MEGA LECTURE

IB DP BIOLOGY

Theme B: Form and Function

B2.1 Membranes and Membrane Transport

Revision Notes · Standard and Higher Level

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Original notes prepared for the IB Diploma Programme Biology course (2025 syllabus)

What the syllabus requires

By the end of B2.1 you should be able to describe the structure of biological membranes and explain how substances cross them. Use this checklist before the exam. Content flagged **(HL)** is examined at Higher Level only.

Understanding	You should be able to...
Phospholipid bilayer	Explain how amphipathic phospholipids form a bilayer in water and why this makes the membrane a selective barrier.
Fluid mosaic model	Describe the arrangement of phospholipids, proteins, cholesterol and carbohydrates, and account for membrane fluidity.
Membrane proteins	State the range of functions carried out by integral and peripheral proteins.
Simple diffusion	Explain passive net movement down a concentration gradient and identify what can cross the bilayer directly.
Facilitated diffusion	Distinguish channel and carrier proteins and explain their selectivity.
Osmosis	Define osmosis in terms of water potential and predict the behaviour of animal and plant cells.
Active transport	Explain movement against a gradient using ATP and pump proteins.
Bulk transport	Describe endocytosis and exocytosis and the role of vesicles.
Sodium–potassium pump (HL)	Describe the pump cycle (3 Na out, 2 K in) and its role in membrane potential and cotransport.

> **Exam note:** SL and HL share most of B2.1. HL adds the detailed sodium–potassium pump mechanism, indirect (secondary) active transport, and the role of cholesterol in controlling fluidity across temperatures.

1. The phospholipid bilayer

Every cell is enclosed by a plasma membrane whose foundation is a double layer of phospholipid molecules. A phospholipid is **amphipathic**: one molecule contains both a water-loving and a water-hating region.

- The **phosphate head** is **hydrophilic** (polar) and is attracted to water.
- The two **fatty-acid tails** are **hydrophobic** (non-polar) and are repelled by water.

Why a bilayer forms in water

Because the cytoplasm inside a cell and the fluid outside are both mainly water, the phospholipids arrange themselves so that the hydrophilic heads face outward into the watery surroundings while the hydrophobic tails point inward, away from water, meeting tail-to-tail in the centre. This self-assembly is spontaneous and driven by the hydrophobic interactions of the tails; no energy input is needed. The result is a stable, self-sealing sheet about 7–10 nm thick with a water-repelling core.

Region of membrane	Character	Faces / points toward
Phosphate heads (outer surfaces)	Hydrophilic, polar	The aqueous cytoplasm and the extracellular fluid
Fatty-acid tails (interior)	Hydrophobic, non-polar	Each other, forming a water-free core

Barrier properties

The hydrophobic core makes the membrane **partially (selectively) permeable**. What can and cannot cross the bilayer directly depends on size, charge and polarity.

Crosses the bilayer easily	Cannot cross directly (needs a protein)
Small non-polar molecules: O_2, CO_2, N_2	Large molecules: glucose, amino acids, sucrose
Small uncharged polar molecules in tiny amounts: water, urea	Ions: Na^+, K^+, Cl^-, Ca^{2+}
Lipid-soluble substances (steroids, some drugs)	Charged or strongly polar molecules of any size

> **Key idea:** The hydrophobic core is the gatekeeper. It repels charged and large polar particles, so those substances can only cross with the help of transport proteins — a fact that underlies every later section.

2. The fluid mosaic model

The accepted description of membrane structure is the **fluid mosaic model** (Singer and Nicolson, 1972). The name captures two ideas: the membrane is **fluid** (its molecules drift and move) and a **mosaic** (proteins of many kinds are scattered through the phospholipid sheet like tiles).

Components

Component	Location / description	Main role
Phospholipids	Two layers forming the fluid framework	Selective barrier; core of the membrane
Integral (transmembrane) proteins	Embedded through the whole bilayer; hydrophobic regions sit in the core	Channels, carriers, pumps, receptors, enzymes
Peripheral proteins	Attached to one surface only, not spanning the bilayer	Support, cell signalling, enzyme activity, anchoring
Cholesterol	Sits between phospholipids in animal membranes	Regulates fluidity and stability (see section 10)
Glycoproteins	Protein with a carbohydrate chain on the outer surface	Cell recognition, receptors, adhesion
Glycolipids	Phospholipid with a carbohydrate chain on the outer surface	Cell recognition, markers

Membrane fluidity

The phospholipids are not fixed. They move sideways within their own layer and their tails flex constantly, so the membrane behaves like a two-dimensional fluid. This fluidity allows the membrane to bend, to fuse during vesicle formation, to self-seal after damage, and lets proteins move to where they are needed. Fluidity increases with temperature and with more unsaturated (kinked) fatty-acid tails; it decreases with more saturated tails and lower temperature.

> **Exam tip:** Carbohydrate chains (in glycoproteins and glycolipids) are found only on the **outer** surface of the membrane. This asymmetry is why they act as recognition and signalling markers facing the outside world.

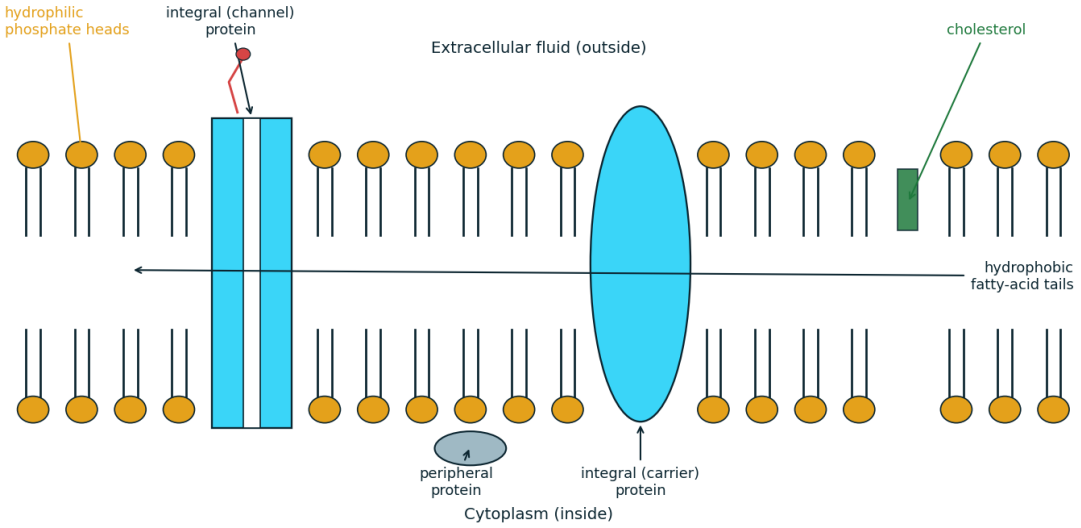

Figure 1. The fluid mosaic model: a phospholipid bilayer (hydrophilic heads facing out, hydrophobic tails meeting in the core) studded with integral channel and carrier proteins, a peripheral protein, cholesterol between the tails, and a carbohydrate chain on the outer surface.

3. Functions of membrane proteins

Membrane proteins give the membrane its versatility. A single membrane carries many protein types, each with a specific job. Examiners often ask you to list and briefly explain these functions.

Function	How the protein achieves it	Example
Channels	Form a hydrophilic pore for a specific ion or molecule to diffuse through	Aquaporins (water); K^+ channels
Carriers (transporters)	Bind a substance, change shape, and release it on the other side	Glucose transporter (GLUT)
Pumps	Use ATP energy to move substances against a gradient	Sodium–potassium pump
Receptors	Bind a specific signalling molecule (hormone) and trigger a cell response	Insulin receptor
Enzymes	Catalyse reactions at the membrane surface	Digestive enzymes on gut epithelium
Cell recognition	Glycoproteins act as identity markers read by other cells	MHC / blood-group antigens

Function	How the protein achieves it	Example
Cell adhesion	Join neighbouring cells to form tissues	Junction proteins between epithelial cells
Electron carriers	Pass electrons along a chain during respiration/photosynthesis	Cytochromes in the inner mitochondrial membrane

> **Memory hook:** "Pumps, Carriers, Channels, Receptors, Enzymes, Recognition, Adhesion." Group them as **transport** (pumps, carriers, channels) and **non-transport** (receptors, enzymes, recognition, adhesion).

4. Simple diffusion

Diffusion is the net movement of particles from a region of higher concentration to a region of lower concentration — that is, **down a concentration gradient** — as a result of their random motion. In simple diffusion the particles pass directly through the phospholipid bilayer.

- It is **passive**: no ATP is used. The energy comes from the kinetic energy of the particles themselves.
- Net movement continues until the concentrations are equal (equilibrium); random motion then continues but there is no *net* movement.
- Only substances that can cross the bilayer take part: small non-polar molecules such as O_2 and CO_2, and small amounts of water.

Rate of simple diffusion increases with a steeper concentration gradient, higher temperature, smaller particle size, and a larger surface area of membrane. In gas exchange, O_2 diffuses into cells and CO_2 diffuses out, each following its own gradient.

> **Definition to learn:** "Diffusion is the net movement of particles from a higher to a lower concentration, down the concentration gradient, due to their random motion." The word **net** earns the mark.

5. Facilitated diffusion

Large or charged particles cannot pass through the hydrophobic core, yet many still move passively across the membrane. They do so by **facilitated diffusion**: diffusion *facilitated* (helped) by transport proteins.

- Still **passive** and still down the concentration gradient — **no ATP** is needed.
- Requires membrane proteins, which makes it **selective**: each protein transports only one type (or a few types) of particle.

Two kinds of protein carry out facilitated diffusion:

Channel proteins	Carrier proteins
Form a water-filled pore lined with hydrophilic groups	Have a binding site for a specific solute
The particle diffuses straight through the open pore	Bind the solute, then change shape to move it across
Often gated — open or close in response to a signal	Slower; work rather like a revolving door

Channel proteins	Carrier proteins
Example: ion channels for Na^+ or K^+; aquaporins for water	Example: GLUT transporters for glucose

Because there is a limited number of transport proteins, facilitated diffusion shows **saturation**: once every protein is working at full rate, adding more solute does not increase the rate. Simple diffusion, by contrast, keeps rising with concentration.

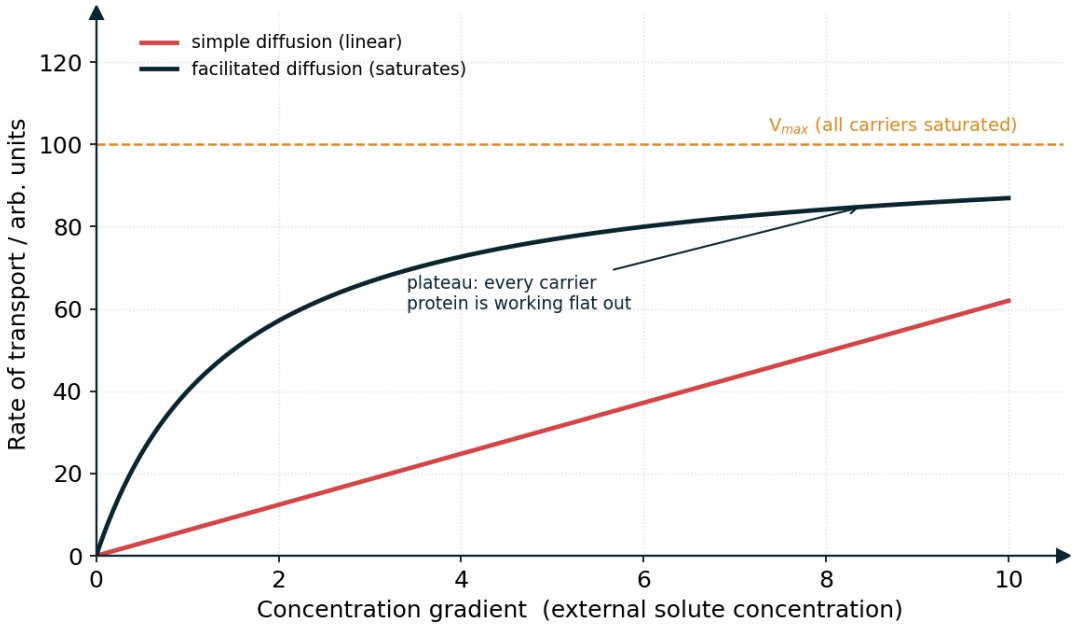

Figure 2. Rate of transport against concentration gradient. Simple diffusion (red) stays linear, but facilitated diffusion (dark) saturates: once every carrier protein is occupied the rate levels off at Vmax (100 arb. units) and adding more solute no longer raises it.

> **Common misconception:** Facilitated diffusion needs proteins but **not** ATP. Needing a protein does not make a process active. “Active” refers to using metabolic energy, not to needing help.

6. Osmosis

Osmosis is the net movement of **water** molecules across a partially permeable membrane, from a region of higher water potential to a region of lower water potential — that is, down the water potential gradient. It is a special case of diffusion that concerns water only.

Water potential

Water potential (symbol Ψ) measures the tendency of water to move out of a solution. Pure water has the highest water potential (set at zero). Adding solute **lowers** water potential, making it negative. Water always moves from higher (less negative) to lower (more negative) water potential. So water moves toward the more concentrated solution.

Comparing solutions

Term (describes the external solution)	Solute concentration vs cell	Water potential vs cell	Net water movement
Hypertonic	Higher solute outside	Lower (more negative) outside	Water leaves the cell
Hypotonic	Lower solute outside	Higher (less negative) outside	Water enters the cell
Isotonic	Equal solute	Equal	No net movement

Effects on cells

Animal cells have no cell wall, so water movement changes their volume directly. Plant cells have a strong cellulose wall that resists swelling, producing different outcomes.

External solution	Animal cell (e.g. red blood cell)	Plant cell
Hypotonic (water enters)	Swells and may burst — **lysis (haemolysis)**	Swells; wall resists; becomes firm and **turgid** (turgor)
Isotonic (no net movement)	Stays normal	Flaccid — slightly limp, wall not pushed
Hypertonic (water leaves)	Shrinks and shrivels — **crenation**	Cytoplasm shrinks from wall — **plasmolysis**

Turgor pressure keeps non-woody plants upright and holds leaves out to the light; wilting is loss of turgor. In a hypertonic soil solution a plant may plasmolyse and die. This is why cells are usually kept in isotonic surroundings, and why saline drips are made isotonic with blood.

> **Watch the direction:** Water moves **toward** the more concentrated (lower water potential) solution. “Hyper” solutions draw water **out** of the cell; “hypo” solutions push water **in**.

7. Active transport

Cells often need to move a substance **against** its concentration gradient — from low to high concentration. This cannot happen passively, so the cell must spend energy. This is **active transport**.

- Direction: **against** the concentration gradient (low → high).
- Energy: requires **ATP** from cell respiration.
- Machinery: uses **carrier proteins that act as pumps**, each specific to its substance.

How a pump works

The substance binds to the pump protein on one side of the membrane. ATP is hydrolysed to ADP + phosphate, and the phosphate group attaches to the pump. This causes the pump to change shape, carrying the substance across and releasing it on the far side, even where it is already more concentrated. The pump then returns to its original shape, ready to repeat.

Examples

- The **sodium–potassium pump** in nerve and other cells (detailed in section 10).

- **Mineral ion uptake by root hair cells**: soil often has a lower ion concentration than the root, so nitrate and other ions are pumped in against the gradient.
- Reabsorption of glucose in the kidney and loading of sugars in phloem also rely on active transport.

> **Evidence link:** A cell doing active transport has many **mitochondria** to supply ATP. If a respiratory poison (e.g. cyanide) stops ATP production, active transport stops — but simple and facilitated diffusion continue, because they need no ATP.

8. Bulk transport: endocytosis and exocytosis

Very large particles, droplets of fluid, and whole macromolecules are too big for any channel or pump. They are moved in bulk using **vesicles** — small membrane sacs pinched from or fused with the plasma membrane. This uses ATP and depends on the fluidity of the membrane.

Endocytosis (taking material in)

The membrane folds inward around the material and pinches off to form a vesicle inside the cell. Two forms are recognised:

- **Phagocytosis** ("cell eating"): engulfing large solid particles, such as a white blood cell taking in bacteria.
- **Pinocytosis** ("cell drinking"): taking in small droplets of extracellular fluid and dissolved solutes.

Exocytosis (sending material out)

A vesicle inside the cell moves to the plasma membrane and **fuses** with it, releasing its contents outside. This exports substances made in the cell, such as digestive enzymes, hormones (e.g. insulin) and neurotransmitters, and adds new membrane at the surface.

> **Remember:** Both endocytosis and exocytosis are **active** (they use ATP) and both rely on membranes being fluid enough to fold, pinch and fuse.

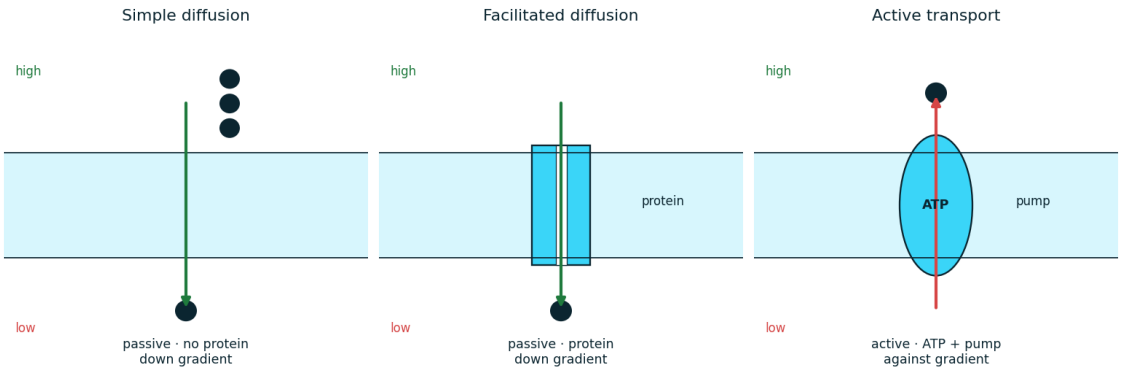

*Figure 3. The three main transport mechanisms. Simple and facilitated diffusion are passive and move solute **down** the gradient (facilitated needs a protein); active transport uses ATP and a pump to drive solute **against** the gradient.*

9. Comparison of transport processes

This table pulls together every mechanism. Learn the three columns — energy, proteins, direction — because exam questions almost always test one of them.

Process	ATP needed?	Proteins needed?	Direction (gradient)	What moves
Simple diffusion	No (passive)	No	Down (high → low)	Small non-polar molecules, O_2, CO_2
Facilitated diffusion	No (passive)	Yes — channels/carriers	Down (high → low)	Ions, glucose, water (aquaporins)
Osmosis	No (passive)	Sometimes (aquaporins)	Down water potential	Water only
Active transport	Yes	Yes — pumps	Against (low → high)	Ions, glucose, amino acids
Bulk transport	Yes	Membrane + motor proteins	Either (in or out)	Large particles, fluids, macromolecules

> **Quick decision:** Against the gradient → active transport (or bulk). Down the gradient and needs a protein → facilitated diffusion. Down the gradient, no protein → simple diffusion. Water across a membrane → osmosis.

10. Higher Level detail (HL)

The sodium–potassium pump (HL)

The sodium–potassium pump (Na^+/K^+-ATPase) is a carrier protein in the plasma membrane that actively exports Na^+ and imports K^+. For every ATP molecule hydrolysed it moves **3 Na^+ out** of the cell and **2 K^+ in**. The cycle:

- Three Na^+ ions from the cytoplasm bind to the pump, which is open to the inside.
- ATP is hydrolysed; a phosphate group attaches to the pump (phosphorylation).
- The pump changes shape, opens to the outside and releases the 3 Na^+ ions.
- Two K^+ ions from outside bind; the phosphate is released.
- The pump returns to its original shape, opening inward and releasing the 2 K^+ ions. The cycle repeats.

Because 3 positive charges leave for every 2 that enter, the inside of the cell becomes **more negative** than the outside. The pump therefore builds both a concentration gradient (high Na^+ outside, high K^+ inside) and a **membrane potential** (a voltage across the membrane). This resting potential is the basis of nerve impulse transmission.

Indirect (secondary) active transport (HL)

The gradients created by the pump store potential energy. A cell can spend that stored energy to move a second substance, without hydrolysing ATP again directly — this is **indirect** or **secondary** active transport, also called **cotransport**.

The classic example is glucose absorption in the small intestine and kidney. A **sodium–glucose symporter (SGLT)** carries Na^+ and glucose together into the cell. Na^+ moves down its steep gradient (into the cell), and this favourable movement drags glucose along with it — **uphill**, against the glucose gradient. The Na^+ gradient that powers this is maintained by the sodium–potassium pump. So ATP is used **indirectly**: the pump spends it to keep Na^+ low inside, and the symporter exploits the resulting gradient.

	Direct (primary) active transport	Indirect (secondary) active transport
Energy source	ATP hydrolysed by the carrier itself	The ion gradient set up earlier (ATP used elsewhere)
Example	Sodium–potassium pump	Sodium–glucose symporter (SGLT)
Movement	The pumped ion goes against its gradient using ATP	One substance goes down its gradient, dragging another up its gradient

Cholesterol, fluidity and temperature (HL)

Cholesterol molecules sit among the phospholipid tails in animal cell membranes and act as a **fluidity buffer**:

- At **high** temperatures cholesterol restrains the movement of phospholipids, reducing fluidity and stopping the membrane becoming too leaky.
- At **low** temperatures it keeps phospholipids apart, preventing them packing tightly, so the membrane does not become rigid and freeze up.

The net effect is a membrane whose fluidity stays roughly constant over a range of temperatures, keeping it stable and appropriately permeable. Cholesterol also reduces the permeability of the membrane to small water-soluble molecules and ions.

> **HL exam focus:** Be ready to (i) state the 3:2 Na:K ratio and explain the resulting membrane potential, (ii) explain why cotransport is called “indirect” active transport, and (iii) describe cholesterol's dual role at high and low temperatures.

11. Worked examples and exam skills

Worked example 1 — predicting cell behaviour

A red blood cell is placed in a solution of pure water. Predict and explain what happens.

Analysis: Pure water has a higher water potential than the cell cytoplasm, so the solution is **hypotonic** to the cell. Water enters the cell by osmosis, down the water potential gradient.

Answer: Water moves in; the cell swells. Because a red blood cell has no cell wall to resist the pressure, it bursts — this is **lysis (haemolysis)**.

Extension: A plant cell in the same solution would swell but not burst; its wall resists, so it becomes **turgid** instead.

Worked example 2 — classifying a transport process

A kidney cell takes up glucose from a region where glucose is **less** concentrated than inside the cell, using energy indirectly from a sodium gradient. Name and classify this process.

Reasoning: Movement is **against** the glucose gradient, so it must be active. It uses a sodium gradient rather than direct ATP hydrolysis by the glucose carrier, so it is **indirect (secondary) active transport**, carried out by a sodium–glucose symporter **(HL)**.

Answer: Cotransport / indirect active transport.

Worked example 3 — explaining the need for energy

Root hair cells absorb nitrate ions even though the soil solution has a much lower nitrate concentration than the cell. Explain why this requires ATP.

Answer: Nitrate is moving from a low concentration (soil) to a high concentration (inside the cell) — against the concentration gradient. Diffusion cannot move a substance up its gradient, so the cell uses carrier proteins acting as pumps. These need energy from ATP (made in respiration) to change shape and carry the ion across. Without ATP the uptake would stop.

Link: This is why root hair cells and other transporting cells contain many mitochondria.

Worked example 4 — osmosis in potato tissue (data skill)

Cylinders of potato of equal starting mass are left for 30 minutes in sucrose solutions of different concentration, then reweighed. Interpret the pattern below.

Sucrose concentration / mol dm^{-3}	0.0	0.2	0.4	0.6
Change in mass / %	+8	+2	–3	–9

Interpretation: In dilute solutions (0.0, 0.2 mol dm^{-3}) the solution has a higher water potential than the potato cells, so water enters by osmosis and mass increases. In concentrated solutions (0.4, 0.6) the external water potential is lower, water leaves the cells and mass decreases.

Skill: The concentration at which mass change is **zero** (here between 0.2 and 0.4 mol dm^{-3}, found by reading where the line crosses the x-axis) is **isotonic** with the cells — it estimates the cells' own water potential.

Common pitfalls

- Saying “osmosis is the movement of solutes.” Osmosis is the movement of **water only**, across a partially permeable membrane.
- Calling facilitated diffusion “active” because it uses proteins. It is **passive** — no ATP.
- Forgetting that active transport **always** needs ATP and moves substances **against** the gradient.
- Confusing hypertonic and hypotonic. Water moves toward the **lower** water potential (more concentrated) solution.

- Writing that a plant cell “bursts” in pure water. The cell wall prevents bursting; the cell becomes **turgid**.
- Omitting the word **net** from diffusion and osmosis definitions.
- Using raw Na, K without charges. Always write the ions as Na^+ and K^+.

Quick-reference summary

Term	One-line reminder
Amphipathic	Having both hydrophilic (head) and hydrophobic (tail) regions
Fluid mosaic model	Fluid phospholipid bilayer with a mosaic of proteins, cholesterol and carbohydrates
Simple diffusion	Passive, no protein, down gradient, small non-polar molecules
Facilitated diffusion	Passive, needs channel/carrier proteins, down gradient, selective
Osmosis	Passive net movement of **water** down the water potential gradient
Active transport	Needs ATP + pump proteins; moves substances **against** the gradient
Endocytosis / exocytosis	Bulk transport in / out using vesicles; needs ATP
Na^+/K^+ pump (HL)	3 Na^+ out, 2 K^+ in per ATP; creates the membrane potential
Cotransport (HL)	Indirect active transport powered by an existing ion gradient

Test yourself

Attempt these without notes; full answers follow.

1. Explain, in terms of hydrophilic and hydrophobic regions, why phospholipids form a bilayer in water. [3]
2. Why can oxygen cross the membrane by simple diffusion but a sodium ion cannot? [3]
3. Distinguish between a channel protein and a carrier protein. [2]
4. A plant cell is placed in a hypertonic solution. Describe and name what happens to it. [3]
5. State three differences between facilitated diffusion and active transport. [3]
6. Explain why cells carrying out active transport contain many mitochondria. [2]
7. (HL) Describe how the sodium–potassium pump produces a membrane potential. [4]
8. (HL) Explain why glucose uptake by a sodium–glucose symporter is called indirect active transport. [3]

Answers

1. Phospholipids are amphipathic; the phosphate heads are hydrophilic and the fatty-acid tails are hydrophobic. In water the heads face outward toward the water on both sides while the tails point inward away from water, forming two layers with the tails meeting in a hydrophobic core.

2. Oxygen is a small, non-polar molecule, so it dissolves in and passes through the hydrophobic core easily. A sodium ion is charged (Na^+) and hydrated, so it is repelled by the hydrophobic core and cannot cross the bilayer directly; it needs a channel or pump protein.

3. A channel protein forms an open hydrophilic pore through which a specific particle diffuses; a carrier protein binds the solute and changes shape to move it across. (Both are passive in facilitated diffusion.)

4. The external solution has a lower water potential, so water leaves the cell by osmosis. The cytoplasm and cell membrane shrink and pull away from the cell wall. This is **plasmolysis**; the cell becomes plasmolysed and loses turgor.

5. Facilitated diffusion: passive / no ATP, down the gradient, uses channels or carriers. Active transport: uses ATP, against the gradient, uses pump proteins. (Any three contrasting points.)

6. Active transport requires ATP as its energy source. Mitochondria carry out aerobic respiration to produce this ATP, so cells doing a lot of active transport need many mitochondria to supply enough energy.

7. (HL) The pump uses ATP to move 3 Na^+ out of the cell for every 2 K^+ it moves in. Because more positive ions leave than enter, the inside of the cell becomes more negative than the outside. This charge difference across the membrane is the membrane (resting) potential.

8. (HL) The symporter itself does not hydrolyse ATP. It uses the Na^+ concentration gradient, letting Na^+ move into the cell down its gradient while dragging glucose in against the glucose gradient. That Na^+ gradient is created and maintained by the sodium–potassium pump, which does use ATP — so the energy is supplied **indirectly**.