ and K^+ channels** open or close as the membrane voltage changes, carrying the nerve impulse.
- **Na^+/K^+ pump**, an **exchange transporter**: 3 Na^+ out, 2 K^+ in per ATP, both against their gradients. With K^+ leaking out, the inside is negative: the membrane potential, about −70 mV.

STEP 1
Na^+ bind
Three Na^+ bind from the cytoplasm.

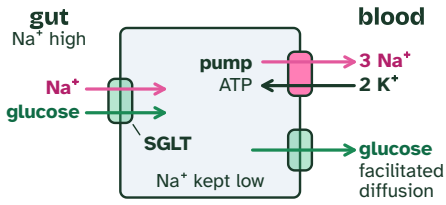
STEP 2
ATP
Phosphorylated, it changes shape and releases Na^+ outside.

STEP 3
K^+ bind
Two K^+ bind; phosphate off, shape back, K^+ released inside.

B2.1.16 HIGHER LEVEL

Glucose *hitches a ride*

- The **Na^+/K^+ pump** on the blood side uses ATP to keep **Na^+ low inside** the gut lining cell.
- The **SGLT** on the gut side lets Na^+ in only with glucose: Na^+ moving down its gradient carries **glucose up its gradient**.
- **Indirect active transport**: the cotransporter spends no ATP. Used in the **small intestine** and the **nephron**, so no glucose is lost in urine.



WATCH OUT

Six mistakes that *cost marks*

- ✕ **Facilitated diffusion is passive.** It uses a protein but no energy.
- ✕ **Small is not enough.** Na^+ is smaller than O_2, but its charge keeps it out of the bilayer.
- ✕ **Aquaporins do not pump water.** Water goes through by osmosis, whichever way the solutes decide.
- ✕ **Integral does not mean "crosses the membrane".** One layer is enough, if part is among the tails.
- ✕ **Cholesterol does not just stiffen.** Give both ends: less fluid when warm, less stiff when cold.
- ✕ **The SGLT spends no ATP.** Stop the pump and it stops too, as the Na^+ gradient runs down.

COVER THE SHEET

Can you *answer these?*

1. Explain why phospholipids form a bilayer in water.
2. Explain why O_2 crosses the bilayer but Na^+ does not.
3. Distinguish integral from peripheral proteins.
4. Explain osmosis, and the role of aquaporins.
5. Compare facilitated diffusion with active transport.
6. Draw the fluid mosaic model; state two roles of its sugars.
7. Explain how fatty acids and cholesterol set fluidity. HL
8. Distinguish endocytosis from exocytosis. HL
9. Outline the gated channels and the pump in a neuron. HL
10. Explain why the SGLT is indirect active transport. HL
11. Outline the role of CAMs in tissues. HL

IN THE EXAM

Name the method, then the protein, the direction and the energy: "facilitated diffusion through a channel protein, down the concentration gradient, no ATP".

GO FURTHER

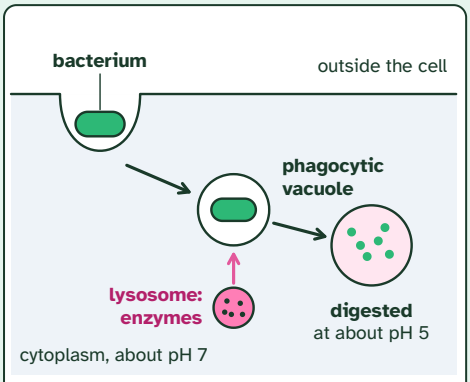
Animated figures, a dry lab and a marked Check are in the full guide online.

A cell of *rooms*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Membranes split a eukaryotic cell into compartments: enzymes kept close, clashing processes kept apart.



Lysosomes show both advantages. Enzymes held concentrated and acid, sealed off from the cytoplasm.

B2.2.3 START HERE

Why compartments *help*

- Membranes divide the cytoplasm of a eukaryote into **compartments**, each holding its own enzymes and conditions.
- **Lysosomes:** sacs of digestive enzymes that work at about pH 5. Loose in the cytoplasm they would digest the cell.
- A white blood cell wraps a bacterium in a **phagocytic vacuole**; lysosomes **fuse with it** and digest the bacterium there, sealed off.

ADVANTAGE 1

Concentration

Enzymes and substrates packed into a small space meet more often, so **reactions run faster**.

ADVANTAGE 2

Separation

Incompatible processes are kept apart, and each compartment keeps its own conditions, such as pH.

B2.2.1

What counts as an *organelle*

- An **organelle** is a discrete part of a cell, its structure **adapted** to a specific job.
- **Fractionation:** cells are broken in **cold, isotonic buffer**, then spun faster and faster; the largest, densest parts (nuclei) pellet first.
- **Nature of science:** the **ultracentrifuge** let each organelle be studied on its own. New techniques drive progress.

Organelles discrete units

Nucleus, mitochondria, chloroplasts, ER, Golgi, lysosomes, vesicles, **ribosomes** and the **plasma membrane**.

Not organelles not separate units

Cytoplasm (everything inside), **cytoskeleton** (runs through the whole cell), **cell wall** (outside the membrane).

B2.2.2

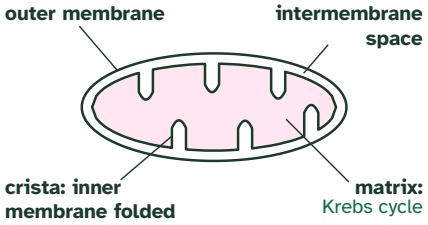
Genes behind a *wall*

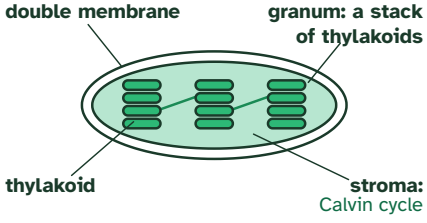
- Transcription copies a gene into mRNA; translation reads the mRNA at a ribosome.
- The nuclear envelope **separates transcription from translation**.
- So the mRNA can be **modified before it meets a ribosome**: only finished mRNA is read, and the right protein is made.

	PROKARYOTE	EUKARYOTE
Transcription	In the cytoplasm	In the **nucleus**
Translation	At once, on mRNA still being made	In the **cytoplasm**, later
mRNA edited first?	No: ribosomes may meet it at once	Yes: **introns** cut out, ends protected

B2.2.4 and 5 HIGHER LEVEL

Mitochondrion and chloroplast: one *design*





- Both have a **double membrane**.
- In both, pumped protons build a steep gradient that drives **ATP synthase**.

ADAPTATION	MITOCHONDRION: AEROBIC RESPIRATION	CHLOROPLAST: PHOTOSYNTHESIS
Small inner space	A tiny **intermembrane space**: pumped protons build a **steep gradient** fast.	A tiny space **inside each thylakoid**: the same steep gradient, fast.
Large membrane area	Inner membrane folded into **cristae**: room for many electron transport chains and ATP synthases.	Many **thylakoid membranes**, stacked in grana: room for many photosystems, so more light caught.
Enzymes kept together	The **matrix** holds the **Krebs cycle** enzymes and substrates, so they meet often.	The **stroma** holds the **Calvin cycle** enzymes (Rubisco most of all) and substrates.

B2.2.6 HIGHER LEVEL

Two membranes, many *doors*

- A **double membrane** keeps the genes in their own compartment; the outer one runs on into the rough ER.
- **Nuclear pores**, each a complex of proteins, control what crosses.
- **In mitosis and meiosis** the envelope **breaks into vesicles** so the spindle can reach the chromosomes; the vesicles fuse again afterwards.

OUT THROUGH PORES	IN THROUGH PORES
mRNA and ribosome subunits, to the cytoplasm.	**Enzymes** for copying DNA and making mRNA.

B2.2.7 HIGHER LEVEL

Made here, sent *there*

- A ribosome has a **small and a large subunit**, each of RNA and protein; eukaryote ribosomes are **80S**.
- All start in the cytoplasm. A **signal sequence** at the start of a new protein takes its ribosome to the rough ER.

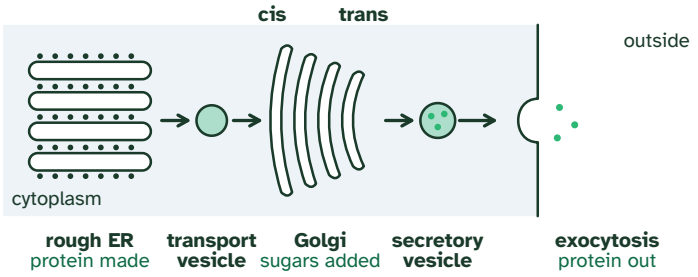
Free ribosomes in the cytosol
Make proteins **kept in the cell**, such as the enzymes of glycolysis.

Bound ribosomes on the rough ER
Thread the protein into the ER lumen, for **secretion**, a membrane or a lysosome. Secreting cells are full of rough ER.

B2.2.8 HIGHER LEVEL

Finish, label, *ship*

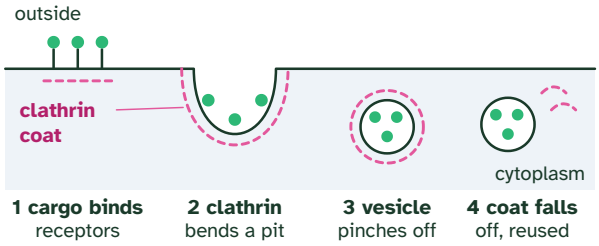
- A stack of flattened, curved sacs of membrane: the **cisternae**.
- **In:** vesicles from the rough ER fuse with the receiving (cis) face.
- **Processed:** sugars are added to make **glycoproteins**; some proteins are trimmed or folded further.
- **Out:** sorted at the far (trans) face into vesicles; a **secretory vesicle** releases its protein by **exocytosis**.



B2.2.9 HIGHER LEVEL

Bubbles that *carry*

- A **vesicle** is a small sac of membrane. It buds from one membrane and fuses with another: ER to Golgi, Golgi to surface or lysosome.
- Its membrane joins the one it fuses with, so exocytosis **adds membrane** to the surface.
- **Clathrin** links into a cage on the cytoplasmic face, **bending the membrane into a pit** that pinches off.



WATCH OUT

Six mistakes that *cost marks*

- ✕ **An organelle needs no membrane round it.** Ribosomes have none; the plasma membrane is one. Both count.
- ✕ **Lysosomes do not empty their enzymes into the cytoplasm.** Digestion stays inside membrane, in the vacuole they fuse with.
- ✕ **Mitochondria do not make energy.** They transfer energy from food to ATP.
- ✕ **The light-dependent reactions are on the thylakoid membranes.** The Calvin cycle is in the stroma.
- ✕ **Free and bound ribosomes are the same kind.** A ribosome binds the ER only while making a protein with the signal.
- ✕ **The Golgi does not make proteins.** It receives them from the rough ER, then modifies and sorts them.

COVER THE SHEET

Can you *answer these?*

1. State two organelles, and two cell parts that are not.
2. Explain why separating nucleus and cytoplasm helps.
3. Outline how lysosomes show both advantages.
4. Explain how the mitochondrion is adapted to make ATP. HL
5. Outline the adaptations of the chloroplast. HL
6. Explain the pores and breakdown of the nuclear envelope. HL
7. Distinguish proteins made by free and bound ribosomes. HL
8. Outline the role of the Golgi in secretion. HL
9. Describe the role of clathrin in forming a vesicle. HL

IN THE EXAM

Tie each structure to its job with "so" ("cristae give a large surface for ATP synthase, so more ATP is made"); for compartments, name **both** advantages: concentration and separation.

GO FURTHER

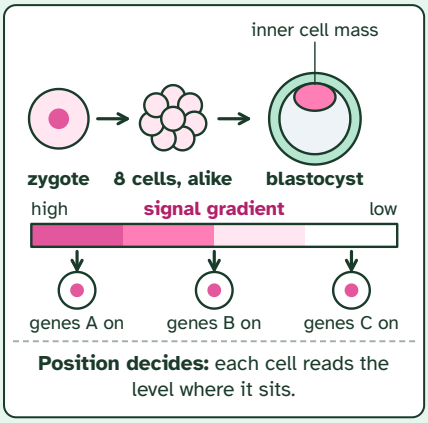
Animated figures, a film of one protein leaving the cell and a quick check in every chapter are in the full guide online.

One cell, many *kinds*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Every cell has the same genes. Cells specialise by switching on different ones, and their size and shape suit the job.



Position decides: each cell reads the level where it sits.

B2.3.1 START HERE

From one cell to *many kinds*

- A sperm fertilises an egg to make one cell, the **zygote**. It divides by mitosis into cells that are all alike: **unspecialised**.
- By about day 5 the ball is a hollow **blastocyst**. Its inner cell mass will form the body; its outer layer helps form the placenta.
- Every cell keeps **the same genes**. **Differentiation** is each cell switching on some genes and leaving others off.
- Some cells release **signal molecules** that spread out, making a **concentration gradient**. Each cell switches on the genes that match the level where it sits.

B2.3.2 TWO PROPERTIES

What makes a *stem cell*

PROPERTY 1
Divides endlessly
Keeps making stem cells: self-renewal.

PROPERTY 2
Differentiates
Daughters follow different pathways.

- Often **one daughter stays a stem cell**: a lifelong supply.
- They could **replace damaged tissue**, as after a burn.

B2.3.3

Stem cell *niches*

NICHE 1
Bone marrow
Makes every blood cell: red, white and platelets.

NICHE 2
Hair follicle
Its bulge makes new hair and helps heal cuts.

- A **niche**: where adult stem cells live, and all round them.
- It can **maintain** its stem cells, resting, or **promote** their division and differentiation.

B2.3.4

Three levels of *potency*

- **Potency**: how many kinds of cell it can still become.
- **Embryo: totipotent** at first, but soon **pluripotent**.
- **Adult:** marrow stem cells are **multipotent**: blood cells.

POTENCY, WIDEST FIRST

Total, Plenty, Many

T **Totipotent** any cell, and the placenta

P **Pluripotent** any body cell, not the placenta

M **Multipotent** a few related cells

B2.3.5 THE RANGE IN HUMANS

Size suits the *job*

CELL	SIZE	WHAT TO SAY
Red blood cell	**About 8 µm**	Fits the narrowest capillaries.
White blood cell	**10 to 15 µm**	A little bigger than a red cell.
Sperm	**Head 5 µm**	Small and light, to swim.
Egg	**About 0.1 mm**	Large: food for the embryo.
Muscle fibre	**Several cm**	Contracts as one unit.
Neuron	**Up to 1 m**	Thin, so all near the surface.

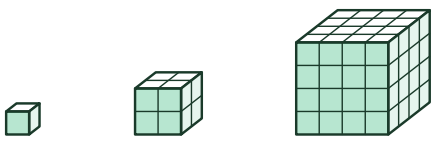
×100 000+
range of human cell sizes

0.1 mm
the egg: just visible by eye

B2.3.6

Why cells stay *small*

- Exchange rate depends on **surface area**; the need, on **volume**.
- Double the side: area ×4, volume ×8, so the **ratio halves**.
- A big cell has a **long way to its middle**, so cells divide.
- **A model:** cells are not cubes, but any shape scales the same way.



1 cm side
6 cm² ÷ 1 cm³
ratio 6 : 1

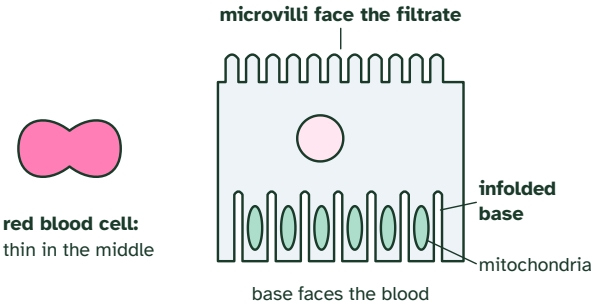
2 cm side
24 cm² ÷ 8 cm³
ratio 3 : 1

4 cm side
96 cm² ÷ 64 cm³
ratio 1.5 : 1

Shapes for *exchange*, muscle and gametes

B2.3.7 HIGHER LEVEL

Flatten, fringe, *fold*

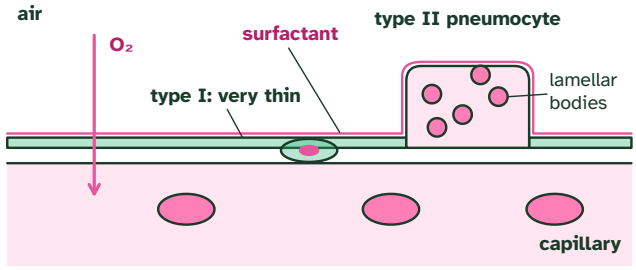


- Each raises the **surface area to volume ratio**, size unchanged.

FLATTEN	FRINGE	FOLD
Thin cells Biconcave red blood cells; type I pneumocytes.	**Microvilli** Brush border of proximal convoluted tubule cells.	**Invagination** Their base folds in; mitochondria power active transport.

B2.3.8 HIGHER LEVEL

Two cells, one *wall*



Type I most of the surface
Extremely thin (about 0.1 µm over a capillary), so gases diffuse a **very short distance**.

Type II fewer and thicker
Cytoplasm full of **lamellar bodies**: vesicles that release **surfactant** onto the lining.

- Surfactant lowers surface tension: alveoli **do not stick shut**.
- One tissue, **two cell types**: two jobs need two adaptations.

B2.3.9 HIGHER LEVEL

Is a muscle fibre a *cell*?

- Both are packed with **contractile myofibrils**: the stripes.

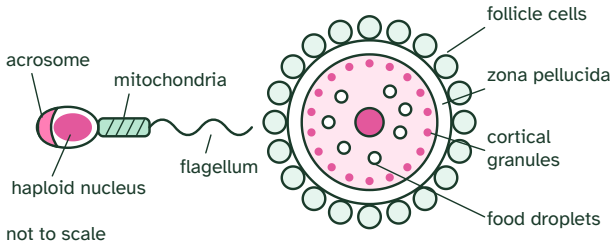
	STRIATED FIBRE	CARDIAC MUSCLE
Branching	None: one cylinder.	Branched; joined at **intercalated discs**.
Length	Several cm.	Much shorter cells.
Nuclei	Hundreds, at the edge.	One, sometimes two.
Why	Contracts its whole length at once.	Spreads the signal: the heart squeezes as one.

YES, A CELL
One membrane
Continuous, as in any cell.

NO, NOT A CELL
Many nuclei
Made by fusing many cells.

B2.3.10 HIGHER LEVEL

Small and fast, big and *stocked*



- Both human gametes are **haploid**, with one set of chromosomes.
- **Sperm:** **acrosome** enzymes digest a way in; mitochondria make ATP for the flagellum.
- **Egg:** large, with **lipid and protein** food; cortical granules let only one sperm in.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Specialised cells keep all their genes.** Unused ones are switched off.
- ✕ **Pluripotent means any body cell.** Multipotent means a few kinds.
- ✕ **A niche is a place, not a cell type.** It controls the stem cells in it.
- ✕ **A bigger cell has more surface, not less.** It is the area per unit of volume that falls.
- ✕ **Microvilli are not cilia.** They do not beat; they add surface.
- ✕ **Type II cells do not exchange gases.** Their job is surfactant.

COVER THE SHEET

Can you *answer these?*

1. Explain how a signal gradient makes embryo cells differ.
2. State the two properties of stem cells.
3. Outline what a stem cell niche does, with two examples.
4. Distinguish totipotent, pluripotent and multipotent cells.
5. Compare the sizes of a sperm and an egg cell.
6. Calculate the surface area to volume ratio of a 3 cm cube.
7. Describe three ways cells raise their ratio. HL
8. Explain how the two pneumocytes are adapted. HL
9. Discuss whether a striated muscle fibre is a cell. HL
10. Outline two adaptations each of sperm and egg. HL

IN THE EXAM

Name the feature, then link it to its job ("extremely thin, so a short diffusion distance"); in a ratio sum, **show area and volume** before you divide.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY | B3.1 | SL AND HL

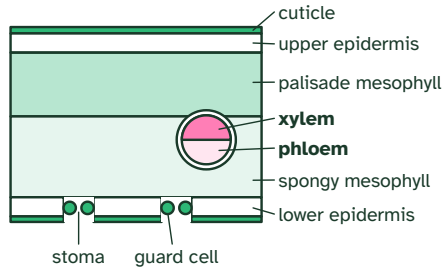
REVISION ON TWO PAGES

How gases get *across*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Gases cross by diffusion, so every exchange surface is thin, moist, permeable and large, and something keeps the gradient across it steep.



Draw it like this. Ruled label lines; no cells.

B3.1.8 START HERE

Draw the *leaf*: a plan diagram

- A **plan diagram** shows where each tissue is: **one outlined region** per tissue, with no cells drawn.
- Top to bottom: cuticle, upper epidermis, **palisade mesophyll**, **spongy mesophyll**, lower epidermis. *Cats Usually Purr Softly Lazily.*
- Veins run through the mesophyll, the **xylem towards the upper surface** and the phloem towards the lower.
- Keep the proportions the micrograph shows.

B3.1.1, B3.1.2

Why size needs a *surface*

- Every cell respires, plant cells too, so it swaps O_2 and CO_2 by **diffusion**, quick only over a cell or two.
- As an organism grows, its **surface area to volume ratio falls** and its centre gets further from the outside, so it needs an **exchange surface**.

TOO	MANY	PINK	LEAVES
Thin A short path to cross.	**Moist** Gases dissolve first.	**Permeable** Lets gases through.	**Large area** More crosses at once.

B3.1.3

Keeping the *gradient* steep

- Diffusion only works while there is a **concentration gradient**.
- **Gills:** water holds about **30 times less oxygen** than air, so a fish pumps a one-way stream of water over them.

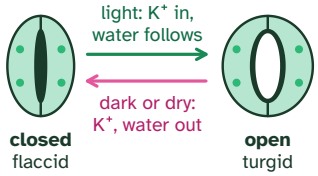
THREE THINGS — *Very Fast Vans*

V	F	V
Vessels dense capillaries at the wall	**Flow** blood that never stops	**Ventilation** fresh air, or water

B3.1.7

A leaf built for *gas exchange*

PART	WHAT IT DOES FOR GAS EXCHANGE
Waxy cuticle	Keeps water in, so gases must go **through the stomata**.
Epidermis	One clear layer of tightly fitted cells; it makes the cuticle.
Guard cells	Open the stoma to let CO_2 in; **close it to save water**.
Spongy mesophyll	Loosely packed; its **moist cell walls** are the exchange surface.
Air spaces	Join every stoma to every mesophyll cell.
Veins	**Xylem** replaces the water lost; **phloem** carries sugars away.



The wall is thicker on the pore side, so turgid guard cells bow apart.

B3.1.9

Transpiration, the cost of open stomata

- The **loss of water vapour** from leaves and stems, a **consequence of gas exchange**: water evaporates inside the leaf and diffuses out of open stomata.

WHAT CHANGES THE RATE — *Lazy Teens Hate Wednesdays*

L	T	H	W
Light opens stomata	**Temperature** faster	**Humidity** slower	**Wind** faster

B3.1.10 SKILLS

Counting *stomata*

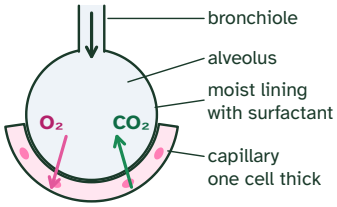
- Stomata **per mm²**, counted on a scaled micrograph or a **leaf cast** of clear nail varnish.
- **Nature of science: repeat the count** in random high-power fields: a more reliable mean; the spread is real variation.

STEP 1	STEP 2	STEP 3
Count Mean of five: 13.	**Area** πr^2 = 0.159 mm².	**Divide** 13 ÷ 0.159 ≈ 82.

B3.1.4

The *alveolar* lung

- **A branched network of bronchioles:** trachea, two bronchi, then over twenty divisions, so **no alveolus is far from an airway**.
- **High surface area: hundreds of millions of alveoli**, about 70 m^2 in all; air and blood are less than 1 µm apart.
- **Extensive capillary beds:** every alveolus is wrapped in capillaries.
- **Surfactant** (phospholipids and proteins) weakens the pull of the water lining, so **alveoli stay open** as you breathe out.



B3.1.5 AIR FLOWS FROM HIGH PRESSURE TO LOW

Ventilation: *pressure* moves the air

Breathing in muscles contract

The **diaphragm contracts** and flattens; the **external intercostals** lift the ribs up and out. Chest volume rises, so pressure falls: **air flows in**.

Breathing out passive at rest

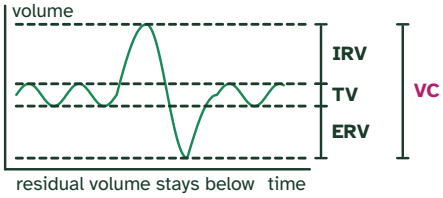
The muscles relax, the diaphragm domes up and the stretched lungs recoil. Volume falls, so pressure rises: air flows out.

- **Forced breathing out:** the **internal intercostals** pull the ribs down and in; the **abdominal muscles** push the diaphragm up.

B3.1.6 SKILLS

Measuring lung *volumes*

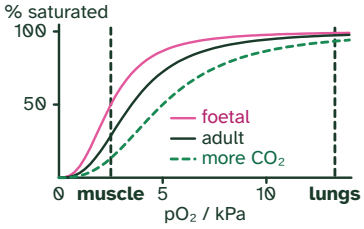
- **Tidal volume (TV):** one ordinary breath, about 0.5 dm^3 at rest.
- **IRV, ERV:** the extra beyond an ordinary breath in, or out.
- **Vital capacity** = **TV + IRV + ERV**; take your best of three.



B3.1.11, B3.1.13 HIGHER LEVEL

Haemoglobin and the *S-shaped* curve

- Four **haem groups** bind O_2 **cooperatively**: each O_2 bound makes the next bind more easily, so the curve is an **S**.
- **Flat top:** about 97% saturated at the lungs. **Steep middle:** a small fall in pO_2 **releases a lot**.
- **Foetal haemoglobin** (gamma chains for beta) lies to the left: **higher affinity**, so it takes O_2 from the mother.



B3.1.12 HIGHER LEVEL

The Bohr *shift*

- **Allosteric binding**: CO_2, and the H^+ it makes in red cells, bind the chains away from the haem and **lower the affinity**.
- So the curve moves right and **more O_2 is released where respiration is fastest**. In the lungs CO_2 leaves and it moves back.

Which way: **Left Loads, Right Releases**.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Breathing is not gas exchange.** Breathing is ventilation; gas exchange is diffusion across the alveolus wall.
- ✕ **Plants respire too**, in the light and the dark. In bright light, faster photosynthesis hides it.
- ✕ **The diaphragm moves down to breathe in.** It contracts and flattens; it domes up as it relaxes.
- ✕ **Vital capacity is not all the air in the lungs.** About a litre, the residual volume, always stays.
- ✕ **A curve to the right means lower affinity.** More oxygen is given up, not taken.
- ✕ **CO_2 does not take oxygen's place on the haem.** It binds elsewhere on the chains.

COVER THE SHEET

Can you *answer these?*

1. Explain why a large organism needs an exchange surface.
2. Outline how the gradient is kept steep at an alveolus.
3. Describe four adaptations of the lungs for gas exchange.
4. Explain how the muscles draw air into the lungs.
5. Define tidal volume and vital capacity.
6. Outline how a leaf is adapted for gas exchange.
7. Draw a plan diagram of a dicot leaf in section.
8. Explain why transpiration rises in warm, windy air.
9. Outline how to find stomatal density reliably.
10. Explain the S shape of the dissociation curve. HL
11. Explain the benefit of the Bohr shift. HL

IN THE EXAM

Keep the words apart: ventilation moves air; gas exchange is diffusion across the wall. On a curve, **say which way it moves, then what that does to affinity**.

GO FURTHER

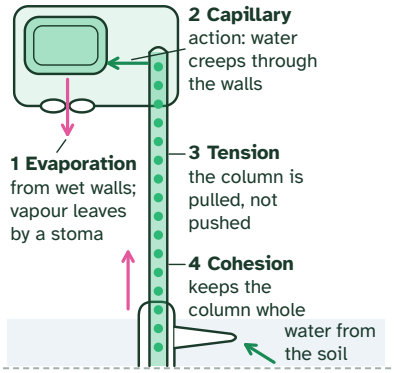
Animated figures, a dry lab and a marked Check are in the full guide online.

Fluids under *pressure*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Fluids flow from high pressure to low. Each vessel is built for the pressure it carries: thick to withstand it, thin to exchange.



Read it from the leaf down.

B3.2.7 START HERE

Water is *pulled* up from the top

- **Transpiration**: water evaporates from the wet walls of leaf cells and leaves through the stomata. The walls refill by **capillary action**, drawing water out of the xylem.
- That puts the xylem water under **tension** (a negative pressure potential), which draws the whole column up. **Cohesion** keeps the column continuous.
- The energy is the sun's: the plant spends **none of its own** lifting water.

THE PULL, FROM THE LEAF DOWN

Every Cool Tree Climbs

E Evaporation from the wet cell walls	**C** Capillary action through the walls	**T** Tension xylem water pulled	**C** Cohesion keeps the column whole

B3.2.8

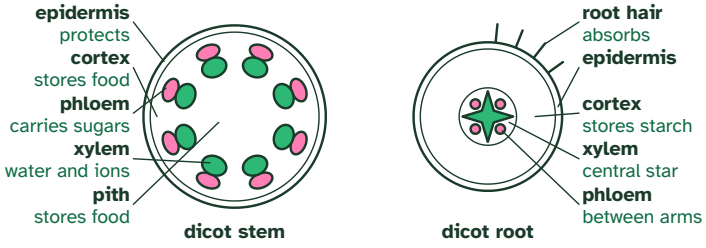
Xylem: built for *tension*

- Vessels are **dead**, empty tubes.
- **No contents, no end walls:** water flows **unimpeded**.
- **Lignified walls: lignin** stops them collapsing under tension.
- **Pits**, gaps in the lignin: water passes in and out sideways.

B3.2.9 and 10 SKILLS: PLAN DIAGRAMS

Stem and root in *section*

- **Stem:** a **ring of vascular bundles**; in each, phloem outside, xylem inside.
- **Root:** one **central core**: xylem a star, phloem between its arms.



Outlines only, no cells; annotate each tissue. Stem, outside in: *Eat Cake, Pass Xmas Pudding*.

B3.2.1, 2, 3 and 5

Arteries, capillaries, *veins*



artery thick wall, narrow lumen — **vein** thin wall, wide lumen — **capillary** one cell thick

Micrographs: judge the wall against the lumen.

	ARTERY	CAPILLARY	VEIN
Job	Away from the heart at **high pressure**.	Exchange with the tissues.	Back to the heart at low pressure.
Wall	Thick layers of **muscle** and **elastic fibres**.	One cell thick; some with **fenestrations**.	Thin and **flexible**, little muscle.
Lumen	Narrow, usually round.	5 to 10 µm, much branched.	Wide, often flattened.
So	Withstands pressure; **elastic recoil** maintains it.	**Large surface area**, short diffusion path.	Muscles squeeze it; **valves** stop backflow.

B3.2.4 SKILLS

Taking a *pulse*

- Feel the **radial** (wrist) or **carotid** (neck) pulse.
- **Two fingertips**, never the thumb: it has a pulse.
- Scale to **beats a minute**; check against a smartwatch.

18 × 4 beats in 15 s	**72** beats a minute

B3.2.6

When a coronary artery *blocks*

STEP 1	STEP 2	STEP 3
Atheroma Fatty plaque narrows the lumen.	**Thrombus** A clot forms on a cracked plaque.	**Occlusion** Muscle beyond dies: a **heart attack**.

- **Risks:** high LDL, smoking, high blood pressure, inactivity, obesity.
- **Data:** r runs from −1 to +1. A strong correlation (saturated fat and CHD) **does not prove a cause**; a weak one can count against a hypothesis.

Tissue fluid, the *heart* and the phloem

B3.2.11 to 13 HIGHER LEVEL

Tissue fluid: *out and back*

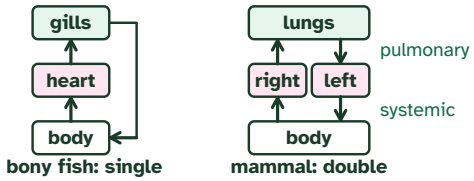
- **Out:** arteriole pressure forces plasma out: **pressure filtration**.
- **Back:** pressure is lower at the venule end: most **drains back**.
- **Excess** enters lymph vessels (gaps, **valves**), then veins in the neck.

Plasma in the capillary **Many proteins**, red cells, platelets.
Tissue fluid round the cells **Very few proteins**, no red cells. Cells take O_2 and glucose; give CO_2.

B3.2.14 HIGHER LEVEL

One loop or *two*

- **Bony fish:** heart **once** a circuit; low pressure to the body.
- **Mammal: pumped again after the lungs**; high pressure.



B3.2.15 HIGHER LEVEL

The heart, *part by part*

- **Cardiac muscle:** branched, intercalated discs; **myogenic**.
- The **SA node** (pacemaker), in the right atrium, starts each beat.
- **Atria** receive from veins; **ventricles** pump into arteries.
- A **septum** parts the sides; **coronary arteries** feed the wall.

VALVES, IN BLOOD ORDER — *Tiny Penguins Bake Apples*

T Tricuspid right AV	**P** Pulmonary semilunar	**B** Bicuspid left AV	**A** Aortic semilunar

B3.2.16 HIGHER LEVEL: LEFT SIDE, FROM THE SA NODE

One *cardiac cycle*

ALL **Atria** Contract first.	VALVES **Ventricle** Bicuspid shuts.	SWING **Squeeze** All valves shut.
OPEN **Outflow** Aortic opens.	SHUT **Slackens** Aortic shuts.	FILL **Fills** Bicuspid opens.

- Systolic over diastolic: about **120/80 mmHg**.

B3.2.17 HIGHER LEVEL

Root *pressure*

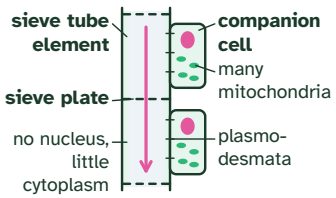
- Root cells pump mineral ions into the xylem by **active transport**.
- Water follows by **osmosis**, building a **positive pressure potential** that pushes it up a few metres.
- **When** transpiration fails: humid air, or spring before leaves open.

B3.2.18 HIGHER LEVEL

Phloem: *source to sink*

- **Sieve tubes: sieve plates**, few organelles, **no nucleus**: little blocks the flow.
- **Companion cells:** mitochondria make ATP to **load sucrose**; plasmodesmata link the two.
- Water follows by osmosis at a **source**; **mass flow** takes sap to a **sink**, up or down, to be unloaded.

Lazy Otters Push Fish Upstream: load, osmosis, pressure, flow, unload



WATCH OUT

Six mistakes that *cost marks*

- ✕ **The plant does not pump water up the xylem.** Evaporation pulls it.
- ✕ **Arteries are named by direction, not oxygen.** The pulmonary artery carries oxygen-poor blood.
- ✕ **The pulse is a pressure wave,** not blood rushing past.
- ✕ **Correlation is not causation.** A clue, never a proof.
- ✕ **Tissue fluid is not blood.** No red cells, very few proteins.
- ✕ **Pressure moves the valves,** not muscles. Cords only stop the flaps turning inside out.

COVER THE SHEET

Can you *answer these?*

1. Explain how transpiration draws water up the xylem.
2. Outline three adaptations of xylem vessels.
3. Draw plan diagrams of a dicot stem and root.
4. Distinguish an artery from a vein in a micrograph.
5. Describe how to measure a resting heart rate.
6. Outline how a coronary artery becomes occluded.
7. Explain how tissue fluid forms and returns. HL
8. Compare single and double circulation. HL
9. Describe one cardiac cycle, naming each valve. HL
10. Explain how root pressure is generated. HL
11. Explain how companion cells aid translocation. HL

IN THE EXAM

Name the pressure: tension (negative) pulls xylem water up; root pressure and loaded phloem sap are **positive** and push. Then say what sets up the difference.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY B3.3 HL

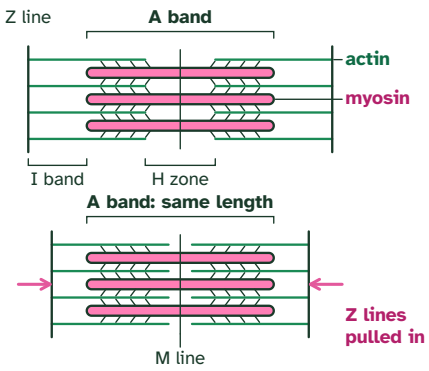
REVISION ON TWO PAGES

Muscles only *pull*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Actin slides between myosin to shorten each sarcomere. Muscles only pull, so skeletons, joints and antagonistic pairs turn that pull into movement.



Top relaxed, bottom contracted. Draw Z lines at the ends, actin from them, myosin in the middle; label the bands.

B3.3.2 START HERE

Sliding *filaments* shorten the sarcomere

- A muscle fibre is packed with myofibrils, each a chain of **sarcomeres**. One sarcomere runs from **Z line to Z line**.
- Thin **actin** filaments are anchored to the Z lines. Thick **myosin** filaments lie in the middle, centred on the M line.
- In contraction the actin **slides between the myosin** towards the M line. **Neither filament shortens**.
- So the **I band and H zone shorten**. The A band, the length of the myosin, stays the same.

THE CYCLE, REPEATED WHILE CALCIUM IS PRESENT

Cats use big paws, always

C Calcium released by the impulse	**U** Uncover tropomyosin moves aside	**B** Bind heads latch onto actin	**P** Pull the power stroke	**A** ATP head lets go, cocks again

B3.3.1

Everything alive *moves*

- Movement is universal, and each body is **adapted to how it moves**.
- It lets organisms find food, escape, find a mate and disperse.

Motile moves its whole body
Atlantic salmon: blocks of muscle down each side bend the streamlined body and sweep the tail.

Sessile fixed in one place
Acorn barnacle: cemented to rock, it sweeps feathery legs out to catch plankton; its larva swims. A **Venus flytrap** snaps its leaf shut.

B3.3.3

Titin and *antagonistic* pairs

- A muscle exerts force **only when it contracts**: it pulls, and cannot push itself long again.
- **Titin**, the largest protein in the body, runs from Z line to myosin. It **recoils after contraction** and **prevents overstretching**.
- The **biceps** bends the elbow and the **triceps** straightens it: as one contracts, it **stretches the other**.

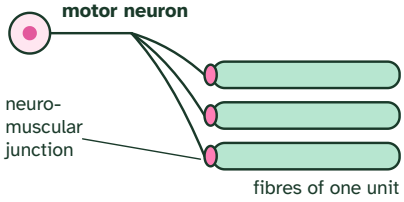
LENGTHENED BY
Titin
elastic recoil

LENGTHENED BY
Antagonist
stretches it

B3.3.4

The *motor unit*

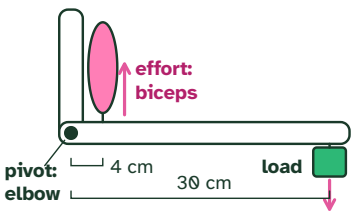
- **One motor neuron and the fibres it supplies**, each met at a **neuromuscular junction** (a synapse).
- A unit's fibres contract together. More force means **recruiting more units**: small ones (eye) for fine control, large ones (thigh) for force.



B3.3.5

Skeletons: *anchorage* and levers

- A muscle must pull on something firm: the skeleton is its **anchorage**, joined to it by tendons.
- **Arthropods:** an **exoskeleton**, muscles inside. **Vertebrates:** an **endoskeleton**, muscles outside.
- Bones are **levers**: the joint is the pivot, the muscle the effort, against a load.
- With these distances the biceps pulls with **7.5 times the load**, but moves the hand far and fast.



B3.3.7 APPLICATION OF SKILLS

Range of *motion*

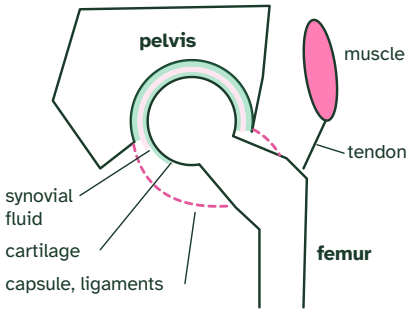
- The **angle a joint moves through**, in each direction.
- **Measure it** with a **goniometer**, arms along the two bones, or by computer analysis of images.
- Ranges differ between people: bone shape, ligaments and muscles set them.

Hinge knee, elbow
One plane: flexes and extends.

Ball and socket hip, shoulder
Many: flexion and extension, abduction and adduction, rotation.

B3.3.6 A BALL AND SOCKET SYNOVIAL JOINT

Inside the *hip joint*



PART	WHAT IT DOES
Femur and pelvis	The levers. The head of the femur is a **ball** in a **socket** in the pelvis.
Cartilage	Smooth cover on the bone ends: **reduces friction**, absorbs shock.
Synovial fluid	Fills the cavity in the capsule and **lubricates** the joint.
Ligaments	Join **bone to bone**: hold the joint together, limit movement.
Muscles, tendons	Muscles pull the femur; tendons join **muscle to bone**.

Name the femur and pelvis; you need not name the muscles or ligaments.

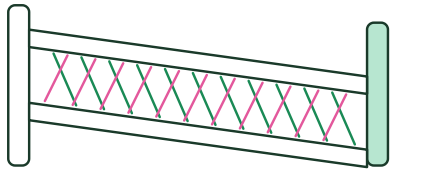
B3.3.8

Intercostals: an *antagonistic* pair

- Two layers between each pair of ribs, **fibres at right angles**, so they move the ribcage in **opposite directions**.
- **Breathing in:** raised ribs increase the volume, so pressure falls and air enters. Quiet breathing out is passive recoil.
- As one layer contracts it stretches the other, **storing potential energy in titin**.

I E **Inhale: External**
ribs up and out

E I **Exhale: Internal**
ribs down and in, forced only



Green: external, down and forward. Pink: internal, down and back.

B3.3.9

Four reasons for *locomotion*

- Moving costs energy and risk, so it must pay. Know **one example of each**.

REASON 1
Foraging
Honeybees fly to flowers.

REASON 2
Escaping danger
A gazelle outruns a cheetah.

REASON 3
Finding a mate
Male moths follow a scent.

REASON 4
Migration
Arctic terns, pole to pole.

B3.3.10

Marine mammals built to *swim*

- **Streamlined:** smooth and tapered, few projections, so **less drag** and less energy used.
- **Flippers:** forelimbs, bones still inside, that **steer and brake**.
- **Fluke:** the tail **beats up and down**, driven by back muscles; a fish tail beats side to side.
- **Blowhole:** nostrils on top of the head, closed on a dive, for **periodic breathing**. One breath swaps most of the lung air.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Neither filament shortens.** Actin slides between myosin.
- ✕ **The A band keeps its length.** It is the length of the myosin; the I band and H zone shorten.
- ✕ **Muscles never push.** Titin and the antagonist lengthen them.
- ✕ **Ligaments join bone to bone; tendons join muscle to bone.** They are often swapped.
- ✕ **Quiet breathing out is passive.** The internal intercostals contract only to force air out.
- ✕ **More force means more units.** The fibres of one unit all contract together.

COVER THE SHEET

Can you *answer these?*

1. Distinguish motile from sessile organisms, with examples.
2. Explain how a sarcomere shortens.
3. Outline how a muscle returns to its resting length.
4. State what a motor unit is made of.
5. Outline two roles of a skeleton.
6. Outline the roles of the parts of the hip joint.
7. Compare the range of motion of the knee and the hip.
8. Explain how the intercostals act as an antagonistic pair.
9. State four reasons for locomotion, with examples.
10. Describe two swimming adaptations of whales.

IN THE EXAM

Say what slides ("actin slides between myosin"), then **what shortens** (sarcomere, I band, H zone) and **what does not** (both filaments, the A band).

GO FURTHER

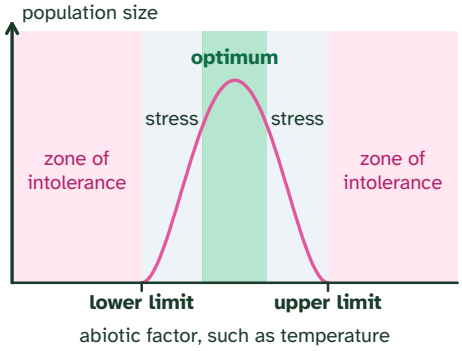
Animated figures, a dry lab and a marked Check are in the full guide online.

Each species in its *place*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Abiotic conditions decide where a species can live. Its adaptations set its range of tolerance; on land, climate sets the biome.



Draw it like this. A hump that reaches zero at the lower and upper limits.

B4.1.3, B4.1.4 START HERE

Abiotic variables and the *range of tolerance*

- Where a species is found depends on **abiotic variables**, for plants and animals alike.
- Each species copes with a set span of each variable: its **range of tolerance**. Its **adaptations decide where the limits fall**.
- **Optimum:** the population is largest. **Zones of stress:** individuals survive but grow and reproduce less. **Zones of intolerance:** beyond the limits, it cannot survive.
- A **limiting factor** is the one that sets the edge of a species' distribution.

Plants abiotic variables
Light, temperature, water, soil pH, minerals, salinity and wind.

Animals abiotic variables
Temperature, water, oxygen (in water especially), salinity and shelter.

B4.1.1

A *habitat*

- A habitat is the **place where an organism lives**. The word fits any level: one organism, a population, a species or a community.
- Each habitat has its own abiotic conditions. A **full description** gives three things, here for marram grass:

1 Location on the map
Coasts of north-west Europe.

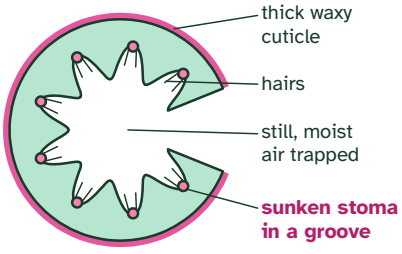
2 Physical conditions
Loose sand, salt spray, wind.

3 Type of ecosystem
Sand dunes.

B4.1.2 SAND DUNES

Marram grass

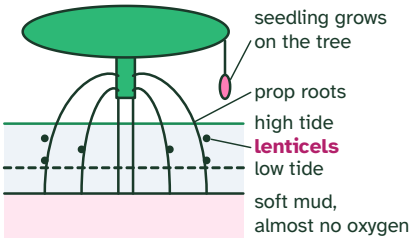
- *Ammophila arenaria*, on dunes where the sand is **dry, salty and blowing**.
- In dry weather the **leaf rolls up**, so **sunken stomata** among hairs open into still, moist air: little water is lost.
- Roots reach metres down to water; **rhizomes** spread sideways. Buried by sand, it grows up through it.



B4.1.2 MANGROVE SWAMPS

Red mangrove

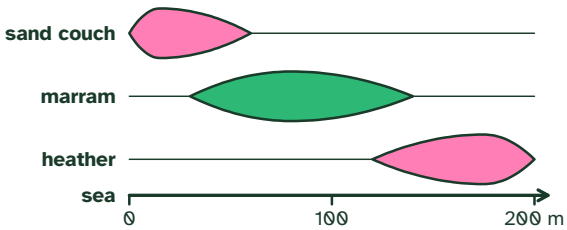
- *Rhizophora mangle*, between the tides on tropical coasts, over **salty mud with almost no oxygen**.
- Arching **prop roots** brace it; **lenticels** in them take in air when the tide is out.
- Roots **keep most salt out**; salt that gets in is stored in **old leaves, which are shed**. Seedlings grow on the tree.



B4.1.4 APPLICATION OF SKILLS

Correlate with a *transect*

- Collect your own data in a **natural or semi-natural habitat** (shaped by people, but wild species dominate).
- Lay a **line where conditions change**, such as a beach inland. At set intervals, place a **quadrat** and record each species.
- Measure abiotic factors there with **sensors**: a soil pH probe, a light meter, a temperature probe, an anemometer for wind.
- A **kite diagram** plots each species as a band whose width is its abundance. A transect shows **correlation, not cause**.

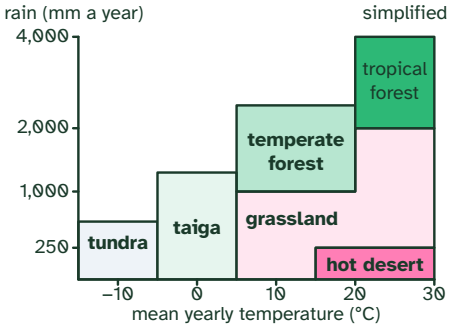


Sand couch tolerates the most salt; heather needs acid soil rich in humus.

B4.1.6, B4.1.7

Climate decides the *biome*

- On land, **temperature and rainfall** matter most: for any combination of the two, **one natural ecosystem type** is likely to develop.
- A biome: ecosystems with **similar communities**, as **similar abiotic conditions** select the same solutions (**convergent evolution**). **Cacti** (Americas) and **euphorbias** (Africa) are unrelated, yet both have pleated, water-storing stems and spines for leaves.



BIOME	CLIMATE
Tropical forest	Hot all year (about 25 to 28 °C); over 2,000 mm of rain.
Temperate forest	Mild, four seasons, rain all year; deciduous broadleaved trees.
Taiga	Long cold winters, short summers; conifers.
Grassland	Too dry for forest; hot summers, cold winters or a dry season.
Tundra	Very cold, a short cool summer, frozen ground; no trees.
Hot desert	Under about 250 mm of rain a year; hot days, cold nights.

B4.1.5

What a *coral reef* needs

- Coral polyps lay down **calcium carbonate** skeletons; **zooxanthellae** (algae in their cells) photosynthesise and **give most of the food**.
- **Acidification:** $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$ (**pH falls**); $H^+ + CO_3^{2-} \rightarrow HCO_3^-$, so **fewer carbonate ions**: slower skeleton growth.

FIVE CONDITIONS FOR A REEF

D Depth: mostly under 50 m: light for the algae	**T** Temperature: warm, about 23 to 29 °C	**S** Salinity: full-strength sea water	**C** Clarity: little mud to block light	**P** pH: about 8.2, plenty of carbonate

B4.1.8

Too dry, too wet: *hot desert* and *rainforest*

	HOT DESERT *water is short, heat is high*	TROPICAL RAINFOREST *light is short, rain is heavy*
Plant	**Saguaro cactus *Carnegiea gigantea*** Pleated stem **stores water**; **spines** for leaves; wide shallow roots; **CAM**: stomata open only at night.	**Kapok tree *Ceiba pentandra*** Grows **above the canopy** into full sun; **buttress roots** in thin soil. Many leaves have a **drip tip**.
Animal	**Fennec fox *Vulpes zerda*** **Huge ears lose heat**; nocturnal, burrows by day; furred soles; **concentrated urine**.	**Three-toed sloth *Bradypus*** **Very slow metabolism** on leaves; curved claws to hang; **algae** in its fur hide it.

Either the common or the scientific name is accepted in an exam.

Saguaro: Sonoran Desert. Fennec fox: Sahara.

WATCH OUT

Five mistakes that *cost marks*

- ✕ **A transect shows correlation, not cause.** Wind, salt, pH and humus change together; an experiment finds the limit.
- ✕ **Stress is not intolerance.** Under stress a species survives but breeds less; beyond a limit it cannot survive.
- ✕ **A rolled marram leaf does not shut its stomata.** They open into moist air, so the vapour gradient is small.
- ✕ **CAM is not photosynthesis at night.** CO_2 taken in at night is used by day, stomata shut.
- ✕ **A biome needs both variables.** 12 °C with 500 mm of rain is grassland, not forest.

COVER THE SHEET

Can you *answer these?*

1. Outline the three things a full habitat description gives.
2. Explain one adaptation each of marram and mangrove.
3. State two abiotic variables each for plants and animals.
4. Draw a range of tolerance and label its zones.
5. Outline how a transect links a plant to soil pH.
6. Explain why coral reefs form only in shallow, clear water.
7. State the axes of a biome graph.
8. Explain why cacti and euphorbias look alike.
9. Explain two adaptations of a named desert animal.

IN THE EXAM

Name the species, the adaptation and the abiotic problem it solves: "the marram leaf rolls, so its sunken stomata open into still, moist air and **less water is lost**".

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY B4.2 SL

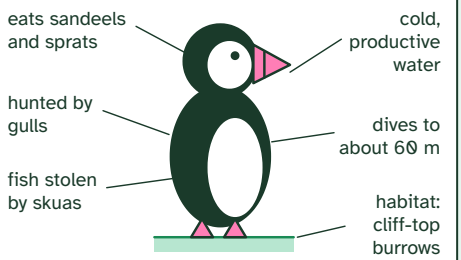
REVISION ON TWO PAGES

Every species has a *niche*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

A niche is how a species lives: what it eats, what eats it and what it can tolerate. No two species can share one.



The Atlantic puffin, *Fratercula arctica*. All of this is its niche; the cliff is only its habitat.

B4.2.1 START HERE

A habitat is an address; a niche is a *job*

- The **ecological niche** of a species is its **role in the ecosystem**: how it lives there, not only where.
- **Biotic** interactions are with other living things: food, predators, competitors, parasites, mutualists.
- **Abiotic** interactions are with physical and chemical conditions: temperature, water, light, oxygen.
- Both affect its **growth, survival and reproduction**, including how it obtains food. The **habitat** is only where it lives.

WHAT GOES INTO A NICHE

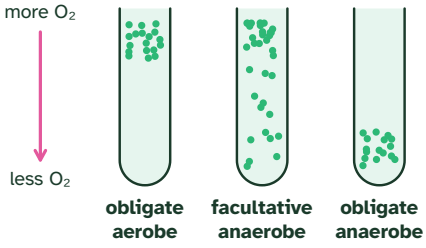
Hungry Ants Raid Insects

H	**Habitat** where it lives	**A**	**Activity** when it is active	**R**	**Resources** food, water, nest sites	**I**	**Interactions** predators, prey, competitors, partners

B4.2.2 TOLERANCE OF OXYGEN

Oxygen: needed, optional or *poison*

- **Obligate aerobes need oxygen**: without aerobic respiration they cannot make enough ATP.
- **Facultative anaerobes grow with or without oxygen**, but faster with it.
- **Obligate anaerobes cannot grow, or die,** where oxygen is present.



Broth open to the air: oxygen falls with depth

B4.2.8 INFER DIET FROM A SKULL

Reading a diet in the *teeth*

- **Nature of science:** a theory from living mammals lets us **deduce the diet of extinct species** from their skulls.
- **Skill:** from a skull, judge the size of the molars, the depth of the jaw and whether there is a crest.
- The cave of *H. floresiensis* holds stone tools and the bones of pygmy elephants.

Herbivore *Paranthropus robustus*
Large, flat, thickly enamelled molars and premolars, a heavy jaw and a **sagittal crest** for big chewing muscles.

Omnivore *Homo sapiens*, *H. floresiensis*
Smaller molars, and varied teeth for biting and grinding. No crest.

B4.2.3 to B4.2.7 AUTOTROPHS, HETEROTROPHS AND BOTH

Five ways to *feed*

MODE	WHO	HOW IT GETS CARBON COMPOUNDS OR ENERGY	REMEMBER
P **Photosynthesis** B4.2.3	Plants, algae and several groups of prokaryotes.	**Autotroph:** light energy makes glucose from carbon dioxide and water; oxygen is released.	Cyanobacteria do it **without chloroplasts**.
H **Holozoic** B4.2.4	**All animals**, as heterotrophs.	Food is **ingested, digested internally**, absorbed and assimilated; the rest is egested.	Order: *I Despise All Algebra Exams*
M **Mixotrophic** B4.2.5	Some protists: *Euglena*; many ocean plankton.	**Both autotrophic and heterotrophic**: photosynthesises in light; absorbs or ingests food in the dark.	**Facultative** (*Euglena*): either mode alone; **obligate**: both.
S **Saprotrophic** B4.2.6	Some fungi and bacteria: the **decomposers**.	**Heterotroph: secretes enzymes onto dead matter**, then absorbs the soluble products.	Frees nutrients from dead matter for producers.
A **Archaea** B4.2.7	One of the **three domains**; metabolically very diverse.	ATP from light, or from oxidising inorganic chemicals or carbon compounds.	Learn the three energy sources; no names needed.

Autotrophs make their own carbon compounds; heterotrophs take them ready-made.

Either the common or the scientific name is accepted.

Adaptations, and why every niche is *unique*

B4.2.9, B4.2.10 PHYSICAL, CHEMICAL AND BEHAVIOURAL

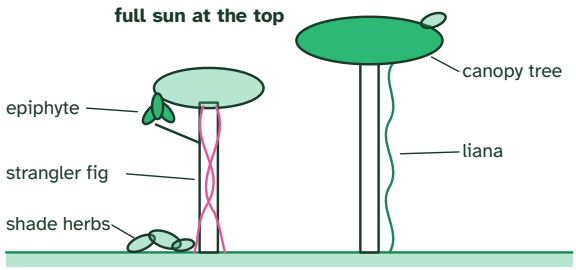
Arms races over food: *defence* and attack

ADAPTATION	PLANT RESISTS	HERBIVORE FEEDS	PREDATOR ATTACKS	PREY RESISTS
P **Physical** a structure	**Thorns** on acacias, spines on cacti, stinging hairs on nettles, silica in grasses.	**Chewing** mandibles in caterpillars; a **piercing** stylet in aphids, into the phloem.	**Pit organs** sense warm prey; a cheetah's long legs reach about 100 km/h.	Porcupine **quills**, armadillo armour, stick insect **camouflage**.
C **Chemical**	**Toxic secondary compounds** in seeds and leaves: nicotine, caffeine.	Some **detoxify** them, as koalas do in the liver; monarchs resist them.	Rattlesnakes kill with **venom**; a pit viper tastes the air to follow a trail.	Poison dart frogs carry **toxins** in their skin, advertised by bright colours.
B **Behavioural**	Plants cannot run away, so they defend where they stand. Each side selects for the other: an **arms race**.		Wolves **hunt in packs**, wearing down and surrounding elk.	Meerkat sentries give **alarm calls**; zebras herd; opossums play dead.

B4.2.11

Racing for the *light*

- In a rainforest, **light is in short supply**: the canopy absorbs nearly all of it, and the floor gets about 1 to 2%.
- **Lianas** climb trees, so need little trunk. **Strangler figs** start as epiphytes, root down and kill their host.

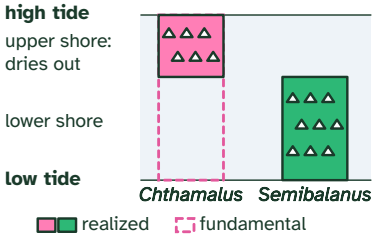


Top to floor: *Can Little Elves Steal Herbs*

B4.2.12

Fundamental and realized niches

- **Fundamental:** the **potential** niche, from **adaptations and tolerance limits**.
- **Realized:** the **actual** niche, when **competing with other species**.
- **Connell, 1961:** with *Semibalanus* scraped off, *Chthamalus* survived right down the shore.



B4.2.13

No two species can share a *niche*

- Species needing one limited resource **compete**.
- With the same niche, one in time removes the other: **competitive exclusion**.
- **So every niche is unique.** Partitioning lets similar species share a habitat.

OUTCOME 1
Elimination
Gause: *Paramecium aurelia* outgrew *P. caudatum*, which died out.

OUTCOME 2
Restriction
Each keeps to part of its fundamental niche, as warblers do in different parts of a spruce.

WATCH OUT

Five mistakes that *cost marks*

- ✕ **A niche is not a habitat.** The habitat is only where it lives.
- ✕ **Saprotrophs do not ingest.** They digest outside the body.
- ✕ **Facultative anaerobes grow best with oxygen:** it gives more ATP.
- ✕ **The realized niche is the smaller one,** cut down by competition.
- ✕ **A liana is not a parasite.** It uses the tree only for support.

COVER THE SHEET

Can you *answer these?*

1. Distinguish a habitat from a niche.
2. Describe where each oxygen group grows in broth.
3. Compare saprotrophic and holozoic nutrition.
4. Deduce the diet of a hominid with a sagittal crest.
5. Outline one plant defence and one prey defence.
6. Explain how a strangler fig reaches the light.
7. Explain how Connell showed a realized niche.
8. State the two possible outcomes of competition.

IN THE EXAM

Say what sets each limit: a tolerance limit, such as drying out, bounds the **fundamental** niche; competition bounds the **realized** one.

GO FURTHER

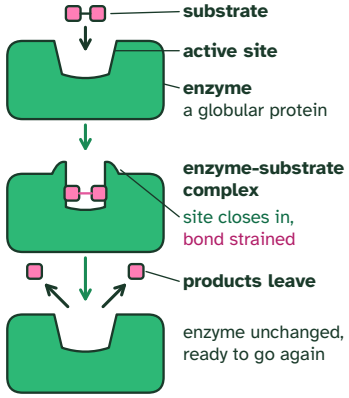
Animated figures, a dry lab and a marked Check are in the full guide online.

How *enzymes* work

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

An enzyme works because of its shape. Change the active site and you change, slow or stop the reaction.



Draw it like this. The site changes shape as the substrate binds; the enzyme comes out unchanged.

C1.1.4, C1.1.5 START HERE

The *active site* and induced fit

- Enzymes are **globular proteins**: chains folded into a compact, roughly round shape that dissolves in water.
- The **active site** is the small region where the substrate binds. It is made of **only a few amino acids**.
- Interactions between amino acids **all through the folded chain** hold the site in shape and give it the right charges for catalysis.
- **Induced fit**: as the substrate binds, **both substrate and enzyme change shape**. The site closes in and strains the substrate's bonds.

WHAT HAPPENS AT THE ACTIVE SITE

Bind, Bend, Break, Bye

B **Bind**	substrate enters the active site
B **Bend**	both change shape, bonds strained
B **Break**	bonds break and form: products
B **Bye**	products leave, enzyme free

C1.1.1

Enzymes as *catalysts*

- A catalyst **speeds up a reaction without being used up**, so one enzyme works again and again.
- Many cell reactions are possible but **far too slow** at body temperature. Heating would denature the cell's proteins.
- **Speed matters** for digestion, growth and fast responses.

5 million years for half the bonds in starch to break in water alone

1 ms about, for each bond, with amylase

C1.1.2, C1.1.3

Metabolism: build and break

- **Metabolism**: the web of linked reactions in an organism. The product of one is the substrate of the next.
- Enzymes are **specific**, so a cell needs **many different enzymes**, and it controls metabolism through them.

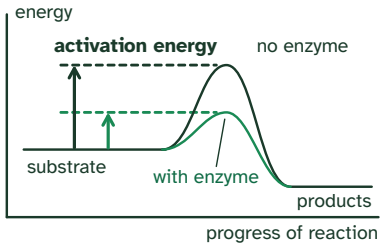
Anabolic *Add*: builds, takes in energy
Condensation of monomers: **protein synthesis**, **glycogen formation**. Also **photosynthesis**.

Catabolic *Cut*: breaks, releases energy
Hydrolysis of macromolecules in digestion; **oxidation** of substrates in respiration.

C1.1.10

A lower *activation energy*

- **Breaking bonds** in the substrate **takes in energy**; **making bonds** in the products **releases energy**.
- An enzyme **lowers the activation energy**, so many more molecules react at 37 °C. The energy released overall does not change.

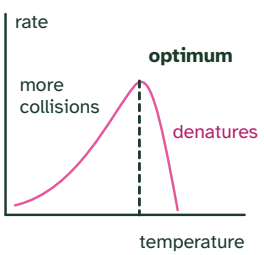


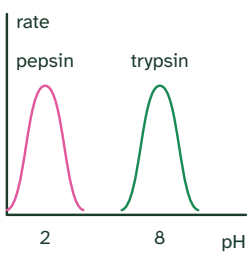
C1.1.6, C1.1.8

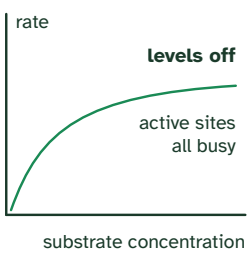
Collisions, and the *three graphs*

- Random **molecular motion** brings substrate and active site together. They react only after a **collision**, the right way round.
- **One partner can be still:** an enzyme **embedded in a membrane**, or a **large substrate held still**.
- **Temperature: more collisions** up to the optimum, then **denaturation**: a steep fall.
- **pH:** each enzyme has **its own optimum**. **Substrate:** the rate **levels off**.

NATURE OF SCIENCE
Sketch graphs are models
They show the general pattern, and are tested against results from enzyme experiments.







T **Tigers**	Temperature: collisions, then denaturation
P **Prefer**	pH: charges in the active site
S **Steak**	Substrate: collisions, then saturation

Measuring enzymes, and how cells *control* them

C1.1.7

A good fit, or *denatured*

- The site's shape and charges fit its substrate: **enzyme-substrate specificity**. **Weak interactions** hold that shape.
- Heat or extreme pH break them, so the **active site changes shape** and stops working: **denaturation**.

C1.1.9

Measuring a rate

- Rate: a **change per unit time** (catalase: O_2 in a gas syringe), from experiments or **secondary data**.
- **Initial rate:** the **gradient of a tangent** at time zero. **End point: rate = 1 ÷ time**.

C1.1.12 HIGHER LEVEL

Metabolism makes *heat*

- No transfer is **100% efficient** (about a third of glucose's energy reaches ATP), so **heat is inevitable**.
- **Mammals and birds** use it to keep a **constant body temperature**; a bumblebee shivers to warm up.

C1.1.11, C1.1.13 HIGHER LEVEL

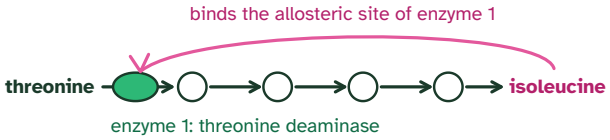
Inside or out, *chain* or cycle

PATHWAY	WHERE	KIND
Glycolysis glucose to pyruvate	**Intracellular:** cytoplasm	**Linear**
Krebs cycle	**Intracellular:** mitochondrial matrix	**Cyclical**
Calvin cycle	**Intracellular:** chloroplast	**Cyclical**
Digestion	**Extracellular:** gut, by secreted enzymes	Hydrolysis

C1.1.16 HIGHER LEVEL

Feedback inhibition

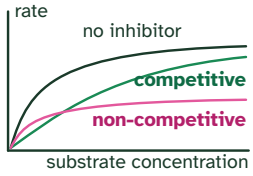
- The **end product** of a pathway inhibits **the first enzyme** at its allosteric site.
- More product slows the pathway; using it up speeds it again, so **production matches use**.



C1.1.14, C1.1.15, C1.1.17 HIGHER LEVEL

Three ways to *stop* an enzyme

	COMPETITIVE	NON-COMPETITIVE	MECHANISM-BASED
Binds	The **active site**: a substrate look-alike. Reversible.	An **allosteric site**: a **conformational change** alters the active site, reversibly.	The active site, by a **covalent bond**. **Irreversible**.
Add substrate	**Rate climbs back** to the same maximum	The **lower maximum** stays	No help: the site stays blocked
Example	**Statins** on HMG-CoA reductase: less cholesterol	Isoleucine on its first enzyme (below)	**Penicillin** on transpeptidase, which cross-links walls



Penicillin: without cross-links a bacterial wall is weak and the cell bursts. **Resistance:** a changed transpeptidase binds penicillin poorly but still cross-links.

WATCH OUT

Five mistakes that *cost marks*

- ✕ **Enzymes are not used up.** The substrate changes; the enzyme comes out as it went in.
- ✕ **Heat denatures; it does not kill.** Cold does not denature: it only slows collisions.
- ✕ **A level curve is not "substrate used up".** The active sites are all busy.
- ✕ **An enzyme does not give energy.** It only lowers the activation energy.
- ✕ **A non-competitive inhibitor never touches the active site.** More substrate cannot undo it.

COVER THE SHEET

Can you *answer these?*

1. Explain how enzymes benefit a cell by lowering activation energy.
2. Distinguish anabolic from catabolic reactions.
3. Describe induced-fit binding, and how denaturation stops it.
4. Explain the shapes of the temperature and substrate graphs.
5. Outline how to find an initial rate from a graph.
6. Compare glycolysis and the Krebs cycle. HL
7. Explain why metabolism generates heat. HL
8. Distinguish competitive from non-competitive inhibition. HL
9. Explain how isoleucine controls its own production. HL
10. Explain how penicillin kills bacteria. HL

IN THE EXAM

Explain a graph with two ideas: collisions for the rise, **denaturation** for the fall. Quote numbers from its axes.

GO FURTHER

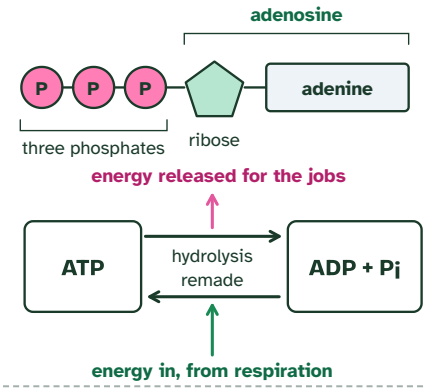
Animated figures, a dry lab and a marked Check are in the full guide online.

How cells make *ATP*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Cells release energy from carbon compounds step by step, and use it to make ATP: the one molecule every job spends.



Draw it like this. Phosphate circles, a ribose pentagon, an adenine rectangle.

C1.2.1 to 3 START HERE

ATP, the cell's *energy currency*

- **Adenosine triphosphate** is a **nucleotide** (adenine, ribose, phosphate) with two more phosphates in a chain.
- **Why it suits:** soluble, so it moves freely; **stable** until an enzyme acts; releases a **modest amount** of energy, enough for one step of a job; remade quickly.
- **Spending it:** **hydrolysis** of ATP to **ADP and phosphate** releases energy. Remaking ATP from ADP and phosphate **needs energy**, from respiration.

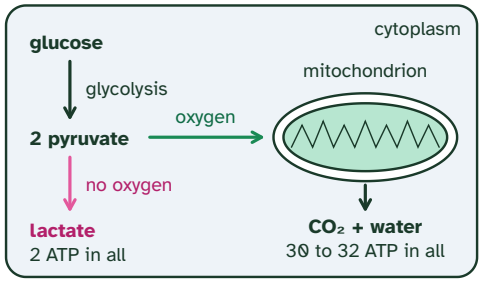
WHAT ATP PAYS FOR — *BAM*

- **B** **Building** macromolecules (anabolism)
- **A** **Active transport** pumping against the gradient
- **M** **Movement** of the cell, or of chromosomes

C1.2.4

A system for making *ATP*

- Respiration uses energy from **carbon compounds** to make ATP, in every cell, all the time.
- **Not burning:** energy is released **step by step**, each step with its own enzyme.
- **Substrates:** mainly **glucose and fatty acids**, but a wide range of carbon compounds can be used.
- **Not gas exchange:** that is gases **diffusing across a surface**, with no reaction and no energy released.



C1.2.5 HUMANS

With oxygen and *without*

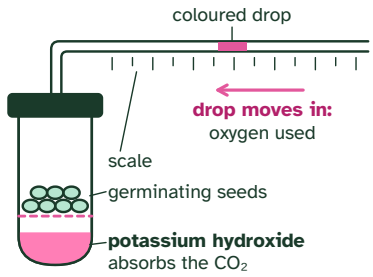
	AEROBIC	ANAEROBIC
Substrates	Glucose, fatty acids, others	Glucose only
Oxygen	**Needed**	**Not needed**
ATP yield	**About 30 to 32**	**2 per glucose**
Waste	Carbon dioxide and water	**Lactate**; no CO_2
Where	Cytoplasm, then **mitochondria**	Cytoplasm: **no mitochondria**
Equation	glucose + oxygen → carbon dioxide + water	glucose → lactate

ANAEROBIC IN HUMANS IS — *LOW*

- **L** **Lactate** the waste product
- **O** **Only 2 ATP** per glucose
- **W** **Without oxygen** in the cytoplasm

C1.2.6 SKILLS

Measuring the *rate*



- Measure **oxygen taken up**, CO_2 given out or fuel used, **per gram per minute**.
- KOH absorbs the CO_2, so the drop moves **towards** the seeds as they use O_2.
- **Control:** glass beads for seeds; take its drop's movement off.
- **Variables:** temperature, germination stage, seed mass and kind.

STEP 1 **Read** Both drops, start and end.

STEP 2 **Correct** Take off the control.

STEP 3 **Volume** πr^2 × distance.

STEP 4 **Rate** ÷ time ÷ mass.

C1.2.7 HIGHER LEVEL

Redox and NAD

- **Oxidation** is loss of electrons, **reduction** is gain; they happen together, as **redox**.
- A hydrogen atom is a proton and an electron, so removing hydrogen (**dehydrogenation**) **oxidises** the substrate.
- **NAD accepts the hydrogen** and is reduced: reduced NAD carries it, and its energy, to the electron transport chain.

REMEMBER — *OIL RIG*

- **O** **Oxidation** Is Loss of electrons
- **R** **Reduction** Is Gain of electrons

Inside respiration, *step by step*

C1.2.8 HIGHER LEVEL

Glycolysis: glucose to pyruvate

- In the **cytoplasm**, no oxygen: glucose becomes **two pyruvate** in about ten steps, **each catalysed by a different enzyme**. Net: **2 ATP and 2 reduced NAD**.

PENGUINS	LOVE	ORANGE	ANCHOVIES
Phosphorylation 2 ATP spent; sugar made reactive.	**Lysis** 6C split into two 3C.	**Oxidation** Hydrogen to NAD.	**ATP formation** 4 ATP made.

C1.2.9 and 10 HIGHER LEVEL

Giving *NAD* back

- Without oxygen, **pyruvate takes the hydrogen** from reduced NAD, **regenerating NAD**: glycolysis goes on.

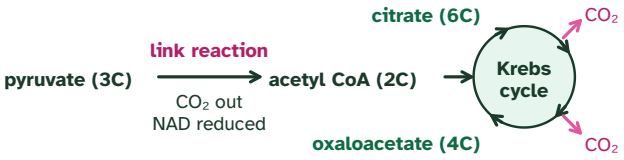
Human muscle pyruvate → lactate
Net 2 ATP. Same route as yeast; only the **last step** differs.

Yeast pyruvate → ethanol + CO_2
Baking: CO_2 raises dough. **Brewing:** ethanol is kept.

C1.2.11 and 12 HIGHER LEVEL

Link reaction and *Krebs cycle*

- **Link:** in the matrix, pyruvate is **decarboxylated and oxidised**; coenzyme A carries the **acetyl group** on, as it does from fats.
- **Krebs:** acetyl + oxaloacetate → **citrate**; **four oxidations** (dehydrogenations) and **two decarboxylations** remake oxaloacetate. A turn gives 3 reduced NAD, 1 reduced FAD, 1 ATP.



C1.2.17 HIGHER LEVEL

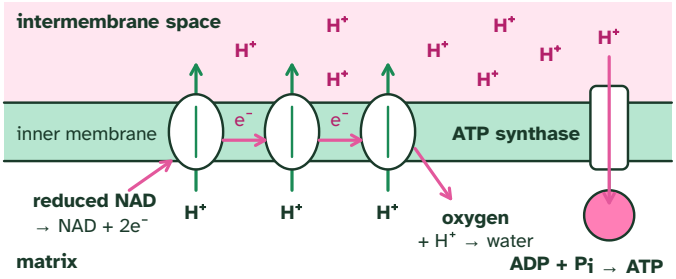
Lipid or *carbohydrate*?

	LIPID	CARBOHYDRATE
Per gram	**About 37 kJ**	**About 17 kJ**
Why	**Less O**, more H and C to oxidise	Half its mass is oxygen
Route in	As **acetyl CoA** (2C)	Through **glycolysis**
No oxygen	Cannot be used	Can be used

- Only **glycolysis works without oxygen**, and fatty acids skip it: a sprint runs on carbohydrate.

C1.2.13 to 16 HIGHER LEVEL

The chain, the gradient and *ATP synthase*



- Reduced NAD from glycolysis, the link and Krebs **gives a pair of electrons** to the first carrier, and becomes NAD again.
- Electrons pass along the carriers; the energy released **pumps protons** into the intermembrane space: a **proton gradient**.
- **Chemiosmosis:** protons flow back through **ATP synthase**, which couples their energy to **phosphorylating ADP**.
- **Oxygen**, the **terminal electron acceptor**, takes electrons and protons, making **water**, so electrons keep flowing.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **ATP is not an energy store.** It is spent and remade constantly.
- ✕ **Energy is not stored in the bond.** Breaking any bond takes energy.
- ✕ **Respiration is not gas exchange.** It is chemistry inside cells; gas exchange is diffusion.
- ✕ **Humans make lactate; yeast make ethanol and CO_2.** Never the other way round.
- ✕ **The chain makes a proton gradient, not ATP.** ATP synthase makes ATP, and it is not a pump.
- ✕ **Oxygen ends up in water.** The CO_2 comes from the fuel's carbon.

COVER THE SHEET

Can you *answer these?*

1. Explain two properties that suit ATP as energy currency.
2. Distinguish respiration from gas exchange.
3. Compare aerobic and anaerobic respiration in humans.
4. Calculate a rate: 24 mm in 10 min, 1 mm bore, 2 g.
5. Explain why dehydrogenation is oxidation. HL
6. Outline the four stages of glycolysis. HL
7. Explain how yeast make dough rise. HL
8. Outline what happens to pyruvate in the matrix. HL
9. Explain how chemiosmosis makes ATP. HL
10. Explain why fat yields more energy per gram. HL

IN THE EXAM

Name the place and the carrier ("in the matrix, NAD is reduced"). Lactate and ethanol only **give NAD back**.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY | C1.3 | SL AND HL

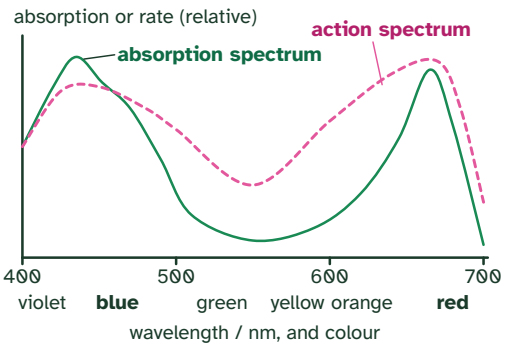
REVISION ON TWO PAGES

Light into *sugar*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Photosynthesis turns light energy into chemical energy, splitting water for hydrogen to fix carbon dioxide into sugar.



Draw it like this. Wavelengths and colours on the axis, red to violet: *Richard Of York Gave Battle In Vain*

C1.3.5, C1.3.6 START HERE

Absorbed light and *used* light

- A pigment absorbs a wavelength only if the photon's energy **matches a jump an electron can make**. The **excited electron**'s energy becomes chemical energy.
- Chlorophyll absorbs **blue and red** and little green. **Green is reflected**, so leaves look green.
- **Absorption spectrum:** how much of each wavelength the pigments absorb. **Action spectrum:** the **rate of photosynthesis** at each wavelength.
- **Alike:** both peak in blue and red. **Unlike:** the action spectrum's green dip is shallower and its blue peak lower.
- **Skill:** rate = O_2 produced (or CO_2 consumed) ÷ time, for each wavelength. Plot rate against wavelength: that is the action spectrum.

C1.3.1 to 3

Light energy into *carbon compounds*

- Photosynthesis **transforms light energy into chemical energy** in carbon compounds: most of the chemical energy in ecosystems.
- **Carbon dioxide is converted to glucose** using hydrogen from **splitting water**.
- **Oxygen is a by-product** in plants, algae and cyanobacteria. It **comes from the water**, not from CO_2.

Word equation learn it

carbon dioxide + water → **glucose** + oxygen, with light energy and chlorophyll over the arrow.

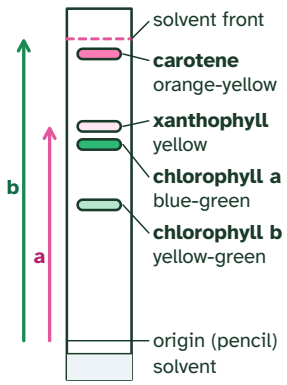
Where the atoms go

Glucose's carbon and oxygen come from CO_2, its hydrogen from water. The O_2 gas comes from water.

C1.3.4 SKILL

Separating pigments by *chromatography*

- Leaf extract is spotted on a pencil origin. The solvent climbs paper or a thin-layer plate and carries each pigment **at its own speed**.
- **R*f* = distance moved by pigment ÷ distance moved by solvent front**, both from the origin; to the middle of the band.
- **Identify by colour and R*f***, against a table made with the same solvent. R*f* is always below 1.



R*f* = **a** ÷ **b**. Values change with the solvent

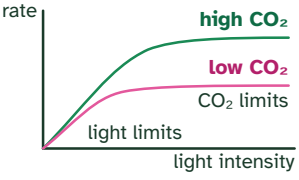
C1.3.7 SKILL

Limiting factors

- The **limiting factor** is the one in shortest supply. Raise it and the rate rises, **until another factor limits**.
- **Vary one:** move a lamp, add sodium hydrogencarbonate, use a water bath. Count oxygen bubbles or time leaf discs to float.
- **Hypotheses** are provisional and need repeated testing. Name the **independent and dependent variables**.

Lazy Cats Toast

L Light splits water	**C** CO_2 carbon to fix	**T** Temp. enzymes



C1.3.8

CO_2 *enrichment* experiments

- Plants in the **CO_2 expected later this century**, beside plants in today's air, **predict future photosynthesis** and growth.

Enclosed greenhouse more control

CO_2 from a cylinder; temperature, light, water and nutrients **controlled**. A controlled variable: temperature.

FACE free-air CO_2 enrichment

Rings of pipes in a field or forest keep **real soil, weather and competition**. A controlled variable: crop variety.

Inside the chloroplast: *thylakoid* and Calvin cycle

C1.3.9, C1.3.10 HIGHER LEVEL

Photosystems: pigments in an *array*

- An **array of chlorophyll and accessory pigments**, **always in a membrane**: in chloroplast thylakoids and in cyanobacteria.
- Pigments pass **energy** to the **reaction centre**, a special chlorophyll that **emits an excited electron**.
- **Why an array:** one pigment alone could do no part of photosynthesis. Many catch more light and wavelengths, and pass energy on before it is lost.

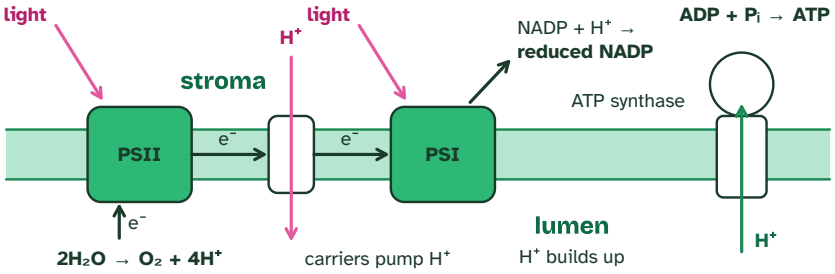
C1.3.19 HIGHER LEVEL

The two halves *need each other*

- The thylakoids make **ATP and reduced NADP**; the Calvin cycle spends them and hands back ADP, phosphate and NADP.
- **No light:** no ATP or reduced NADP is made, so **the Calvin cycle stops** seconds later.
- **No CO_2:** NADP is not handed back, so PSI fills, the chain backs up and **photosystem II stops**.

C1.3.11 to 14 HIGHER LEVEL

The thylakoid: a system for the *light-dependent* reactions



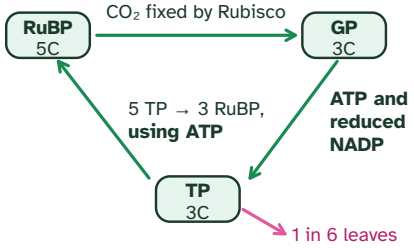
Photolysis: *Please Eat Oranges*. **P**rotons to the lumen, **E**lectrons to PSII, **O**xygen out.

- **Photolysis:** **photosystem II** refills with electrons from water. **Oxygen is waste**; from about 2.4 billion years ago it built up in the air, with immense effects on life and rocks.
- **Chemiosmosis:** the chain of carriers **pumps protons** into the lumen; they flow back through **ATP synthase**, making ATP.
- **NADP** takes **two electrons from photosystem I** and a proton from the stroma: reduced NADP.
- **Non-cyclic:** electrons from PSII to PSI to NADP. **Cyclic:** from PSI round the chain again, ATP only.

C1.3.15 to 18 HIGHER LEVEL

The Calvin cycle: *fix*, reduce, regenerate

- **Fix:** **Rubisco** joins CO_2 to **RuBP**, giving two **glycerate 3-phosphate (GP)**. It is slow and poor at low CO_2, so the stroma holds a lot: the **most abundant enzyme on Earth**.
- **Reduce:** **reduced NADP and ATP** turn GP into **triose phosphate (TP)**.
- **Regenerate:** **five TP make three RuBP**, using ATP. For glucose, five-sixths of all TP is recycled.
- **Products:** **all carbon** in the organism was fixed here. Sugars, lipids, amino acids and nucleotides come by pathways **traced back to the cycle**, adding nitrate and phosphate.



Fresh Rolls Rise: **F**ix, **R**educe, **R**egenerate.

WATCH OUT

Five mistakes that *cost marks*

- ✕ **The oxygen comes from water, not CO_2.** CO_2's oxygen ends up in glucose and water.
- ✕ **A limiting factor does not stop photosynthesis.** It is the one in shortest supply.
- ✕ **An action spectrum is a rate, not absorption.** It shows what the plant does with each colour.
- ✕ **Photosystem II splits water; photosystem I reduces NADP.** Electrons pass through II first.
- ✕ **"Light-independent" is not "in the dark".** The Calvin cycle needs ATP and reduced NADP.

COVER THE SHEET

Can you *answer these?*

1. State the word equation for photosynthesis.
2. Outline how to find a pigment's R*f*.
3. Compare absorption and action spectra.
4. Describe how to vary light intensity in an experiment.
5. Distinguish greenhouse and FACE experiments.
6. Explain the advantage of a pigment array. HL
7. Explain how a thylakoid makes ATP. HL
8. Outline the three stages of the Calvin cycle. HL
9. State where all of a plant's carbon was fixed. HL
10. Explain why lack of CO_2 stops photosystem II. HL

IN THE EXAM

Pair the terms consistently: "NADP and reduced NADP" or "$NADP^+$ and NADPH", never mixed. And **say where**: thylakoid membrane, lumen or stroma.

GO FURTHER

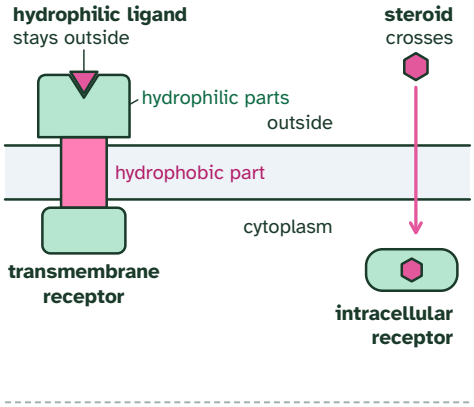
Animated figures, a dry lab and a marked Check are in the full guide online.

How cells read *signals*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

A ligand binds a receptor that fits it, and the receptor sets off a response inside the cell. Only target cells respond.



Draw it like this. The ligand fits a site on the receptor; only a steroid gets inside.

C2.1.1 and 6 START HERE

A *ligand* and its receptor

- A receptor is a **protein with a binding site** whose shape and charge fit one signalling chemical: the **ligand**.
- Binding changes the receptor's shape and starts a response. Only **target cells**, with the right receptor, respond.
- **Hydrophilic ligand** (a peptide, adrenaline): cannot cross the bilayer, so it binds a **transmembrane receptor**, with **hydrophobic amino acids** in the bilayer and hydrophilic ones either side.
- **Hydrophobic ligand** (a steroid): diffuses through the bilayer and binds an **intracellular receptor** in the cytoplasm or nucleus.

FOUR RECEPTOR TYPES, ONE EXAMPLE EACH

C Ion channel acetylcholine	**G** G protein adrenaline	**T** Tyrosine kinase insulin	**I** Intracellular steroid hormones

C2.1.3 and 5 FUNCTIONAL CATEGORIES IN ANIMALS

Four kinds of *signal*, near and far

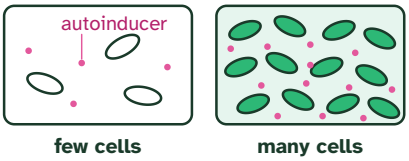
CATEGORY	RELEASED BY	HOW IT TRAVELS	RANGE AND TIMING
Hormone	An endocrine gland.	In the **blood**, to target cells anywhere in the body.	**Distant.** Slow, and often lasts hours or longer.
Neurotransmitter	A neuron.	**Diffuses** across a synaptic gap, about 20 nm wide.	**Local.** Acts in milliseconds; quickly removed.
Cytokine	Immune and other cells.	To nearby cells, sometimes distant ones.	**Mostly local.** Changes cell behaviour to coordinate a defence.
Calcium ions	Stores inside a cell.	Into the cytoplasm.	**Inside cells.** A signal within and between cells.

The four differ in where they are made, how far they go and how long they last.

C2.1.2 SIGNALS IN BACTERIA

Bacteria that *count*

- **Quorum sensing:** each bacterium releases an **autoinducer**; the more cells, the higher its concentration.
- At a **threshold concentration** it binds receptors in the bacteria and switches genes on.
- *Vibrio fischeri*, packed in a squid's light organ, switches on genes for **luciferase**: **bioluminescence**.



few cells
below threshold:
dark

many cells
above threshold:
luciferase on, glow

C2.1.4

Many kinds of *chemical*

- Each chemical has **its own receptor**, so thousands of signals work at once without confusion.
- A **steroid** crosses membranes and lasts; a **peptide** waits in vesicles, ready to release.

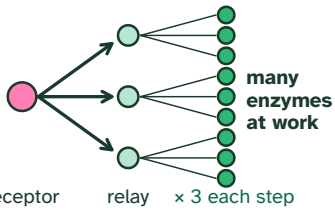
Hormones three groups
Amines (adrenaline, thyroxin), **proteins** (insulin, ADH), **steroids** (oestradiol, testosterone).

Neurotransmitters four kinds
Amino acids (glutamate, GABA), **peptides** (endorphins), **amines** (dopamine, serotonin), the gas **nitric oxide**.

C2.1.7

A *chain* of events

- Binding **switches the receptor on**; the ligand need not enter the cell.
- This starts a **signal transduction pathway**: each molecule activates the next, until the cell responds.
- Each step activates many of the next, so the **signal is amplified**.

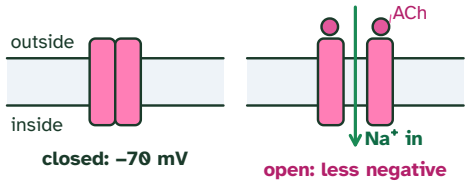


Four receptors at *work*, and feedback

C2.1.8

A receptor that is a *gate*

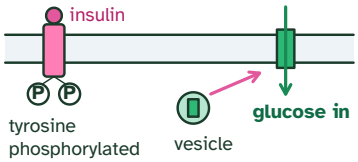
- The **acetylcholine receptor** is itself an **ion channel**: no pathway is needed.
- Acetylcholine binds, the receptor changes shape and the channel opens.
- **Positive ions**, mostly sodium, diffuse in. The inside becomes less negative (**depolarises**), which may trigger an action potential.



C2.1.11

Insulin: a *tyrosine kinase*

- Insulin, a protein, binds a receptor in the membrane; its inside part **phosphorylates tyrosine**.
- A **sequence of reactions** moves **vesicles of glucose transporters** to the membrane: more glucose enters.



C2.1.14

Feedback: *down* or up

- The **result of a pathway acts back on it**, so a cell does not keep on responding.

Negative opposes the change
Keeps a variable steady. Insulin lowers blood glucose; as glucose falls, beta cells release less insulin.

Positive amplifies the change
Oxytocin makes the uterus contract, causing more oxytocin. It needs an end: here, the birth.

C2.1.9 and 10

G proteins and adrenaline

- Humans have **hundreds** of **G protein-coupled receptors**, for hormones, neurotransmitters, light and smells.
- A G protein is off holding GDP. The ligand-bound receptor makes it **swap GDP for GTP**: on.
- **Adrenaline** on a liver cell: **cAMP is the second messenger**, and each step amplifies.
- **Two names:** adrenaline and epinephrine both mean "on the kidney". Shared names let scientists everywhere share findings.

THE ADRENALINE PATHWAY, IN ORDER

RGACK: rack up the glucose

R Receptor adrenaline binds	**G** G protein GDP out, GTP in	**A** Adenylyl cyclase switched on	**C** cAMP made from ATP	**K** Kinases glycogen to glucose

C2.1.12 and 13

Steroids switch on *genes*

- **Oestradiol, progesterone, testosterone** cross the membrane and bind a site on an intracellular receptor, **activating it**.
- The active receptor **binds specific DNA sequences** and **promotes transcription**.

OESTRADIOL
GnRH cells, hypothalamus
Low levels early in the cycle reduce GnRH release; high levels for long enough raise it, so LH surges.

PROGESTERONE
Endometrium
Switches on genes that thicken the lining, with more glands and blood vessels, ready for implantation.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **The gas is nitric oxide, NO.** N_2O is laughing gas.
- ✕ **A transmembrane receptor's ligand stays outside.** The receptor, not the ligand, switches on the G protein.
- ✕ **cAMP is the second messenger.** Adrenaline is the first.
- ✕ **Insulin does not carry glucose.** It brings more transporters to the membrane.
- ✕ **No receptor, no response.** Progesterone enters every cell, but only target cells respond.
- ✕ **Positive feedback is not "good" feedback.** It amplifies a change, so it needs an end.

COVER THE SHEET

Can you *answer these?*

1. State what is meant by a ligand.
2. Outline quorum sensing in *Vibrio fischeri*.
3. Distinguish between hormones and neurotransmitters.
4. State an amine, a protein and a steroid hormone.
5. Explain why a steroid binds an intracellular receptor.
6. Describe how acetylcholine changes membrane potential.
7. Outline how adrenaline acts on a liver cell.
8. Explain how insulin increases glucose uptake.
9. Describe the effect of progesterone on its target cells.
10. Distinguish positive from negative feedback.

IN THE EXAM

Write the adrenaline chain in order; each link can earn a mark: receptor, G protein, adenylyl cyclase, **cAMP (second messenger)**, kinases, glycogen to glucose.

GO FURTHER

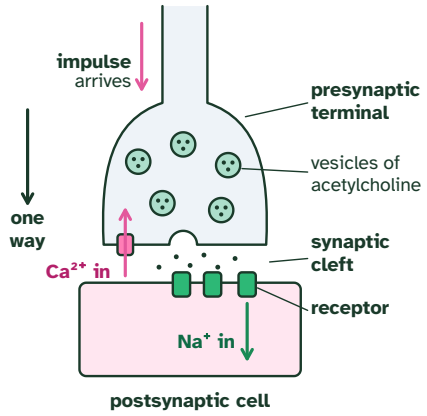
Animated figures, a dry lab and a marked Check are in the full guide online.

THE ONE IDEA

Pumps build ion gradients and channels let ions rush down them. An impulse is that rush; a synapse passes it on as a chemical.

How neurons *signal*

What to know, what to draw and what to say. Nothing else.



Draw it like this. Vesicles above, receptors below, the cleft between; arrows for Ca^{2+} in and Na^{+} in.

C2.2.5 to 7 START HERE

A *synapse* passes it on as a chemical

- A synapse joins a neuron to another neuron or to an **effector cell**, a muscle fibre or gland. A **synaptic cleft** about 20 nm wide keeps them apart.
- Vesicles are in the presynaptic terminal and receptors on the postsynaptic membrane, so the signal crosses **one way only**.
- An impulse depolarises the terminal, **calcium channels open** and Ca^{2+} diffuses in. Inside, calcium is the signal that makes vesicles fuse and release their neurotransmitter.
- Acetylcholine, at every neuromuscular junction and many other synapses, diffuses across and binds **transmembrane receptors**. Na^{+} flows in: an **excitatory postsynaptic potential** (EPSP).

ACROSS A SYNAPSE, IN ORDER — *All Cats Very Rarely Bark*

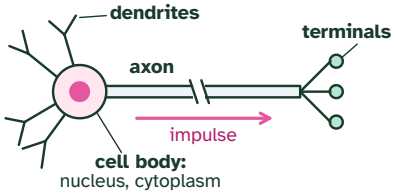
ALL	CATS	VERY	RARELY	BARK
Action potential arrives at the terminal.	**Calcium** channels open, Ca^{2+} in.	**Vesicles** fuse and release.	**Receptors** bind it, Na^{+} in.	**Breakdown** an enzyme clears it.

C2.2.1

One cell, long *fibres*

- The **cell body** holds the nucleus and cytoplasm; nerve fibres of varying length run from it.
- **Dendrites:** many short fibres that receive signals.
- **Axon: one long fibre**, up to a metre, carrying impulses away. Impulses are conducted along the fibres.

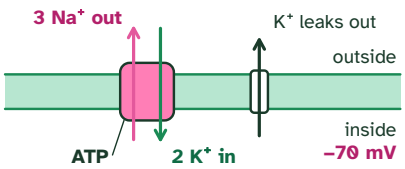
A nerve is a bundle of fibres from many neurons; a neuron is one cell.



C2.2.2

The *resting* potential

- The **sodium-potassium pump** uses ATP to move **3 Na^{+} out and 2 K^{+} in**, both against their gradients.
- Na^{+} is left high outside, K^{+} high inside. The voltage across is a **membrane potential**: the membrane is polarised.
- The inside is **negative, about −70 mV**: K^{+} leaks out more easily than Na^{+} leaks in, and large negative molecules cannot leave.



C2.2.3

An impulse is an *action potential*

- For about a millisecond a stretch of membrane **reverses its voltage**, the inside turning positive, then flips back.
- Each stretch sets off the next, so the impulse is **propagated** along the fibre without fading.
- It is electrical because **positively charged ions** move across the membrane. No electrons flow along it, as in a wire.

1 ms	Na^{+}, K^{+}
one impulse lasts	cross in an impulse

C2.2.4 SKILLS: CORRELATION

Why some impulses are *faster*

FIBRE	WIDTH	SPEED
Small, unmyelinated	about 1 µm	**about 1 m/s**
Squid giant axon unmyelinated	up to 1 mm	**20 to 25 m/s**
Mammal, myelinated	about 10 µm	**50 to 60 m/s**

Myelin wins in a fibre 100 times thinner.

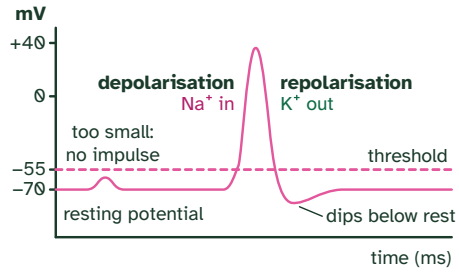
Faster if *Wide* or *Wrapped*

- Speed is **positively correlated** with axon diameter, and **negatively** with animal size.
- **r** runs from −1 to +1: its sign is the direction, its size the strength. Near 0, no straight-line link.
- **R^2** is the share of the variation in speed that goes with diameter: r = 0.9 gives **R^2 = 0.81**, or 81%.
- A correlation **does not show cause**: that needs a mechanism or an experiment.

Inside the *action potential*, and how synapses decide

C2.2.8 and 10 HIGHER LEVEL

One *action potential*, read off a trace



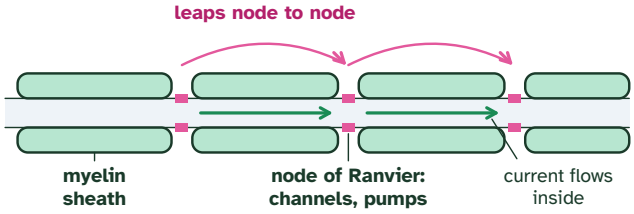
- At the **threshold potential**, about −55 mV, **voltage-gated Na⁺ channels** open. Below it, nothing.
- **Depolarisation:** Na⁺ diffuses in and the inside reaches about +30 to +40 mV.
- **Repolarisation:** Na⁺ channels shut, **voltage-gated K⁺ channels** open and K⁺ diffuses out; they close slowly, so it dips below rest.
- **A trace** is voltage against time at one place. **Impulses per second** = spikes ÷ seconds: 12 in 3 s is 4 a second.

In order: *Tickle Salty Pickles Dance* (threshold, sodium in, potassium out, dip).

C2.2.9 and 11 HIGHER LEVEL

Passing it *along*

- **Local currents:** Na⁺ **diffuses along inside** the axon while positive ions outside move the other way: the next stretch reaches **threshold**.
- **Myelin** insulates; channels and pumps are **clustered at nodes of Ranvier**. The impulse leaps node to node: **saltatory conduction**, faster and using less ATP.



C2.2.12 HIGHER LEVEL

Chemicals from *outside*

- An **exogenous chemical** changes a synapse by fitting one of its proteins.

Neonicotinoids a pesticide
Bind insect acetylcholine receptors and are not broken down, so **synaptic transmission is blocked**.

Cocaine a drug
Binds the carrier that takes dopamine back into the presynaptic neuron: it **blocks reuptake**, so dopamine builds up.

One silences a synapse; the other turns it up.

C2.2.13 and 14 HIGHER LEVEL

Inhibition and summation

- An inhibitory neurotransmitter lets Cl^- in or K^+ out: the membrane is **hyperpolarised** (an IPSP).
- EPSPs and IPSPs from many neurons add up (**summation**), with an **all or nothing** result: a full impulse or none.

C2.2.15 HIGHER LEVEL

Pain at *free* nerve endings

- Free nerve endings in the skin have **channels for positive ions** that open to heat, acid or **capsaicin** in chilli.
- Positive ions enter; at threshold, impulses pass to the **brain**, where pain is perceived.

C2.2.16 HIGHER LEVEL

Consciousness emerges

- Each neuron only adds its inputs and fires or does not.
- Consciousness is an **emergent property**: it arises from neurons **interacting**, not from any one of them.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **The pump does not make the impulse.** Channels do, Na⁺ in then K⁺ out; the pump keeps the gradients.
- ✕ **Ions through channels diffuse.** No ATP is used: never write "Na⁺ is pumped in".
- ✕ **A stronger stimulus gives more impulses, not bigger ones.** Every impulse is the same size.
- ✕ **The impulse does not jump the cleft.** A chemical crosses; calcium only triggers its release.
- ✕ **Acetylcholine is not taken back whole.** It is broken down in the cleft; only the choline returns.
- ✕ **Hyperpolarised means more negative than rest.** It is not a large depolarisation.

COVER THE SHEET

Can you *answer these?*

1. Draw and label a neuron.
2. Explain how the resting potential is generated.
3. State why a nerve impulse is electrical.
4. Compare squid giant and small unmyelinated axons.
5. Explain how acetylcholine causes an EPSP.
6. Describe an action potential on a trace. HL
7. Explain saltatory conduction. HL
8. Distinguish neonicotinoids from cocaine. HL
9. Explain summation of EPSPs and IPSPs. HL
10. Outline how chilli causes pain. HL
11. Explain why consciousness is emergent. HL

IN THE EXAM

Each long answer is a **sequence**: one step per sentence, and **name the ion and its direction** every time (Na^+ in, K^+ out, Ca^{2+} in).

GO FURTHER

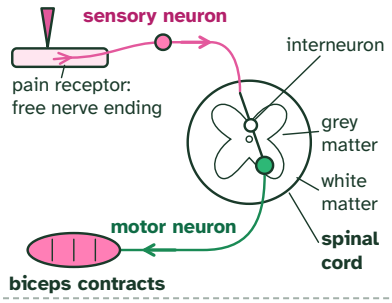
Animated figures, a dry lab and a marked Check are in the full guide online.

How a body works as *one*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Nerves, hormones and blood link an animal's organs, and phytohormones a plant's, so each works as one whole.



Draw it like this. Sensory in, an interneuron in grey matter, motor out.

C3.1.6, 7 and 9 START HERE

The pain *reflex arc*

- **Input: sensory neurons** carry impulses from receptor cells to the CNS: the spinal cord and the cerebral hemispheres.
- **Output: motor neurons** carry impulses from the CNS to muscles, which are **stimulated to contract**. Voluntary movements start in the cerebral hemispheres.
- **Pain reflex:** a free nerve ending in the hand (receptor), sensory neuron, **one interneuron in the grey matter**, motor neuron, biceps (effector).
- It is **involuntary** and completed in the spinal cord, so the hand moves **before** the brain is aware. The effector is a **skeletal muscle**.

C3.1.1 and 2

Many parts, *one animal*

- **Integration**: coordinating a system's parts so they perform an **overall function**.
- **Hierarchy:** cells, tissues, organs, body systems: each a **subsystem** of the next.
- **Emergent property**: one the whole has and none of its parts has.

Cheetah parts
Long legs, flexible spine, big heart and lungs.

Cheetah whole emergent
Top land speed: an **effective predator**.

C3.1.3

Nerves, hormones and *blood*

	NERVOUS	ENDOCRINE
Signal	Impulses along neurons	Hormones from glands, in the blood
Speed	A fraction of a second	Seconds to minutes
Reaches	One muscle or gland	Only cells with its **receptor** respond
Lasts	Usually a moment	Often minutes to days

- **Blood transports materials and energy**: oxygen from lungs to muscles, glucose to the brain, urea to the kidneys, heat to the skin.

C3.1.4 and 10

The brain *integrates*

- **Cerebral hemispheres:** combine inputs from several senses, compare them with memory and **choose a response**.
- They **learn and remember**; each kind of memory depends on its own regions.
- **Cerebellum: coordinates skeletal muscle contraction** and **balance**, but does not start movements.

C3.1.5

Conscious or not

- The spinal cord is an **integrating centre for unconscious processes**, in its grey matter.

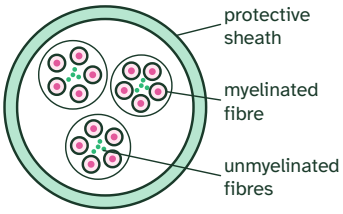
Conscious aware, in control
Speaking: the cerebral hemispheres.

Unconscious no awareness
A reflex, the heartbeat.

C3.1.8

Inside a *nerve*

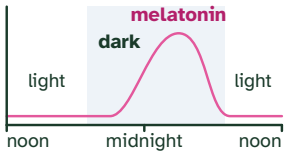
- A nerve is a **bundle of nerve fibres**: the axons of many neurons.
- Most carry **sensory and motor** fibres.



C3.1.11

Melatonin and sleep

- A **circadian rhythm**: a cycle of about 24 hours, kept by a clock in the hypothalamus.
- The **pineal gland** secretes melatonin, **low by day, high at night**, as light on the eyes switches it off. It makes you sleepy: a cycle of sleeping and waking.



C3.1.12

Epinephrine: ready to run

- In danger the **adrenal glands** secrete epinephrine (adrenaline); the blood takes it all over the body.
- A faster, stronger heartbeat; wider airways; glucose from the liver; blood sent to the muscles.
- So **more oxygen and glucose reach the muscles** for **intense contraction**.

Feedback, the gut, and how *plants* signal

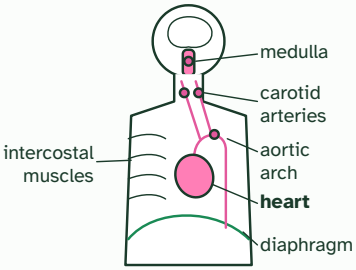
C3.1.14 and 15 THE RESPONSE REVERSES THE CHANGE

Feedback sets heart rate and *breathing*

	HEART RATE *C3.1.14*	VENTILATION RATE *C3.1.15*
Receptors	**Baroreceptors** (aortic arch, carotid arteries) sense stretch: **blood pressure**. **Chemoreceptors** there and in the brainstem: pH, O_2, CO_2.	**Chemoreceptors in the brainstem** monitor **blood pH**. CO_2 forms carbonic acid, releasing H^+: **more CO_2, lower pH**.
Control	The **medulla** sends impulses to the heart.	The **medulla** sends impulses more often.
Response	**Heart rate and stroke volume** change, reversing it.	**Diaphragm and intercostals** work harder: CO_2 out, pH back.

Receptor, control centre, effector: *Rabbits Can Escape*

Both are negative feedback



Pink dots: receptor sites. Arteries: baroreceptors and chemoreceptors. Medulla: chemoreceptors

C3.1.13

The *hypothalamus* in charge

- The hypothalamus **controls the pituitary gland**, whose hormones **control other endocrine glands**.
- **Thyroid:** its hormone raises metabolism; as it rises, both secrete less: **negative feedback**.

C3.1.16

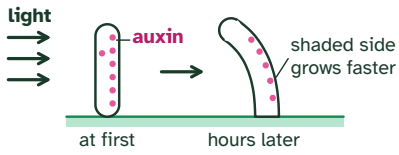
Peristalsis: who is in charge

- Muscle **contracts behind** the food and relaxes in front.
- **Voluntary (CNS):** starting to **swallow**; **egestion** of faeces.
- **Involuntary, between:** the **enteric nervous system** coordinates passage.

C3.1.17 and 18 HIGHER LEVEL

Growing towards *light*

- **Positive phototropism**: growth towards light from one side.
- Drawings are **qualitative**; the **angle of curvature** is quantitative. Photos square-on: accurate. Repeats: reliable.



C3.1.19 to 21 HIGHER LEVEL

Auxin on the move

- **Phytohormones**: **varied** chemical signals for growth, development and responses.
- Auxin diffuses in, not out. **Efflux carriers** on one side **actively transport** it on, concentrating it.
- It makes cells **secrete H^+ into the apoplast**; acid **loosens cellulose cross links**, so cells elongate.

C3.1.22 and 23 HIGHER LEVEL

Roots, shoots, *ripening*

- Shoot tips send **auxin** down (side roots form); root tips send **cytokinin** up (shoot cells divide): **growth is integrated**.
- **Ethylene stimulates ripening**, and ripening makes more ethylene: **positive feedback**.
- So fruit ripen **rapidly and together**, ready for animals that spread seeds.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **A reflex is completed in the spinal cord.** The brain is told afterwards; nothing is decided.
- ✕ **Baroreceptors sense stretch, so pressure.** pH, oxygen and CO_2 are for chemoreceptors.
- ✕ **CO_2, through pH, normally drives breathing.** Low oxygen matters only when it falls far.
- ✕ **A nerve is not a neuron.** It is a bundle of fibres from many neurons.
- ✕ **Light lowers melatonin.** Darkness lets it rise.
- ✕ **The lit side still grows.** The shaded side grows more; nothing pulls the shoot.

COVER THE SHEET

Can you *answer these?*

1. Outline an emergent property, using the cheetah.
2. Distinguish nervous from hormonal signalling.
3. Compare the roles of the cerebrum, cerebellum and spinal cord.
4. Draw a pain reflex arc, and a nerve in transverse section.
5. Explain how melatonin sets a cycle of sleep and waking.
6. Explain how epinephrine prepares the body to run.
7. Outline how the hypothalamus controls the thyroid.
8. Explain how exercise raises heart and ventilation rates.
9. State what controls each stage of moving food along the gut.
10. Explain how auxin bends a shoot, and how to measure it. HL
11. Explain why fruit ripening is rapid and synchronised. HL

IN THE EXAM

Name every part of the loop: the receptor and where it is, the **medulla**, the effector, and that the change is **reversed**.

GO FURTHER

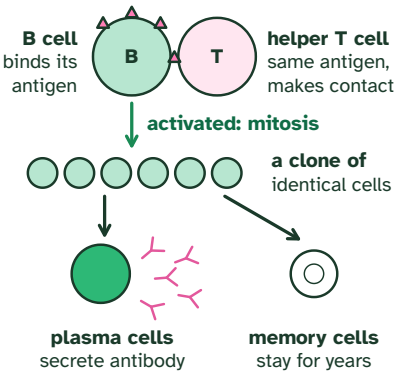
Animated figures, a dry lab and a marked Check are in the full guide online.

How the body *fights* infection

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Barriers keep pathogens out; phagocytes eat what gets in; lymphocytes make specific antibodies and keep memory cells. That memory is immunity.



Draw it like this. Two signals, then mitosis: one clone, two fates.

C3.2.6 to 9 START HERE

One B cell fits: *clonal selection*

- An **antigen** is a recognition molecule, usually a **protein or glycoprotein** on the outside of a pathogen. Lymphocytes recognise it; they circulate in the blood and gather in **lymph nodes**.
- You carry a huge number of B cells, each making **one specific antibody**. Only a few fit any one antigen; the antigen selects them.
- **Activation needs two things:** the B cell binds its antigen, and an **activated helper T cell** for the same antigen makes contact and sends chemical signals.
- The activated B cell divides by **mitosis** into a clone. Most become **plasma cells** secreting that antibody in quantity; some become memory cells.

Red blood cells carry antigens too: transfused blood of another group can trigger antibodies.

CLONAL SELECTION IN FIVE STEPS — *Rude Aliens Might Steal Rockets*

R	**Recognise** receptor fits antigen	**A**	**Activate** helper T contact	**M**	**Multiply** mitosis, a clone	**S**	**Secrete** plasma cells	**R**	**Remember** memory cells

C3.2.1

Pathogens

- A **pathogen** is an organism that causes disease; passed from person to person, it gives an **infectious disease**.
- Usually **viruses, bacteria, fungi and protists**. **Archaea** are not known to cause human disease.
- **Careful observation:** Snow mapped cholera deaths round one London pump (1854); Semmelweis cut childbed fever in Vienna by hand washing.

C3.2.2

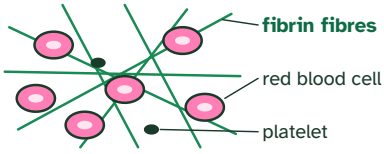
Skin and *mucous membranes*

- **Physical barrier:** tough outer layer of **dead, keratin-filled cells**, with no gaps.
- **Chemical barrier:** sweat and oils make it **acidic**; sweat and tears carry **lysozyme**, which splits bacterial walls.
- **Openings** are lined by **mucous membranes**: sticky mucus traps microbes, and cilia sweep it to the throat.

C3.2.3

Sealing a cut: *clotting*

- **Platelets** stick at the cut and **release clotting factors**, which start a cascade.
- At its end **thrombin** converts soluble **fibrinogen** into insoluble **fibrin** fibres.
- The fibrin mesh **traps red blood cells**: a clot, which dries into a scab.



In order: *Penguins Frequently Catch Minnows* (platelets, factors, cascade, mesh)

C3.2.4

Innate against *adaptive*

Innate born with it

Broad categories of pathogen, the same way every time; **does not change** during life. Its cells: the **phagocytes**.

Adaptive learns

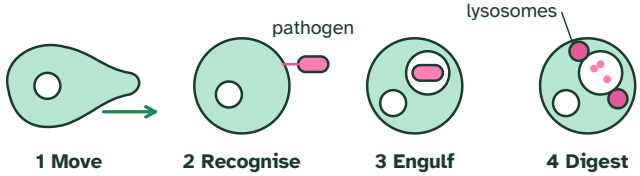
A **specific** response to one pathogen. Builds a **memory**, so each response is more effective. Its cells: the **lymphocytes**.

- **Example:** after chickenpox, a second meeting with the virus years later causes no illness. That is the adaptive system.

C3.2.5

Phagocytes eat what gets in

- Phagocytes leave the blood at an infection and move to it by **amoeboid movement**.
- Receptors **recognise** the pathogen; it is **engulfed by endocytosis** into a vesicle, and lysosomes fuse with it: their **enzymes digest** it.



Remember the four: *My Rhino Eats Dinner*

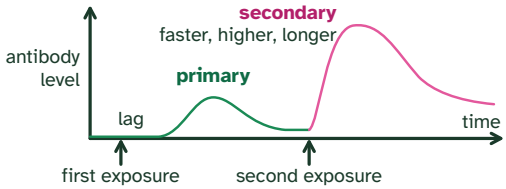
54

Immunity, *drugs* and disease in populations

C3.2.10, C3.2.16

Memory cells and vaccines

- **Immunity** is the ability to eliminate an infectious disease. It comes from **memory cells**: long-lived lymphocytes that can make the specific antibody.
- Meet it again: memory cells respond at once, with more antibody, faster.
- A **vaccine** contains **antigens**, or **DNA or RNA coding for an antigen**, so it gives immunity **without causing the disease**.
- **Example:** mRNA COVID-19 vaccines code for the spike protein.



C3.2.11, C3.2.12

HIV and AIDS

- HIV passes in **body fluids**: blood (shared needles), unprotected sex, mother to baby (birth, breast milk); never by touch.
- It infects and kills **helper T cells**, so **B cells cannot be activated** and fewer antibodies are made.
- Then **AIDS**: death from **opportunistic infections**, not HIV itself.

C3.2.17

Herd immunity

- Enough people immune: **transmission is greatly impeded**.
- It shields those who **cannot be vaccinated**: we **depend on each other**.
- About $1 - 1/R_0$ must be immune: **95%** for measles, R_0 12 to 18.
- **Nature of science:** side effects are minimal, not nil; media report work still under evaluation.

C3.2.18 SKILLS

Reading *COVID-19* data

PERCENTAGE	WORK IT OUT
change	(new – old) ÷ old × 100 40 → 160: **+300%**
difference	difference ÷ mean × 100 18 and 2: **160%**

- **Correlation is not causation**. Check what is counted, how many, over what time.

C3.2.13, C3.2.14

Antibiotics and resistance

	BACTERIUM	HUMAN CELL
Wall	Penicillin blocks its building	None
Ribosome	70S: tetracyclines block it	80S, not hit

No wall or ribosomes of its own: antibiotics **fail against viruses**.

- A chance mutation lets one bacterium survive: the drug is the **selection pressure**. Plasmids spread genes for several drugs: **multiresistant** MRSA.
- **Careful use** slows it. **Screening chemical libraries** finds new ones, such as halicin.

C3.2.15 MOST NEW HUMAN DISEASES BEGAN IN ANIMALS

Zoonoses: from animals to us

DISEASE	HOST AND ROUTE
Tuberculosis	Cattle (*Mycobacterium bovis*): unpasteurised milk, close contact.
Rabies	Dogs and bats: a bite, virus in saliva.
Japanese encephalitis	Pigs and wading birds: *Culex* mosquito bites.
COVID-19	Bat viruses, probably via another animal; then **person to person**.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Antibodies are not made in advance.** The matching B cell is selected.
- ✕ **An antigen alone does not activate a B cell.** A helper T cell must activate it too.
- ✕ **Memory cells give immunity, not plasma cells.** Plasma cells soon die.
- ✕ **Antibiotics do not kill viruses.** A virus has no wall or ribosomes.
- ✕ **Bacteria become resistant, not people.** The drug selects them.
- ✕ **HIV kills helper T cells, not B cells.** So no B cells are activated.

COVER THE SHEET

Can you *answer these?*

1. State four kinds of pathogen.
2. Outline how skin and clotting keep pathogens out.
3. Outline the four stages of phagocytosis.
4. Distinguish innate from adaptive immunity.
5. Explain how a B cell is activated and cloned.
6. Explain how HIV leads to AIDS.
7. Explain why antibiotics fail against viruses.
8. Describe the routes of two zoonoses.
9. Explain how vaccines protect a whole population.
10. Calculate the percentage change from 50 to 20.

IN THE EXAM

Antibody production, in order: antigen binds the B cell, an **activated helper T cell** makes contact, **mitosis** gives a clone, **plasma cells** secrete, **memory cells** remain.

GO FURTHER

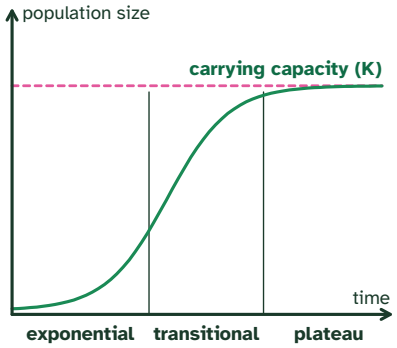
Animated figures, a dry lab and a marked Check are in the full guide online.

How many, and *why*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Populations grow until limited resources, predators and disease push back. Every interaction in a community helps set how many of each species there are.



Draw it like this. Three phases, no lag phase, levelling off at K.

C4.1.7, C4.1.8 START HERE

The *sigmoid* growth curve

- **Exponential:** resources are plentiful and little limits growth, so **births far exceed deaths**; numbers double in a fixed time, again and again.
- **Transitional:** resources run short, so the **growth rate slows**. **Plateau:** births plus immigration **equal deaths plus emigration**.
- **A model:** the curve is an **idealised simplification**; real populations overshoot and crash. Grow yeast or duckweed to collect your own data.
- **Test it:** plot numbers on a **log scale** against time on an ordinary scale. Exponential growth gives a **straight line**.

Case study, St Matthew Island: plenty of lichen, no predators. Reindeer rose exponentially, ate out the lichen and crashed.

29	6,000	42
reindeer released in 1944	by 1963	by 1966

C4.1.1, C4.1.2

One species, one *area*

- A **population**: one species in one area, interacting and, normally, **breeding**.
- **Reproductive isolation** separates populations: frogs either side of a motorway never meet.
- Counting all is rarely possible, so count a **random sample** (every spot equally likely) and scale up.

NATURE OF SCIENCE

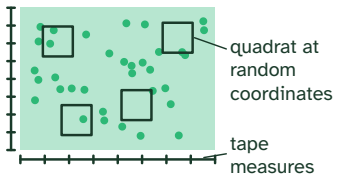
Sampling error

The estimate minus the true size. A bigger sample shrinks it; it never vanishes.

C4.1.3 SESSILE ORGANISMS

Random *quadrats*

- For **sessile organisms**: plants, barnacles, limpets.
- Tapes make a grid; **random numbers** give coordinates.
- **Estimate** = **mean per m² × area**.
- **Standard deviation:** how much counts vary round the mean. Large means patchy, so less certain.



C4.1.4 MOTILE ORGANISMS

Mark, release, *recapture*

- For **motile organisms**. Mark M, release, wait, then catch N, of which R are marked.
- **Lincoln index: M × N ÷ R**. Mark 20; recatch 15, 5 marked: 20 × 15 ÷ 5 = 60.
- **It assumes:** marks last and do no harm; equal chance of capture; full mixing; no births, deaths or migration.

20	5/15	60
marked	recaught	estimate

C4.1.5, C4.1.6

Carrying capacity and *feedback*

- **Carrying capacity** (K): the largest population an environment can support long term, set by the **limited resource** that runs short first: food, water, light, space, minerals.
- **Density-dependent factors** hit harder in a crowd: above K births fall and deaths rise; below K the reverse. That is **negative feedback**.

1	2	3
Competition for resources.	**Predation** more prey, easier hunting.	**Pathogens, pests** spread fast in a crowd.

- **Density-independent** factors (flood, frost, fire) knock numbers away from K but **never push them back**.

C4.1.9

Rivals and *allies*

- One species needs **exactly the same resources**, so **intraspecific competition** is fierce when food, light, territory or mates run short.
- Members **cooperate** when it gains each more than it costs.

Competition within a species

Tree seedlings shade each other out. Red deer stags fight in the rut. Great tits defend feeding territories.

Cooperation within a species

Emperor penguins huddle, taking turns outside. Wolves hunt in packs. Meerkats take turns as sentries.

Communities: how species *interact*

C4.1.10, C4.1.11 PLANTS, ANIMALS, FUNGI AND BACTERIA

A *community*: six interactions

- **Community**: **all the interacting populations** in an area.

INTERACTION	EFFECT	EXAMPLE
Herbivory	+ / −	Rabbits graze grass.
Predation	+ / −	Lynx kill snowshoe hares.
Competition	− / −	Grey and red squirrels.
Mutualism	+ / +	*Rhizobium* in bean roots.
Parasitism	+ / −	A tick sucks deer blood.
Pathogenicity	+ / −	Chytrid fungus kills frogs.

C4.1.12

Mutualism: both gain

Legume nodules (Fabaceae)
Rhizobium fixes nitrogen into ammonium for the plant, and gets sugars and a low-oxygen home.

Orchid mycorrhizae (Orchidaceae)
The fungus gives seeds sugars and minerals so they germinate; adult orchids pass sugars back.

Zooxanthellae in hard corals
Algae make most of its food by photosynthesis; the coral gives shelter, CO_2 and nitrogen compounds.

C4.1.13

Invasive species

- **Endemic**: native. **Invasive**: introduced, spreads and does harm.
- It wins by using a **shared resource more efficiently**.
- **Grey squirrels** digest tannin-rich acorns that reds cannot; reds have largely gone from England and Wales.

C4.1.14

Testing for *competition*

- Better **without the other** species: competition **indicated, not proved**.
- **Lab:** Gause's two *Paramecium* thrived alone; together one died out.
- **Field:** random sampling, or removal: without *Balanus*, *Chthamalus* lived lower (Connell).
- **Nature of science:** experiments manipulate; observations record.

C4.1.15 APPLICATION OF SKILLS

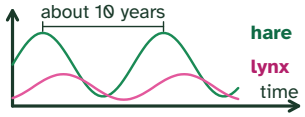
Chi-squared: *association*

- **Presence or absence** of two species in random quadrats, as a 2 × 2 table. H_0: independent.
- E = row total × column total ÷ grand total; $\chi^2 = \Sigma\ (O - E)^2 \div E$.
- **1 degree of freedom**: above **3.84** ($p = 0.05$) is significant. "Both" O below E: negative.

C4.1.16

Predator and prey

- **Hudson's Bay Company** fur records: snowshoe hares and lynx cycle, lynx a year or two behind.
- More hares, more lynx; hares crash, then lynx starve: **density-dependent**.



C4.1.17

Top-down or bottom-up

- **Top-down**: predators. **Bottom-up**: food. **One usually dominates**.

Top-down sea otters
Otters hunted out: urchins graze kelp to bare rock.

Bottom-up a lake
Fertiliser runs in: algae bloom, all above changes.

C4.1.18

Chemical *weapons*

- A **chemical released** into the environment **deters competitors**.

Allelopathy a plant
Black walnut releases juglone; nearby plants wilt and die.

Antibiotic a microbe
Penicillium secretes **penicillin**, killing rival bacteria.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **No lag phase:** exponential, transitional, plateau.
- ✕ **Never place quadrats by eye:** you pick thick patches.
- ✕ **Lost marks inflate the Lincoln index:** R falls.
- ✕ **Frost does not regulate:** it never pushes back to K.
- ✕ **χ^2 does not prove competition:** soils may differ.
- ✕ **Parasites seldom kill hosts:** pathogens cause disease.

COVER THE SHEET

Can you *answer these?*

1. Describe how to estimate a plant population with quadrats.
2. Calculate N: 20 marked, then 5 of 15 recaught marked.
3. Outline the sigmoid curve's phases and what holds it at K.
4. State an example of each interspecific relationship.
5. Distinguish competition from cooperation within a species.
6. Describe what both partners gain in one mutualism.
7. Outline three tests for interspecific competition.
8. Distinguish top-down from bottom-up control.

IN THE EXAM

Lincoln index or χ^2: write the formula, substitute, calculate, then **say what it means** (for χ^2, compare with 3.84 and name the association).

GO FURTHER

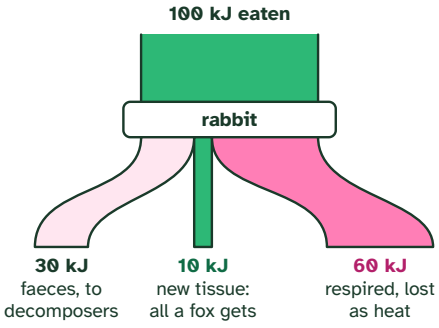
Animated figures, a dry lab and a marked Check are in the full guide online.

Energy *flows*, matter cycles

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Energy arrives as light and leaves as heat, so it passes through once. Carbon and every other element are recycled.



Follow 100 kJ. Band widths are to scale: only the green tenth reaches the next level.

C4.2.12 to 14 START HERE

Energy is *lost* at every step

- Only a small share of one level's energy, often **about a tenth**, ends up in the next level.
- **The rest:** parts not eaten and food not absorbed (faeces) go to decomposers; most absorbed energy is **respired and lost as heat**.
- No transfer is 100% efficient: heat is released **when ATP is made and when it is used**, in autotrophs and heterotrophs alike. No organism turns heat back into chemical energy.
- Less energy each step means fewer or smaller organisms: **less biomass**, but not less energy per gram. So chains rarely have **more than five levels**.

WHERE A LEVEL'S ENERGY GOES

1. **Not eaten** roots, bark, bones, bodies
2. **Not absorbed** out in the faeces
3. **Respired** lost as heat
4. **Passed on** about 10%, to the next level

C4.2.1, C4.2.2

Light in, *heat* out

- Sunlight, caught in photosynthesis, is the **principal energy source** for most ecosystems.
- **Exceptions: caves**, and the **deep ocean** below about 200 m.
- **Nature of science:** this is like a **law**: it describes a pattern and predicts, but does not explain. Vent communities, found in 1977, narrowed it to "most".

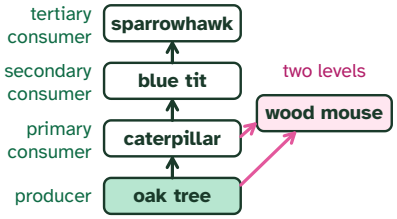
Open system energy and matter cross
A wood or a pond: most ecosystems.

Closed system only energy crosses
A sealed jar: light in, heat out.

C4.2.3, 4, 10

Chains and *trophic levels*

- Feeding passes the food's **carbon compounds**, and the **chemical energy** in them, to the consumer.
- Arrows point **from the eaten to the eater**: the way energy and biomass go.
- Chains link into a web. A varied diet puts an animal on **different levels in different chains**.



C4.2.5

Food for *decomposers*

- **Faeces**, **dead parts** and **whole dead organisms** are still **carbon compounds holding energy**.
- Decomposers respire them, releasing CO_2 and heat, and leave **mineral ions** that plants take up.
- Not drawn on food chains, but **energy from every level** reaches them.

Detritivores digest inside
Earthworms, woodlice and millipedes eat dead matter.

Saprotrophs digest outside
Most fungi and many bacteria secrete enzymes, then absorb.

C4.2.6 to 9 AUTOTROPHS AND HETEROTROPHS

Make it or *take it*

ORGANISM	CARBON FROM	ENERGY FROM	EXAMPLE
P **Photoautotroph** an autotroph	**Simple inorganic substances**: CO_2, water, ions such as nitrate.	**Light.**	Plants, algae and cyanobacteria.
C **Chemoautotroph** an autotroph	The same: it **fixes CO_2**, like a plant.	**Oxidation reactions.** Oxidising inorganic chemicals releases energy.	**Iron-oxidising bacteria**: Fe^{2+} to Fe^{3+}, orange rust in iron-rich streams.
H **Heterotroph** takes from others	Carbon compounds **from other organisms**: digested, absorbed, then **assimilated** into its own.	**Its food.**	Animals digest in the gut; fungi and many bacteria outside their cells.
R **All of them** C4.2.9	Every organism, autotroph or heterotroph, **respires**.	**Respiration.** Oxidising carbon compounds releases energy.	Plants respire day and night, as foxes do.

Autotrophs need energy for **carbon fixation** and the **anabolic** reactions that build macromolecules.

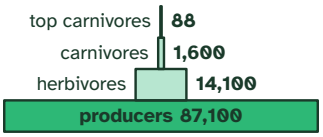
Heterotrophs digest proteins and nucleic acids first.

Production, and carbon going *round*

C4.2.11 DRAW IT TO SCALE

Energy *pyramids*

- One bar a level, producers at the bottom, width **in proportion to energy**.
- Units: **kJ m⁻² yr⁻¹**. Efficiency = level ÷ level below × 100.
- Never upside down: each level **loses energy** before the next.



Silver Springs, Florida (Odum), kJ m⁻² yr⁻¹

C4.2.15, 16

Building *biomass*

- **Primary:** carbon compounds **accumulating in biomass by autotrophs**, in g m⁻² yr⁻¹.
- **Net** = gross − respiration.
- **Secondary:** biomass built by heterotrophs. **Lower than primary**: much is respired to CO_2 and water.

Net primary production, g m⁻² yr⁻¹

2,000+	<100
rainforest	hot desert

C4.2.21, 22

A two-way *trade*

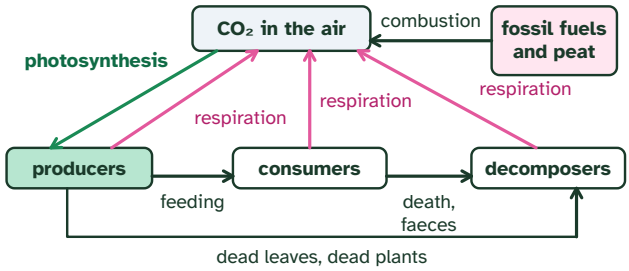
- Aerobic respiration needs **O_2 from photosynthesis**; photosynthesis needs **CO_2 from respiration**.
- On land, 100 billion tonnes of carbon go each way a year: **huge fluxes**.
- **Every element** is recycled; **decomposers** return them.

Photosynthesis autotrophs	CO_2 in, O_2 out.
Respiration all organisms	O_2 in, CO_2 out.

C4.2.17 to 19

The *carbon* cycle, sinks and sources

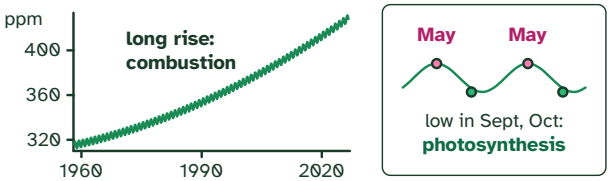
- Energy passes through once; **carbon is recycled** by photosynthesis, feeding and respiration.
- **Sink:** photosynthesis exceeds respiration, a **net uptake of CO_2** (a growing forest, a peat bog). **Source:** a **net release**.
- **Combustion** of biomass, peat, coal, oil and gas releases CO_2. Lightning fires are natural; **humans have greatly increased** the rate.
- **Formed at different times:** wood in years, peat over thousands, coal about 300 million years ago.



C4.2.20

Reading the *Keeling* curve

- Monthly CO_2 at **Mauna Loa**, Hawaii, since 1958: from about 315 to **over 420 ppm**.
- **Yearly wiggle:** most land is northern. In its summer **photosynthesis exceeds respiration** and CO_2 falls; in winter respiration raises it.
- **Long rise:** **combustion of fossil fuels** and deforestation release carbon faster than it is taken back.



WATCH OUT

Six mistakes that *cost marks*

- ✕ **Arrows point to the eater.** Energy goes from rabbit to fox.
- ✕ **Energy is not used up.** It ends as heat; the total is conserved.
- ✕ **Plants respire too.** Every living cell respires, day and night.
- ✕ **Chemoautotrophs fix CO_2.** Iron gives energy, not carbon.
- ✕ **Decay gives plants ions, not energy.** Roots absorb ions.
- ✕ **Winter heating does not cause the wiggle.** Combustion drives the rise; the wiggle is northern photosynthesis.

COVER THE SHEET

Can you *answer these?*

1. Distinguish an open system from a closed one.
2. Draw a food chain and label its trophic levels.
3. State three sources of energy for decomposers.
4. Compare a chemoautotroph with a heterotroph.
5. Calculate producer to herbivore efficiency above.
6. Explain why chains rarely pass five levels.
7. Explain why secondary production is lower.
8. Draw a carbon cycle with three processes.
9. Explain the wiggle and the rise in the Keeling curve.
10. Outline how respiration depends on photosynthesis.

IN THE EXAM

Name the loss and where it goes ("lost as heat in respiration", "in faeces, to decomposers"). For the Keeling curve, **give the wiggle and the rise separate causes**.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY | D1.1 | SL AND HL

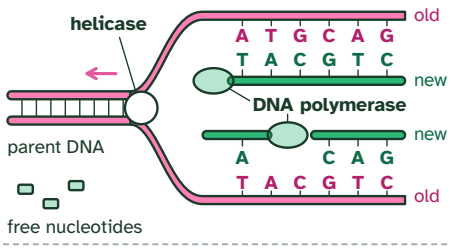
REVISION ON TWO PAGES

How DNA is *copied*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Each old strand is a template. Base pairing makes every new strand its exact complement, so both copies keep the original sequence.



Draw it like this. Old strands pink, new strands green; each new base pairs with the base opposite it.

D1.1.2, D1.1.3 START HERE

Unzip, pair, build: *semi-conservative*

- **Helicase unwinds the double helix** and **breaks the hydrogen bonds** between the bases, so the two strands part at the replication fork.
- Each old strand is a **template**. Free nucleotides line up by **complementary base pairing**: A with T, C with G, and nothing else fits.
- **DNA polymerase joins the free nucleotides** into a new strand, each matched to the template. One works on each strand.
- **Semi-conservative**: each daughter molecule is **one whole old strand and one whole new strand**. Only one base fits each template base, so the copy is **highly accurate**.

D1.1.1

An *exact* copy

- Replication copies a DNA molecule with an **identical base sequence**: the same bases in the same order.
- It is needed for **reproduction** (a bacterium splits in two), **growth** and **tissue replacement** (skin, gut lining, blood cells).
- A change that slips through is a **mutation**, which is why the copy must be exact.

Replication copies the DNA
The whole molecule, not one gene, before every division.

Cell division comes after
Each new cell gets one full copy.

D1.1.4 AMPLIFYING DNA

PCR: a *millionfold* copy

- The **polymerase chain reaction** copies one chosen stretch of DNA: it **amplifies** a tiny sample.
- **Primers:** two short single strands of DNA, one for **each end of the target**. They give the polymerase a start and choose what is copied.
- **Taq polymerase**, from *Thermus aquaticus* of hot springs, is **not denatured at 95 °C**, so it survives every cycle.
- Each cycle **doubles the copies**: up to 2^n after n cycles, a billion after 30.

ONE CYCLE IN A THERMAL CYCLER

Dragons Always Exhale

D **Denaturation**
about 95 °C: hydrogen bonds break, strands separate

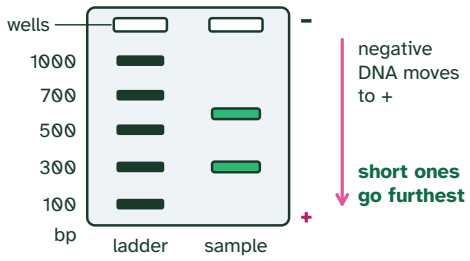
A **Annealing**
about 55 °C: primers bind to each end

E **Extension**
about 72 °C: Taq builds the new strands

D1.1.4 SEPARATING DNA

Gel electrophoresis: sorted by *size*

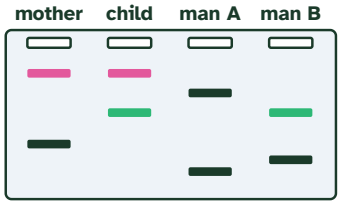
- Phosphates give DNA a **negative charge**, so it moves **towards the positive electrode**.
- The gel is a mesh: **long fragments are held back more**, so **short ones travel furthest**.
- A **DNA ladder** of known sizes gives the scale, in base pairs (bp). To size a band, find the ladder band level with it.
- Each band is millions of fragments of one length, which is why PCR comes first.



D1.1.5 APPLICATIONS

DNA *profiling*

- PCR copies **short tandem repeats** (STRs) at several markers; people differ in the number of repeats. The gel sorts them by length.
- **Forensic:** a match at every marker is strong evidence; **one clear mismatch excludes**. **Paternity:** a child's band that the mother lacks **must come from the father**.
- **Nature of science:** reliability rises with more measurements: **more markers, fewer false matches**.
- **Other uses:** diagnosing infections (the COVID-19 test), inherited conditions, identifying species, ancient DNA.



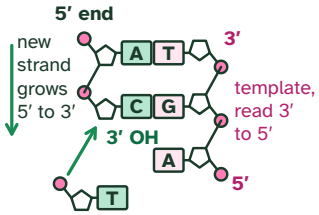
Pink: from the mother. Green: from the father (man B, not man A).

The fork in *detail*: direction, fragments, proofreading

D1.1.6 HIGHER LEVEL

Only ever at the *3′ end*

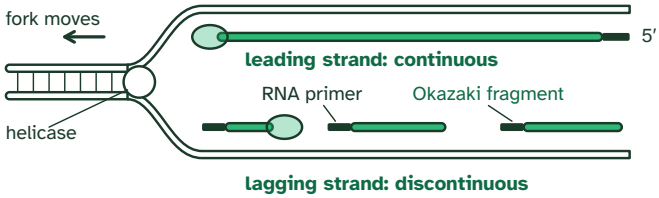
- A strand has a **5′ terminal** (free phosphate) and a **3′ terminal** (free OH on a 3′ carbon).
- DNA polymerase joins a new nucleotide's **5′ phosphate to the 3′ OH**: new strands **grow 5′ to 3′**.
- The template is **antiparallel**: it is read 3′ to 5′.



D1.1.7 HIGHER LEVEL

Leading and *lagging* strands

- The **leading strand** grows towards the fork: made **continuously**.
- The **lagging strand** grows away from the fork, so it is made **discontinuously**, in short **Okazaki fragments**.
- An **RNA primer** starts every new piece: **once on the leading strand**, but **once per Okazaki fragment** on the lagging strand.



D1.1.8 HIGHER LEVEL

The enzymes at the *fork*, in order

THE PROKARYOTIC SYSTEM

Hungry Pandas Prefer Plain Lettuce

H	**Helicase**	unwinds, breaks hydrogen bonds (D1.1.3)
P	**Primase**	makes each short RNA primer
P	**Polymerase III**	extends primers 5′ to 3′; builds most DNA
P	**Polymerase I**	removes RNA primers, puts DNA in their place
L	**Ligase**	seals each nick in the backbone

- Primers are RNA, so **polymerase I swaps them for DNA**; **ligase** then makes the last covalent bond where fragments meet.

D1.1.9 HIGHER LEVEL

DNA *proofreading*

- **DNA polymerase III** checks the nucleotide it has just added: it **checks as it builds**.

1 in 10^5 wrong without proofreading

1 in 10^7 with it

STEP 1
Mismatch
A base that does not pair with the template is added.

STEP 2
Remove
Polymerase III removes it from the **3′ terminal**.

STEP 3
Replace
It adds a **correctly matched** nucleotide.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Semi-conservative is about the molecule.** Each strand is wholly old or wholly new.
- ✕ **Helicase breaks hydrogen bonds between bases.** The sugar and phosphate backbone stays whole.
- ✕ **DNA polymerase does not make bases.** It joins whole nucleotides, already made.
- ✕ **Long fragments travel less far.** The gel holds them back; they are not "heavier".
- ✕ **Polymerase I removes primers, not polymerase III.** Ligase adds no nucleotides.
- ✕ **The lagging strand is not copied later.** Both strands are made at the same time.

COVER THE SHEET

Can you *answer these?*

1. State three reasons why cells replicate their DNA.
2. Explain how base pairing makes replication accurate.
3. Outline the roles of helicase and DNA polymerase.
4. Describe one cycle of PCR, with its temperatures.
5. Explain why DNA fragments separate by size in a gel.
6. Explain how a profile can exclude a man as a father.
7. Explain why a new strand grows only 5′ to 3′. HL
8. Distinguish the leading from the lagging strand. HL
9. State the functions of DNA polymerase I and ligase. HL
10. Describe how DNA polymerase III proofreads. HL

IN THE EXAM

Name the enzyme and the bond: helicase breaks **hydrogen bonds**; DNA polymerase makes **covalent bonds**. For PCR, give each step its temperature and its purpose.

GO FURTHER

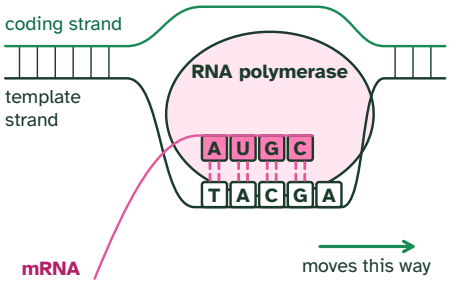
Animated figures, a dry lab and a marked Check are in the full guide online.

From gene to *protein*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

A gene's base sequence is copied into mRNA, then read three bases at a time to set the order of amino acids in a polypeptide.



Draw it like this. RNA polymerase parts the strands; each RNA base pairs with the template, held by hydrogen bonds (dashed).

D1.2.1, D1.2.2 START HERE

Transcription: a gene copied into RNA

- Transcription is the **synthesis of RNA** on the DNA **template strand**.
- **RNA polymerase** does the whole job: it **parts the two DNA strands** and **joins each new nucleotide** to the last with a covalent bond.
- **Complementary base pairing** chooses every base: A on the template takes **uracil (U)**, T takes A, C takes G, G takes C.
- The pairs are held by **hydrogen bonds**: weak enough to break as the enzyme passes, specific enough to copy exactly. The RNA matches the coding strand, with U for T.

TEMPLATE BASE, RNA BASE — *Apples Under Cars Garage*

A Adenine pairs with U	**U** Uracil replaces T in RNA	**C** Cytosine pairs with G	**G** Guanine pairs with C

D1.2.3 and 4

Read for a *lifetime*

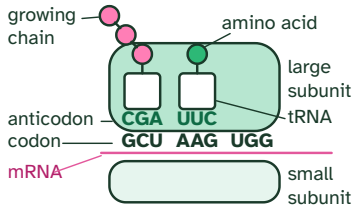
- Reading a template opens its hydrogen bonds for a moment; the **base sequence does not change**, so one gene gives many identical mRNAs.
- **Somatic cells that never divide** (most nerve cells of the outer brain) must **conserve their sequences** for life.
- **Not all genes are expressed** at once: transcription is where a gene is **switched on or off**.

Beta cell pancreas	Transcribes the insulin gene.
Skin cell same genes	Does not transcribe it.

D1.2.5 to 7

Translation: three RNAs

- The **base sequence of mRNA** sets the **amino acid sequence** of a polypeptide, at a ribosome.
- mRNA binds the **small subunit**; the **large subunit holds two tRNAs** at once.
- Each tRNA carries one amino acid and an **anticodon** that pairs with an mRNA **codon** by hydrogen bonds (A with U, C with G).



D1.2.8

A code written in *threes*

- **Why three:** four bases read singly give 4 meanings, in pairs 16: too few for 20 amino acids. Triplets give 64.
- **Degenerate**: most amino acids have **more than one codon**, but no codon means two.
- **Universal**: almost every organism reads **each codon as the same amino acid**.
- **AUG** is the start codon (methionine); **UAA, UAG, UGA** are stops.

4 one base	**16** two bases	**64** three bases

D1.2.9, D1.2.10 ELONGATION

One codon at a *time*

- **Skill:** deduce a polypeptide from mRNA with the codon table (it is given). Start at AUG, read in threes, end at a stop.

MRNA	AUG	GCU	AAG	UGG	UAA
chain	Met	Ala	Lys	Trp	stop

STEP 1	STEP 2	STEP 3
Bind A tRNA pairs with the next codon.	**Bond** A **peptide bond** joins its amino acid to the chain.	**Move** The ribosome moves **one codon**; the empty tRNA leaves.

- At a **stop codon** no tRNA pairs: the chain is released.

D1.2.11

One base, one *amino acid*

- **Sickle cell:** haemoglobin beta gene, codon 6: **GAG to GUG**, so **Glu to Val**.
- Non-polar Val replaces charged Glu, so at low oxygen haemoglobin forms **stiff fibres** that sickle red cells.

codon	5	6	7
normal	CCU Pro	GAG Glu	GAG Glu
sickle	CCU Pro	GUG Val	GAG Glu

A BASE SUBSTITUTION GIVES — *Same, Swapped, Stopped*

S Silent the same amino acid	**S** Missense a different amino acid	**S** Nonsense a stop: chain ends early

From the *promoter* to a working protein

D1.2.12 HIGHER LEVEL

Five prime to *three prime*

- A strand has a **5′ end** (phosphate on carbon 5′) and a **3′ end** (free OH on carbon 3′).
- **5′ to 3′ transcription**: each nucleotide joins the **3′ end** of the RNA; the template is read 3′ to 5′.
- **5′ to 3′ translation**: the ribosome moves from the 5′ end of the mRNA towards the 3′ end.
- The coding strand runs the same way as the mRNA, so written 5′ to 3′ their sequences match (U for T).

D1.2.13, D1.2.14 HIGHER LEVEL

The *promoter*, and non-coding DNA

- The **promoter**, just before a gene, is not transcribed. **Transcription factors** bind it; only then can RNA polymerase bind and start.

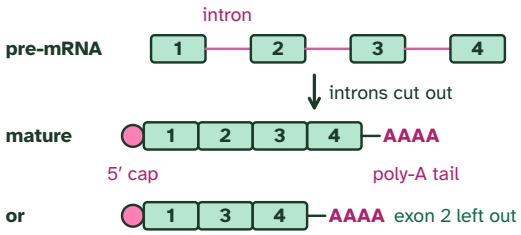
NON-CODING	CODES FOR NO POLYPEPTIDE
Regulators	Promoters, and other sites factors bind.
Introns	Transcribed, then cut out of the RNA.
Telomeres	Repeats that protect the chromosome ends.
rRNA, tRNA genes	Transcribed, never translated.

D1.2.15, D1.2.16 HIGHER LEVEL

Capped, *cut* and tailed

- In eukaryotes, **pre-mRNA** becomes **mature mRNA** in the nucleus.
- **Splicing: introns are removed** and the **exons joined**.
- A **5′ cap** and a **3′ poly-A tail stabilise** the mRNA.
- **Alternative splicing**: other combinations of exons let **one gene code for several polypeptides**.

In, Exit: introns stay in the nucleus; exons exit in the mRNA.



D1.2.17 HIGHER LEVEL

Starting the *chain*

- **Small subunit:** binds the **5′ end**, slides to AUG.
- **Initiator tRNA** (UAC, Met) pairs; **large subunit** joins.
- Initiator sits in P; a second tRNA binds at A.

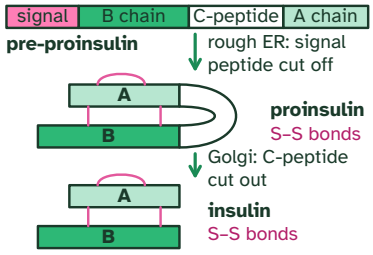
THREE TRNA SITES — *Arrive, Pass, Exit*

A site a tRNA arrives	**P site** holds the chain	**E site** empty tRNA exits

D1.2.18, D1.2.19 HIGHER LEVEL

Finished, then *recycled*

- Many polypeptides must be **modified before they work**.
- **Insulin:** the **signal peptide** is cut off, then the **C-peptide**.
- **Proteasomes** break down tagged proteins for reuse: a proteome needs **constant breakdown and synthesis**.



WATCH OUT

Six mistakes that *cost marks*

- ✕ **RNA polymerase parts the DNA, not helicase.** One enzyme does it all.
- ✕ **mRNA is complementary to the template.** It matches the coding strand, U for T.
- ✕ **Codons are on mRNA, anticodons on tRNA.** DNA has neither.
- ✕ **Degenerate: several codons, one amino acid.** Never the reverse.
- ✕ **Peptide bonds join amino acids.** Hydrogen bonds hold codon to anticodon.
- ✕ **Introns leave the RNA, not the gene.** The DNA keeps them.

COVER THE SHEET

Can you *answer these?*

1. Outline the roles of RNA polymerase.
2. Explain how two cells with the same genes differ.
3. Describe the roles of mRNA, ribosomes and tRNA.
4. Explain why the genetic code is a triplet code.
5. Describe one step of elongation.
6. Explain how sickle cell anaemia arises.
7. Explain 5′ to 3′ transcription. HL
8. State four kinds of non-coding DNA. HL
9. Distinguish pre-mRNA from mature mRNA. HL
10. Describe the roles of the A, P and E sites. HL
11. Outline how pre-proinsulin becomes insulin. HL

IN THE EXAM

Given DNA? Write the mRNA first (template A gives U), then **start at AUG and read in threes**. Name each bond: "peptide" or "hydrogen".

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

When a gene *changes*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

A mutation changes the base sequence of a gene. What it does depends on what happens to the codons, and so to the polypeptide.

Original four amino acids

ATG GCA TTC GAA

Met Ala Phe Glu

Substitution one changed

ATG GCA CTC GAA

Met Ala Leu Glu

Insertion frame shifted

ATG GGC ATT CGA A

Met Gly Ile Arg

Deletion C lost, frame shifted

ATG GAT TCG AA

Met Asp Ser

Read it in threes. One base swapped changes one codon; one base added or lost changes all that follow.

D1.3.1 START HERE

Three ways to *change* a gene

- A gene mutation is a **change to the base sequence** of a gene: a structural change to the DNA itself.
- **Substitution: one base swapped** for another. The gene keeps its length and at most one codon changes.
- **Insertion:** one or more **bases added**. **Deletion:** one or more **bases lost**. Both change the length of the gene.
- A ribosome reads in threes with nothing to mark where a codon ends, so an insertion or deletion can **change every codon after it**.

WHAT A SWAPPED BASE CAN DO — *Same, Mistake, Stop*

- **S** **Same: silent** — new codon, same amino acid
- **M** **Mistake: missense** — one amino acid different
- **S** **Stop: nonsense** — a stop codon: chain cut short

D1.3.2

One base *swapped*

- The code is **degenerate**: most amino acids have several codons, usually differing only at the third base.
- So a substitution **may or may not change an amino acid**.
- A **single-nucleotide polymorphism** (SNP) is a base substitution found in some members of a population.
- **Missense is not always harmful:** it matters most in a key place, such as an active site.

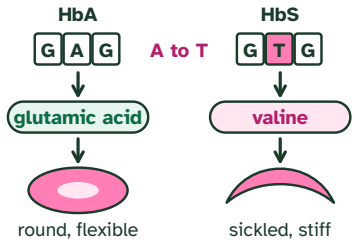
GGU to GGA silent
Both code for glycine: no change.

GAG to GAA silent too
Both code for glutamic acid: the sickle codon, unharmed.

D1.3.2 THE EXAMPLE

Sickle cell, one base

- In the sixth codon of beta globin, **A is replaced by T**: GAG becomes GTG.
- **Glutamic acid** (charged) becomes **valine** (non-polar): missense.
- At low oxygen haemoglobin S forms stiff fibres; cells sickle and **block small vessels**.
- Two copies of HbS give **sickle cell disease**.



D1.3.3

Bases *added or lost*

- Adding or losing one or two bases shifts the reading frame: a **frameshift**.
- Every codon after it can change and an **early stop codon** is likely (3 of the 64 codons are stops), so the polypeptide **almost never works**.
- A multiple of three keeps the frame, but whole amino acids are gained or lost.
- **Large insertions or deletions** usually stop a polypeptide working.

1 or 2 bases frame shifted
Every codon after it changes.

3 bases frame kept
One amino acid gained or lost.

D1.3.4

Where mutations *come from*

- **No outside cause:** rare **errors in DNA replication or repair** that proofreading misses.
- **Mutagens: chemicals** (benzo[a]pyrene and nitrosamines in tobacco smoke, aflatoxin from a mould, mustard gas) and **radiation**.

MUTAGENS — *Smoke, Sun, Scans*

- **S** **Smoke** — chemicals in tobacco smoke
- **S** **Sun** — ultraviolet: joins two neighbouring thymines
- **S** **Scans** — ionising: X-rays, gamma rays, radon

D1.3.5

Mutation is *random*

- Mutation can happen **anywhere in the base sequence** of a genome.

1 **Not equal odds**
Some bases mutate more often, such as C beside G.

2 **Not on demand**
No known natural mechanism changes a chosen base for a trait.

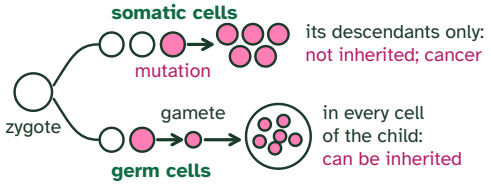
- Bacteria do not mutate to resist an antibiotic: **resistant mutants were already there**, and the drug kills the rest.

Who inherits a mutation, and how genes are *edited*

D1.3.6

Germ cells and somatic cells

- **Somatic cell:** only that cell's descendants carry it; it is **not inherited**.
- Somatic mutations in **genes that control cell division** can lead to **cancer**.
- **Germ cell:** via a gamete and zygote it reaches **every cell of the offspring**.



D1.3.7

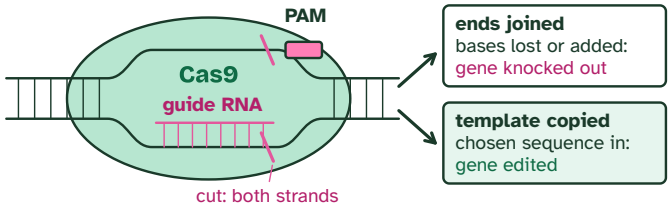
The source of all *variation*

- Every allele began as a mutation: the **original source of all genetic variation**.
- For one organism most mutations are **neutral or harmful**; for a species they are **essential for evolution** by natural selection.
- **Nature of science:** commercial genetic tests read SNPs and report disease risk. **Without expert interpretation** they can mislead: a raised risk is not a diagnosis.

D1.3.9 HIGHER LEVEL

CRISPR and Cas9: cut, then repair

- **Cas9**, an enzyme, carries a **guide RNA** of about 20 bases. Where the guide pairs, next to a **PAM**, it cuts both strands.
- The **cell's repair** makes the change: a knockout, or an edit copied from a template.
- **Success:** a patient's blood stem cells, edited to make **fetal haemoglobin**, treat sickle cell disease.
- **Nature of science:** some uses raise **ethical issues**; rules differ by country, so there is an effort to **harmonise** them.



D1.3.8 HIGHER LEVEL

Gene *knockout*

- A gene is made **inoperative**. How the organism differs from a **normal one** shows what the gene does.
- Model organisms: mice, zebrafish, yeast, *Arabidopsis*.
- **Libraries of knockout organisms**, one strain per gene, exist for some model species.

D1.3.10 HIGHER LEVEL

Conserved sequences: two hypotheses

- **Conserved:** the same or similar **across a species or group**; **highly conserved:** the same **over long periods of evolution**.
- **Function:** the product needs it, so **selection removes changes**; silent ones build up.
- **Slower mutation:** fewer changes arise at all, silent ones too.

	region X		region Y	
species A	GCT	AAG	TGG	CAT
species B	GCA	AAA	TGG	CAT
species C	GCC	AAG	TGG	CAT
species D	GCG	AAA	TGG	CAT
amino acid	Ala	Lys	Trp	His
	third bases vary		nothing varies	

WATCH OUT

Five mistakes that *cost marks*

- ✕ **A substitution changes at most one amino acid.** A frameshift can change all of them.
- ✕ **Mutations are not made on demand.** Selection acts on changes already there.
- ✕ **A somatic mutation is not inherited.** A smoker's lung cell does not make his sperm.
- ✕ **Cas9 only cuts.** The cell's repair makes the change; a near match can be cut by mistake.
- ✕ **Conserved does not mean unmutated.** Mutations arise there; selection removes them.

COVER THE SHEET

Can you *answer these?*

1. Distinguish substitutions, insertions and deletions.
2. Explain why a SNP may not change a polypeptide.
3. Describe the base and amino acid change in sickle cell.
4. Explain why losing one base is worse than losing three.
5. State two causes of mutation, and why it is random.
6. Compare germ cell and somatic cell mutations.
7. Outline how a knockout reveals what a gene does. HL
8. Explain how CRISPR-Cas9 can edit a gene. HL
9. Distinguish two hypotheses for conserved sequences. HL

IN THE EXAM

Follow the change down the chain: base, codon (or reading frame), amino acid, then the polypeptide's function. For sickle cell write both: **A to T**, and **glutamic acid to valine**.

GO FURTHER

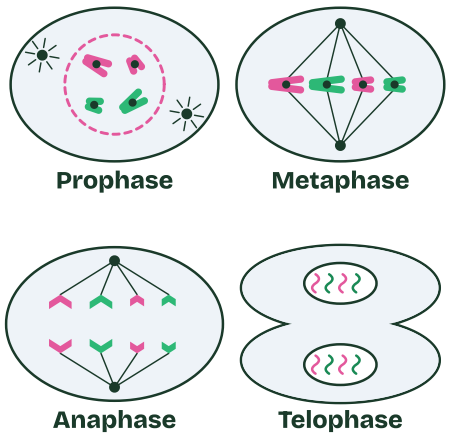
Animated figures, a dry lab and a marked Check are in the full guide online.

One cell becomes *two*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Copy the DNA, then share it out. Mitosis gives two identical nuclei; meiosis gives four haploid, varied ones.



Draw it like this. Each chromosome two chromatids until anaphase; pink and green for the two of each pair.

D2.1.7 START HERE

Mitosis makes two *identical* nuclei

- **Prophase:** chromosomes **condense**, the nuclear membrane breaks down and the spindle forms.
- **Metaphase:** microtubules from both poles attach at each centromere; chromosomes **line up on the equator**.
- **Anaphase:** centromeres separate and **sister chromatids** are pulled to opposite poles.
- **Telophase:** a nuclear membrane forms round each group and the chromosomes uncoil. Then cytokinesis.

Sister chromatids are copies, and each nucleus gets one of every chromosome: so the nuclei are **genetically identical** to each other and the parent.

THE FOUR PHASES, IN ORDER

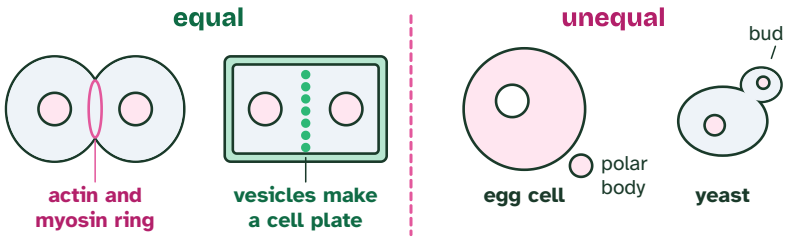
Make your own: four words, P M A T

P Prophase condense, membrane goes	**M** Metaphase line up in the middle	**A** Anaphase chromatids pulled apart	**T** Telophase two nuclei form

D2.1.1 to 3

Splitting the *cytoplasm*

- A parent (mother) cell divides into **two daughter cells**: the nucleus first, then the cytoplasm (**cytokinesis**).
- **Animal:** a **ring of actin and myosin** contracts and pinches the membrane in. **Plant:** vesicles fuse into a **cell plate**, the new membranes and wall.
- Usually equal, but **unequal** in human **oogenesis** and yeast **budding**. Each daughter needs at least **one mitochondrion** (and plastid): these arise only by division.



D2.1.4 to 6

Copy, coil, *move*

- Nuclear division comes first, so no daughter cell is left **anucleate**.
- **Replication first:** each chromosome becomes **two sister chromatids** (two DNA molecules) held at the centromere until anaphase.
- **Condense:** DNA winds round **histones** and supercoils. **Move:** spindle **microtubules** and motor proteins.

Mitosis growth, repair	Keeps the chromosome number and genome.
Meiosis gametes	Halves the chromosome number; makes genetic diversity.

D2.1.8 SKILLS

Name the *phase*

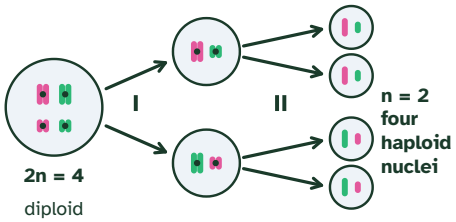
- Name phases in diagrams and in root tip cells seen down a microscope or in a micrograph, **one clue each**.

NOT DIVIDING	1	2	3	4
Interphase	**Prophase**	**Metaphase**	**Anaphase**	**Telophase**
Round nucleus, dark nucleolus, no separate chromosomes.	Thick threads; the nuclear edge fading.	A band across the middle (end on, a ring).	Two groups moving apart, often V shapes.	Two groups at the ends, new nuclei, often a cell plate.

D2.1.9

Meiosis *halves* the number

- **Diploid (2n):** two sets of chromosomes, one from each parent. **Haploid (n):** one set. Humans: 2n = 46, n = 23.
- **Meiosis I** separates **homologous chromosomes**; **meiosis II** separates **sister chromatids**: two rounds of segregation.
- One replication, two divisions: one diploid nucleus gives **four haploid nuclei**.
- Fertilisation restores 2n, so a **sexual life cycle** needs meiosis.



D2.1.10

Down syndrome

- **Non-disjunction**: a pair (meiosis I) or two chromatids (meiosis II) **fail to separate**; both go to one pole.
- A gamete with two chromosome 21s plus a normal one gives **trisomy 21**: 47 chromosomes. The chance rises with the mother's age.

D2.1.11

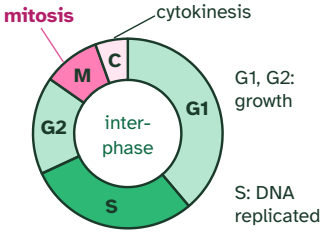
Every gamete *different*

- **Shuffle (random orientation):** each **bivalent** lines up either way in metaphase I: 2^n combinations, over 8 million (2^{23}) in humans.
- **Swap (crossing over)** in prophase I: non-sister chromatids swap ends, giving **new combinations of alleles**.

D2.1.12 to 14 HIGHER LEVEL

Growth and the *cell cycle*

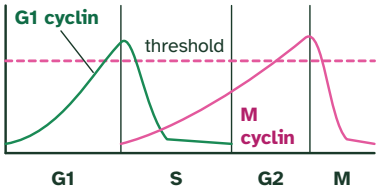
- **Proliferation:** growth in **plant meristems** and **early embryos**; replacement and wound healing in **skin**.
- **Interphase is busy:** proteins and DNA made; mitochondria and chloroplasts **grow and divide**.



D2.1.15 HIGHER LEVEL

Cyclins open the gates

- Different cyclins **rise and fall** through the cycle.
- A **threshold** of a specific cyclin is needed to pass each **checkpoint**; then it is broken down.
- A cyclin is a go signal: it activates the enzymes that start the next stage.



D2.1.16 and 17 HIGHER LEVEL

When control *fails*

- **Proto-oncogene** mutated to an **oncogene**: division stimulated. **Tumour suppressor** lost: division not stopped.
- **Primary tumour:** where it starts. **Secondary:** where spread cells grow.

Benign not cancer
Slow division; stays in place, often in a capsule.

Malignant cancer
Fast division; **invades** neighbouring tissue and spreads (metastasis).

Mitotic index = cells in mitosis ÷ total cells

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Cytokinesis is not a phase of mitosis.** Mitosis divides the nucleus; cytokinesis, the cytoplasm.
- ✕ **Interphase is not a resting phase.** The cell grows and copies its DNA.
- ✕ **A replicated chromosome still counts as one.** A human cell entering mitosis has 46 chromosomes, 92 chromatids.
- ✕ **The halving happens in meiosis I.** Meiosis II separates chromatids, as mitosis does.
- ✕ **Crossing over is between non-sister chromatids** of a pair; sister chromatids are identical anyway.
- ✕ **A tumour is not always a cancer.** Only a malignant tumour invades and spreads.

COVER THE SHEET

Can you *answer these?*

1. Outline how cytokinesis differs in animal and plant cells.
2. Distinguish the roles of mitosis and meiosis.
3. Explain why mitosis gives genetically identical nuclei.
4. Identify the phase with chromosomes on the equator.
5. Outline the two rounds of segregation in meiosis.
6. Explain how non-disjunction can cause Down syndrome.
7. Explain two ways meiosis makes gametes vary.
8. Outline what happens in G1, S and G2. HL
9. Describe how cyclins control the cell cycle. HL
10. Distinguish a benign from a malignant tumour. HL

IN THE EXAM

Name the structure that moves: chromosomes in meiosis I, chromatids in mitosis and meiosis II. A mitotic index divides by **all** the cells counted.

GO FURTHER

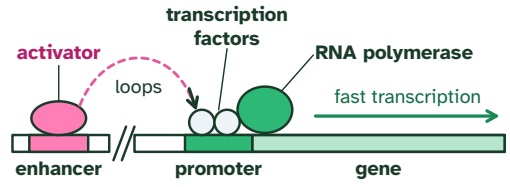
Animated figures, a dry lab and a marked Check are in the full guide online.

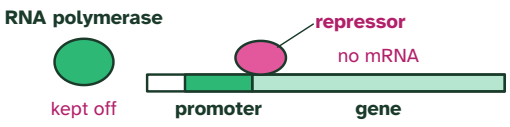
Same genes, different *cells*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Nearly every cell carries the same genes. What makes a cell what it is: which genes it expresses, and how much.





Sequences and proteins. Promoter and enhancer are DNA; the proteins that bind them switch the gene up or down.

D2.2.2 START HERE

Switches on the *DNA*

- Transcription is regulated by **proteins that bind specific base sequences** in the DNA; each recognises its own sequence.
- **Promoter:** the sequence just before a gene where **RNA polymerase binds**. In eukaryotes it needs **transcription factors** bound there first to help it attach.
- **Enhancer:** a sequence that can be thousands of bases away. **Activators** bound to it **raise the rate** of transcription; the DNA loops so they touch the promoter proteins.
- **Repressors** bind the DNA and **reduce or stop** transcription.

THE FOUR SWITCHES

P	**Promoter**	DNA: RNA polymerase binds
T	**Transcription factors**	proteins: help it attach
E	**Enhancer**	DNA: far away
R	**Repressor**	protein: blocks transcription

D2.2.1

From gene to *phenotype*

- Gene expression: how the information in a gene has an **effect on the phenotype**, through **what its protein does**, very often as an enzyme.
- **Example:** a non-functional tyrosinase makes little or no melanin: one form of **albinism**.

STAGE 1
Transcription
The gene is copied into mRNA.

STAGE 2
Translation
Ribosomes make the polypeptide.

STAGE 3
Function
Tyrosinase makes melanin.

D2.2.5

One genome, many *cells*

- **Genome:** all of a cell's DNA, the **same in nearly every cell** of one organism.
- **Transcriptome:** all the RNA transcribed at a given time.
  Proteome: all the proteins made.
- **No cell expresses all its genes**; the pattern decides **how it differentiates**.

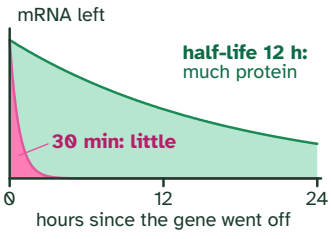
GENE	BETA CELL	RED CELL
Insulin	**on**	off
Haemoglobin	off	**on**
Rhodopsin	off	off
Respiration enzymes	**on**	**on**

Red cell: a red blood cell precursor.

D2.2.3

How long *mRNA* lasts

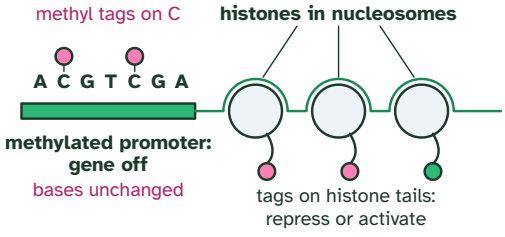
- Ribosomes translate an mRNA again and again until **nucleases** break it down.
- In human cells mRNA lasts from **minutes to days**. The longer it lasts, the **more protein** is made.
- Controlling breakdown **regulates translation**. Globin mRNA lasts a day or more; mRNA for some transcription factors, minutes.



D2.2.4, D2.2.6

Epigenetic *tags*, not new sequences

- **Epigenesis:** the development of **patterns of differentiation** as a zygote divides into the cells of an embryo.
- Epigenetic changes alter the **phenotype, not the genotype**: the DNA base sequence stays the same.
- **Promoter:** methyl groups on **cytosines in a promoter** repress transcription of the gene downstream.
- **Histones:** methyl groups on amino acids in histone tails can **repress or activate** transcription. How is beyond the course.



Tags that last, and signals from *outside*

D2.2.7, D2.2.9

Tags passed on, or *wiped clean*

- **Epigenetic inheritance:** a **phenotype passed on with no change in DNA sequence**: tags remain through mitosis or meiosis.
- **Mitosis:** enzymes methylate the new strand where the old one is tagged, so **a liver cell makes liver cells**.
- **Gametes:** most tags are **removed from egg and sperm**, so the zygote can make **every kind of cell**.
- **Not all:** some remain and **depend on the parent**, a gene off in one parent's copy and on in the other's. Many control growth.

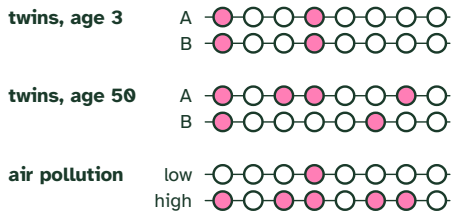
	LIGER	TIGON
Parents	Lion father, tigress mother	Tiger father, lioness mother
Size	**Larger than both parents**	No larger, often smaller
Tags	Strong growth genes, weak brakes	Weak growth genes, strong brakes

Same mix of genes: the tags differ. One explanation

D2.2.8, D2.2.10

The environment leaves *marks*

- Diet, stress, smoking and pollution can **add or remove tags**, changing gene expression.
- **Air pollution:** children who breathe more carry more methyl tags on an immune gene's promoter, and **express it less**.
- **Monozygotic twins** share their base sequence, so differences in their tags come from the **environment**.
- Twins' tags are alike when young and **differ more with age**, more so if they lived apart.

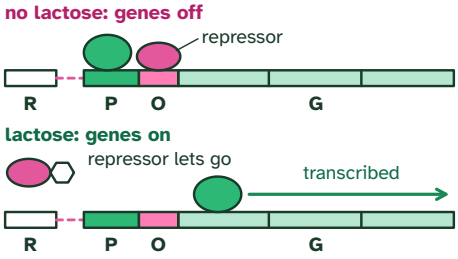


Pink: a methylated site. A cartoon of the pattern, not data.

D2.2.11

Signals from *outside*

- **Hormone:** oestrogen, a steroid, **passes through the membrane** and binds a receptor inside target cells (uterus lining).
- Together they act as a **transcription factor**, raising transcription of genes for growth and division.
- **Lactose in *E. coli*:** a repressor binds the **operator**, so RNA polymerase cannot transcribe the lac genes.
- A form of lactose **binds the repressor**, which lets go: enzymes are made **only when lactose is present**.



FOUR PARTS OF AN OPERON

R	**Regulatory gene**	makes the repressor
P	**Promoter**	RNA polymerase binds
O	**Operator**	the repressor binds
G	**Genes**	transcribed together

WATCH OUT

Six mistakes that *cost marks*

- ✕ **A promoter is DNA, not a protein.** Transcription factors, activators and repressors are the proteins that bind it.
- ✕ **A gene does not code for a trait.** It codes for a polypeptide; the trait comes from the protein.
- ✕ **Cells differ in the genes they express, not the genes they have.** A skin cell carries the insulin gene.
- ✕ **Methylation does not change the base.** A methylated C still pairs with G; the sequence reads as before.
- ✕ **Twins who differ have not changed genes.** Their tags, and so their expression, differ.
- ✕ **Ligers and tigons share their genes.** Only the parent each tag came from differs.

COVER THE SHEET

Can you *answer these?*

1. Outline how the tyrosinase gene affects skin colour.
2. Describe the roles of promoters, enhancers and transcription factors.
3. Explain how mRNA lifetime regulates translation.
4. Distinguish genome, transcriptome and proteome.
5. State the effects of promoter and of histone methylation.
6. Explain how tags keep a pattern of expression in mitosis.
7. Explain why ligers grow larger than tigons.
8. Outline what twin studies show about gene expression.
9. Describe how lactose switches on the lac operon.

IN THE EXAM

Name the DNA sequence and the protein that binds it, then whether transcription rises or falls. In epigenetics, add **"the base sequence is unchanged"**.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY | D2.3 | SL AND HL

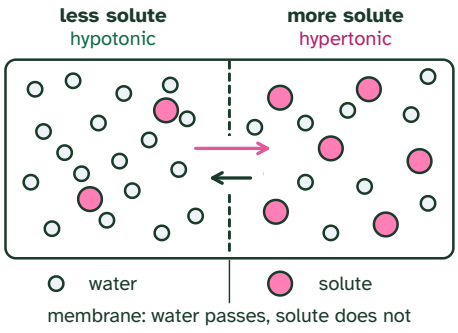
REVISION ON TWO PAGES

Water follows the *solute*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Water moves by osmosis towards the more concentrated solution. Whether a cell has a wall decides if it bursts or turns turgid.



Read it like this. Water crosses both ways; more crosses into the more concentrated side.

D2.3.2 and 3 START HERE

Water goes to the *higher* solute concentration

- **Osmosis:** the net movement of water across a **partially permeable membrane**, which lets water through but not the solute.
- Water crosses both ways all the time. More crosses **from the less concentrated solution to the more concentrated** one, so that is the net direction.
- A cell in a **hypotonic** solution **gains water**; in a **hypertonic** one it **loses water**.
- **Isotonic:** water still crosses, as fast each way. This is a **dynamic equilibrium**, with no net change, not no movement.

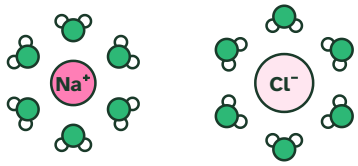
COMPARE BY SOLUTE CONCENTRATION — *never by "water concentration"*

Hypertonic	Hypotonic	Isotonic
more solute than the other solution	less solute than the other solution	the same solute concentration

D2.3.1

Solvation in water

- Water is polar: a δ− oxygen and two δ+ hydrogens.
- **Ions:** water is **attracted to both positive and negative ions** and wraps each in a shell: solvation.
- **Polar molecules** such as glucose form **hydrogen bonds** with water through their –OH groups.



oxygens (δ−) face in — hydrogens (δ+) face in

D2.3.5

No wall, *no limit*

- **Hypotonic:** the cell **swells and can burst**. **Hypertonic:** it shrinks; a red blood cell puckers: **crenation**.
- **Freshwater unicells** such as *Paramecium*: a **contractile vacuole** pumps out the water that keeps entering, using ATP.
- **Multicellular animals** keep blood plasma and **tissue fluid isotonic** with their cells.



swells, bursts — no net change — crenated

D2.3.6

The wall *pushes back*

- **Hypotonic:** the membrane presses on the wall, which presses back: **turgor pressure**. No bursting.
- **Isotonic: flaccid**, the membrane just touching the wall.
- **Hypertonic:** the membrane **pulls away from the wall**: **plasmolysis**. Outside solution fills the gap.

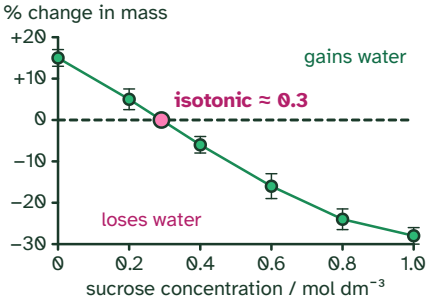


turgid — flaccid — plasmolysed

D2.3.4 APPLICATION OF SKILLS

Potato cores in *sucrose*

- Weigh and measure cores, soak them in a range of sucrose solutions, then **blot** and weigh again.
- **Hypotonic:** cores gain mass, lengthen, go firm. **Hypertonic:** they lose mass, shorten, go floppy.
- Use **percentage change**, so cores of different sizes compare fairly.
- Where the mean line **crosses zero** is the isotonic concentration, usually between two tested points.



Repeats reliability
Give a **standard deviation** for each set and a **standard error** of the mean, drawn as error bars. No formulae to learn.

Mass or length which to trust
Mass changes are **larger** and measured **more precisely**, so they usually give the clearer result.

Isotonic solutions and *water potential*

D2.3.7

Isotonic in medicine

- Isotonic solutions cause **no net water movement**, so cells keep their size and shape.
- Isotonic means the same **solute concentration** as the cells, not the same substance.
- Some drips carry **glucose** at a strength that keeps them close to isotonic too.

EXAMPLE 1

Intravenous fluids

A drip runs straight into the blood. Normal saline, 0.9% NaCl, replaces water and salts; pure water would burst red blood cells.

EXAMPLE 2

Donor organs

A kidney for transplant is flushed and bathed in a cold isotonic solution. The cold slows its metabolism.

D2.3.8 and 9 HIGHER LEVEL

Water runs *downhill*

- **Water potential, ψ:** the **potential energy of water per unit volume**, in **kilopascals (kPa)**.
- It cannot be measured absolutely, so it is given **relative to pure water** at atmospheric pressure and 20 °C, set at zero.
- Water moves from **higher to lower water potential**, from higher to lower potential energy, as a ball rolls downhill.
- Solutes lower ψ, so any solution is negative. Pressure raises it.

0 kPa
pure water: the reference

−800 < −300
more negative is lower

D2.3.10 and 11 HIGHER LEVEL

$\psi = \psi s + \psi p$ in cells with walls

PART	WHAT IT IS	VALUES
ψs solute potential	Set by the dissolved solutes	**Zero** for pure water, **negative** for any solution: more solute, more negative
ψp pressure potential	The pressure of the contents on the wall	**Positive** in turgid cells, **zero** when flaccid, **negative** in xylem under tension

Into pure water hypotonic

Flaccid cell: ψ = −800 + 0 = −800 kPa, below 0, so water enters. ψp rises until ψ = 0: **turgid**, ψp about equal and opposite to ψs.

Into −1200 kPa hypertonic

The cell (−800) is higher, so water leaves. ψp falls to zero, the membrane pulls away, and water leaves until ψs = −1200: **plasmolysed**.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Say "towards the higher solute concentration".** The IB wants solute concentration, never "water concentration".
- ✕ **Isotonic is not no movement.** Water crosses both ways at the same rate: a dynamic equilibrium.
- ✕ **Hypotonic and hypertonic compare two solutions.** Say what the solution is hypotonic to: "hypotonic to the cell".
- ✕ **A turgid plant cell does not burst.** The wall presses back; only cells with no wall burst.
- ✕ **The gap in a plasmolysed cell is not empty.** It fills with outside solution, which passes freely through the wall.
- ✕ **−800 kPa is lower than −300 kPa.** Water moves to the more negative ψ; a turgid cell in pure water has ψ = 0.

COVER THE SHEET

Can you *answer these?*

1. Describe how a sodium ion and a chloride ion are each surrounded by water.
2. State the direction of net water movement between a hypotonic and a hypertonic solution.
3. Explain why water still crosses the membrane of a cell in an isotonic solution.
4. Outline how to find the isotonic sucrose concentration of potato tissue.
5. Compare what happens to a red blood cell and a plant cell in pure water.
6. Explain why intravenous fluids and organ storage solutions are isotonic.
7. State the reference point for water potential and its units. HL
8. Explain, using ψs and ψp, why a plant cell becomes turgid in pure water. HL

IN THE EXAM

Name the solutions by solute concentration ("the solution is hypertonic to the cell"), then **give the net direction** and its effect on the cell. With water potentials, **add ψs and ψp before comparing**: ψs alone gives the wrong answer.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY | D3.1 | SL AND HL

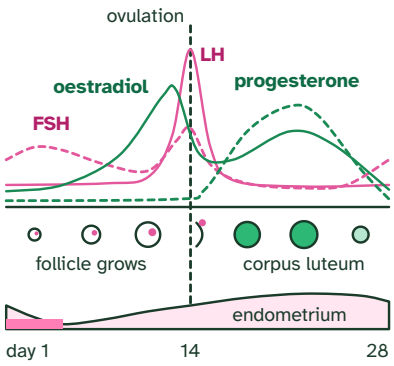
REVISION ON TWO PAGES

How new *life* begins

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Meiosis breaks up the parents' allele combinations and fertilization makes new ones. In humans, hormones time every step.



Read it like this. Pink: pituitary hormones. Green: ovarian. Dashed: FSH and progesterone. Pink band: the period.

D3.1.5 START HERE

Two cycles, four *hormones*

- **From the pituitary:** FSH and LH. **From the ovary:** oestradiol and progesterone. The ovarian and uterine cycles together are the **menstrual cycle**.
- Oestradiol first **inhibits FSH and LH** (negative feedback); at a high level it **triggers the LH surge** (positive feedback).

DAYS 1 TO 13
Follicle
FSH grows a follicle; its oestradiol rebuilds the lining.

ABOUT DAY 14
Ovulation
The LH surge makes the follicle release its egg.

DAYS 15 TO 28
Corpus luteum
Its progesterone keeps the lining thick and inhibits FSH and LH.

NO EMBRYO
Period
Progesterone and oestradiol fall; the lining is shed.

D3.1.1 and 2

Copies or *combinations*

Asexual mitosis
Identical offspring, suited to the environment the parent is **adapted** to.

Sexual meiosis
New combinations of alleles: variation to adapt when the environment changes.

- **Meiosis breaks up the parental combinations** of alleles.
- **Fusion of gametes** (fertilization) **makes new combinations**.

D3.1.3

One travels, one *waits*

- The **male gamete travels** to the female one, so it is **small**, with almost no food.
- The egg stays put, so it can be **large**, with food reserves.
- So males make **vast numbers** of gametes; females make few and invest more in each.

10^8
sperm a day

1
egg a cycle

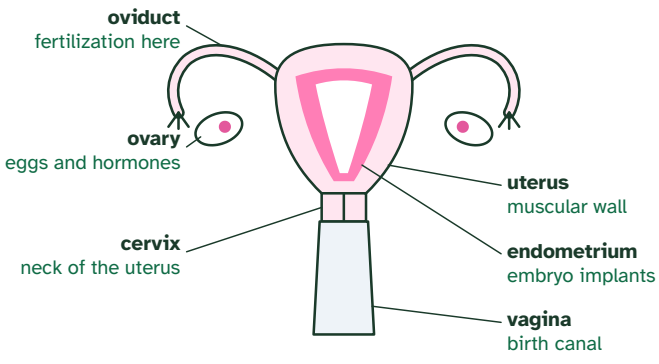
D3.1.6 and 7

Fertilization and *IVF*

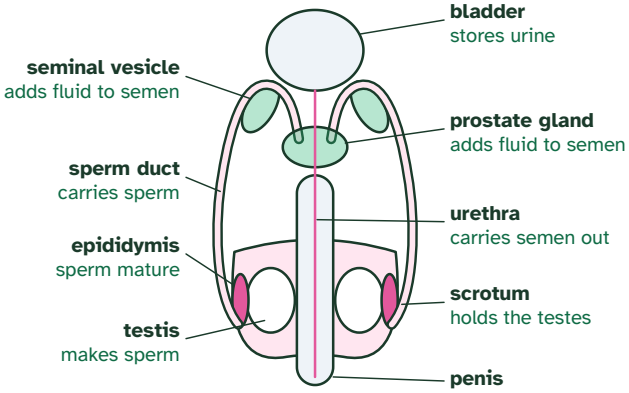
- The sperm's membrane **fuses with the egg's**; its nucleus enters, its **tail and mitochondria** are destroyed.
- Both nuclear membranes dissolve; all the chromosomes join a **joint mitosis**: two diploid nuclei.
- **IVF:** a drug **suspends** her own FSH and LH; artificial FSH doses cause **superovulation**.
- A trigger (usually hCG) matures the eggs; they are fertilized in a dish and an embryo placed in the uterus.

D3.1.4 SKILLS: NAME EACH PART AND ITS JOB

Draw and *annotate* both systems



Female-typical, from the front

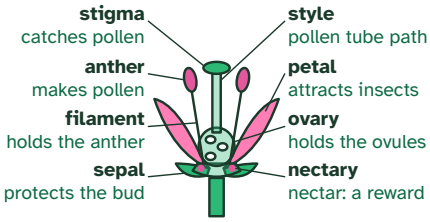


Male-typical, from the front

Flowers and seeds, then *pregnancy*

D3.1.8 to 10 OUTSIDE IN: SWEET PEAS SMELL CLEAN

From *pollen* to seed



- **Gametes:** the egg cell forms in an **ovule**; male gametes inside **pollen grains**, made in anthers.
- **Pollination**: pollen from anther to stigma. A **pollen tube** grows down the style; a male gamete fuses with the egg; the zygote grows into an **embryo**.
- It is **sexual even in a hermaphrodite** flower: male and female gametes still fuse.
- **Cross-pollination**, by animals or wind, is made likelier: pollen and stigma **ripen at different times**, or there are **separate male and female** flowers or plants.

D3.1.11

Refusing its *own* pollen

- **Selfing is inbreeding:** more offspring with two copies of an allele, so **diversity and vigour fall**.
- **Self-incompatibility**: genes stop its own pollen fertilizing it, so gametes are **from different plants**.

D3.1.12

Seeds that travel and *wake*

- **Dispersal** moves seeds from the parent, after fertilization: **less competition**. Pollination comes before.
- **Germination** needs water, oxygen and warmth ("*Wow! Oh, wow!*"). The radicle grows first.
- **Enzymes mobilise the food store** for the growing tips.

D3.1.13 to 20 HIGHER LEVEL

Puberty, gametes and *pregnancy*

STATEMENT	THE POINT	WHAT TO KNOW
Puberty D3.1.13	**GnRH starts it**	The hypothalamus releases more GnRH, so the pituitary releases more LH and FSH, so the gonads make more sex hormones: the changes of puberty.
Gametogenesis D3.1.14	**4 sperm, 1 egg**	Both: mitosis, growth, two meiotic divisions, differentiation. Sperm: four equal cells, from puberty. Egg: unequal divisions give one egg and polar bodies, from before birth.
Polyspermy D3.1.15	**One sperm only**	**Acrosome reaction** (sperm): enzymes digest a path through the zona pellucida. **Cortical reaction** (egg): enzymes change the zona, so no other sperm pass.
Blastocyst D3.1.16	**A ball, then implant**	The zygote divides by mitosis in the oviduct: a hollow ball of cells by about day 5. About a week after fertilization it implants in the endometrium.
Pregnancy test D3.1.17	**It detects hCG**	The embryo, then the placenta, secretes hCG; some reaches the urine. A free coloured monoclonal antibody binds it; a fixed one holds it at the test line.
Placenta D3.1.18	**Villi: a large area**	The two bloods never mix. To the foetus: oxygen, glucose, amino acids, antibodies; back: CO_2 and urea. So the foetus stays in the uterus to a later stage.
Pregnancy D3.1.19, birth	**Progesterone**	From the corpus luteum (kept alive by hCG), then the placenta. At birth it falls, so oxytocin rises: contractions stretch the cervix, more oxytocin: positive feedback.
HRT D3.1.20, NOS	**Correlation only**	Early studies: less coronary heart disease (CHD) with HRT. Randomized controlled trials: a small increase. HRT users had higher socioeconomic status, which itself lowers CHD risk.

WATCH OUT

Four mistakes that *cost marks*

- ✕ **Pollination is not fertilization.** It only delivers the pollen.
- ✕ **Gametes are made by meiosis, not mitosis.** The zygote has 46 chromosomes, not 23.
- ✕ **LH triggers ovulation; falling progesterone brings the period.** LH does not cause menstruation.
- ✕ **The acrosome reaction is the sperm's; the cortical reaction is the egg's.** Two events, not one.

COVER THE SHEET

Can you *answer these?*

1. Compare sexual with asexual reproduction.
2. Draw the female system and annotate four parts.
3. Explain the feedback in the menstrual cycle, and in IVF.
4. Draw and annotate an insect-pollinated flower.
5. Compare spermatogenesis with oogenesis. HL
6. Explain the hormonal control of childbirth. HL
7. Explain why early HRT studies misled. HL

IN THE EXAM

Give each hormone its source and action ("LH from the pituitary triggers ovulation") and **name the feedback**.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY | D3.2 | SL AND HL

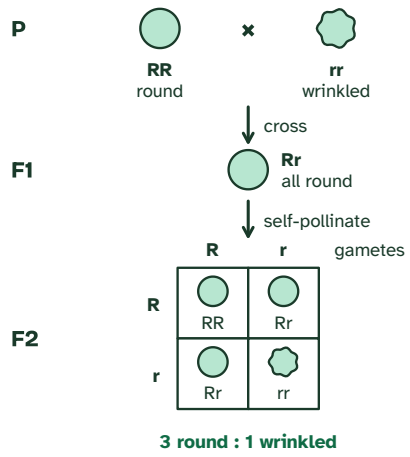
REVISION ON TWO PAGES

How genes are *inherited*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Each gamete carries one allele of every gene. Dominance, the environment and the chromosome a gene sits on decide what shows.



Draw it like this. Gametes on the edges of the Punnett grid. It gives chances, not exact counts.

D3.2.1, D3.2.2 START HERE

Halve, fuse, then *cross*

- Meiosis makes **haploid gametes**, one chromosome from each pair. Fertilisation fuses two into a **diploid zygote**, with **two copies of each autosomal gene**.
- This loop is shared by **all eukaryotes with a sexual life cycle**. In humans n = 23 and 2n = 46.
- **In flowering plants:** male gametes are in **pollen**, female gametes in ovules in the ovary, so a cross needs **pollination**.
- A pea flower makes both, so it can **self-fertilise**. For a cross, remove its anthers early and carry pollen from the other parent to its stigma.
- Breeders use crosses to make **new crop and ornamental varieties**.

THE GENERATIONS OF A CROSS

Parents, First, Follows

P	**P generation** the parents you choose
F1	**F1 generation** their offspring
F2	**F2 generation** offspring of two F1 plants

D3.2.3, D3.2.4

Genotype and *phenotype*

- A **gene** is one place on a chromosome; an **allele** is one version of it (Y or y).
- Genotype: the alleles you inherit. The same two: **homozygous** (YY, yy). Two different: **heterozygous** (Yy).
- Phenotype: the observable traits, from **genotype and environment**.
- **In humans:** ABO group is genotype only; a scar is environment only; height and skin colour are both.

D3.2.5

Dominant and *recessive*

- A **dominant** allele shows in one copy or two. A **recessive** allele shows only with no dominant allele.
- So **YY and Yy look the same**; only yy differs.
- **Why:** often the recessive allele makes no working protein, and **one working copy makes enough**.

YY	Yy	yy
yellow	yellow	green

D3.2.6

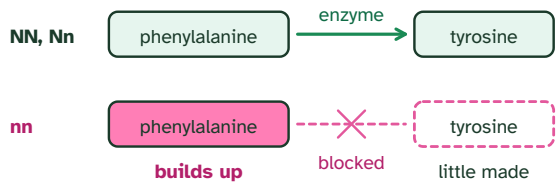
Phenotypic *plasticity*

- One genotype develops different traits in different conditions, by **varying gene expression**.
- **The genotype does not change**, and the change can be **reversible** in a lifetime.
- **Shade:** a cutting grows taller with broader leaves than one from the same plant in sun.
- **Also:** skin tans and fades; an Arctic hare is white in winter.

D3.2.7

PKU: one faulty *enzyme*

- An **autosomal recessive** disease. The gene codes for **phenylalanine hydroxylase**, which converts phenylalanine to tyrosine.
- **nn:** no working enzyme, so **phenylalanine builds up** and can damage the developing brain.
- **Nn carriers** have no symptoms. Two carriers: a **1 in 4 chance** of PKU for each child.
- Newborn screening and a **low-phenylalanine diet** change the phenotype, not the genotype.



D3.2.8 to 10

Many alleles; *codominance*

- **SNP**: a place in the genome where people differ by **a single base**.
- A gene pool can hold **any number of alleles** of a gene; a diploid individual inherits **only two**.

ABO	GROUP A	GROUP B	GROUP AB	GROUP O
Genotype	I^AI^A or I^Ai	I^BI^B or I^Bi	I^AI^B	ii
Marker	A	B	A and B	neither

Three alleles, four groups.

Apple, Banana, Both, Orange

Codominance dual phenotype
I^AI^B: red cells carry both the A and the B marker.

Incomplete dominance intermediate phenotype
Four o'clock, *Mirabilis jalapa*: C^RC^R red, C^WC^W white, C^RC^W pink. Pink × pink: 1 red : 2 pink : 1 white.

74

Sex, families, spreads and *two genes* at once

D3.2.11, D3.2.12

Sex and *haemophilia*

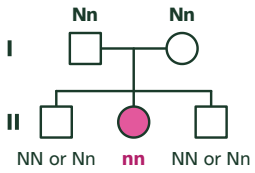
- XX female, XY male: the **sperm decides** male-typical or female-typical traits. The X has **far more genes** than the Y.
- **Haemophilia:** a recessive allele on the X, so a clotting protein is faulty. Write **X^H and X^h**; the Y gets no letter.
- A male has one X, so **one recessive allele shows**. Below, a carrier mother.

SPERM	EGG, NORMAL X	EGG, FAULTY X
X^H	X^HX^H girl	X^HX^h carrier girl
Y	X^HY boy	**X^hY haemophilia**

D3.2.13

Reading a *pedigree*

- **Nature of science:** find the pattern by **inductive reasoning**, then a person's genotype by **deductive reasoning**.
- Relatives' children are more often **homozygous for a harmful recessive**: the reason close-relative marriage is banned.

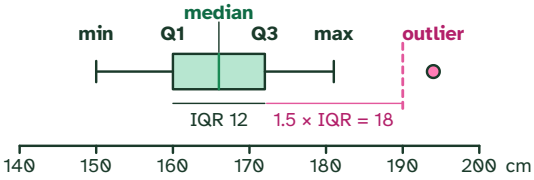


- Square male, circle female, **filled affected**.
- **Unaffected parents, affected child:** recessive.
- **Affected girl, unaffected father:** not X-linked recessive.

D3.2.14, D3.2.15

Continuous variation and *box plots*

- **Discrete:** a few types (ABO). **Continuous:** any value in a range, from **polygenic inheritance**, environment or both (skin colour).
- **Mean** sum ÷ number; **median** the middle value; **mode** the most frequent.
- **Box plot:** six aspects. An **outlier** is over **1.5 × IQR** beyond Q1 or Q3.



D3.2.16, D3.2.17 HIGHER LEVEL

Dihybrid crosses

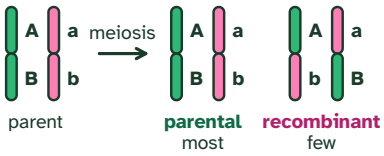
- **Segregation**: homologues part in meiosis I, one allele per gamete.
- **Independent assortment**: pairs line up either way; YyRr gives YR, Yr, yR, yr.
- YyRr × YyRr: **9 : 3 : 3 : 1**. YyRr × yyrr: **1 : 1 : 1 : 1**.
- **Nature of science:** Mendel's second law fails for linked genes.

9 : 3 : 3 : 1 is (3 : 1) × (3 : 1).

D3.2.18 to 20 HIGHER LEVEL

Linkage and *recombinants*

- A database gives a gene's **locus** and polypeptide: HBB and HBA1 are on different chromosomes; HBD is by HBB.
- **Linked genes** share a chromosome, so **fail to assort independently**. A crossover makes **recombinants**, seen in gametes, genotypes and phenotypes.



D3.2.21 HIGHER LEVEL

The *chi-squared* test

- **Null:** no real difference between O and E. **Alternative:** a real one.
- $\chi^2 = \Sigma (O - E)^2 \div E$; degrees of freedom (df) = classes − 1.
- Over the critical value at **p = 0.05**: **reject the null**.
- The F2 is a **sample** of the population.

3.84	7.81
critical, 1 df	critical, 3 df

WATCH OUT

Six mistakes that *cost marks*

- ✕ **A gene is not an allele.** Alleles are its versions.
- ✕ **Dominant does not mean common.** It only says what shows in a heterozygote.
- ✕ **Plasticity is not mutation.** The genotype stays.
- ✕ **Codominance is not intermediate.** AB cells carry both markers; a pink four o'clock is in between.
- ✕ **Sons never get X alleles from fathers.** They get his Y.
- ✕ **Not significant does not prove the null.** The data are just not enough to reject it.

COVER THE SHEET

Can you *answer these?*

1. Describe how to cross two pea plants.
2. Explain why YY and Yy have the same phenotype.
3. Outline phenotypic plasticity, and how PKU is treated.
4. Deduce the blood groups of children of $I^Ai \times I^Bi$.
5. Explain why haemophilia is commoner in males.
6. Distinguish inductive from deductive reasoning.
7. State the six aspects a box plot shows.
8. Explain why linked genes do not give 9 : 3 : 3 : 1. HL
9. State when a χ^2 test rejects the null hypothesis. HL

IN THE EXAM

Show every cross in order: parents' genotypes, gametes, Punnett grid, then the ratio in words. For sex linkage, put alleles on the X (X^hY).

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY | D3.3 | SL AND HL

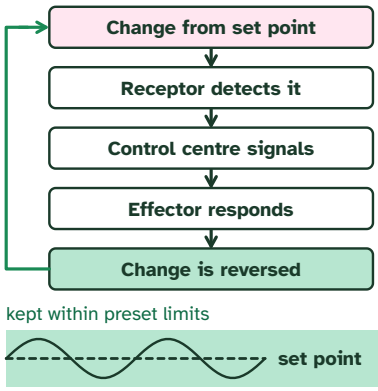
REVISION ON TWO PAGES

Keeping the inside *steady*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

A receptor, a control centre and an effector hold each variable near its set point. The response always reverses the change: negative feedback.



Negative does not mean bad. It means the response opposes the change.

D3.3.1, D3.3.2 START HERE

Homeostasis by *negative feedback*

- **Homeostasis**: keeping the internal environment within **preset limits** around a set point, even when conditions outside change.
- Every loop has a **receptor**, a **control centre** and an **effector**. The **response reverses the change**, so it is negative feedback.
- It works **from above and below** the set point, and switches itself off once the change is reversed.
- **Not positive feedback:** that makes the change bigger, so the variable **runs away from the set point**. It suits all-or-nothing events such as childbirth.

FOUR VARIABLES HELD STEADY IN HUMANS

T Temperature	**P** pH	**G** Glucose	**O** Osmotic
core about 37 °C	blood 7.35 to 7.45	4 to 6 mmol L^{-1} fasting	blood about 0.3 osmol L^{-1}

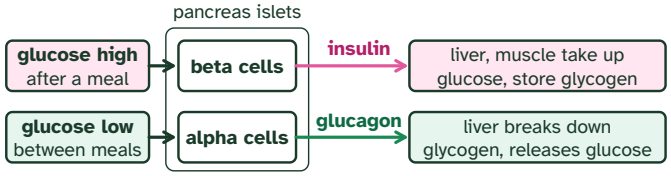
D3.3.3

Blood glucose: *two hormones*

- Hormones travel in the blood; only **target cells with the receptor** respond. The control centre is the **pancreas**.
- **High: beta cells** secrete **insulin**; target cells take up glucose. **Low: alpha cells** secrete **glucagon**; the liver releases glucose.

THE INSULIN RESPONSE — *BITS*

B Beta cells detect high glucose	**I** Insulin secreted into blood	**T** Target cells take up glucose	**S** Store the extra as glycogen



D3.3.4

When control breaks: *diabetes*

- Diabetes is a **long-term failure to control blood glucose**.

Type 1 little or no insulin
The **immune system destroys the beta cells**. Usually starts young; cannot yet be prevented. **Treat:** monitor glucose, inject insulin.

Type 2 insulin resistance
Insulin is made but **target cells respond poorly**. **Risks:** obesity, inactivity, a diet high in sugar and fat, age, family history. **Prevent, treat:** diet, exercise, healthy body mass; then drugs.

- High glucose with **plenty of insulin** points to **type 2**; with little insulin, type 1.

D3.3.5, D3.3.6

Thermoregulation: keeping heat in, *letting it out*

- **Receptors: peripheral thermoreceptors** in the skin; the hypothalamus senses the blood.
- **Control centre:** the **hypothalamus**; nerve impulses go to muscle, adipose tissue and skin.
- **Hormones:** the **pituitary** releases TSH; the thyroid releases **thyroxin**, raising metabolic rate.
- Birds and mammals also use **behaviour**; only human details are needed.

EFFECTOR	TOO COLD	TOO HOT
Skin arterioles	**Vasoconstriction**: less warm blood near the surface, less heat lost.	**Vasodilation**: more blood near the surface; heat lost by radiation.
Sweat glands	Little sweat.	**Sweat** evaporates, taking heat away.
Skeletal muscle	**Shivering** makes heat.	No shivering.
Hair erector muscles	**Hair erection** traps air (little use in people).	Hairs lie flat.
Brown adipose tissue	**Uncoupled respiration**: protons bypass ATP synthase, so energy is released as heat, not ATP.	Less heat made.

D3.3.7 to D3.3.10 HIGHER LEVEL

The kidney: filter, then *take back*

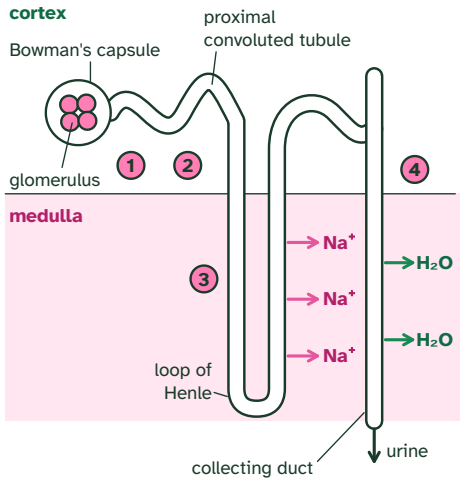
- **Excretion**: removing **waste products of metabolism**, such as urea (made in the liver from excess amino acids).
- **Osmoregulation**: keeping blood **osmotic concentration** within narrow limits, about 0.3 osmol L^{-1} (osmoles per litre).

1 · GLOMERULUS
Ultrafiltration
High pressure forces water and small solutes into Bowman's capsule. Blood cells and large proteins stay in the blood.

2 · PROXIMAL CONVOLUTED TUBULE
Reabsorption
All the glucose and most ions return by active transport; water follows by osmosis. Urea mostly stays: it is excreted.

3 · LOOP OF HENLE
A salty medulla
The ascending limb pumps Na^+ out actively and is impermeable to water, so the medulla stays concentrated.

4 · COLLECTING DUCT
Water taken back
Aquaporins let water leave by osmosis into the salty medulla. Water is never pumped.



Pink: Na^+ pumped out. Green: water leaving by osmosis.

- Concentrated blood: **osmoreceptors in the hypothalamus** detect it, the **pituitary releases more ADH**, and **vesicles fuse with the membrane**, adding aquaporins.
- After drinking a lot: ADH falls and aquaporins are taken back **into vesicles**, so plenty of dilute urine is made.

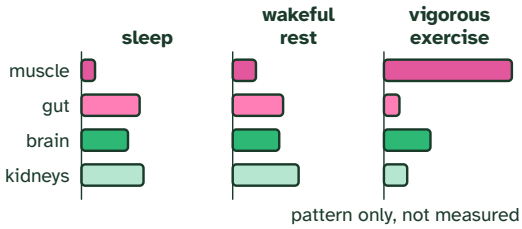
BLOOD TOO CONCENTRATED — *OAARS*

O Osmoreceptors detect it	**A** ADH from pituitary	**A** Aquaporins into membrane	**R** Reabsorb more water	**S** Small concentrated urine

D3.3.11 HIGHER LEVEL

Blood goes where it is *needed*

- Arterioles share out the blood: smooth muscle relaxes to **dilate** (more flow) or contracts to **constrict** (less).
- **Vigorous exercise:** muscles get **most of the blood**; gut and kidneys much less. **Wakeful rest:** shared more evenly. **Sleep:** muscles need little.
- The **brain gets a steady supply** at all times.



pattern only, not measured

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Negative feedback is not bad feedback.** The response opposes the change, from above or below.
- ✕ **Glucagon is a hormone; glycogen is the store.** Spell both carefully.
- ✕ **Type 1 is not caused by sugar.** It is an immune attack on the beta cells.
- ✕ **Vessels do not move to the skin.** Skin arterioles change width, changing the flow near the surface.
- ✕ **Brown fat makes heat, not ATP.** Protons bypass ATP synthase.
- ✕ **Excretion is not osmoregulation.** Removing urea is excretion; controlling water is osmoregulation.

COVER THE SHEET

Can you *answer these?*

1. State four variables kept steady by homeostasis.
2. Explain why homeostasis uses negative feedback.
3. Describe how blood glucose falls after a meal.
4. Distinguish type 1 from type 2 diabetes.
5. Outline the roles of the hypothalamus and thyroxin.
6. Explain how vasodilation and sweating cool you.
7. Distinguish excretion from osmoregulation. HL
8. Outline ultrafiltration and reabsorption. HL
9. Explain how the loop of Henle helps save water. HL
10. Describe how ADH changes the collecting duct. HL
11. Compare blood flow to muscle in sleep and exercise. HL

IN THE EXAM

In a feedback answer, name all four parts: receptor, control centre, effector and a response that **reverses the change**, from above or below the set point.

GO FURTHER

Animated figures, a dry lab and a marked Check are in the full guide online.

IB BIOLOGY | D4.1 | SL AND HL

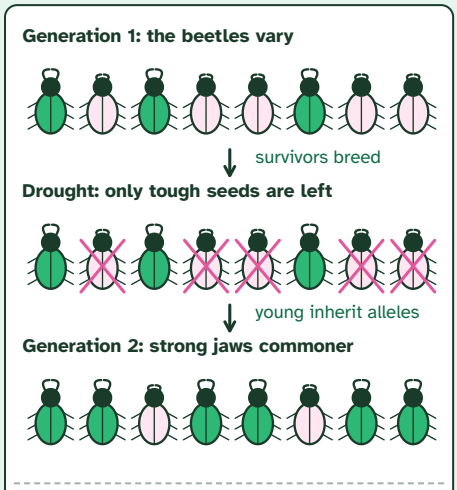
REVISION ON TWO PAGES

Who survives, who *breeds*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Individuals vary and more are born than survive. Those best suited leave more offspring, so their heritable traits become commoner.



Green: strong jaws for tough seeds. No beetle changed; the population did.

D4.1.1 START HERE

The mechanism of *evolution*

- **Natural selection** drives evolution: individuals whose traits suit the conditions **leave more offspring**, so those traits become commoner.
- It never stops: it sorts every generation **over billions of years**, giving the **biodiversity of life**. Nothing tries and nothing is planned.
- **Nature of science:** Darwin's theory **replaced Lamarckism** (changes from use and disuse passed on): a **paradigm shift**, one explanation replaced by a better one.

THE LOGIC, IN ORDER (A TEACHING AID) *Icy Cubs Eat Anything Growing Enormous*

I Inherited variation heritable differences	**C** Competition more young than resources	**E** Environment pressures sort them
A Adaptations helpful traits selected	**G** Genes allele frequencies shift	**E** Evolution the population changed

D4.1.2

Sources of *variation*

- Selection can only choose between individuals that **differ in their alleles**.
- Mutations arise **by chance**, never because they are needed.

Mutation new alleles
A change in the base sequence: the **only source of new alleles**. In animals, only in cells that make gametes.

Sexual reproduction new mixes
Crossing over, independent assortment and fertilisation **shuffle existing alleles**.

D4.1.3, D4.1.4

Competition and *pressures*

- **Overproduction**: far more offspring than survive (a frog lays hundreds or thousands of eggs).
- **Carrying capacity** is set by what runs short: **food, water, shelter, space**; for plants, light and minerals.
- So they **compete**, and the winners leave more offspring.
- **Abiotic:** heat, frost or drought is **density-independent**: a frost kills about the same share of a sparse or crowded patch.

D4.1.5, D4.1.6

Fitness and heredity

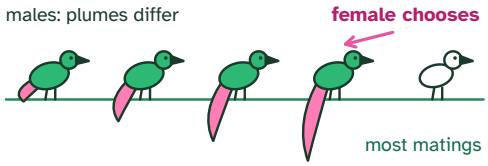
- In **intraspecific competition** for limited food, the better adapted are more likely to survive and breed.
- **Fitness**: a genotype's **survival value** (living to breed) and **reproductive potential** (offspring left).
- **Acquired traits are not heritable**: a body-builder's muscles are not in the base sequence of the genes in gametes.

0
fitness of a cat that lives 15 years but raises no kittens

D4.1.7

Sexual selection

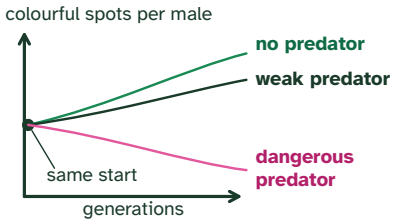
- Selection for **success in getting mates**: one sex (usually males) competes (**intrasexual**), or one (usually females) chooses (**intersexual**).
- A trait that wins mates is often a **sign of overall fitness**.
- **Birds of paradise:** males with the finest **plumage** and displays leave most young.
- **Cost:** long feathers hinder flight; bright colour draws predators.



D4.1.8 APPLICATION OF SKILLS

Endler's *guppies*

- Females prefer colourful males (**sexual selection**); predators see them (**natural selection**).
- Ponds **the same except the predator**: none, weak or dangerous; a model of the streams.
- **Result:** a dangerous predator gave **fewer, duller spots**; none or a weak one, more colour.
- **Interpret: differences between ponds** show selection.



Selection in the *gene pool*

D4.1.9 to D4.1.11 HIGHER LEVEL

The *gene pool* and neo-Darwinism

- A **gene pool** is all the genes, and their different alleles, in a population.
- **Allele frequency**: copies of one allele ÷ all alleles of the gene.
- **Database skill: isolated populations** differ. The sickle-cell allele (rs334) is very rare in northern Europe, common in parts of West Africa.
- **Neo-Darwinism:** selection joined to genetics. Evolution is a **change in allele frequencies**.

0.5 → 0.625
J after a drought kills the 4 jj of 20 beetles (20 J of 32 left)

D4.1.15 HIGHER LEVEL

Artificial selection

- Breeders **deliberately choose** which crops or domestic animals breed; the alleles for the chosen traits become commoner.
- The mechanism is the same as natural selection: **heritable variation** sorted by who breeds.

Artificial deliberate
A person chooses the parents; the change is the aim.

Antibiotic resistance natural selection
An **unintended consequence**: the drug kills susceptible bacteria and spares the resistant ones, which already existed.

D4.1.12 HIGHER LEVEL

Directional, stabilising, disruptive



- **Directional:** antibiotic resistance in bacteria.
- **Stabilising:** human birth weight.
- All three **change allele frequencies**, even stabilising: alleles for the extremes become rarer.

Remember: *Drive, Squeeze, Divide*

D4.1.13, D4.1.14 HIGHER LEVEL

The *Hardy-Weinberg* equation

- **p + q = 1**; random mating gives **$p^2 + 2pq + q^2 = 1$** (AA, Aa, aa).
- **Working back:** 18 of 200 beetles are recessive: $q^2 = 0.09$, q = 0.3, p = 0.7, 2pq = 0.42 (84 carriers).
- **Not a fit?** A condition fails, such as **non-random mating** or survival differing between genotypes.

CONDITIONS FOR EQUILIBRIUM

Large Rats Make Most Spaghetti

L Large population	**R** Random mating	**M** Migration none	**M** Mutation none	**S** Selection none

eggs \ sperm	A p = 0.6	a q = 0.4
A p	AA p^2 0.36	Aa pq 0.24
a q	Aa pq 0.24	aa q^2 0.16

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Individuals do not evolve.** Populations do, over generations.
- ✕ **Mutations are not a response to need.** They arise by chance.
- ✕ **Fittest is not strongest.** It means most offspring that breed.
- ✕ **Acquired traits are not inherited.** Training changes muscles, not the genes in gametes.
- ✕ **Stabilising selection still changes allele frequencies.** The mean stays; the extremes go.
- ✕ **Antibiotic resistance is not artificial selection.** Nobody chose which bacteria bred.

COVER THE SHEET

Can you *answer these?*

1. Explain why replacing Lamarckism was a paradigm shift.
2. Distinguish the roles of mutation and sexual reproduction.
3. Outline how overproduction and frost act in selection.
4. Explain why an acquired trait cannot evolve.
5. Describe sexual selection in birds of paradise.
6. Deduce why dangerous-predator ponds had duller guppies.
7. Outline what a gene pool is. HL
8. Distinguish stabilising from disruptive selection. HL
9. Calculate p if 16% show a recessive trait. HL
10. Explain why resistance is natural selection. HL

IN THE EXAM

Explain in ICE AGE order: variation, competition, a named pressure, **the better adapted leave more offspring**, then **allele frequencies change** in the population.

GO FURTHER

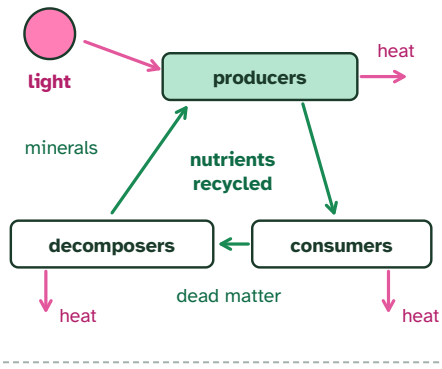
Animated figures, a dry lab and a marked Check are in the full guide online.

Ecosystems that *last*

What keeps them stable, and how people tip them. What to know, draw and say.

THE ONE IDEA

An ecosystem stays stable while energy flows in, nutrients cycle and its species can cope. People can push it past that.



Energy flows, matter cycles. Light in, heat out; the same atoms go round.

D4.2.1, D4.2.2 START HERE

What keeps an ecosystem *stable*

- **Stability:** the **same community and processes** carry on for a very long time. Populations still rise and fall, but stay within limits.
- **Evidence:** the **Daintree** rainforest has lasted over 100 million years, the **Namib** desert at least 55 million. Fossil pollen, the age of the rocks and ancient lineages show it.
- A stable ecosystem needs **all four** things below. Lose any one and it starts to change.

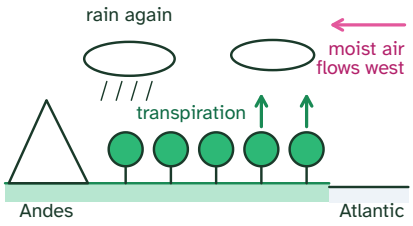
THE FOUR REQUIREMENTS — *Every Nest Gets Care*

E Energy: a constant supply, almost always sunlight	**N** Nutrients: recycled by decomposers	**G** Genetic diversity: variation, so populations can adapt	**C** Climate: temperature and rainfall within tolerance

D4.2.3

The Amazon: a *tipping point*

- Trees **transpire** vast amounts of water vapour. It **cools** the land, and moist air flows carry it west to fall as rain.
- **Deforestation** cuts transpiration: less rain, longer dry seasons. Below a **minimum area** the forest could die back to savanna.
- That area is **uncertain**: estimates range from about 20% to 40% loss.



Skill: % change = (new – original) ÷ original × 100. 4.0 to 3.3 million km² is **–17.5%**.

D4.2.4

A model in a *jar*

- A **mesocosm** is a small model ecosystem that can be controlled and repeated, to test one variable.
- Aquatic or microbial ones work better than terrestrial ones. Care for any animals under IB guidelines.
- **Example:** a sealed jar of pondweed, snails and pond-mud microbes can stay balanced for months.

Sealed glass vessel better
No matter enters or leaves, so nutrients must be recycled inside. **Energy still crosses**: light in, heat out.

Open tank weaker
Matter can enter and leave, so the model is not a closed system.

D4.2.5

Keystone species

- A keystone species has a **disproportionate effect** on community structure for its numbers. Remove it and the **ecosystem can collapse**.
- **Sea otters** eat sea urchins, which graze kelp. Without otters, urchins strip the kelp forest and the species living in it go.
- **Paine:** sea stars removed, mussels took over the rock.
- A keystone can be a predator, an ecosystem engineer or a mutualist.

15	8
species with sea stars	once they were removed

D4.2.6

Harvesting *sustainably*

- Sustainable when the **rate of harvesting is lower than the rate of replacement**.
- **Assess it by** monitoring population size, age structure and catch per unit effort.

Brazil nut a plant on land
Gathered from wild trees. Where gathering was heavy, **few young trees** were found: no replacement.

Atlantic cod a sea fish
Grand Banks trawlers took far more than replacement. The stock **collapsed in 1992**.

D4.2.7

Can a *farm* last?

- A farm is a simplified ecosystem: every harvest carries minerals away. Its sustainability depends on five factors.
- **Inputs:** nitrogen fertiliser is made with fossil fuel; phosphate is mined from rock that will run out.
- **Fixes:** cover crops and contour ploughing against erosion; fertiliser little and often; legumes and manure for nitrogen.

FIVE FACTORS — *Every Lazy Ivy Poisons Crops*

E Erosion of soil	**L** Leaching nutrients	**I** Inputs fertiliser	**P** Pollution chemicals	**C** Carbon footprint

Pollution, rewilding and *succession*

D4.2.8 IN ORDER: LITTLE ALGAE LOVE DIRTY DARK DITCHES

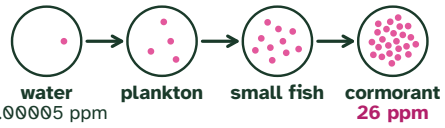
Eutrophication from leaching

LITTLE	ALGAE	LOVE	DIRTY	DARK	DITCHES
Leaching	**Algal bloom**	**Light blocked**	**Death**	**Decomposers**	**Deoxygenation**
Fertiliser washes in	Algae multiply	Plants below die	Algae die too	Bacteria: BOD rises	Fish die

D4.2.9

Biomagnification

- **DDT** and **mercury** are taken in faster than they are broken down or excreted: they **bioaccumulate**.
- Most prey biomass is respired, but the toxin stays: **concentration rises at each trophic level**.
- DDT thinned the eggshells of birds of prey; mercury harms the nervous system.



D4.2.10

Plastic in the *oceans*

- Plastics are **not biodegradable**: decomposers cannot digest most of them, so they persist.
- **NOS:** media coverage of research shifted public opinion, driving action.

Macroplastic visible
Entangles, blocks guts: turtles, seals, **Laysan albatross** chicks on Midway.

Microplastic under about 5 mm
Eaten by plankton and filter feeders; carries toxins up food chains.

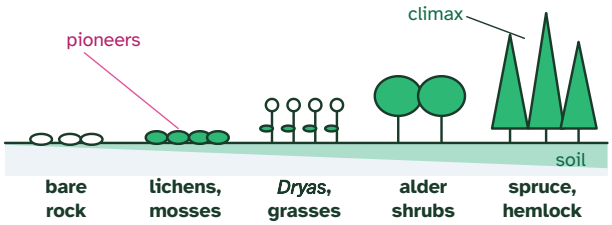
D4.2.11

Rewilding

- Restores **natural processes**: bring back **apex predators** and keystone species, reconnect habitats over large areas, minimise human impact.
- **Hinewai Reserve**, New Zealand: browsers kept out, **gorse left as a nurse crop**; native trees overtop it.
- **Yellowstone:** grey wolves returned in 1995; riverside trees grew back in places.

D4.2.12, D4.2.13 HIGHER LEVEL: GLACIER BAY, ALASKA

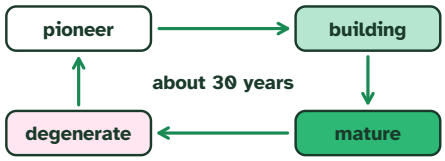
Succession and its *causes*



- Triggered by **abiotic** (glacier retreat, fire) or **biotic** (new species, disease) change. **Primary:** no soil at first; **pioneers** make it.
- Five things **increase**: plant size, primary production, species diversity, food web complexity, nutrient cycling (*Slowly Plants Spread Feeding Nature*).

D4.2.14, D4.2.15 HIGHER LEVEL

Cycles, climax and arrest



- **Cyclical:** heather (*Calluna vulgaris*; either name scores) patches cycle out of step: the moor stays the same.
- Succession tends to a **climax community**. **Arrested succession**: livestock graze tree seedlings; drained wetlands stay farmland.

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Stable is not unchanging.** Populations still rise and fall, but stay within limits.
- ✕ **Keystones need not be common.** Effect, not numbers.
- ✕ **A sealed jar still gets energy.** Light enters and heat leaves; only matter is sealed in.
- ✕ **Nitrate does not use up oxygen.** Bacteria decomposing the dead algae do: that is the BOD.
- ✕ **Microplastic is still plastic.** Breaking plastic up does not make it biodegradable.
- ✕ **Divide by the original area.** Not by the area left.

COVER THE SHEET

Can you *answer these?*

1. State the four requirements for stability.
2. Explain why the Amazon may have a tipping point.
3. Explain why a sealed mesocosm is the better model.
4. Outline why sea otters are a keystone species.
5. Outline how harvesting and farming can be sustainable.
6. Explain how leaching raises the BOD of a lake.
7. Explain why DDT is highest in top predators.
8. Outline two effects of plastic on marine life.
9. Outline how Hinewai Reserve was rewilded.
10. Outline primary and arrested succession. HL

IN THE EXAM

Answer eutrophication, the Amazon and biomagnification as chains: every link in order, each **naming its mechanism** (transpiration, BOD, respiration).

GO FURTHER

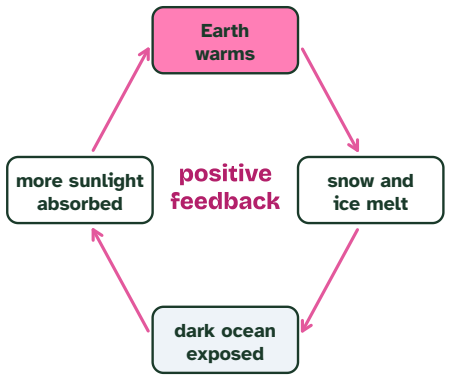
Films, a sealed-jar dry lab and a marked Check are in the full guide online.

When the climate *shifts*

What to know, what to draw and what to say. Nothing else.

THE ONE IDEA

Extra carbon dioxide and methane warm the Earth. Warming feeds itself, and habitats, ranges and the timing of life all move with it.



Follow the loop. Each turn adds more warming, so the feedback is positive.

D4.3.2 START HERE

Warming that makes *more warming*

- A **positive feedback cycle**: a change sets off effects that make the same change bigger, so warming becomes faster warming.
- **Snow and ice** reflect most sunlight (**high albedo**). As they melt, the dark ocean beneath absorbs that light, warms and melts more ice.
- **The other loops add carbon:** warm water **holds less dissolved CO_2**; peat and permafrost decompose; thawing permafrost **releases methane**; drought brings more fires.

THE FIVE FEEDBACK LOOPS

Icy Oceans Push Polar Fires

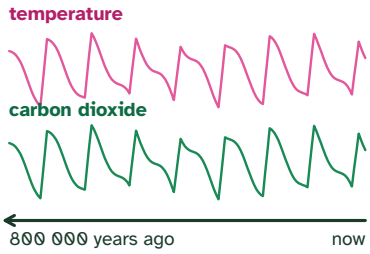
I Ice less sunlight reflected	**O** Ocean deep CO_2 released	**P** Peat dries and decomposes	**P** Permafrost CO_2 and methane	**F** Fires drought burns carbon

D4.3.1

The *anthropogenic* causes

- **Greenhouse effect:** greenhouse gases absorb infrared from the warm surface and re-emit some back down. Adding more **strengthens the effect**.
- **Carbon dioxide:** mostly **burning coal, oil and gas**; also clearing forests and making cement.
- **Methane:** cattle and sheep, rice paddies, landfill, gas and coal leaks. Stronger per molecule, but it lasts only about a decade.

Methane sources: *Cows Rarely Leave Gas*



Ice cores: the two rise and fall together. Shape only, not data.

Correlation not proof
Positive: both increase together. **Negative:** one increases as the other decreases.

Causation other evidence
CO_2 **absorbs infrared**, shown in the lab and by satellites. That confirms the link.

D4.3.3

The taiga *tips*

- Boreal forest (taiga) has long stored more carbon than it loses: **net carbon accumulation**.
- Warmer temperatures and **less winter snow** bring drought: primary production falls and trees brown (**forest browning**).
- Fires grow more frequent and intense, burning centuries of soil carbon: **legacy carbon combustion**.
- When losses beat growth, the forest flips from sink to source: a **tipping point**.

BEFORE
Net sink
Growth beats losses.

AFTER
Net source
Fire and decay beat growth.

D4.3.4 POLAR HABITATS

Ice that *leaves early*

- **Landfast ice** is sea ice frozen to the coast; **sea ice** floats free. Warming melts both earlier, so animals lose habitat.
- Emperors raise one chick a year, so they **cannot replace many lost years**.
- Either the common or the scientific name is accepted in an exam.

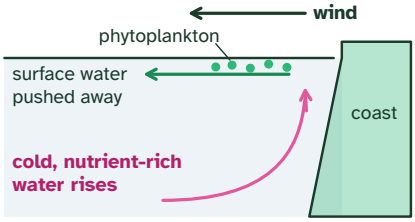
Emperor penguin *Aptenodytes forsteri*
Breeds on Antarctic landfast ice. **Early break-out** drops chicks into the sea before they can swim.

Walrus *Odobenus rosmarus*
Rests on Arctic sea ice between dives. As it retreats, walruses **haul out on land**, far from food.

D4.3.5

When *upwelling* fails

- **Upwelling:** winds push surface water from a coast and **cold, nutrient-rich water rises**.
- A warmer surface is lighter, so layers stop mixing: upwelling **weakens, starts later or stops**.
- Fewer nutrients: **primary production falls**, so less energy flows up marine food chains.

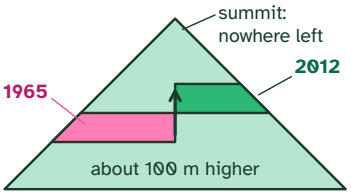


Reefs, ranges and the *timing* of life

D4.3.6

Shifting *ranges*

- Warming moves each species' zone **poleward and upslope**; populations follow by dispersal.
- **New Guinea:** most bird species on Mount Karimui **moved uphill**, about 100 m, from 1965 to 2012.
- **North American trees:** many **spread north**; more **contract** in the south.



D4.3.7

Coral reefs *collapse*

- Polyps build reefs of **calcium carbonate**. **Zooxanthellae**, algae in their cells, give most of their food.
- **Loss of corals** collapses the reef ecosystem, home to a quarter of marine species.

More CO_2 acidification
Carbonic acid uses up carbonate ions: **calcification is suppressed**.

Warmer water bleaching
Weeks at 1 °C over the usual summer maximum: corals **expel their zooxanthellae**, whiten and starve.

D4.3.8

Putting carbon *back*

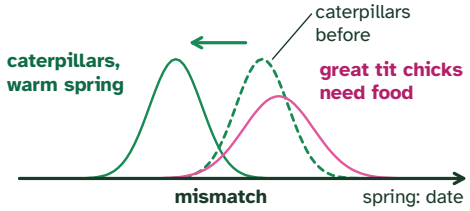
- **Afforestation:** planting trees where no forest has grown for a long time.
- **Forest regeneration:** letting a cleared or burnt forest grow back.
- **Peat restoration:** re-wetting drained bogs. Peat forms in **waterlogged soil**, in temperate and boreal zones, and very fast in some tropical swamps.

NATURE OF SCIENCE
Still debated
Non-native plantations or **rewilding with natives**: which sequesters more carbon?

D4.3.9, D4.3.10 HIGHER LEVEL

Phenology and lost synchrony

- **Phenology**: research into the timing of flowering, budburst, bud set, migration and nesting.
- **Photoperiod** is the same on a date every year; **temperature** varies. Warming moves only temperature-cued events.
- **Greenland:** chickweed (*Cerastium arcticum*) grows earlier; reindeer (*Rangifer tarandus*) arrive by day length: fewer calves survive.
- **Oak woods:** caterpillars peak earlier; great tit (*Parus major*) chicks **hatch after the feast**.



D4.3.11 HIGHER LEVEL

More *beetle* generations

- Spruce bark beetle (*Ips typographus*) larvae feed under spruce bark, killing the tree.
- Each generation needs a **set amount of warmth**: one in a cold year, two in a warm one, three in the hottest.

D4.3.12 HIGHER LEVEL

Evolution in tawny owls

- Tawny owl (*Strix aluco*) colour is **heritable**. In snowy winters, grey owls have **higher fitness**.
- Less snow weakens selection against brown, so the **brown variant becomes more common**: evolution.

1 in 8
brown, 1960s (Finland)

4 in 10
brown, by 2008

WATCH OUT

Six mistakes that *cost marks*

- ✕ **Correlation is not causation.** Ice cores show CO_2 and temperature together; infrared absorption shows the cause.
- ✕ **Positive feedback amplifies.** It speeds the change up; it is not "good".
- ✕ **CO_2 acidifies; heat bleaches.** Never blame acidification for bleaching.
- ✕ **Warm seas lack nutrients, not light.** A warm layer stops upwelling.
- ✕ **Day length cannot shift.** Only temperature-cued events move earlier.
- ✕ **Owls do not change colour.** The proportion of brown owls changes.

COVER THE SHEET

Can you *answer these?*

1. Outline the sources of anthropogenic CO_2 and methane.
2. Explain how melting sea ice is a positive feedback.
3. Outline how a boreal forest becomes a carbon source.
4. Explain how early ice break-out harms emperor penguins.
5. Explain how warm surface water cuts ocean productivity.
6. Describe two range shifts caused by warming.
7. Distinguish the two threats to coral reefs.
8. Outline three ways to sequester carbon.
9. Explain how warming breaks phenological synchrony. HL
10. Explain why warm years bring more bark beetles. HL
11. Explain why the rise in brown tawny owls is evolution. HL

IN THE EXAM
Write the chain: the climate change (warmer, less ice or snow, more CO_2), what it does to the **habitat or cue**, then the **consequence for the population**.

GO FURTHER
Animated figures, a dry lab and a marked Check are in the full guide online.