REVISION GUIDE

What gets *through* a membrane?

Membranes and membrane transport

A film of fat two molecules thick keeps a cell's contents in and the rest of the world out, yet lets through exactly what the cell needs. Find out how the bilayer works as a barrier, which molecules slip across it, how channel and pump proteins pick what crosses, and at higher level how fluidity, vesicles, gated channels and the sodium-potassium pump work.

11 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-b2-1-membranes-and-membrane-transport

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By the end you can

- [ ] Explain why phospholipids and other amphipathic lipids form bilayers in water B2.1.1
- [ ] Explain why the hydrophobic core of a bilayer is a barrier to ions, polar molecules and large molecules B2.1.2
- [ ] Describe simple diffusion of oxygen and carbon dioxide between the phospholipids B2.1.3
- [ ] Tell integral from peripheral proteins by where they sit in the membrane B2.1.4
- [ ] Explain osmosis across membranes and how aquaporins speed it up B2.1.5
- [ ] Explain how channel proteins let specific ions diffuse through when open but not when closed B2.1.6
- [ ] Explain how pump proteins use ATP to move particles against a concentration gradient B2.1.7
- [ ] Compare the selectivity of simple diffusion with facilitated diffusion and active transport B2.1.8
- [ ] Describe glycoproteins and glycolipids, where their sugars face and their roles in adhesion and recognition B2.1.9
- [ ] Draw the fluid mosaic model with integral and peripheral proteins, glycoproteins, phospholipids and cholesterol, and its hydrophobic and hydrophilic regions B2.1.10
- [ ] Relate the fatty acids in a bilayer to its fluidity, with an example of a membrane adapted to its habitat B2.1.11
- [ ] Explain where cholesterol sits and how it moderates membrane fluidity B2.1.12
- [ ] Explain how fluidity lets vesicles form and fuse, in endocytosis and exocytosis B2.1.13
- [ ] Describe neurotransmitter-gated and voltage-gated ion channels in neurons B2.1.14
- [ ] Describe the sodium-potassium pump as an exchange transporter and its role in the membrane potential B2.1.15
- [ ] Explain sodium-dependent glucose cotransport as indirect active transport, in the small intestine and the nephron B2.1.16
- [ ] Describe how cell-adhesion molecules hold cells together in tissues B2.1.17

Tick each one when you can do it without the book.

01

B2.1.1 LIPID BILAYERS AS THE BASIS OF CELL MEMBRANES

A skin that *builds itself*

A phospholipid has a phosphate head that is attracted to water and two fatty acid tails that are not. A molecule with a hydrophilic part and a hydrophobic part is **amphipathic**. In water, phospholipids arrange themselves so that the heads face the water and the tails face each other, away from it. The result is a sheet two molecules thick: a **lipid bilayer**.

Nothing has to build it. The water molecules bond to each other and to the heads, and the tails are pushed together because water does not bond to them. A bilayer with a free edge would leave tails touching water, so the sheet closes on itself into a continuous layer with no edges. Every membrane in a cell, outside and in, is built on one.

KEY POINTS

- Phospholipids are amphipathic: hydrophilic head, hydrophobic tails.
- In water they form a bilayer by themselves: heads out, tails in.
- The bilayer is continuous: it closes up so no tails are left exposed.

KEY TERMS

amphipathic
Having one part that is hydrophilic (attracted to water) and another that is hydrophobic (not attracted to water), as a phospholipid has.

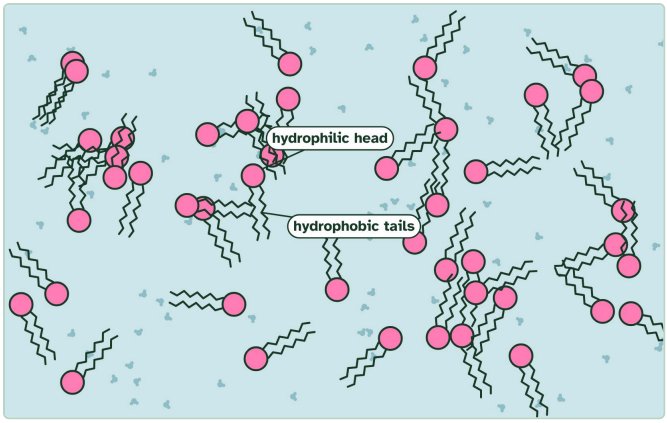
lipid bilayer
A double layer of phospholipids (or other amphipathic lipids), heads facing the water on both sides and tails facing inwards, forming the core of every cell membrane.

ANIMATION · WATCH IT HAPPEN: A BILAYER BUILDS ITSELF

3 MOMENTS

1

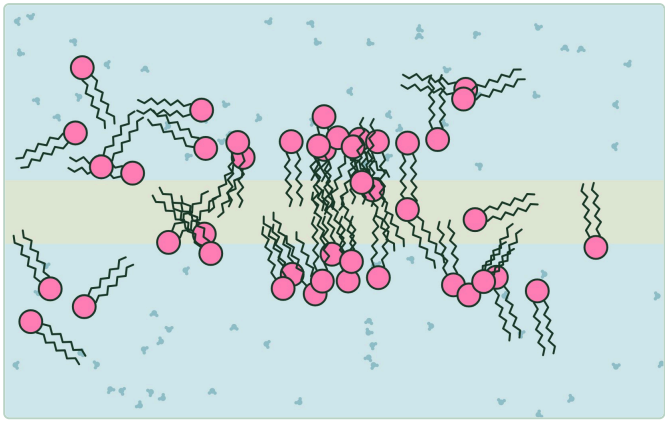
IN THE BILAYER: 0 OF 44



Phospholipids stirred into water point every which way.

2

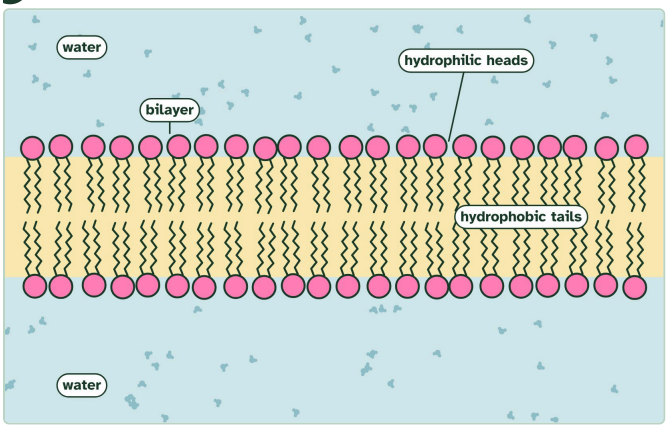
IN THE BILAYER: 6 OF 44



The tails cannot form hydrogen bonds with water, so water crowds the **tails** together.

3

IN THE BILAYER: 44 OF 44



No enzyme placed them and no energy was spent: **water** arranged them.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-b2-1-membranes-and-membrane-transport#bilayer

WATCH OUT

The tails are not "attracted to each other" by a special bond. They end up together because the water holds itself together and squeezes them out.

PREDICT

Phospholipids are shaken in oil instead of water. How would they arrange themselves?

(A) In a bilayer as before, because the shape of a phospholipid always gives the same arrangement

(B) Turned the other way, tails out into the oil and the heads hidden together in the middle

(C) Spread evenly through the oil one by one, because the oil does not attract any part of them

Decide before you look. Answer on page 37.

02

B2.1.2 B2.1.3 LIPID BILAYERS AS BARRIERS SIMPLE DIFFUSION ACROSS MEMBRANES

A wall with *gaps* for small things

The middle of a bilayer is a layer of hydrocarbon tails, and that core is hydrophobic. Ions and polar molecules are surrounded by shells of water and attracted to it; to cross they would have to leave the water and pass through the oily core, so very few do. Large molecules are too big to slip between the phospholipids at all. The bilayer has a low **permeability** to all of these, so it is an effective barrier between the watery cytoplasm and the watery fluid outside.

Small molecules that carry no charge are different. Oxygen and carbon dioxide slip between the moving phospholipids and through the core. They cross by **simple diffusion**: random movement carries more of them from the side where they are more concentrated, so the net movement is down the concentration gradient. The cell spends no energy on it. In a respiring cell oxygen is used up inside, so it keeps diffusing in, and carbon dioxide is made inside, so it keeps diffusing out.

You have met diffusion with your nose. When somebody in a room lets one go, the person beside them smells it first and the far corner last: the particles spread from where they are crowded to where they are few, with nobody pushing them. The first film shows it.

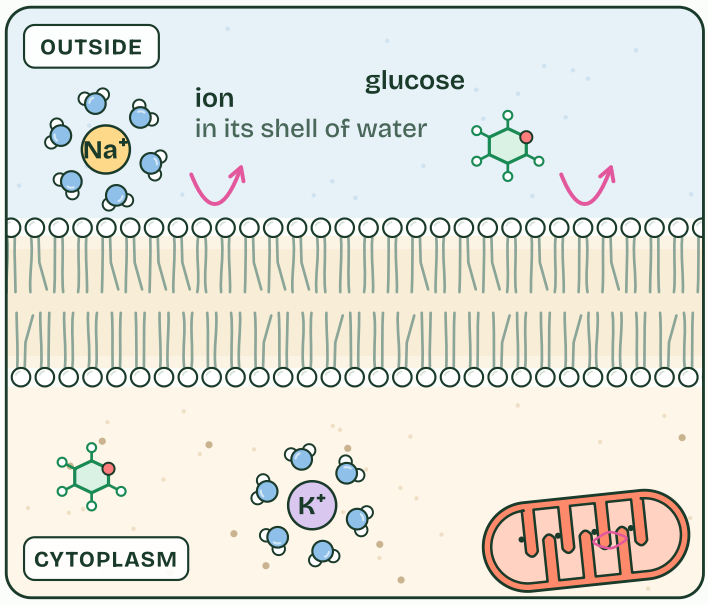
KEY POINTS

- The hydrophobic core keeps out ions, polar molecules and large molecules.
- Small non-polar molecules such as O_2 and CO_2 cross by simple diffusion.
- Simple diffusion is passive and goes down the concentration gradient.

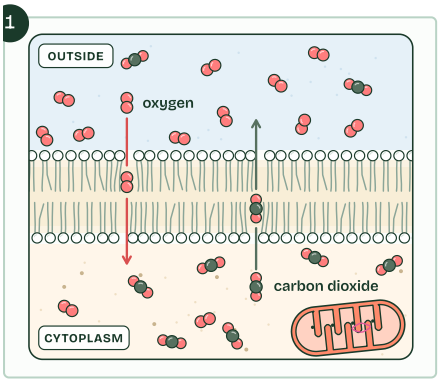
KEY TERMS

permeability
How easily a substance can pass through a membrane.

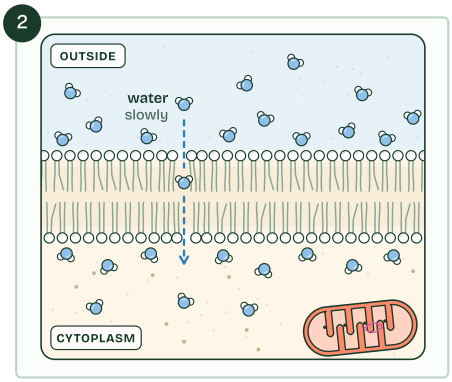
simple diffusion
The net movement of particles from a higher to a lower concentration, directly through the phospholipid bilayer, with no protein involved and no energy used by the cell.



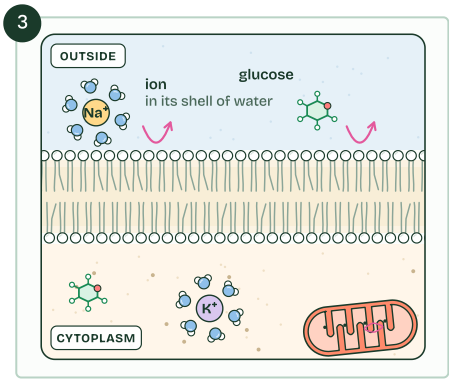
STEP BY STEP 3 STEPS



Oxygen diffuses in and **carbon dioxide** out, between the phospholipids.



Water is polar but small: a little crosses the bilayer, slowly.

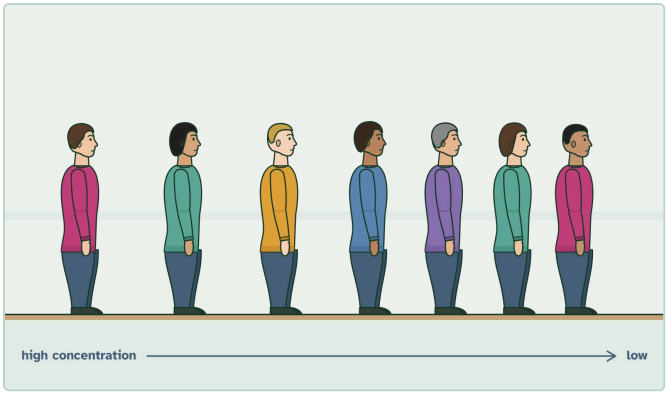


Ions and **polar molecules** such as glucose cannot pass the hydrophobic core.

ANIMATION · WHO SMELT IT FIRST?

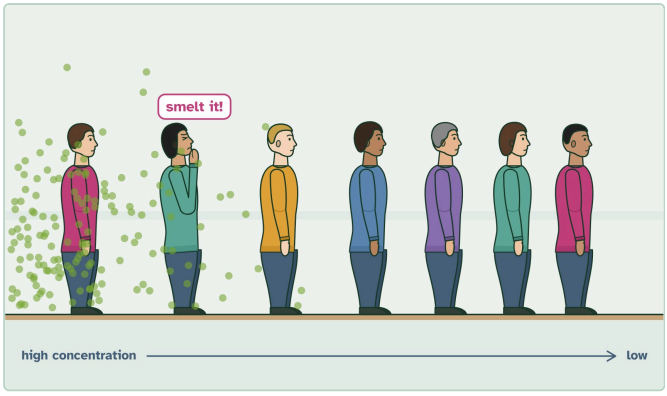
5 MOMENTS

1 NOTHING YET



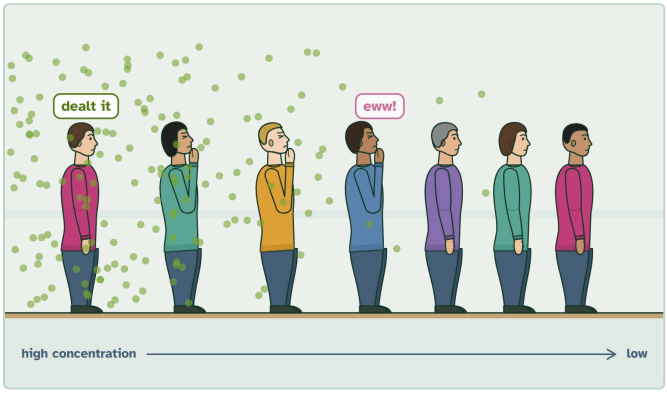
A quiet classroom. Nobody has noticed anything yet.

2 1 OF 6 CAN SMELL IT



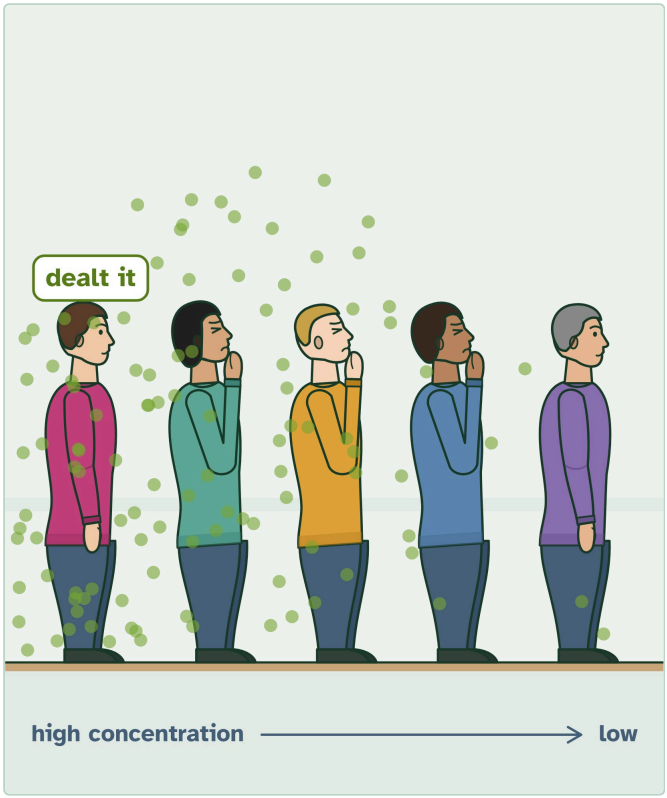
Somebody lets one go. The gas particles start crowded together in one place: a **high concentration**.

3 3 OF 6 CAN SMELL IT



Each particle moves at **random**, yet more wander out of the crowd than back into it. That net movement from high to low concentration is **diffusion**.

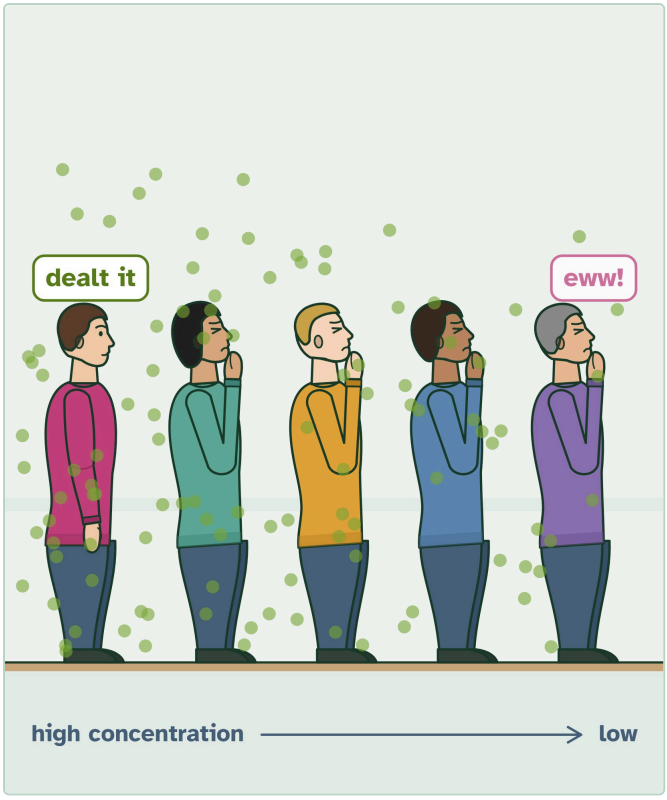
4 3 OF 4 CAN SMELL IT



The nearest nose smells it first, because the concentration is still highest close to the source. Whoever smelt it first is probably sitting beside whoever dealt it.

5

4 OF 4 CAN SMELL IT



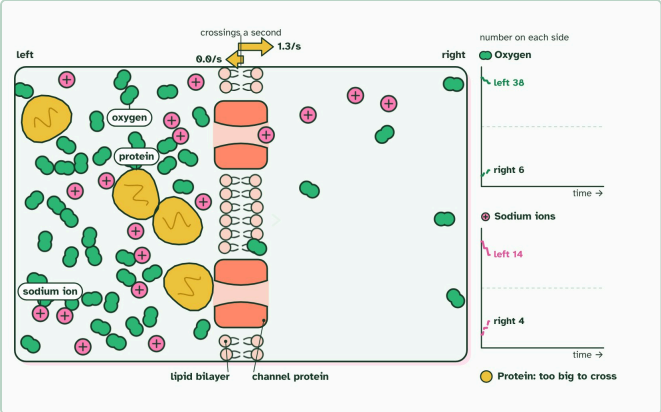
Given time the particles spread through the whole room. Nobody pushed them: diffusion needs no energy, only random motion and a **concentration gradient**.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-b2-1-membranes-and-membrane-transport#barrier

ANIMATION · DIFFUSION ACROSS A MEMBRANE

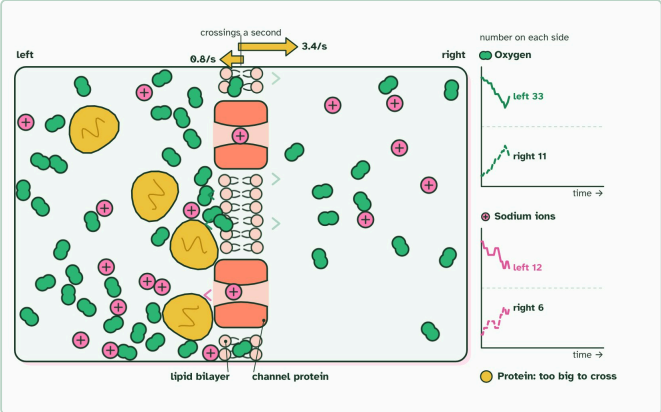
3 MOMENTS

1 RANDOM MOTION



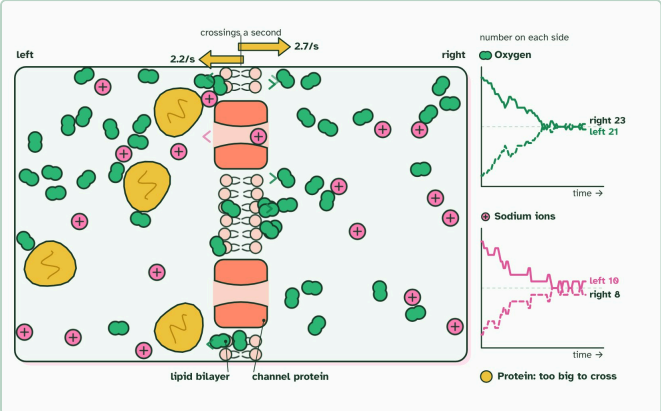
Every particle moves at **random**, bumping into the others and the walls.

2 NET MOVEMENT →



Net movement down the concentration gradient: more cross from the left.

3 DYNAMIC EQUILIBRIUM



Dynamic equilibrium: still crossing both ways, at about the same rate.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-b2-1-membranes-and-membrane-transport#barrier

WATCH OUT

Small size alone does not get a particle through. A sodium ion is smaller than an oxygen molecule but carries a charge, so the bilayer keeps it out.

PREDICT

Rank these from fastest to slowest across a bare bilayer: oxygen, glucose, sodium ions.

(A) Sodium ions, oxygen, glucose: the smallest particle crosses first and the largest crosses last

(B) Oxygen, glucose, sodium ions: non-polar first, then the polar molecule, and the charged ion last

(C) Glucose, oxygen, sodium ions: the cell needs glucose most, so the membrane lets it through first

Decide before you look. Answer on page 37.

B2.1.4 INTEGRAL AND PERIPHERAL PROTEINS IN MEMBRANES

03 Proteins *in* it and *on* it

A bilayer alone would let almost nothing useful through. Most of what a membrane does is done by the proteins in it, and they come in many shapes, places and jobs. They sort into two groups by where they sit.

Integral proteins are embedded in the bilayer. Some cross it completely and have parts in the water on both sides, as channels and pumps do; others sit in one layer only. The part among the tails is hydrophobic, which holds the protein in place. **Peripheral proteins** are not embedded at all. They are attached to the inner or outer surface, to the heads or to an integral protein, and are easier to remove. Their jobs include enzymes, receptors, and anchoring the membrane to the cytoskeleton.

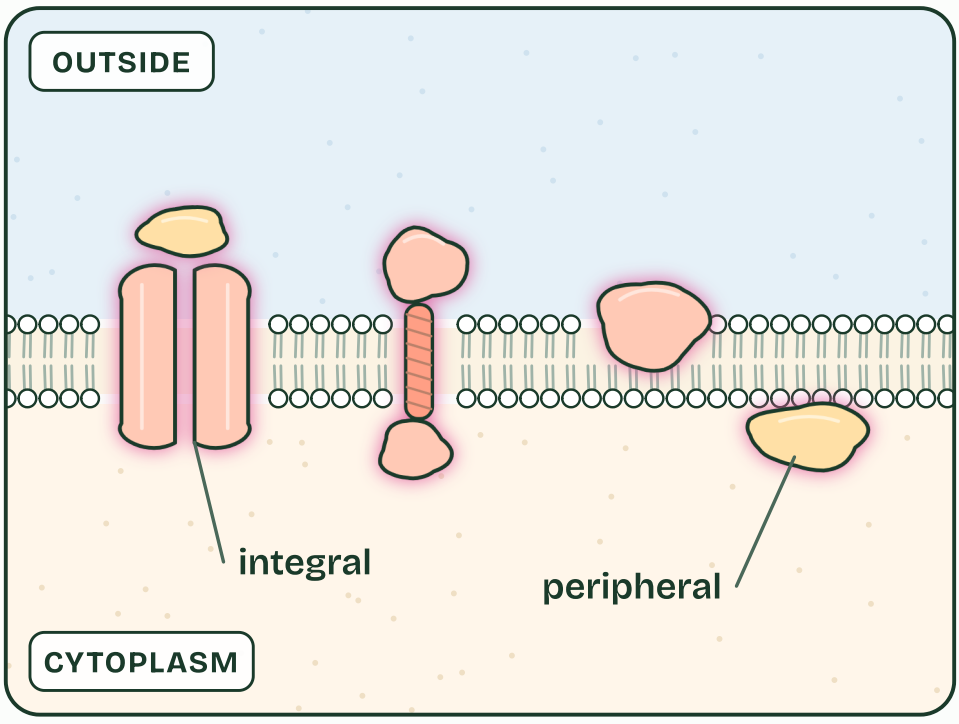
KEY POINTS

- Integral: embedded in one or both layers, with a hydrophobic part among the tails.
- Peripheral: attached to one surface, not embedded.
- Membrane proteins vary in structure, position and function.

KEY TERMS

integral proteins
A protein embedded in one or both layers of the phospholipid bilayer, with a hydrophobic part held among the tails.

peripheral proteins
A protein attached to the inner or outer surface of the bilayer, to the phospholipid heads or to an integral protein, without being embedded among the tails.



A channel protein: integral, spanning both layers, with a pore through the middle for one kind of ion.

A protein embedded in one layer only, on the outer side: still integral, because part of it is held among the tails.

A protein that spans the membrane once: integral. Its middle is hydrophobic, so it sits among the tails; its ends are hydrophilic, in the water each side.

A peripheral protein: held on the inner surface of the membrane, by attraction to the heads or to an integral protein, not among the tails.

A peripheral protein on the outer surface, attached to an integral protein.

WATCH OUT

"Integral" does not mean "crosses the whole membrane". A protein in only one layer is still integral if part of it is among the tails.

PREDICT

A protein is removed from a membrane only by a detergent that breaks up the bilayer. What kind is it most likely to be?

(A) Peripheral, because it is attached so firmly to the surface that only detergent can lift it off

(B) Integral, because a part of it is held among the hydrophobic tails until the bilayer is broken

(C) Neither kind, because every membrane protein can be washed off with a salt solution alone

Decide before you look. Answer on page 37.

B2.1.5 MOVEMENT OF WATER MOLECULES ACROSS MEMBRANES BY OSMOSIS AND THE ROLE OF AQUAPORINS

04 Water's *own* door

Water molecules move at random and cross a membrane in both directions all the time. A membrane lets water through but not most solutes, so when the solute concentration differs on the two sides, the movement is uneven. On the more concentrated side more water molecules are held round solute particles and fewer are free to cross back. So there is a net movement of water towards the higher solute concentration: **osmosis**.

Being small, water can squeeze between phospholipids, but being polar, it does so slowly. Many cells have **aquaporins**: integral proteins with a narrow pore lined with hydrophilic groups. Water passes through in single file, billions of molecules a second through each one, while ions are kept out by the pore's size and charges. Cells that move a lot of water, such as those in the kidney's collecting ducts and in plant roots, have many aquaporins.

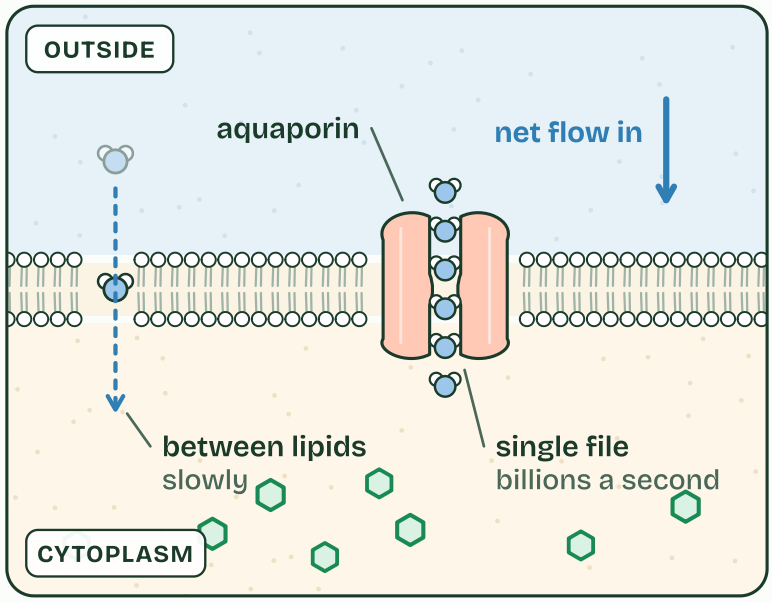
KEY POINTS

- Osmosis: net water movement towards the higher solute concentration.
- It happens because water moves at random and the membrane holds back the solute.
- Aquaporins let water through much faster, in single file, and keep ions out.

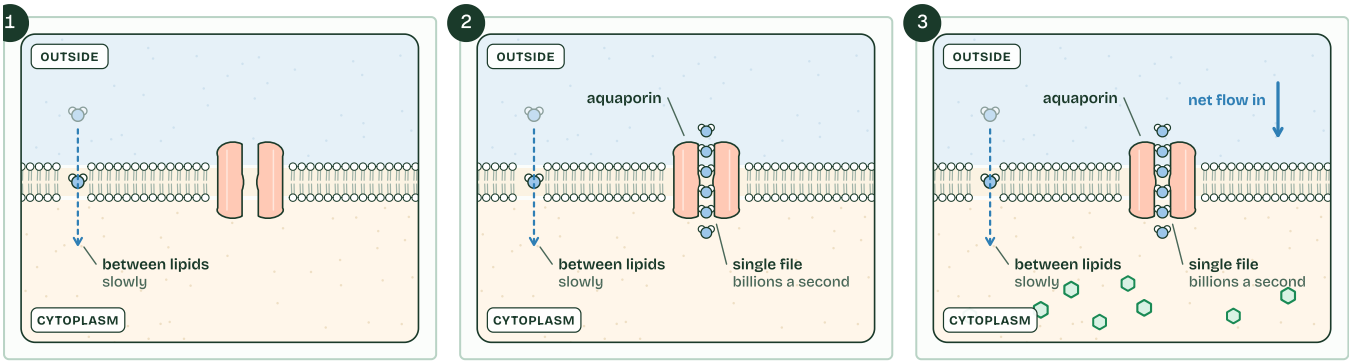
KEY TERMS

osmosis
The net movement of water across a partially permeable membrane, from a lower solute concentration to a higher solute concentration.

aquaporins
A channel protein that lets water molecules pass through the membrane in single file, greatly increasing the membrane's permeability to water.



STEP BY STEP
3 STEPS



A water molecule squeezes **between the phospholipids**: it crosses, but slowly.

Through an **aquaporin**, water passes in single file, very fast.

With more solute inside, more water enters than leaves: **net flow in**.

WATCH OUT

Aquaporins do not pump water. Water goes through them by osmosis, in whichever direction the solute concentrations decide.

PREDICT

A drug blocks the aquaporins in a cell placed in pure water. What happens?

(A) Water stops entering completely, because aquaporins are the only way water can cross a membrane

(B) Water still enters by osmosis through the bilayer, but more slowly than it did before the drug

(C) Water moves out of the cell instead, because the blocked aquaporins reverse the direction of osmosis

Decide before you look. Answer on page 37.

B2.1.6 B2.1.7 B2.1.8 CHANNEL PROTEINS FOR FACILITATED DIFFUSION PUMP PROTEINS FOR ACTIVE TRANSPORT SELECTIVITY IN MEMBRANE PERMEABILITY

05 Channels open, *pumps push*

A **channel protein** has a pore through its middle, lined with hydrophilic groups. Its width and the charges on its lining let through one kind of ion only: a sodium channel passes sodium ions but not potassium. Many channels have a gate. When it is open, ions diffuse through, down their concentration gradient; when it is shut, none pass. This is **facilitated diffusion**: still passive, still down the gradient, but only for the particles that fit.

A **pump protein** moves particles the other way, from low to high concentration. It binds a specific particle on one side, uses energy from ATP to change shape, and releases the particle on the other side. That is **active transport**. Because channels and pumps each handle particular particles, they make the membrane selectively permeable. Simple diffusion is not selective at all: whatever is small and non-polar enough gets through.

KEY POINTS

- Channel: a gated pore for one kind of ion; facilitated diffusion, passive.
- Pump: uses ATP, can move particles against the gradient; active transport.
- Proteins make a membrane selective; simple diffusion depends only on size and polarity.

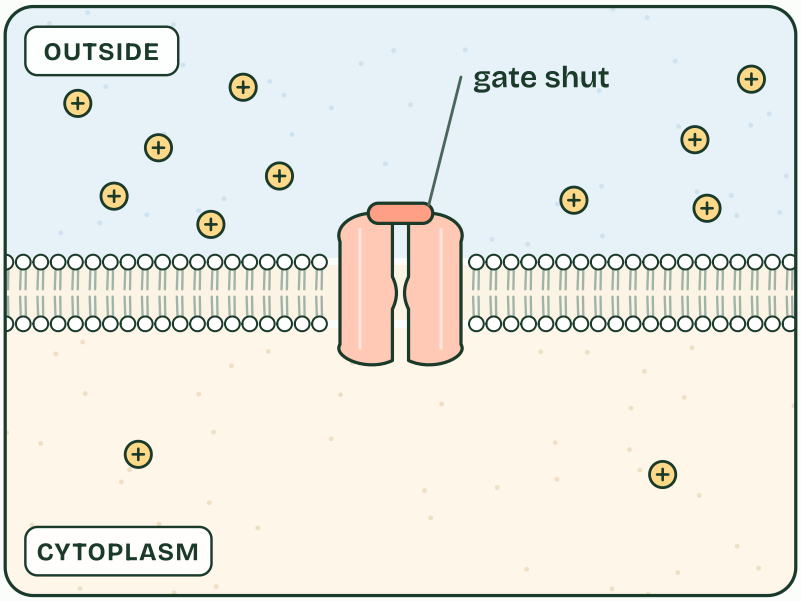
KEY TERMS

channel protein
An integral protein with a hydrophilic pore through which one specific kind of ion or molecule can diffuse when the channel is open.

facilitated diffusion
Diffusion of particles across a membrane through channel or carrier proteins, down the concentration gradient and without energy from the cell.

pump protein
An integral protein that uses energy from ATP to move specific particles across a membrane, which can be against their concentration gradient.

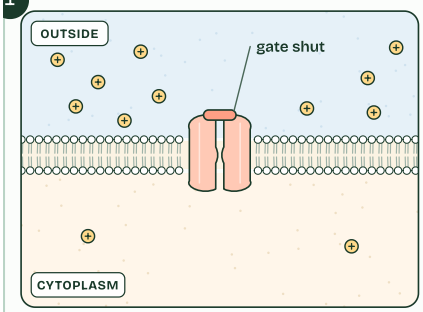
active transport
Movement of particles across a membrane against their concentration gradient, using energy from ATP.



SWITCH IT

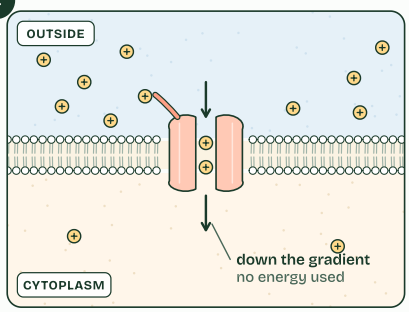
3 SETTINGS

1



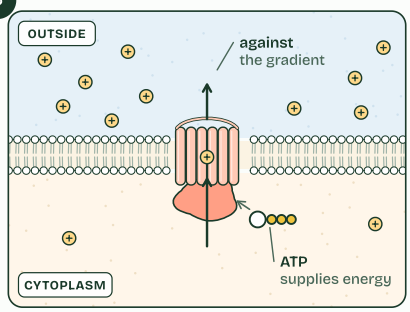
Channel shut

2



Channel open

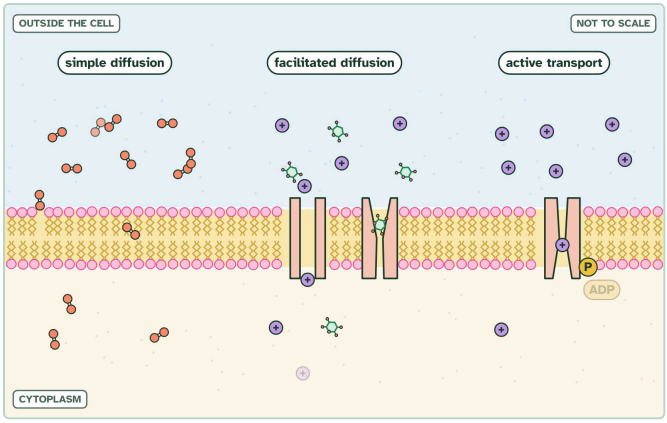
3



Pump

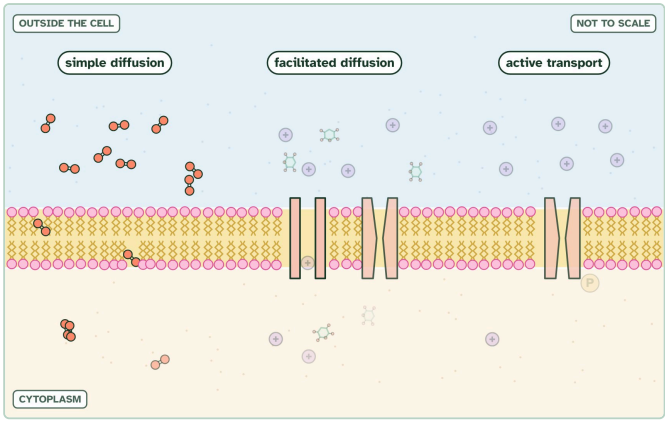
ANIMATION · THE THREE WAYS ACROSS A MEMBRANE
5 MOMENTS

1 ALL THREE



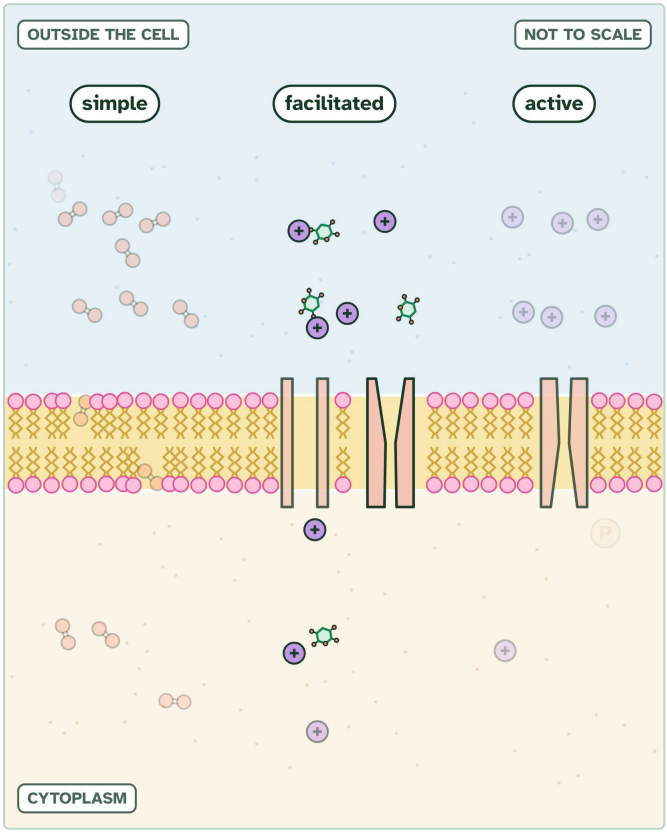
Particles cross a membrane in **three ways**. They differ in which way the particle goes, and in what it costs the cell.

2 SIMPLE DIFFUSION



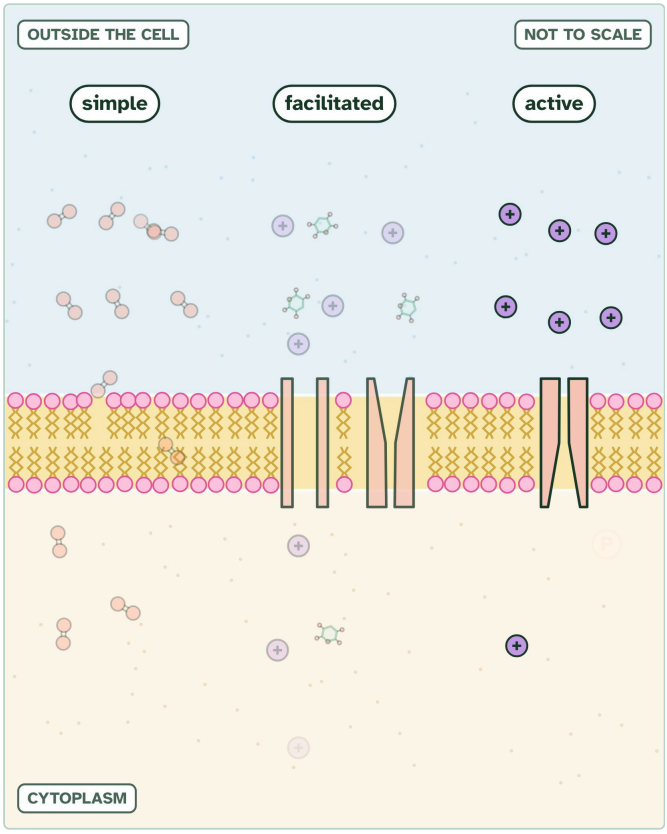
Simple diffusion: small, non-polar molecules such as oxygen slip between the phospholipids, from where there are more of them to where there are fewer. No protein and no ATP.

3 FACILITATED DIFFUSION



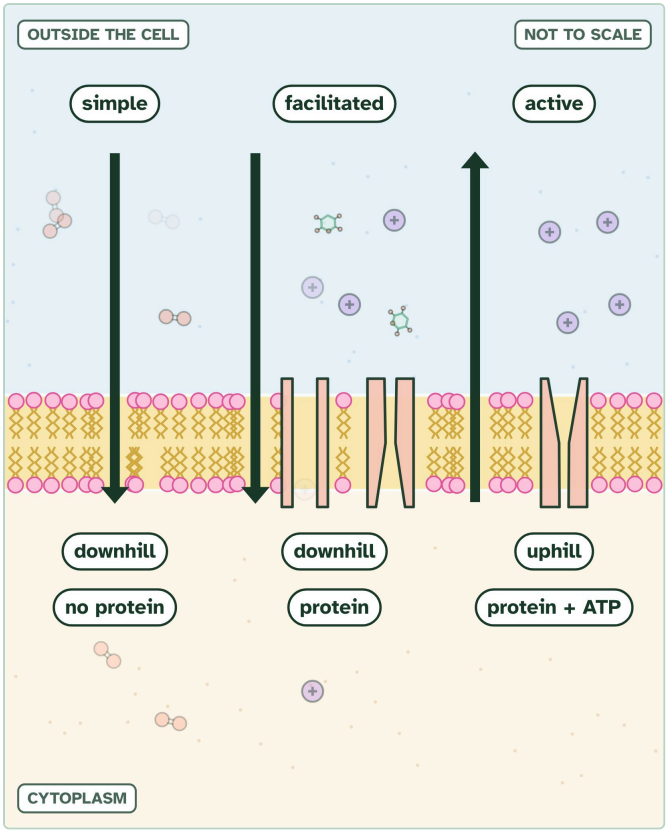
Facilitated diffusion: ions and polar molecules cannot cross the core alone, so a protein lets them. A **channel** is a pore for ions; a **carrier** changes shape to pass glucose. Still downhill, still no ATP.

4 ACTIVE TRANSPORT



Active transport: a pump uses **ATP** to move a particle from where there are fewer to where there are more. Here it pushes Na^+ out, against its gradient.

5 ALL THREE



Two ways go **downhill** and cost the cell nothing. Only active transport goes **uphill**, and it needs a protein and ATP.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-b2-1-membranes-and-membrane-transport#transport

WATCH OUT

Facilitated diffusion uses a protein but no energy. "Uses a protein" does not mean "active".

PREDICT

A poison stops ATP being made in a cell. Which movement stops first?

(A) Potassium ions diffusing out through open channel proteins, down their concentration gradient

(B) Sodium ions being moved out of the cell against their gradient by the cell's pump proteins

(C) Oxygen molecules diffusing in between the phospholipids to reach the mitochondria inside

Decide before you look. Answer on page 37.

REMEMBER IT

Down needs no ATP

D Down	U Up
Diffusion high to low concentration: simple or through a channel, no ATP	**Pump** low to high concentration: active transport, ATP every time

B2.1.9 B2.1.10 STRUCTURE AND FUNCTION OF GLYCOPROTEINS AND GLYCOLIPIDS FLUID MOSAIC MODEL OF MEMBRANE STRUCTURE

06 A *fluid* mosaic

Some membrane proteins and lipids carry short, branched chains of sugars. A protein with sugars attached is a **glycoprotein** and a lipid with sugars a **glycolipid**. The sugars are always on the outer side of the plasma membrane, facing the fluid round the cell. Their exact pattern differs between cell types and between individuals, so they act as identity tags: in **cell recognition** (the ABO blood groups are glycolipid and glycoprotein sugars on red blood cells, and immune cells read them to tell self from non-self) and in **cell adhesion**, sticking cells to each other.

All of this fits the **fluid mosaic model**. Fluid, because the phospholipids and many proteins drift sideways within their layer; mosaic, because the proteins are scattered through the bilayer like tiles. In animal cells cholesterol sits among the phospholipids. When you draw it, show the bilayer with heads and tails, integral and peripheral proteins, a glycoprotein, cholesterol, and label the hydrophilic heads and the hydrophobic core.

KEY POINTS

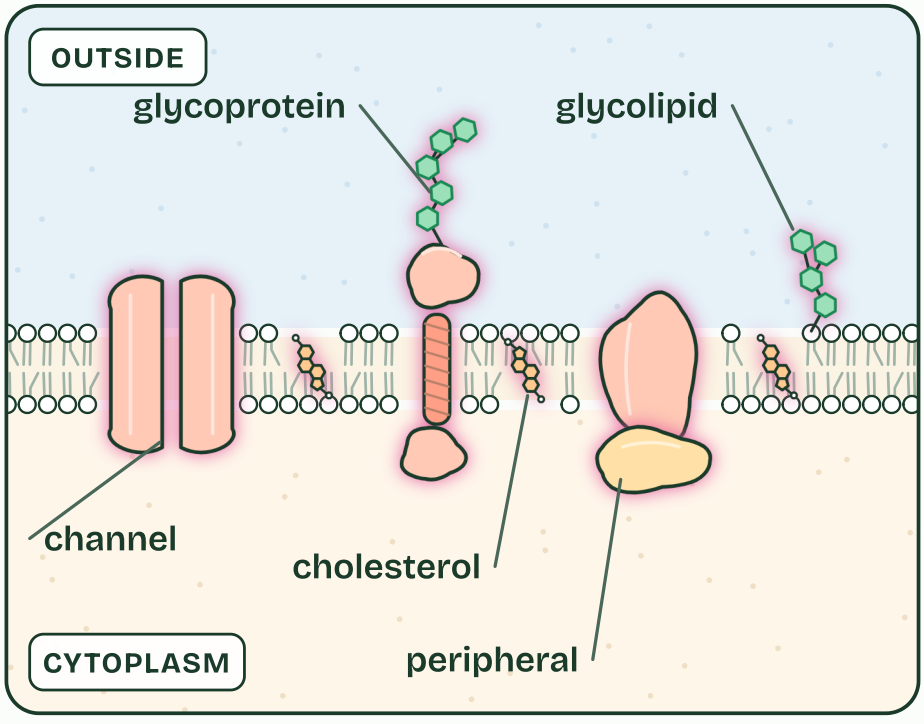
- Glycoproteins and glycolipids: sugars on the outside, for recognition and adhesion.
- Fluid: lipids and proteins move sideways. Mosaic: proteins scattered through it.
- A full drawing: bilayer, integral and peripheral proteins, glycoprotein, cholesterol, regions labelled.

KEY TERMS

glycoprotein
A membrane protein with a carbohydrate chain attached, the carbohydrate facing the outside of the cell.

glycolipid
A membrane lipid with a carbohydrate chain attached, the carbohydrate facing the outside of the cell.

fluid mosaic model
The model of membrane structure in which proteins are scattered in a fluid phospholipid bilayer, like tiles in a mosaic that can move about.



Cholesterol: a small lipid tucked among the phospholipids, its hydroxyl group by the heads and its rings among the tails.

Cholesterol: a small lipid tucked among the phospholipids, its hydroxyl group by the heads and its rings among the tails.

A glycoprotein: a protein with a chain of sugars attached on the outside of the membrane. It is used in cell recognition and cell adhesion.

A peripheral protein, held to the inner surface by the integral protein above it.

Cholesterol: a small lipid tucked among the phospholipids, its hydroxyl group by the heads and its rings among the tails.

A channel protein: integral, crossing the membrane, with a hydrophilic pore through the middle.

An integral protein embedded in the bilayer.

A glycolipid: a phospholipid with a short chain of sugars, on the outer side of the membrane.

NATURE OF SCIENCE

Models change when evidence demands it. In the 1930s Davson and Danielli proposed a bilayer sandwiched between two continuous layers of protein, which matched the three-layer look of membranes in early electron micrographs. Then freeze-fracture, which splits a frozen membrane between its two layers, showed proteins studded through the middle, and experiments fusing a mouse cell with a human cell showed their membrane proteins mixing within minutes. In 1972 Singer and Nicolson replaced the sandwich with the fluid mosaic model, which explained both.

PREDICT

A mouse cell and a human cell are fused, each with its own membrane proteins tagged a different colour. What is seen after 40 minutes at 37 °C?

(A) The two colours stay on their own halves, because each protein is fixed to the spot where it was made

(B) The two colours are mixed all over the hybrid cell, because the proteins drift sideways in the bilayer

(C) The colours fade away completely, because the fused proteins break down once they meet each other

Decide before you look. Answer on page 37.

B2.1.11 HL B2.1.12 HL RELATIONSHIPS BETWEEN FATTY ACID COMPOSITION OF LIPID BILAYERS AND THEIR FLUIDITY CHOLESTEROL AND MEMBRANE FLUIDITY IN ANIMAL CELLS

07 Not too *stiff*, not too *runny*

A membrane has to be fluid enough to bend, to let its proteins move and to form vesicles, but firm enough to hold together. The fatty acid tails set the balance. Saturated tails are straight and pack tightly, so they have high melting points and make a membrane stronger and stiffer. Unsaturated tails have a kink at each double bond, so they cannot pack closely; they have lower melting points and keep a membrane fluid and flexible at the temperatures the cell lives at.

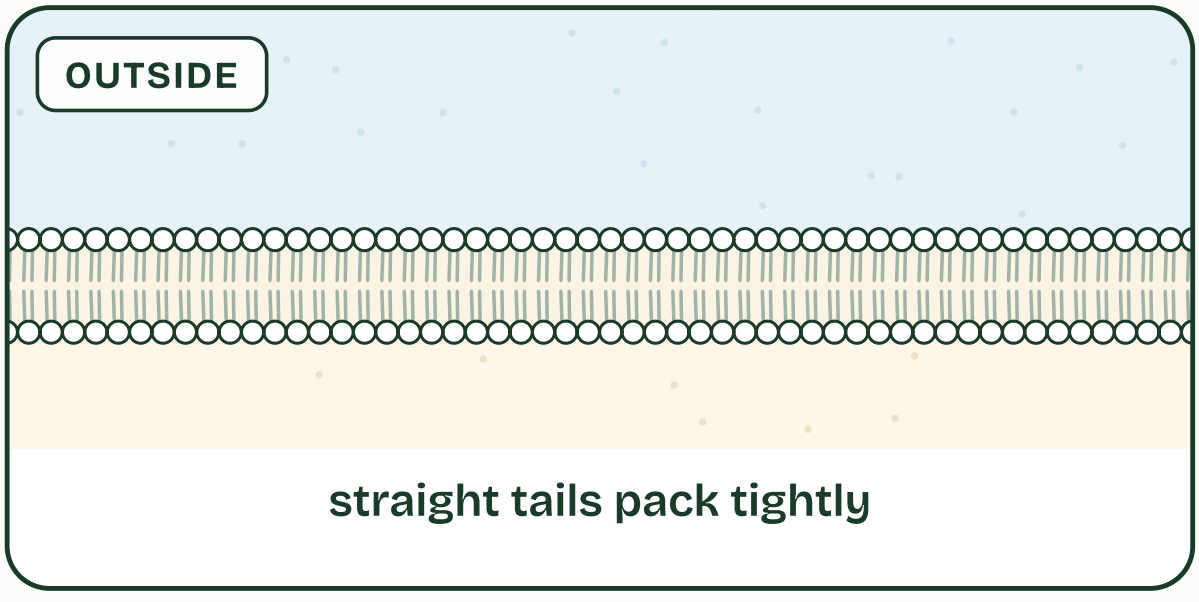
Organisms adjust the mix to their habitat. Antarctic icefish live in water at about −2 °C, and their membranes carry a high share of unsaturated fatty acids, so they stay fluid where ours would set like cold butter. Bacteria in hot springs go the other way, with more saturated tails to stop their membranes becoming too runny. In animal cells, **cholesterol** sits between the phospholipids, its hydroxyl group by the heads and its rigid rings among the tails. It is a moderator: at high temperatures it holds the tails still and stops the membrane becoming too fluid, and at low temperatures it keeps the tails apart and stops them packing into a stiff solid.

KEY POINTS

- Saturated tails: straight, pack tightly, stiffer, stronger at high temperatures.
- Unsaturated tails: kinked, pack loosely, fluid at low temperatures.
- Cholesterol buffers fluidity: less fluid when warm, less stiff when cold.

KEY TERMS

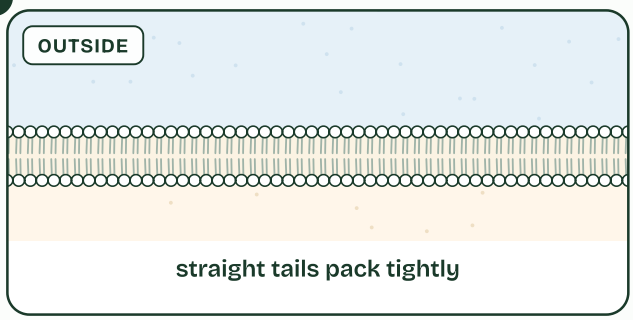
cholesterol
A lipid with a small hydroxyl group and a rigid ring structure, positioned among the phospholipids of animal cell membranes, where it moderates fluidity.



SWITCH IT

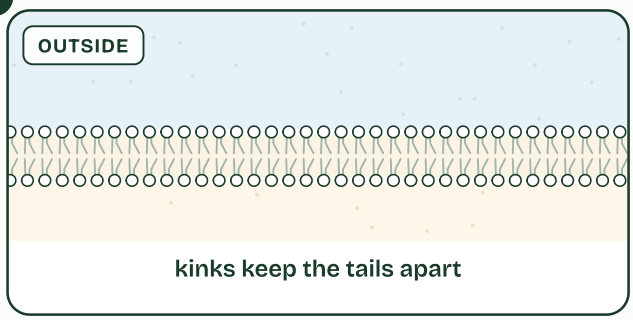
3 SETTINGS

1



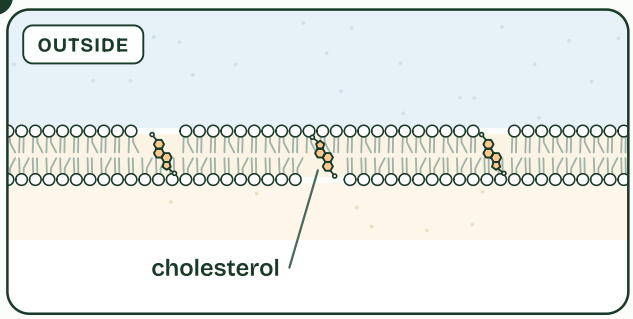
Saturated

2



Unsaturated

3



With cholesterol

WATCH OUT

Cholesterol does not simply "make membranes stiffer". At low temperatures it does the opposite, so say what it does at each end.

PREDICT

Goldfish kept at 5 °C for weeks are compared with goldfish kept at 25 °C. What would you expect in the membranes of the cold fish?

(A) More saturated fatty acids, so that the membranes are stronger and do not split apart in the cold

(B) More unsaturated fatty acids, so that the membranes stay fluid in spite of the lower temperature

(C) The same fatty acids as the warm fish, because the make-up of membranes is fixed by the genes

Decide before you look. Answer on page 37.

08 Pinching off, *joining up*

B2.1.13 HL MEMBRANE FLUIDITY AND THE FUSION AND FORMATION OF VESICLES

Because a membrane is fluid, a patch of it can bend, pinch off as a small sac and close up again with no hole left behind. That sac is a vesicle. In **endocytosis** the plasma membrane folds inwards round material outside the cell and pinches off, carrying it in. Phagocytes take in bacteria this way, and the cells of a newborn's gut take in antibodies from milk. In **exocytosis** a vesicle travels to the plasma membrane and fuses with it, its bilayer joining the membrane's, and its contents are released outside. Gland cells secrete digestive enzymes this way, and neurons release neurotransmitters.

Each time, membrane is moved too. Exocytosis adds the vesicle's membrane to the cell surface; endocytosis takes some away. The proteins that pull the membrane into a bud, such as clathrin in B2.2, need the bilayer to be fluid enough to curve. Both processes use energy from ATP.

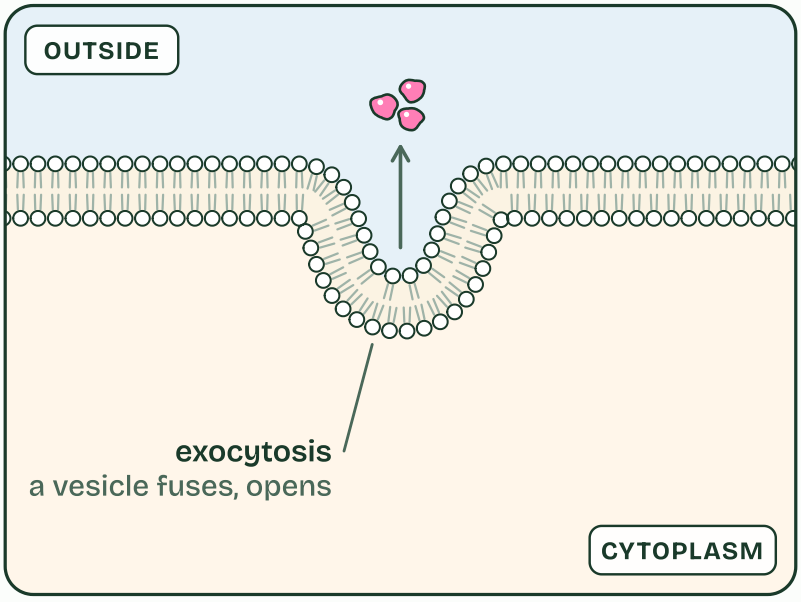
KEY POINTS

- Fluidity lets membranes bend, bud into vesicles and fuse.
- Endocytosis: material taken in by a vesicle pinching off inwards.
- Exocytosis: a vesicle fuses with the membrane and releases its contents.

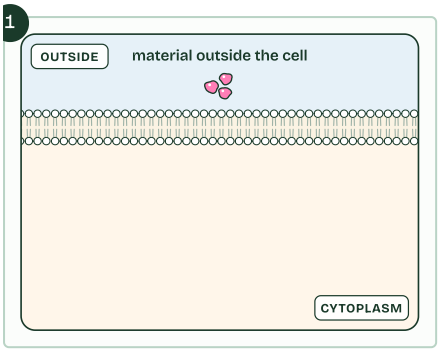
KEY TERMS

endocytosis
Taking material into a cell by folding the plasma membrane around it and pinching it off as a vesicle.

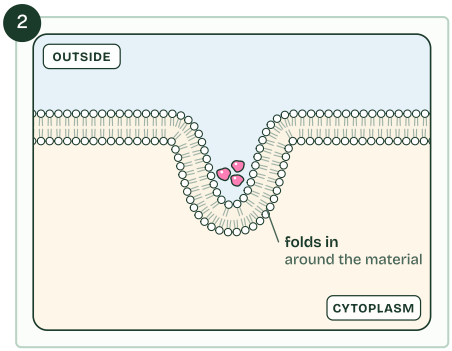
exocytosis
Releasing material from a cell when a vesicle fuses with the plasma membrane and its contents are released outside.



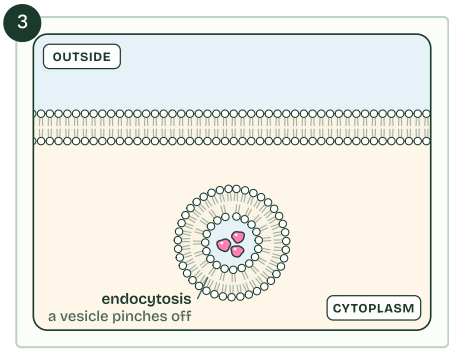
STEP BY STEP 4 STEPS



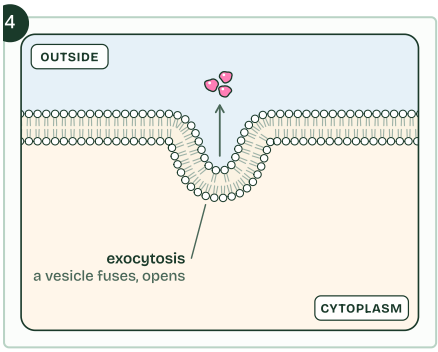
Material outside the cell, next to the plasma membrane.



The fluid membrane **folds in** around it.



The fold pinches off as a **vesicle**: endocytosis. The membrane closes behind it.



The reverse: a vesicle **fuses** with the membrane and opens outside, releasing its contents: exocytosis.

WATCH OUT

In exocytosis the vesicle does not burst on the surface. Its membrane becomes part of the plasma membrane.

PREDICT

A pancreas cell secretes enzymes by exocytosis for an hour without taking any membrane back in. What happens to its plasma membrane?

(A) It stays exactly the same size, because the vesicles burst outside and none of their membrane is kept

(B) It gains area, because the membrane of every vesicle that fuses becomes part of the cell surface

(C) It loses area, because some of the plasma membrane is used up to make the vesicles that leave

Decide before you look. Answer on page 37.

B2.1.14 HL B2.1.15 HL GATED ION CHANNELS IN NEURONS SODIUM-POTASSIUM PUMPS AS AN EXAMPLE OF EXCHANGE TRANSPORTERS

09 Gates and a *pump* in every neuron

Neurons depend on ion channels that open only when told to. A **neurotransmitter-gated** channel opens when a signalling molecule binds to it. The **nicotinic acetylcholine receptor** is one: when acetylcholine binds to its two sites, the channel opens and sodium ions diffuse into the cell. A **voltage-gated** channel opens or closes when the voltage across the membrane changes. The sodium and potassium channels that carry a nerve impulse along an axon are voltage-gated.

For those channels to do anything, there must be gradients to diffuse down. The **sodium-potassium pump** makes them. In each cycle it binds three Na^+ from inside, is phosphorylated by ATP, changes shape, releases the Na^+ outside, binds two K^+, loses the phosphate, changes back and releases the K^+ inside. It is an **exchange transporter**: one kind out, another in. Because three positive charges leave for every two that enter, and because K^+ leaks back out through channels, the inside ends up negative: the **membrane potential**, about −70 mV in a resting neuron.

KEY POINTS

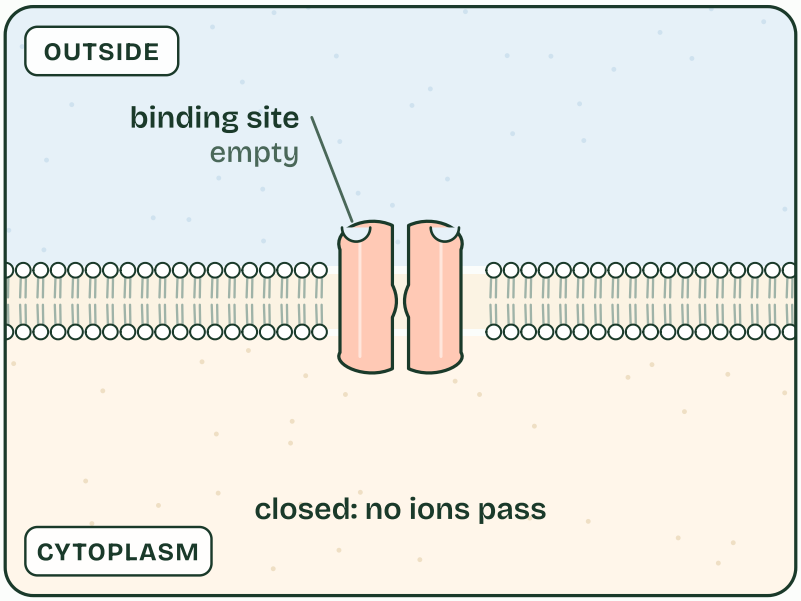
- Neurotransmitter-gated: acetylcholine opens the nicotinic receptor, Na^+ enters.
- Voltage-gated: Na^+ and K^+ channels respond to the membrane voltage.
- Na^+/K^+ pump: 3 Na^+ out, 2 K^+ in per ATP; builds the membrane potential.

KEY TERMS

nicotinic acetylcholine receptor
A sodium channel in the membrane of a neuron or muscle cell that opens when the neurotransmitter acetylcholine binds to it.

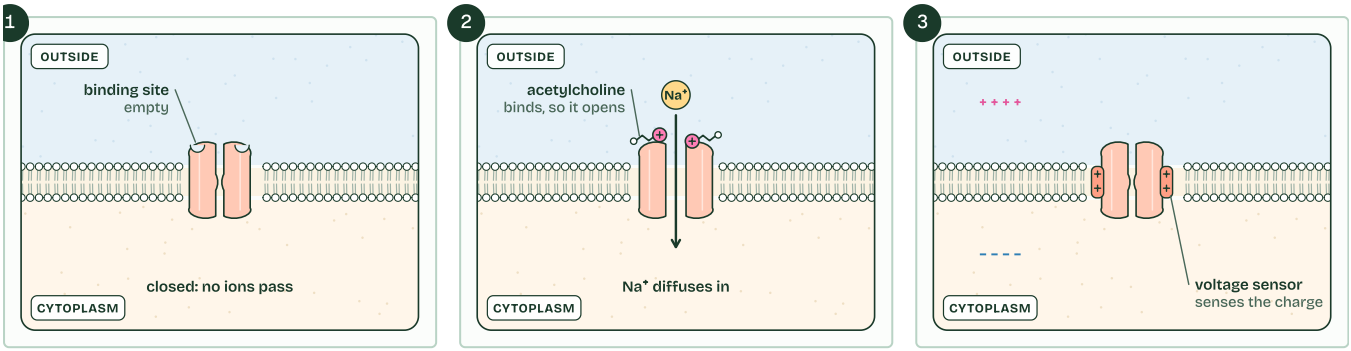
sodium-potassium pump
A pump protein that uses one ATP to move three sodium ions out of a cell and two potassium ions in, both against their concentration gradients.

membrane potential
The difference in charge (voltage) across a membrane; in a resting neuron about −70 mV, the inside negative.



SWITCH IT

3 SETTINGS



No acetylcholine

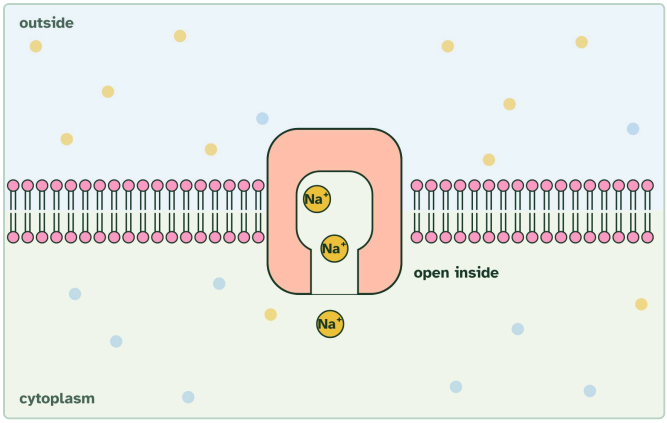
Acetylcholine bound

Voltage-gated

ANIMATION · THE SODIUM-POTASSIUM PUMP

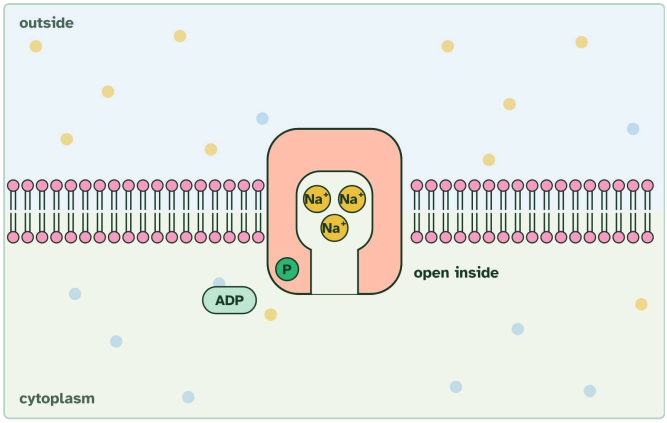
7 MOMENTS

1 NA⁺ BIND



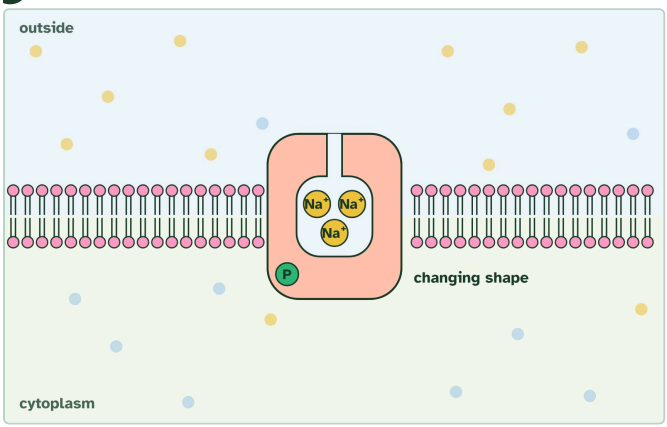
The pump is open to the **cytoplasm**. Three **Na⁺** ions diffuse in and bind to their sites inside it.

2 PHOSPHORYLATED



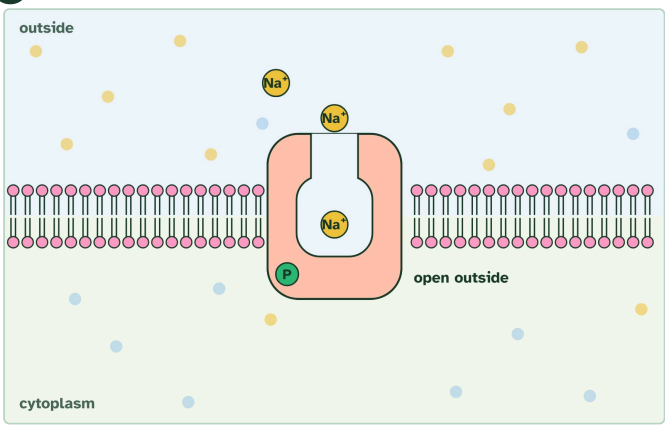
ATP gives the pump a phosphate group: the pump is **phosphorylated**, and ADP is left over.

3 SHAPE CHANGE



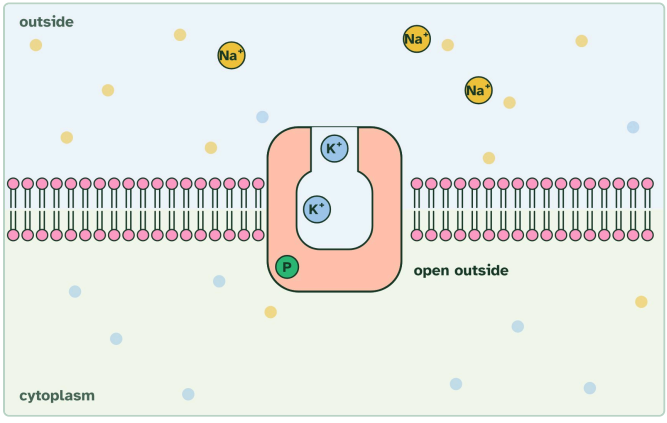
The phosphate makes the pump **change shape**. It closes on the cytoplasm side and opens to the outside.

4 NA⁺ OUT



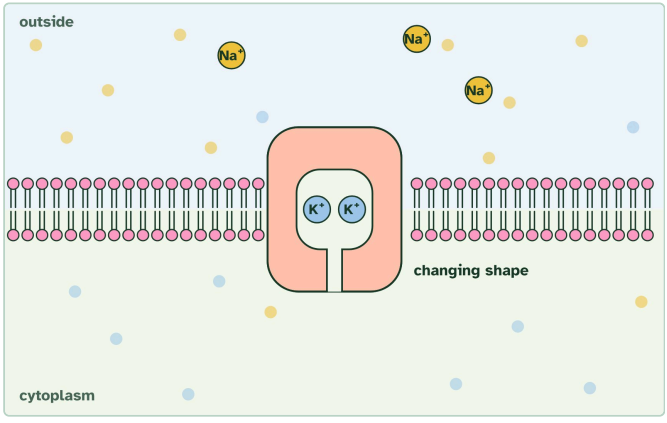
In this shape the sites no longer hold Na⁺, so the three Na⁺ are released **outside**, where Na⁺ is already more concentrated.

5 K⁺ BIND



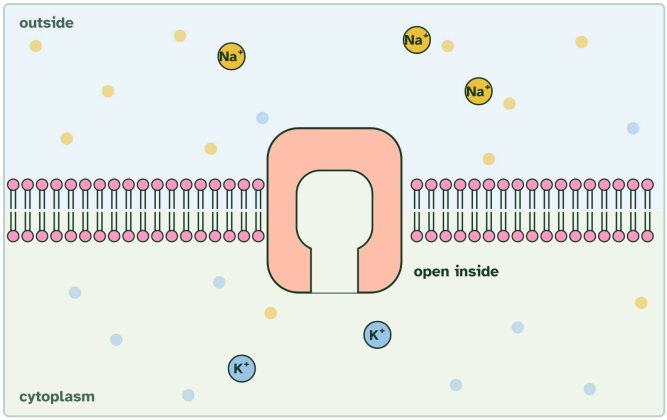
Two **K⁺** ions from outside bind to sites that suit this shape.

6 PHOSPHATE OFF



The phosphate comes off and the pump **changes back**, open to the cytoplasm again.

7 K^+ IN



The two K^+ are released **inside**, where K^+ is already more concentrated. One ATP has moved 3 Na^+ out and 2 K^+ in, both against their gradients.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-b2-1-membranes-and-membrane-transport#gated

WATCH OUT

The pump moves both ions against their gradients: Na^+ out to where Na^+ is already high, K^+ in to where K^+ is already high.

PREDICT

Ouabain stops the sodium-potassium pump. What happens over the next hours in a neuron treated with it?

(A) Sodium builds up outside the neuron, because nothing now lets it diffuse back into the cytoplasm

(B) The sodium and potassium gradients run down, so the membrane potential falls and impulses fail

(C) Nothing changes, because the voltage-gated channels take over the pump's job of moving the ions

Decide before you look. Answer on page 38.

B2.1.16 HL SODIUM-DEPENDENT GLUCOSE COTRANSPORTERS AS AN EXAMPLE OF INDIRECT ACTIVE TRANSPORT

10 Glucose *hitches a ride*

Glucose in the small intestine has to be absorbed even when there is more glucose inside the gut lining cells than in the gut. That is uphill, but no ATP is spent at the transporter that does it. Instead, the sodium-potassium pump on the blood side of each cell keeps the sodium concentration inside low. Sodium in the gut is high, so it tends to diffuse in.

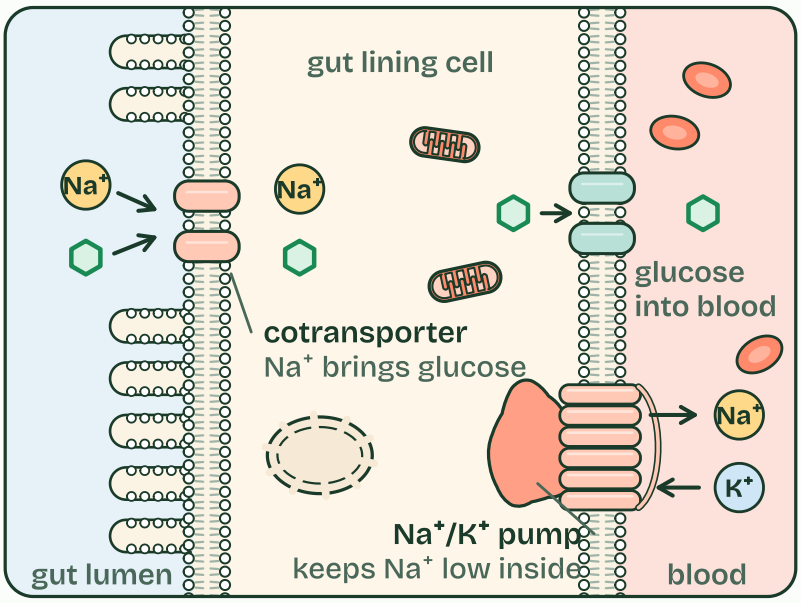
A **sodium-glucose cotransporter** (SGLT) on the gut side lets a sodium ion in only if a glucose molecule comes with it. The sodium going down its gradient drives the glucose up its gradient. Glucose then leaves the cell on the blood side by facilitated diffusion. This is **indirect active transport**: the energy comes from ATP, but it was spent by the pump, building the sodium gradient that the cotransporter uses. The same system in the kidney's nephron takes glucose back out of the filtrate, so none is lost in urine.

KEY POINTS

- The Na^+/K^+ pump keeps Na^+ low inside, using ATP.
- SGLT: Na^+ in down its gradient carries glucose in against its gradient.
- Indirect active transport: in the small intestine and in the nephron.

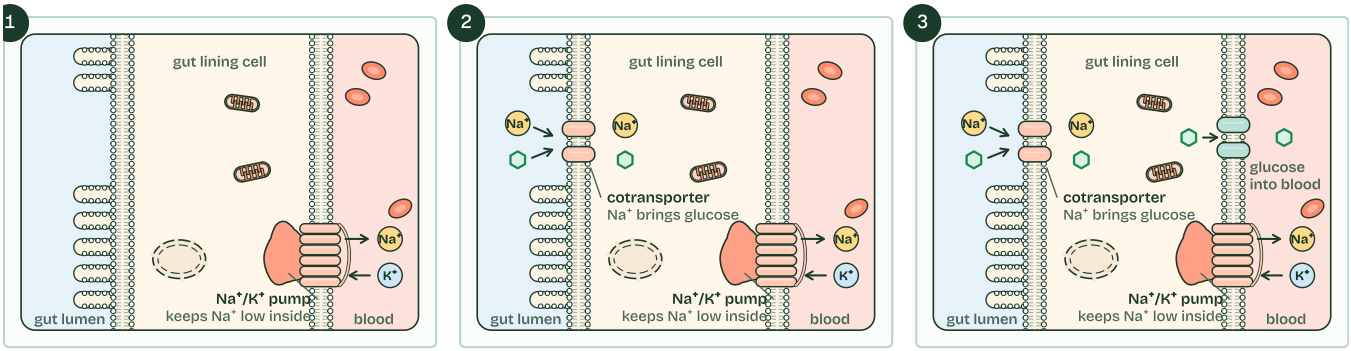
KEY TERMS

sodium-glucose cotransporter A sodium-dependent glucose cotransporter: a protein that moves sodium ions into a cell down their gradient and uses that movement to carry glucose in with them, against its gradient.



STEP BY STEP

3 STEPS



On the blood side, the **Na^+/K^+ pump** uses ATP and keeps Na^+ low inside the cell.

On the gut side, the **cotransporter** lets Na^+ in down its gradient, and glucose comes with it.

Glucose leaves on the blood side by **facilitated diffusion**.

WATCH OUT

The cotransporter itself does not use ATP. If the pump stops, the cotransporter stops too, because the sodium gradient runs down.

PREDICT

Why does glucose appear in the urine when blood glucose is very high, as in untreated diabetes?

(A) The high glucose damages the cotransporters so that they start moving glucose back into the filtrate

(B) There is more glucose in the filtrate than the cotransporters can take back, so the extra is left in it

(C) The pumps run out of ATP when glucose is high, so no sodium gradient remains to drive the cotransport

Decide before you look. Answer on page 38.

11

B2.1.17 HL ADHESION OF CELLS TO FORM TISSUES

Holding *tissues* together

Cells in a tissue are joined to their neighbours. The joins are made by **cell-adhesion molecules** (CAMs): proteins in the plasma membrane whose outer parts bind to CAMs on the next cell, or to the material between cells. Different forms of CAM make different kinds of junction.

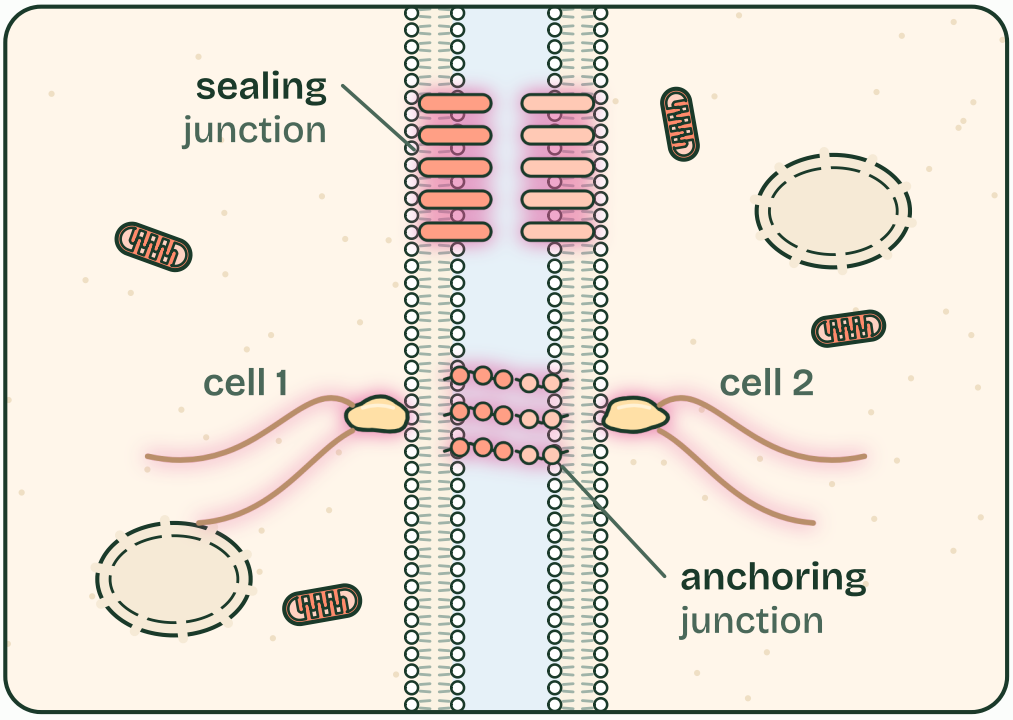
Some junctions seal: CAMs packed in a line near the top of gut lining cells close the gap between them, so the gut's contents cannot leak between the cells and must pass through them, by the transport proteins of the last chapter. Others anchor: CAMs bind across the gap and are tied inside to the cytoskeleton, so tissues such as skin and heart muscle hold together when stretched. Others again let cells pass signals. You do not need to know the names of the CAMs or the junctions, only that different CAMs make different joins.

KEY POINTS

- CAMs: membrane proteins that bind cells to each other.
- Different forms of CAM make different junctions.
- Some seal gaps, some anchor cells against pulling forces.

KEY TERMS

cell-adhesion molecules
Membrane proteins that bind a cell to neighbouring cells or to the material between cells; different kinds form different cell-cell junctions.



CAMs packed close together near the top of the cells seal the gap between them, so fluid cannot leak between the cells.

CAMs from each cell bind each other across the gap and are tied inside to the cytoskeleton, holding the cells together against pulling forces.

WATCH OUT

CAMs are not the sugar tags of chapter 6, though glycoproteins can help cells stick. CAMs are the proteins that make the junctions themselves.

PREDICT

Cancer cells that spread round the body often make less of one kind of CAM. Why might that help them spread?

(A) Fewer CAMs make the cells divide faster, so the tumour grows big enough to burst into blood vessels

(B) Fewer CAMs hold them to their neighbours, so cells can break away from the tumour and move off

(C) Fewer CAMs let more glucose into each cell, so the cells have the energy to swim through the blood

Decide before you look. Answer on page 38.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

active transport 05
Movement of particles across a membrane against their concentration gradient, using energy from ATP.

amphipathic 01
Having one part that is hydrophilic (attracted to water) and another that is hydrophobic (not attracted to water), as a phospholipid has.

aquaporins 04
A channel protein that lets water molecules pass through the membrane in single file, greatly increasing the membrane's permeability to water.

cell-adhesion molecules 11
Membrane proteins that bind a cell to neighbouring cells or to the material between cells; different kinds form different cell-cell junctions.

channel protein 05
An integral protein with a hydrophilic pore through which one specific kind of ion or molecule can diffuse when the channel is open.

cholesterol 07
A lipid with a small hydroxyl group and a rigid ring structure, positioned among the phospholipids of animal cell membranes, where it moderates fluidity.

endocytosis 08
Taking material into a cell by folding the plasma membrane around it and pinching it off as a vesicle.

exocytosis 08
Releasing material from a cell when a vesicle fuses with the plasma membrane and its contents are released outside.

facilitated diffusion 05
Diffusion of particles across a membrane through channel or carrier proteins, down the concentration gradient and without energy from the cell.

fluid mosaic model 06
The model of membrane structure in which proteins are scattered in a fluid phospholipid bilayer, like tiles in a mosaic that can move about.

glycolipid 06
A membrane lipid with a carbohydrate chain attached, the carbohydrate facing the outside of the cell.

glycoprotein 06
A membrane protein with a carbohydrate chain attached, the carbohydrate facing the outside of the cell.

integral proteins 03
A protein embedded in one or both layers of the phospholipid bilayer, with a hydrophobic part held among the tails.

lipid bilayer 01
A double layer of phospholipids (or other amphipathic lipids), heads facing the water on both sides and tails facing inwards, forming the core of every cell membrane.

membrane potential 09
The difference in charge (voltage) across a membrane; in a resting neuron about −70 mV, the inside negative.

nicotinic acetylcholine receptor 09
A sodium channel in the membrane of a neuron or muscle cell that opens when the neurotransmitter acetylcholine binds to it.

osmosis 04
The net movement of water across a partially permeable membrane, from a lower solute concentration to a higher solute concentration.

peripheral proteins 03
A protein attached to the inner or outer surface of the bilayer, to the phospholipid heads or to an integral protein, without being embedded among the tails.

permeability 02
How easily a substance can pass through a membrane.

pump protein 05

An integral protein that uses energy from ATP to move specific particles across a membrane, which can be against their concentration gradient.

simple diffusion 02

The net movement of particles from a higher to a lower concentration, directly through the phospholipid bilayer, with no protein involved and no energy used by the cell.

sodium-glucose cotransporter 10

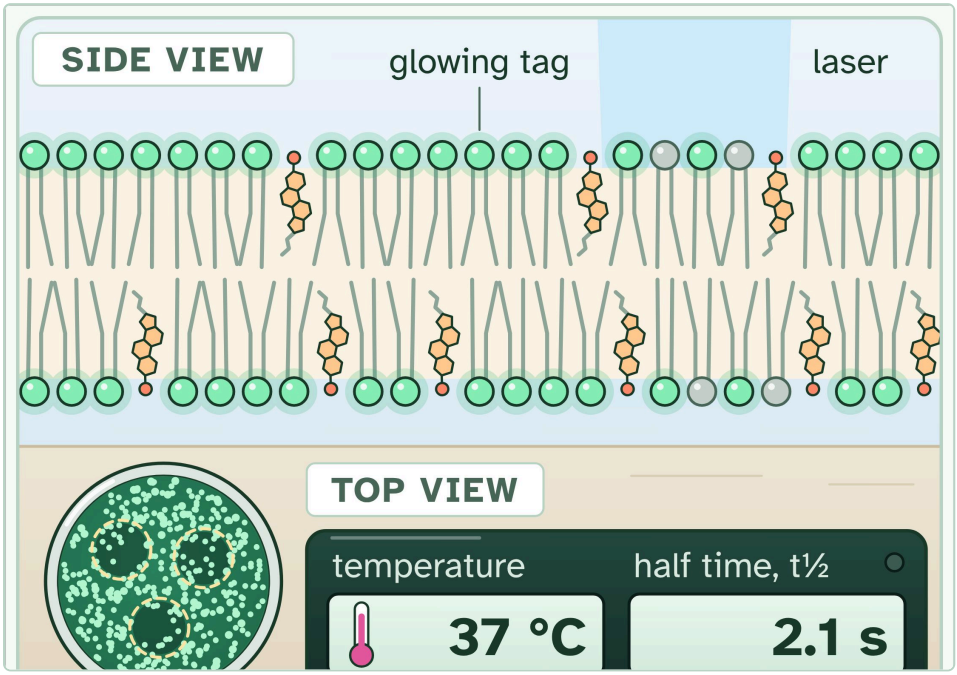
A sodium-dependent glucose cotransporter: a protein that moves sodium ions into a cell down their gradient and uses that movement to carry glucose in with them, against its gradient.

sodium-potassium pump 09

A pump protein that uses one ATP to move three sodium ions out of a cell and two potassium ions in, both against their concentration gradients.

Dry lab: *The membrane fluidity bench*

Bleach a spot on a membrane whose lipids glow and time how fast it lights up again. Change the temperature, the unsaturated fatty acids and the cholesterol, and plot what each does to fluidity.



Run it online: change the variables, run the trials, and the table and graph fill in as you go. `biologybybradford.com/guides/ib-biology-b2-1-membranes-and-membrane-transport#lab`

Your question

How do temperature, unsaturated fatty acids and cholesterol change how freely the lipids in a membrane move? Predict first: will cholesterol make a membrane at 0 °C more fluid or less?

What you can change

The temperature (0 to 45 °C), the share of the fatty acids that are unsaturated (20 to 80%) and the cholesterol (none, some or a lot). Each press bleaches three spots, so you have repeats.

What to record

The recovery half time t½ of each spot: the seconds its brightness takes to get halfway back. A short t½ means a fluid membrane. The numbers are invented to show the pattern real membranes follow; the method, fluorescence recovery after photobleaching, is real.

Find out

- **Warm it up.** Keep 40% unsaturated and no cholesterol. Bleach spots at every temperature from 0 to 45 °C. Where does the half time change most steeply, and what is happening to the tails there?
- **Add kinks.** Repeat at 80% unsaturated. How does the curve move, and why do icefish membranes look like this one?
- **Add cholesterol.** Repeat 40% unsaturated with a lot of cholesterol. Compare the two lines at 0 °C and at 37 °C. Is cholesterol making the membrane more fluid or less?
- **Design a membrane.** Find a mix that keeps t½ between 3 and 10 s from 10 to 45 °C. Which ingredient made the biggest difference?

Record

- For each spot: the temperature, the unsaturated share, the cholesterol and the recovery half time t½ in seconds.
- For each membrane and temperature: the mean t½ of the three spots and their range.
- A graph of mean t½ against temperature, one line for each membrane, and a sentence on each line's shape.
- Download the CSV to keep every spot.

Your question How do temperature, unsaturated fatty acids and cholesterol change how freely the lipids in a membrane move? Predict first: will cholesterol make a membrane at 0 °C more fluid or less?**What you can change**The temperature (0 to 45 °C), the share of the fatty acids that are unsaturated (20 to 80%) and the cholesterol (none, some or a lot). Each press bleaches three spots, so you have repeats.**What to record**The recovery half time t½ of each spot: the seconds its brightness takes to get halfway back. A short t½ means a fluid membrane. The numbers are invented to show the pattern real membranes follow; the method, fluorescence recovery after photobleaching, is real.

Back to living cells

An Antarctic icefish lives in water at about −2 °C, and your own cells work at 37 °C. Use your results to explain what you would expect of the fatty acids in the membranes of the icefish, and what cholesterol does for the membranes of animal cells.

QUESTIONS ON THE LAB

QUESTION 1

One membrane gives t½ = 2 s at 37 °C and another gives t½ = 9 s. Which is more fluid?

(A) The one with 9 s, because a longer half time shows the lipids have more time to move around

(B) The one with 2 s, because tagged lipids from round about drift into the spot faster

(C) They cannot be compared, because a half time measures the laser and not the lipids in a membrane

Answer on page 38.

QUESTION 2

Without cholesterol, t½ falls from 32 s at 10 °C to 2 s at 30 °C. With a lot of cholesterol it falls from 11 s to 5 s. What does this show?

(A) Cholesterol always makes a membrane more fluid, because t½ is lower with it at 10 °C than without it

(B) Cholesterol always makes a membrane stiffer, because t½ is higher with it at 30 °C than without it

(C) Cholesterol evens out fluidity: more fluid when cold, less fluid when warm, so it changes less with temperature

Answer on page 38.

QUESTION 3

Why does each press bleach three spots rather than one?

(A) Three spots are needed before the software is able to draw a full recovery curve for the membrane

(B) Repeats show how much single spots vary, so a mean is more reliable and a real difference can be seen

(C) Bleaching three spots at once makes the recovery quicker, so the experiment fits inside one lesson

Answer on page 38.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on B2.1 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?topics=B2.1&level=HL&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 Phospholipids are shaken in oil instead of water. How would they arrange themselves?

B **Turned the other way, tails out into the oil and the heads hidden together in the middle**

In oil it is the tails that mix with the solvent and the hydrophilic heads that are pushed together. The arrangement depends on the solvent, which is why a bilayer forms only with water on both sides.

02 Rank these from fastest to slowest across a bare bilayer: oxygen, glucose, sodium ions.

B **Oxygen, glucose, sodium ions: non-polar first, then the polar molecule, and the charged ion last**

Oxygen is small and non-polar, so it crosses easily. Glucose is polar and fairly large, so it crosses very slowly. A charged ion is held by its shell of water and barely crosses at all. A membrane does not know what the cell needs: that is the job of its proteins.

03 A protein is removed from a membrane only by a detergent that breaks up the bilayer. What kind is it most likely to be?

B **Integral, because a part of it is held among the hydrophobic tails until the bilayer is broken**

An integral protein's hydrophobic region is held by the tails, so the bilayer itself has to be broken apart. Peripheral proteins are held by weaker attractions at the surface and come off with milder treatments, such as a change in salt concentration.

04 A drug blocks the aquaporins in a cell placed in pure water. What happens?

B **Water still enters by osmosis through the bilayer, but more slowly than it did before the drug**

Some water still crosses between the phospholipids, so osmosis goes on in the same direction, into the cell, but slowly. Aquaporins change the rate, not the direction.

05 A poison stops ATP being made in a cell. Which movement stops first?

B **Sodium ions being moved out of the cell against their gradient by the cell's pump proteins**

Only active transport needs ATP, so the pumps stop. Diffusion through channels and between phospholipids goes on as long as there is a gradient, although without the pumps the ion gradients slowly run down.

06 A mouse cell and a human cell are fused, each with its own membrane proteins tagged a different colour. What is seen after 40 minutes at 37 °C?

B **The two colours are mixed all over the hybrid cell, because the proteins drift sideways in the bilayer**

This was a real experiment (Frye and Edidin, 1970). The proteins mixed within about 40 minutes, so they must move within the membrane: the "fluid" in fluid mosaic. At low temperatures the mixing was much slower.

07 Goldfish kept at 5 °C for weeks are compared with goldfish kept at 25 °C. What would you expect in the membranes of the cold fish?

B **More unsaturated fatty acids, so that the membranes stay fluid in spite of the lower temperature**

Cold makes membranes stiffer, so cold-acclimated fish make more unsaturated fatty acids to keep them fluid. This adjustment, measured in real goldfish, is called homeoviscous adaptation. The genes allow it; the temperature switches it on.

08 A pancreas cell secretes enzymes by exocytosis for an hour without taking any membrane back in. What happens to its plasma membrane?

B **It gains area, because the membrane of every vesicle that fuses becomes part of the cell surface**

Every fused vesicle adds its patch of membrane. Real secretory cells balance this by taking membrane back in by endocytosis, so the surface stays the same size.

09 Ouabain stops the sodium-potassium pump. What happens over the next hours in a neuron treated with it?

B **The sodium and potassium gradients run down, so the membrane potential falls and impulses fail**

Ions keep leaking down their gradients through channels, and nothing moves them back. Na^+ builds up inside, K^+ leaks out, the membrane potential shrinks and the neuron can no longer fire. Channels only ever let ions diffuse.

10 Why does glucose appear in the urine when blood glucose is very high, as in untreated diabetes?

B **There is more glucose in the filtrate than the cotransporters can take back, so the extra is left in it**

There are only so many cotransporters, each working at a set rate. Above a threshold every one is busy, so the extra glucose stays in the filtrate and ends up in the urine.

11 Cancer cells that spread round the body often make less of one kind of CAM. Why might that help them spread?

B **Fewer CAMs hold them to their neighbours, so cells can break away from the tumour and move off**

CAMs hold cells in place. A cell that has lost them comes away more easily, which is one step in a tumour spreading. Losing a CAM does not by itself speed up division.

QUESTIONS ON THE DRY LAB

Q1 One membrane gives t½ = 2 s at 37 °C and another gives t½ = 9 s. Which is more fluid?

B **The one with 2 s, because tagged lipids from round about drift into the spot faster**

The spot lights up again as unbleached lipids diffuse into it. The faster they move, the sooner it is half bright, so a short t½ means a fluid membrane.

Q2 Without cholesterol, t½ falls from 32 s at 10 °C to 2 s at 30 °C. With a lot of cholesterol it falls from 11 s to 5 s. What does this show?

C **Cholesterol evens out fluidity: more fluid when cold, less fluid when warm, so it changes less with temperature**

Each of the first two answers is true at one temperature only. Together they show cholesterol as a moderator: it stops the tails packing solid in the cold and holds them still in the warm, so the membrane's fluidity changes far less over the range.

Q3 Why does each press bleach three spots rather than one?

B **Repeats show how much single spots vary, so a mean is more reliable and a real difference can be seen**

No two spots recover in exactly the same time. With repeats you can take a mean and see the spread, and judge whether two membranes really differ or only seem to.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.