REVISION GUIDE

A membrane that builds itself, and *chooses* what crosses

Membranes and permeability

Phospholipids drop into water and a membrane forms with no instructions. See why, set proteins, cholesterol and sugars into it, work out what crosses it on its own and what needs help, and find what a wall adds outside it.

6 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ap-biology-unit-2-membranes-and-permeability

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By the end you can

- [ ] Explain how the hydrophilic heads and hydrophobic tails of phospholipids arrange themselves into a bilayer with water on both sides 2.3.A
- [ ] Describe integral and peripheral proteins and explain how their hydrophobic and hydrophilic regions place them in the membrane 2.3.A
- [ ] Describe the fluid mosaic model, with cholesterol, glycoproteins and glycolipids, and explain what makes a membrane more or less fluid 2.3.B
- [ ] Explain how the structure of the membrane makes it selectively permeable: which molecules cross the bilayer and which need proteins 2.4.A
- [ ] Describe the cell walls of plants, fungi and prokaryotes and their role in structure and as a barrier 2.4.B

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

01 A barrier that *builds itself*

2.3.A PLASMA MEMBRANE

A **phospholipid** has two ends that want different things. Its phosphate head is charged, so it is **hydrophilic**: it mixes with water. Its two fatty acid tails are non-polar, so they are **hydrophobic**: water pushes them out.

A cell has water on both sides of its membrane: the cytoplasm inside, the tissue fluid or pond outside. So phospholipids settle into a **phospholipid bilayer**: heads facing the water on each side, tails facing each other in the middle, out of the water. Nothing has to arrange them. Water holds itself together by hydrogen bonds and squeezes the tails together, the same hydrophobic effect that folds a protein.

Three thought experiments test the idea; the first is the predict box below. Try the others on paper: what would phospholipids do with water on one side only, and why does a torn membrane close up by itself?

KEY POINTS

- Heads: hydrophilic, facing the water on each side.
- Tails: hydrophobic, facing each other in the middle.
- The bilayer forms by itself, pushed together by water.

KEY TERMS

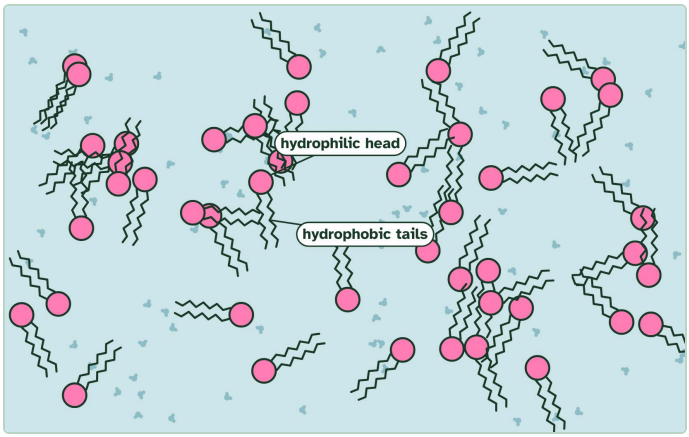
phospholipid
A lipid made of a glycerol joined to two fatty acid tails and a phosphate group. Its head is hydrophilic and its tails hydrophobic.

phospholipid bilayer
Two layers of phospholipids, heads facing the water on each side and tails facing each other in the middle.

ANIMATION · WATCH IT HAPPEN: A BILAYER BUILDS ITSELF

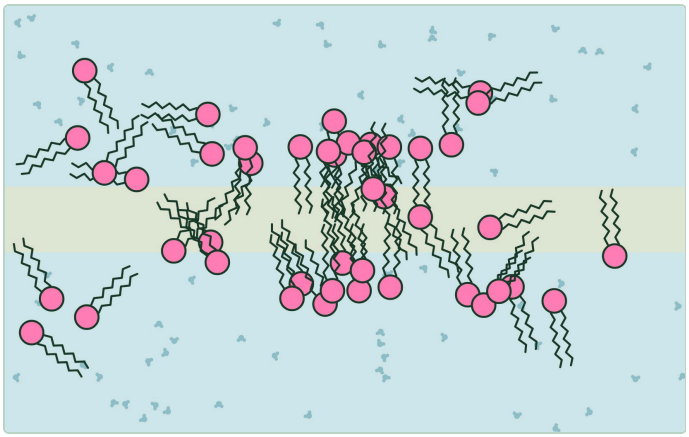
3 MOMENTS

1 IN THE BILAYER: 0 OF 44



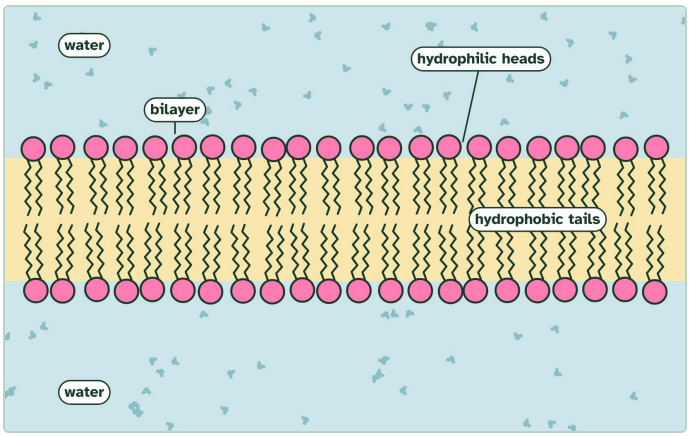
Phospholipids stirred into water point every which way.

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/ap-biology-unit-2-membranes-and-permeability#bilayer

WATCH OUT

The tails are not held together by bonds between them. Water pushes them together, because it hydrogen bonds with itself and not with them.

PREDICT

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

(A) In a bilayer as before, because a phospholipid's shape always gives the same arrangement in any liquid

(B) Turned the other way round, 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 a phospholipid

Decide before you look. Answer on page 18.

02 Proteins in the *bilayer*

2.3.A PLASMA MEMBRANE

Proteins do most of a membrane's work: they carry substances across, receive signals, join cells together and speed up reactions. **Integral proteins** are set into the bilayer, and many span it from one side to the other. **Peripheral proteins** sit on its surface, held to the heads or to an integral protein.

Where a protein sits depends on its amino acids (Unit 1). The part of an integral protein that crosses the tails has amino acids with **nonpolar R groups**: it is hydrophobic, so it stays among the tails. The parts that stick out into the water have **charged and polar R groups**: they are hydrophilic. A peripheral protein is hydrophilic all over, so it never enters the core.

Tap each protein for where it sits and what kind it is.

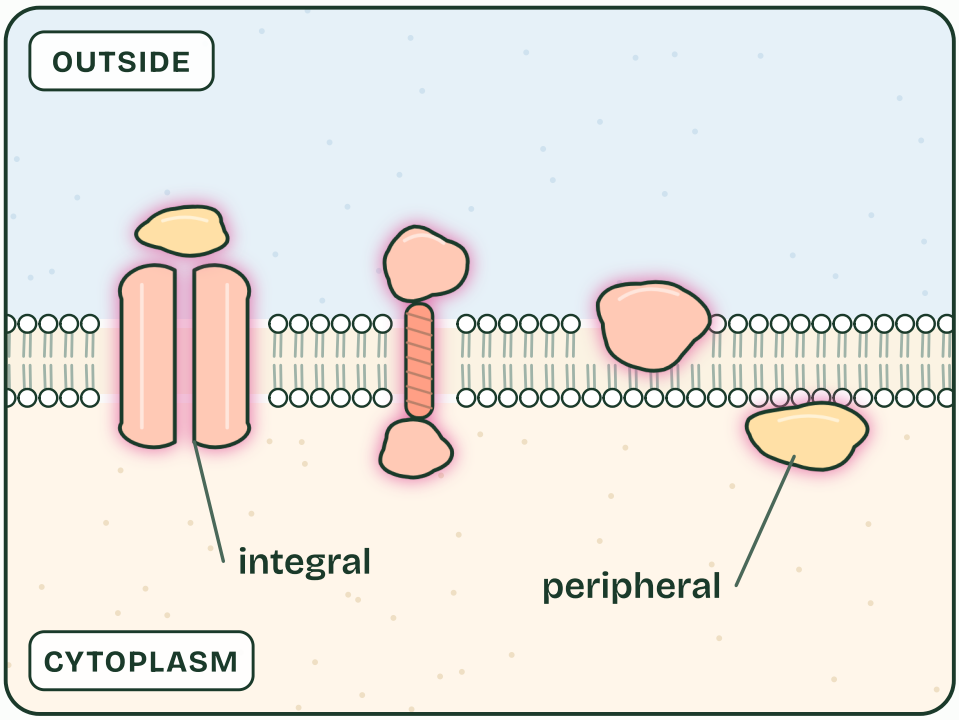
KEY POINTS

- Integral proteins: in the bilayer, often spanning it.
- Peripheral proteins: on the surface.
- Hydrophobic regions (nonpolar R groups) lie among the tails; hydrophilic regions face the water.

KEY TERMS

integral proteins
A protein embedded in the bilayer, often spanning it, held among the fatty acid tails by its hydrophobic region.

peripheral proteins
A protein held on the surface of a membrane, attached to the heads or to an integral protein, not set 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 peripheral protein on the outer surface, attached to an integral protein.

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.

WATCH OUT

A protein that is set into one layer only is still integral: part of it is held among the tails.

PREDICT

A membrane protein has a stretch of about twenty amino acids with nonpolar R groups in the middle of its chain, and charged amino acids at both ends. Where is it?

(A) On the inner surface of the membrane, where its charged ends can bind to the heads of the phospholipids

(B) Spanning the membrane once, the nonpolar stretch among the tails and the charged ends in the water

(C) Loose in the cytoplasm, because a chain with charged ends could not enter the membrane anywhere at all

Decide before you look. Answer on page 18.

03 A *fluid* mosaic

2.3.B PLASMA MEMBRANE

The **fluid mosaic model** describes a membrane as a framework of phospholipids with other molecules set in it, like the tiles of a mosaic: proteins, **cholesterol** (in eukaryotes), and molecules with chains of sugars attached. A **glycoprotein** is a protein with sugars; a **glycolipid** is a lipid with sugars. Their sugars face outward.

It is fluid because nothing is fixed. Phospholipids drift sideways past each other millions of times a second, and most proteins drift too. A membrane behaves more like a film of oil than a skin. That is what lets it seal itself when torn, and bud off or take in vesicles (the next guide).

The sugar chains on the outer surface act as name tags. Each cell type has its own pattern, so cells can recognize each other, and the immune system can tell your cells from invaders. ABO blood groups are differences in the sugar chains on red blood cells.

KEY POINTS

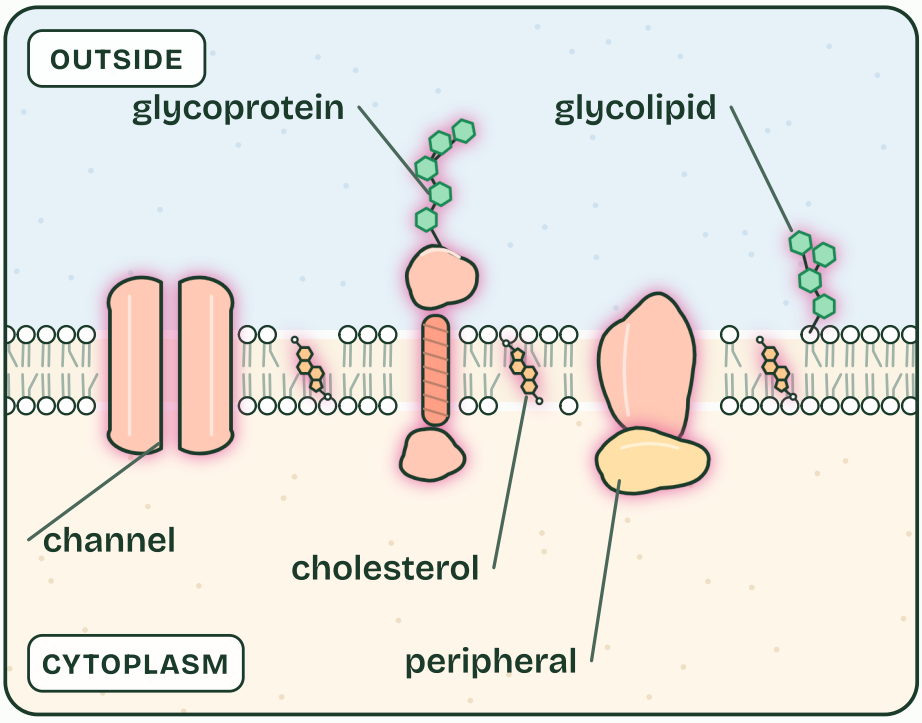
- Phospholipid framework with proteins, cholesterol, glycoproteins and glycolipids.
- Fluid: the molecules move sideways within the membrane.
- Glycoproteins and glycolipids: sugars outside, for cell recognition.

KEY TERMS

fluid mosaic model
The model of membrane structure: a fluid bilayer of phospholipids with proteins, cholesterol, glycoproteins and glycolipids set in it and moving sideways.

glycoprotein
A membrane protein with a chain of sugars attached, on the outer surface, used in cell recognition and adhesion.

glycolipid
A lipid in the membrane with a chain of sugars attached, on the outer surface.



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.

WATCH OUT

The sugar chains are on the outer surface only. The inside of the membrane, facing the cytoplasm, has none.

PREDICT

A mouse cell and a human cell are fused, each with its membrane proteins tagged a different color. An hour later, how are the colors spread?

(A) Still in two halves, one color on each side, because membrane proteins are anchored where they were made

(B) Mixed all over the new cell's membrane, because the proteins drift sideways through a fluid bilayer

(C) Gone from the surface, because the proteins have moved into the cytoplasm once the two membranes met

Decide before you look. Answer on page 18.

04

2.3.B PLASMA MEMBRANE

Not too stiff, not too *runny*

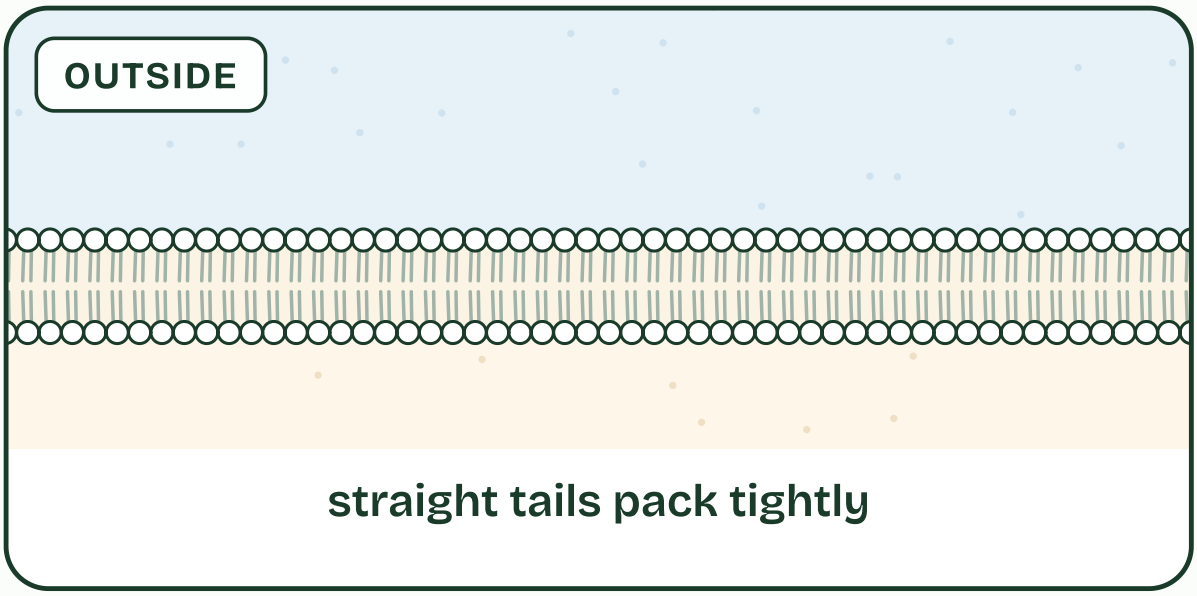
A membrane only works at the right fluidity. Too stiff, and its proteins cannot move or change shape, and vesicles cannot form. Too runny, and it leaks. Three things set it. **Temperature:** warmth makes the phospholipids move faster, and cold slows them. **Fatty acid tails:** saturated tails are straight and pack tightly, so the membrane is stiffer; unsaturated tails have kinks at their double bonds, which keep them apart and the membrane fluid.

Cholesterol buffers the change. Its small rigid rings sit among the tails. When it is warm they hold the phospholipids back, so the membrane stays firm; when it is cold they stop the tails packing together, so it stays fluid.

Organisms adjust. Plants and bacteria in the cold make more unsaturated fatty acids, and the fat in a reindeer's legs, which stay cold, is more unsaturated than the fat near its warm body.

KEY POINTS

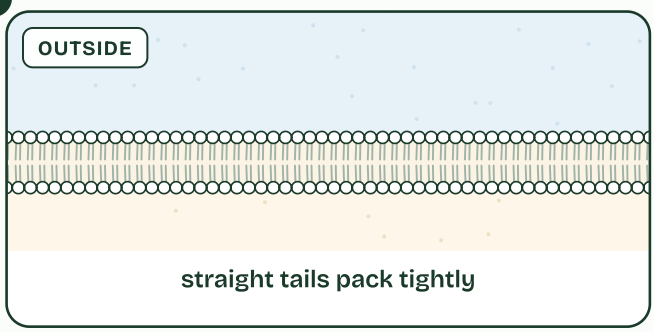
- Warmer: more fluid. Colder: stiffer.
- Unsaturated tails, kinked, keep a membrane fluid; saturated tails pack it tight.
- Cholesterol keeps fluidity steady across temperatures.



SWITCH IT

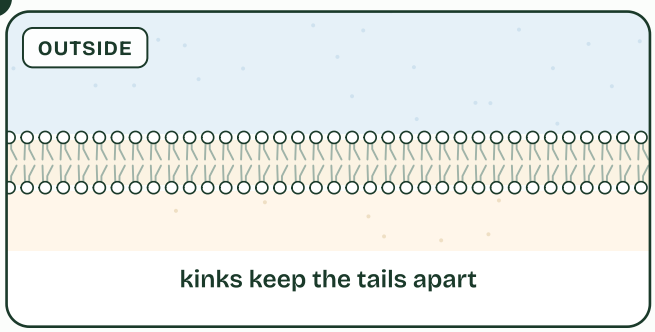
3 SETTINGS

1



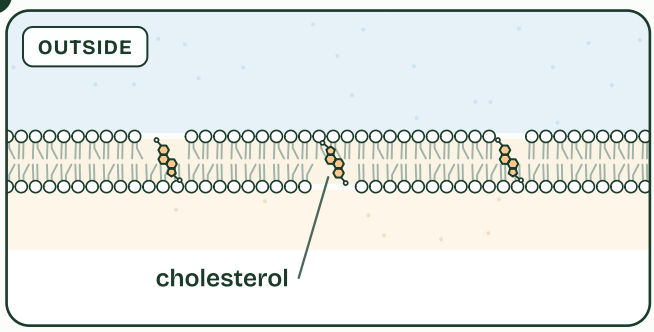
Saturated

2



Unsaturated

3



With cholesterol

WATCH OUT

"Cholesterol always makes a membrane stiffer." It does when warm; in the cold it keeps the membrane fluid. It steadies fluidity both ways.

PREDICT

A fish that lives in icy water is compared with one from a warm reef. What would you expect of its membranes?

(A) More saturated fatty acids, so the tails pack closely and the membrane does not freeze solid in the cold

(B) More unsaturated fatty acids, so the kinked tails keep the membrane fluid at low temperature

(C) No cholesterol at all, because cholesterol would set solid in cold water and block the membrane

Decide before you look. Answer on page 18.

2.4.A MEMBRANE PERMEABILITY

05 What *gets through*

A membrane separates the inside of the cell from the outside, and lets only some things across: it is **selectively permeable**. Its structure decides which. To cross the bilayer on its own, a molecule must pass through the hydrophobic core of tails.

Small nonpolar molecules, such as oxygen, carbon dioxide and nitrogen, dissolve in the core and pass straight through. **Small polar molecules** with no charge, such as water, cross too, but only in small amounts. **Ions**, such as Na^+ and K^+, and **large polar molecules**, such as glucose, are turned back: the hydrophobic core will not let a charged or strongly polar molecule through.

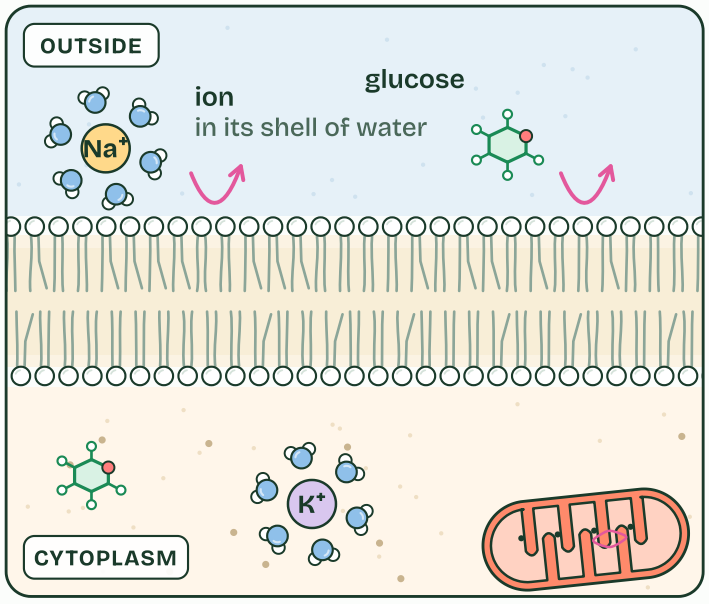
So a cell crosses its own barrier with proteins. Channel and carrier proteins give hydrophilic substances a way through, and because each fits only some substances, the cell chooses what comes in. How they work is the next guide.

KEY POINTS

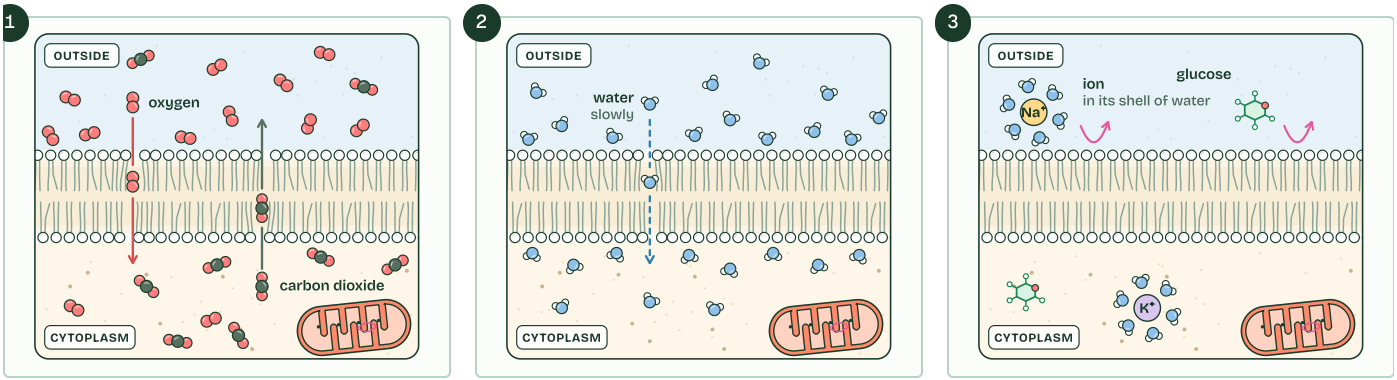
- Small nonpolar: O_2, CO_2, N_2 pass freely.
- Water: small amounts through the bilayer.
- Ions and large polar molecules need channel or transport proteins.

KEY TERMS

selectively permeable
Letting some substances cross and not others. The structure of the membrane decides which.



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.

WATCH OUT

Size is not the whole story. A sodium ion is smaller than an oxygen molecule but cannot cross the bilayer: its charge holds a shell of water around it, and the hydrophobic core will not let it in.

PREDICT

Which will cross a pure phospholipid bilayer, with no proteins in it, fastest?

(A) A glucose molecule, because cells take in so much glucose that their membranes must let it pass easily

(B) A potassium ion, because it is tiny and so it can slip through the gaps between the phospholipid heads

(C) A carbon dioxide molecule, because it is small and nonpolar and dissolves in the hydrophobic core

Decide before you look. Answer on page 18.

06

2.4.B MEMBRANE PERMEABILITY

A wall *outside* the membrane

Plants, fungi and most prokaryotes have a **cell wall** outside the plasma membrane. In every case it is made of **complex carbohydrates**. Plant walls are **cellulose**, long chains of glucose lying side by side. Fungal walls are **chitin**, chains of glucose units carrying nitrogen. Bacterial walls are **peptidoglycan**, sugar chains cross-linked by short peptides.

A wall is a structural boundary. It gives the cell its shape, supports the plant, and stops the cell bursting when water rushes in (a later guide on tonicity). It is also a barrier to some substances: very large molecules and many viruses cannot get through, though water, ions and small molecules pass it freely. The membrane inside still does the choosing.

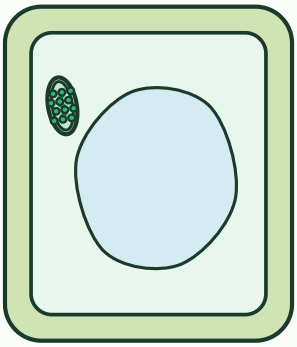
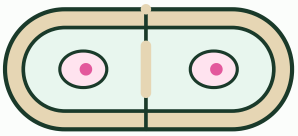
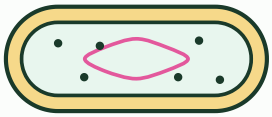
Animal cells have no wall. Their support comes from the cytoskeleton inside and from the material around them, such as collagen.

KEY POINTS

- Plant walls: cellulose. Fungi: chitin. Bacteria: peptidoglycan. All complex carbohydrates.
- A wall gives shape and support and resists bursting.
- Water and small molecules pass a wall; very large ones may not.

KEY TERMS

cell wall
A rigid layer outside the plasma membrane of plants, fungi and most prokaryotes, made of complex carbohydrates. It gives shape and support and resists bursting.

plant	fungus	bacterium
		
cellulose glucose chains side by side	**chitin** glucose units with nitrogen	**peptidoglycan** sugar chains with peptides

In each cell the outer band is the wall and the line just inside it the plasma membrane.

WATCH OUT

A wall is not a second membrane. It has no bilayer and controls little: water and dissolved substances pass through its spaces.

PREDICT

Penicillin stops bacteria building peptidoglycan. Why does it kill bacteria but leave human cells unharmed?

(A) Human cells have no peptidoglycan wall to build, so blocking the enzymes that make it does them no harm

(B) Human cells have a thicker wall of cellulose, which keeps the penicillin out of the cell altogether

(C) Penicillin cannot cross the human plasma membrane because it is large and polar, unlike a bacterium's

Decide before you look. Answer on page 18.

Key terms

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

cell wall 06
A rigid layer outside the plasma membrane of plants, fungi and most prokaryotes, made of complex carbohydrates. It gives shape and support and resists bursting.

fluid mosaic model 03
The model of membrane structure: a fluid bilayer of phospholipids with proteins, cholesterol, glycoproteins and glycolipids set in it and moving sideways.

glycolipid 03
A lipid in the membrane with a chain of sugars attached, on the outer surface.

glycoprotein 03
A membrane protein with a chain of sugars attached, on the outer surface, used in cell recognition and adhesion.

integral proteins 02
A protein embedded in the bilayer, often spanning it, held among the fatty acid tails by its hydrophobic region.

peripheral proteins 02
A protein held on the surface of a membrane, attached to the heads or to an integral protein, not set among the tails.

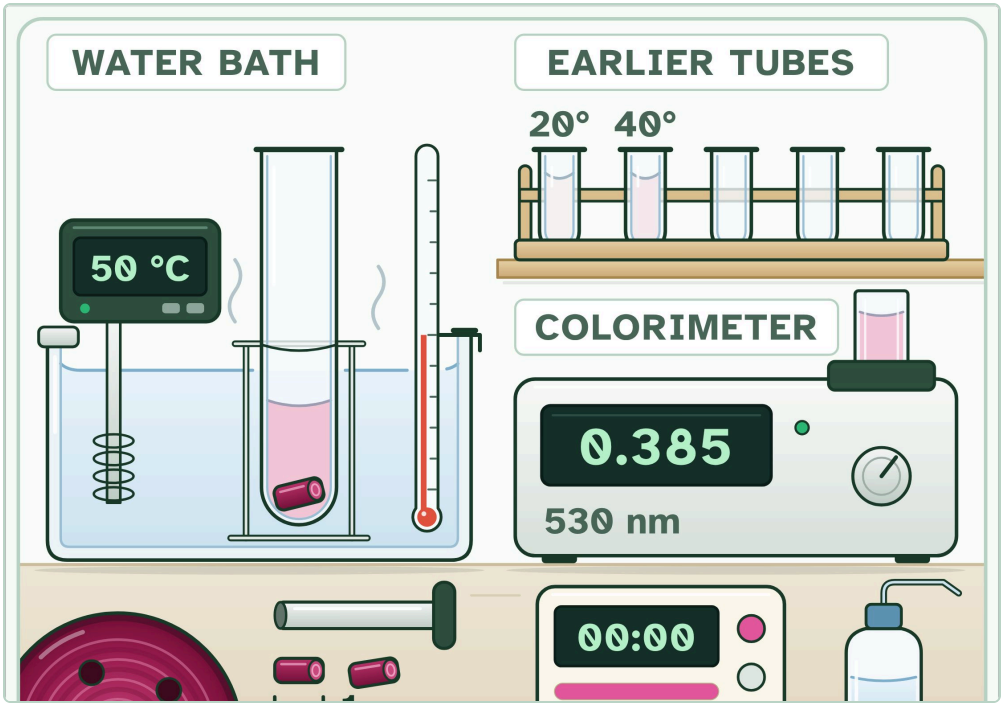
phospholipid 01
A lipid made of a glycerol joined to two fatty acid tails and a phosphate group. Its head is hydrophilic and its tails hydrophobic.

phospholipid bilayer 01
Two layers of phospholipids, heads facing the water on each side and tails facing each other in the middle.

selectively permeable 05
Letting some substances cross and not others. The structure of the membrane decides which.

Dry lab: *Leaky beets*

Beet cells keep their red pigment behind two membranes. Heat cylinders of beet or soak them in ethanol, and read how much red escapes into the water. Find where the membranes give way.



Run it online: change the variables, run the trials, and the table and graph fill in as you go. biologybybradford.com/guides/ap-biology-unit-2-membranes-and-permeability#lab

Your question

How do temperature and ethanol affect the permeability of beet cell membranes to their red pigment? Predict before you start: is there a temperature where it suddenly leaks?

What you can change

The temperature of the water, from 0 to 80 °C, or the concentration of ethanol, from 0 to 70%. Each go is one fresh cylinder, so three goes are three repeats. You can also skip rinsing the cylinder, to see why every method rinses it.

What to record

The absorbance of the water at 530 nm for every cylinder, its color, and the mean at each setting. Graph mean absorbance against temperature or ethanol. The readings are modeled on real class results, with real scatter.

Find out

- **A control first.** Three rinsed cylinders in water at 20 °C. How red does the water get with the membranes intact?
- **Temperature.** Three cylinders at each temperature from 0 to 80 °C. Where does the leaking start, and where does it level off?
- **Ethanol.** The same with ethanol from 0 to 70%. Does a solvent break the membrane at room temperature?
- **Rinse or not.** One unrinsed cylinder at 20 °C. Where does its extra pigment come from?

Record

- Every cylinder's setting, whether it was rinsed, and the absorbance of its water at 530 nm.
- The mean of the three at each setting, and the range.
- A graph of mean absorbance against temperature, and one against ethanol concentration.
- One sentence for each: what has happened to the phospholipids and the proteins where the line rises.

Your question How do temperature and ethanol affect the permeability of beet cell membranes to their red pigment? Predict before you start: is there a temperature where it suddenly leaks?**What you can change**The temperature of the water, from 0 to 80 °C, or the concentration of ethanol, from 0 to 70%. Each go is one fresh cylinder, so three goes are three repeats. You can also skip rinsing the cylinder, to see why every method rinses it.**What to record**The absorbance of the water at 530 nm for every cylinder, its color, and the mean at each setting. Graph mean absorbance against temperature or ethanol. The readings are modeled on real class results, with real scatter.

Back to membranes

Heat and ethanol both turned the water red. Use the fluid mosaic model to explain what keeps the pigment in, and what each treatment does to the membrane.

QUESTIONS ON THE LAB

QUESTION 1

The water stays almost clear up to 40 °C and turns red quickly above 50 °C. Why is there a sudden rise rather than a steady one?

(A) The pigment only dissolves in water above 50 °C, so below that it stays as crystals inside the cells

(B) Above about 50 °C the membrane proteins denature and the bilayer loses its structure, so it leaks

(C) The cell walls soften above 50 °C and stop holding the cells in shape, so the cells burst open

Answer on page 18.

QUESTION 2

Pigment from a cylinder held at 0 °C is lower even than at 20 °C. What does that tell you about the membrane?

(A) Cold makes the membrane less fluid, so the slow leak through an intact bilayer is slower still

(B) Cold kills the cells, so they stop pumping the pigment out of their vacuoles into the water around them

(C) Cold shrinks the cylinder, so it has a smaller surface area and less room for pigment to come out of it

Answer on page 19.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on 2.3, 2.4 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?program=ap&units=U2&ced=2.3,2.4&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 round, tails out into the oil and the heads hidden together in the middle**

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

02 A membrane protein has a stretch of about twenty amino acids with nonpolar R groups in the middle of its chain, and charged amino acids at both ends. Where is it?

B **Spanning the membrane once, the nonpolar stretch among the tails and the charged ends in the water**

The nonpolar stretch is hydrophobic, so it sits among the fatty acid tails, and twenty amino acids coiled into a helix is about the thickness of the bilayer. The charged ends are hydrophilic and stay in the water on either side.

03 A mouse cell and a human cell are fused, each with its membrane proteins tagged a different color. An hour later, how are the colors spread?

B **Mixed all over the new cell's membrane, because the proteins drift sideways through a fluid bilayer**

The colors mix within an hour, and slower at lower temperatures. This experiment, done in 1970, was some of the first evidence that membranes are fluid.

04 A fish that lives in icy water is compared with one from a warm reef. What would you expect of its membranes?

B **More unsaturated fatty acids, so the kinked tails keep the membrane fluid at low temperature**

Cold makes membranes stiff, and the kinks in unsaturated tails keep them apart, so the membrane stays fluid. Cold-water fish, plants and bacteria all shift toward unsaturated fatty acids in the cold.

05 Which will cross a pure phospholipid bilayer, with no proteins in it, fastest?

C **A carbon dioxide molecule, because it is small and nonpolar and dissolves in the hydrophobic core**

Carbon dioxide is small and nonpolar, so it passes through the tails. Potassium ions are charged and glucose is large and polar: both need proteins to cross, which a pure bilayer does not have.

06 Penicillin stops bacteria building peptidoglycan. Why does it kill bacteria but leave human cells unharmed?

A **Human cells have no peptidoglycan wall to build, so blocking the enzymes that make it does them no harm**

Penicillin blocks the enzymes that cross-link peptidoglycan. A growing bacterium with a weak wall bursts as water enters. Animal cells have no wall at all, so the drug has nothing to act on.

QUESTIONS ON THE DRY LAB

Q1 The water stays almost clear up to 40 °C and turns red quickly above 50 °C. Why is there a sudden rise rather than a steady one?

B **Above about 50 °C the membrane proteins denature and the bilayer loses its structure, so it leaks**

Below about 45 °C the membrane is more fluid as it warms but still intact, so only a trace of pigment gets out. Above it, membrane proteins unfold and the bilayer grows too fluid to hold together, so pigment floods out. Like denaturing a protein, it happens over a narrow range.

Q2 Pigment from a cylinder held at 0 °C is lower even than at 20 °C. What does that tell you about the membrane?

A **Cold makes the membrane less fluid, so the slow leak through an intact bilayer is slower still**

A trace of pigment always gets through an intact membrane, and the more fluid the bilayer, the more. At 0 °C the phospholipids move slowly and pack closer, so the leak is smallest. Freezing is different: ice crystals tear membranes, and a thawed beet bleeds.

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.