AP BIOLOGY · 2.5, 2.6, 2.8

BIOLOGY BY BRADFORD

REVISION GUIDE

Downhill for free, uphill *for a price*

Membrane transport

Everything a cell takes in or sends out crosses its membrane one of a few ways. Follow molecules down their gradients through the bilayer and through proteins, pump them back up again with ATP, and move whole proteins and bacteria in vesicles.

8 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ap-biology-unit-2-membrane-transport

Contents

01	Downhill, for free	3
02	A door through the bilayer	6
03	Water in single file	8
04	Charge across a membrane	10
05	Uphill, for a price	12
06	Riding a gradient	15
07	Moving it in bulk	17
08	Which way, and what it costs	19
	Key terms	20
	Dry lab: What gets out of the bag	21
	Check yourself	22
	Answers	23

By the end you can

- [ ] Describe diffusion and passive transport down a concentration gradient, and their role in taking in materials and getting rid of wastes 2.5.A
- [ ] Explain why charged and large polar molecules need channel or carrier proteins, including aquaporins for water and channels for Na+ and K+ 2.6.A
- [ ] Explain how gated ion channels and the movement of ions polarize a membrane 2.6.A
- [ ] Describe active transport and the sodium-potassium pump, and explain why it needs ATP 2.5.A
- [ ] Describe endocytosis, phagocytosis and exocytosis, and why they need energy 2.5.B
- [ ] Identify the mechanism that moves a given substance across a membrane, including cotransport, and justify it 2.8.A

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

01

2.5.A MEMBRANE TRANSPORT

Downhill, *for free*

Molecules in a liquid or gas move all the time, at random. Where there are more of them on one side than the other, more happen to wander from the crowded side to the empty side than the other way. That net movement from a higher to a lower concentration is **diffusion**, and the difference in concentration is a **concentration gradient**.

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.

Moving down a gradient needs no energy from the cell: the random motion of the molecules does it. Any movement across a membrane that goes this way is **passive transport**. It is how cells take in most of what they need and get rid of most of their waste: oxygen in and carbon dioxide out of every cell that respires.

A membrane can only keep up a gradient because it is selectively permeable (the last guide). If everything crossed freely, the two sides would soon be the same. The second film shows three kinds of particle meeting the same membrane.

KEY POINTS

- Diffusion: net movement from higher to lower concentration.
- Passive transport: down the gradient, no energy from the cell.
- Imports materials and exports wastes.

KEY TERMS

diffusion
The net movement of particles from a region where they are more concentrated to one where they are less, by their random motion.

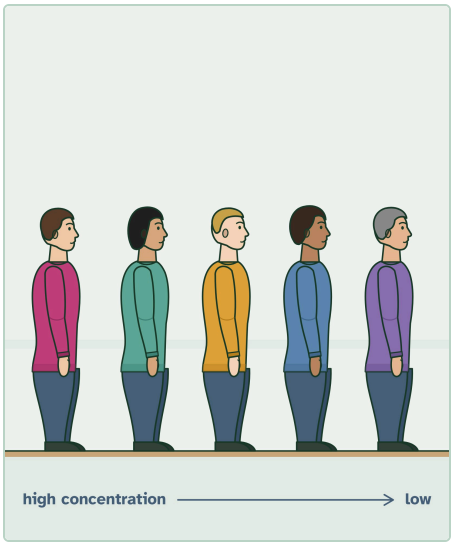
concentration gradient
A difference in the concentration of a substance between two regions, such as the two sides of a membrane.

passive transport
Net movement of a substance across a membrane down its concentration gradient, with no direct input of energy from the cell.

ANIMATION · WHO SMELLED IT FIRST?

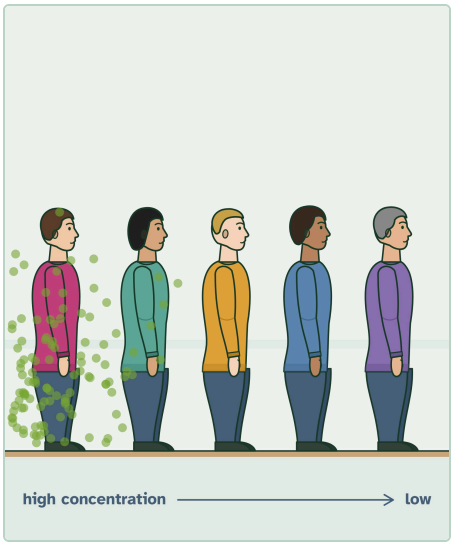
5 MOMENTS

1 NOTHING YET



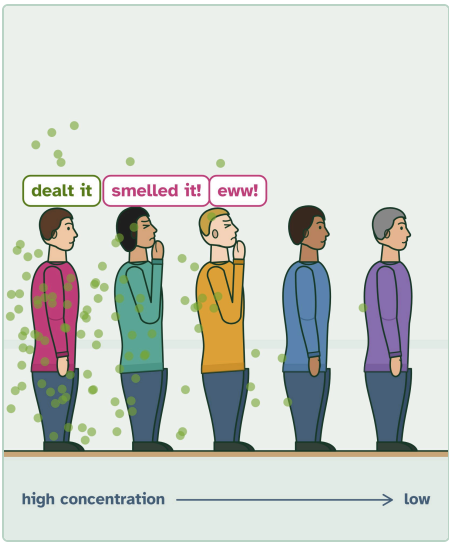
A quiet classroom. Nobody has noticed anything yet.

2 0 OF 4 CAN SMELL IT



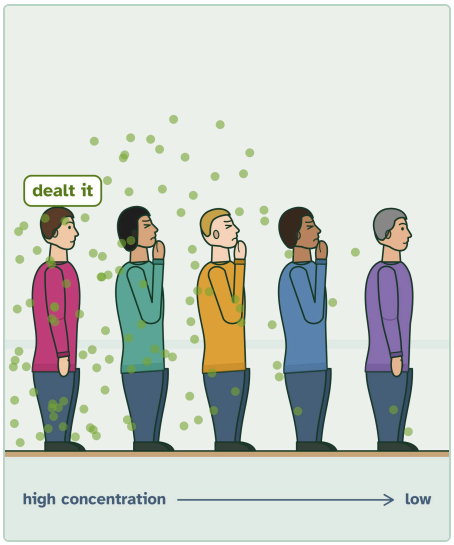
Somebody lets one go. The gas particles start crowded together in one place: a **high concentration**.

3 2 OF 4 CAN SMELL IT



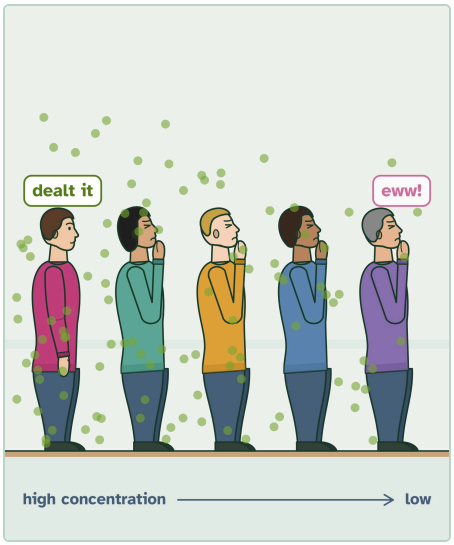
Each particle moves at **random**, yet more wander out of the crowd than back into it. That net movement from high to low concentration is **diffusion**.

4 3 OF 4 CAN SMELL IT



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

5 4 OF 4 CAN SMELL IT

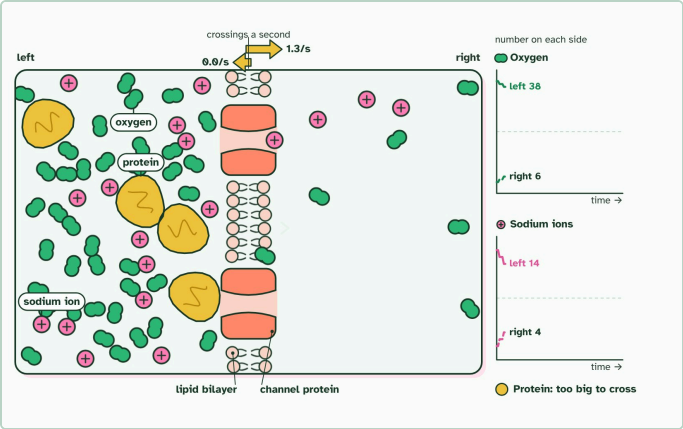


Given time the particles spread through the whole room. Nobody pushed them: diffusion needs no energy, only random motion and a **concentration gradient**.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-2-membrane-transport#gradients

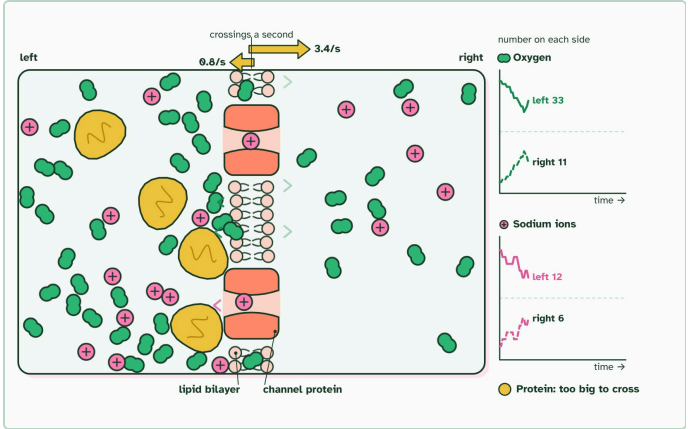
ANIMATION · DIFFUSION ACROSS A MEMBRANE
3 MOMENTS

1 RANDOM MOTION



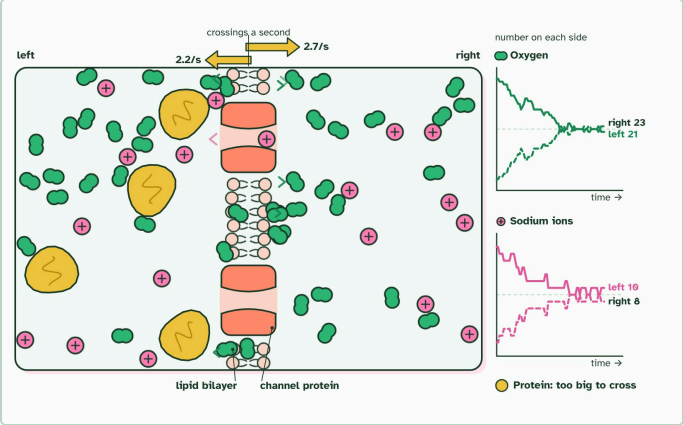
Every particle moves at **random**, bumping into the others and the walls.

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/ap-biology-unit-2-membrane-transport#gradients

WATCH OUT

Diffusion does not stop when the concentrations are equal. Molecules keep crossing both ways; there is just no net movement any more.

PREDICT

Oxygen is at a higher concentration inside a leaf cell in sunlight than in the air spaces around it. Which way does it move, and what does it cost the cell?

(A) Into the cell, because cells always take in oxygen, and the cell spends ATP on pulling it inward

(B) Out of the cell, down its gradient, and the cell spends nothing on it because diffusion is passive

(C) Nowhere at all, because the membrane does not let oxygen through until the cell needs it again

Decide before you look. Answer on page 23.

02

2.6.A FACILITATED DIFFUSION

A door *through* the bilayer

Ions and large polar molecules cannot cross the hydrophobic core, but many still move down their gradients through proteins. That is **facilitated diffusion**: still passive, still downhill, no energy spent, but it needs a protein.

There are two kinds. A **channel protein** is a tunnel with a hydrophilic lining, shaped and charged to let one kind of particle through: a potassium channel passes K^+ and not the smaller Na^+. Many channels have a gate that opens and closes. A **carrier protein** binds its molecule, such as glucose, on one side and changes shape to release it on the other.

Because each protein fits only some substances, a cell controls what crosses by which proteins it puts in its membrane, and how many. Compare the shut channel, the open channel and the pump in the figure: only the pump spends energy.

KEY POINTS

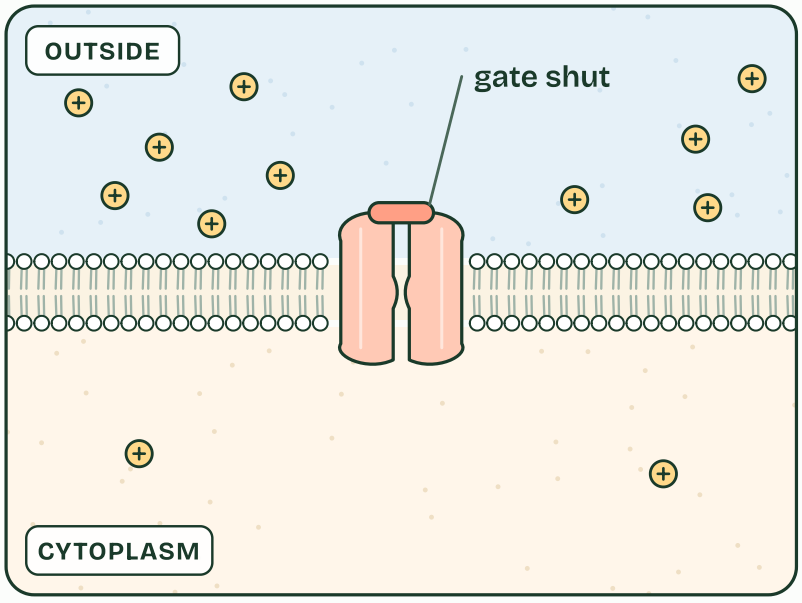
- Facilitated diffusion: passive, down the gradient, through a protein.
- Channels: hydrophilic pores, often gated. Carriers: bind and change shape.
- Each protein is specific to a substance.

KEY TERMS

facilitated diffusion
Passive movement of a substance across a membrane down its concentration gradient, through a channel or carrier protein.

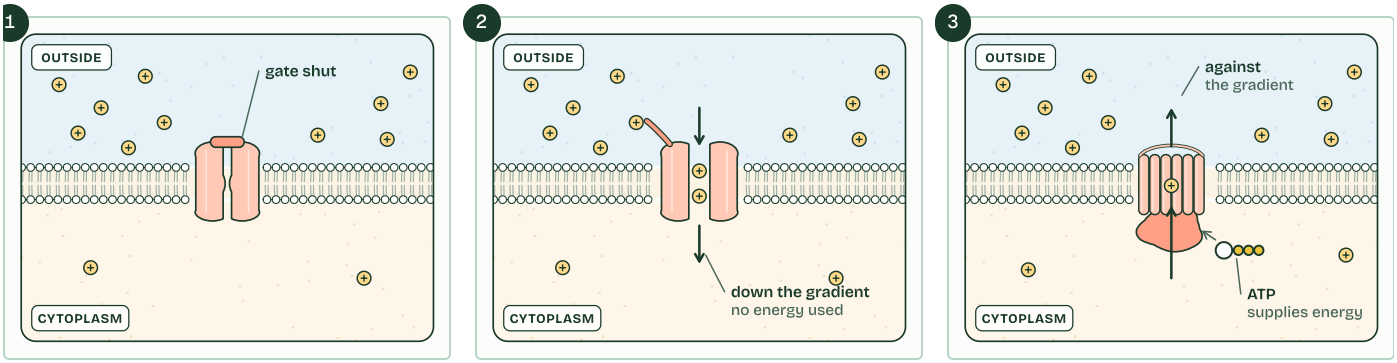
channel protein
A membrane protein with a hydrophilic pore through it, which lets one kind of ion or molecule diffuse across.

carrier protein
A membrane protein that binds a particular molecule and changes shape to release it on the other side.



SWITCH IT

3 SETTINGS



Channel shut **Channel open** **Pump**

WATCH OUT

Facilitated diffusion is not active transport. A protein helps, but the substance still only moves down its gradient, and no ATP is used.

PREDICT

Glucose enters a red blood cell through a carrier protein. What happens to the rate of entry as the glucose outside rises higher and higher?

(A) It rises without limit, because more glucose outside always means a steeper gradient into the cell

(B) It rises, then levels off, because every carrier protein is busy and none is left to carry more

(C) It falls, because high glucose outside makes the carriers change shape and close up the membrane

Decide before you look. Answer on page 23.

03 Water in *single file*

2.6.A FACILITATED DIFFUSION

Water is polar but small, so a little of it slips between the phospholipids. Most cells need far more than that. **Aquaporins** are channel proteins for water: a narrow pore lets water molecules through one at a time, billions a second, while blocking ions, even H^+.

Large quantities of water cross membranes this way. Kidney cells that take water back from urine put extra aquaporins into their membranes when the body is short of water, and take them out again when it has plenty. Plant root cells are full of them.

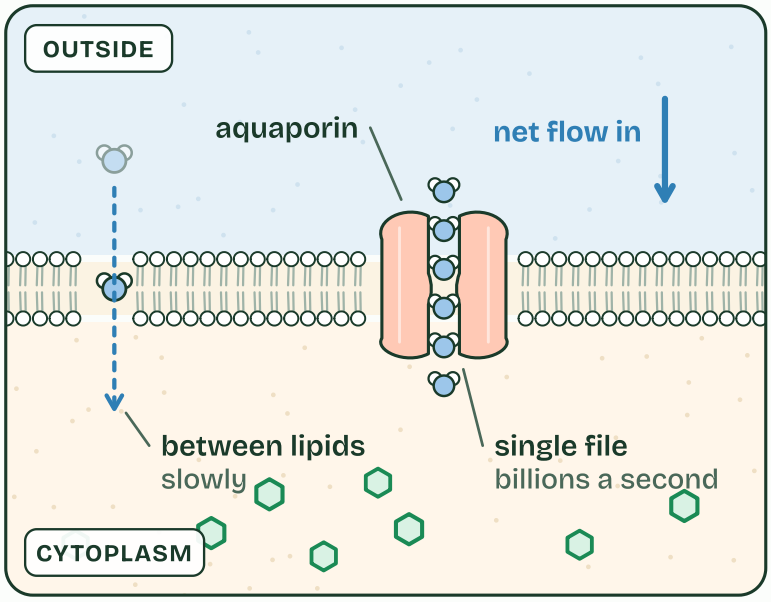
The movement of water across a membrane has its own name, osmosis, and a guide of its own later in the unit. For now: it is passive, and goes where there is relatively less water and more solute.

KEY POINTS

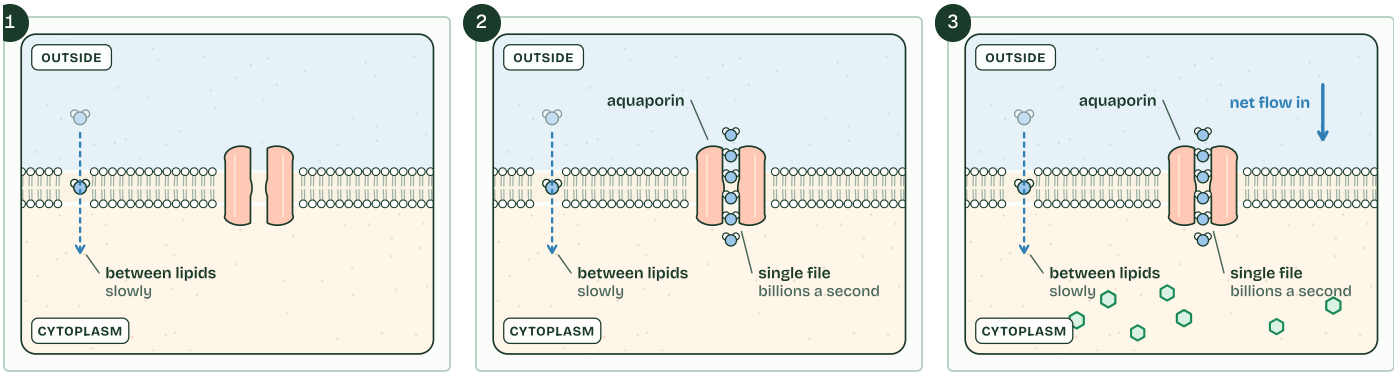
- A little water crosses the bilayer; aquaporins let large amounts through.
- Aquaporins are channels: passive, specific, single file.
- Cells change their water permeability by the number of aquaporins.

KEY TERMS

aquaporins
A channel protein that lets water molecules through the membrane in single file, very fast.



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 moves through them only down its own gradient, as it would through any channel.

PREDICT

A frog's egg normally takes in little water. Scientists inject it with mRNA for an aquaporin and drop it in pure water. What happens?

(A) It takes in water much faster than a normal egg, swells and bursts, because water now has a channel in

(B) It takes in water at the same slow rate, because water already crosses the membrane as fast as it can

(C) It loses water into the pure water, because the aquaporins pump water out of the egg using ATP

Decide before you look. Answer on page 23.

04

2.6.A FACILITATED DIFFUSION

Charge *across* a membrane

Ions such as Na^+ and K^+ cross only through channel proteins. Many of these are **gated**: shut until something opens them. A **ligand-gated** channel opens when a signal molecule binds to it, as at a synapse when acetylcholine arrives. A **voltage-gated** channel opens when the charge across the membrane changes, as when a nerve impulse passes.

Because ions carry charge, moving them separates charge across the membrane. Most cells keep the inside negative compared with the outside, a difference called the **membrane potential**. The membrane is **polarized**. When gated Na^+ channels open, Na^+ floods in down its gradient and the inside briefly turns positive: that is how a neuron sends a signal.

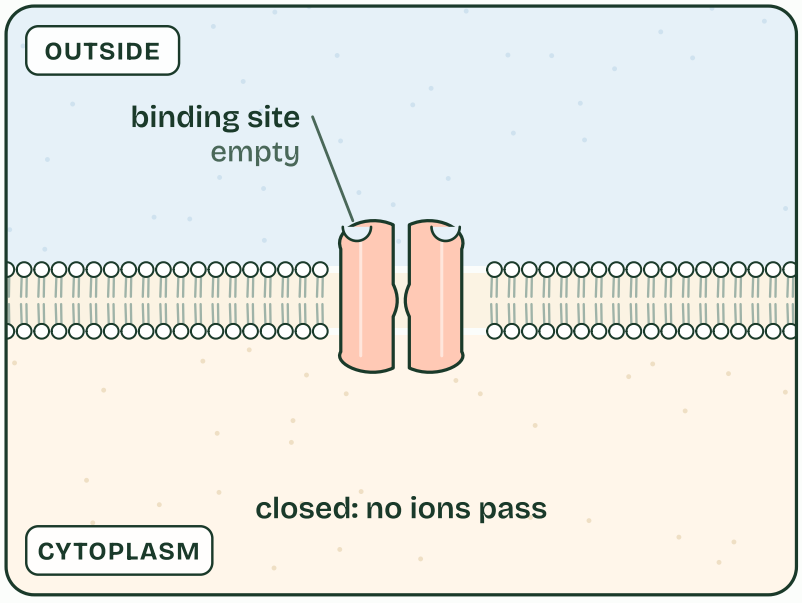
Switch between the three channels: which signal opens each, and which way do the ions go?

KEY POINTS

- Ions cross only through channel proteins, often gated.
- Ligand-gated: open when a molecule binds. Voltage-gated: open when the charge changes.
- Unequal ions make a membrane potential: the membrane is polarized.

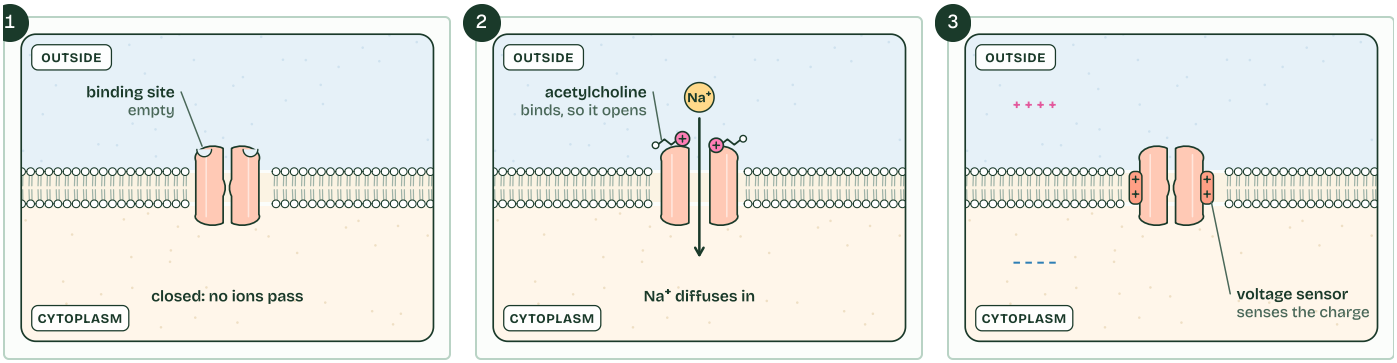
KEY TERMS

membrane potential
The difference in electrical charge between the inside and outside of a cell, made by unequal distribution of ions. Usually negative inside.



SWITCH IT

3 SETTINGS



No acetylcholine | Acetylcholine bound | Voltage-gated

WATCH OUT

An open channel does not decide the direction. Ions flow through it down their gradient, which for Na^+ is usually inward.

PREDICT

A toxin from pufferfish blocks the voltage-gated sodium channels of nerve cells. What happens to the nerves?

(A) They fire more often, because sodium can no longer leave the cell and builds up inside the neuron

(B) They cannot send impulses, because Na+ cannot rush in when the charge across them changes

(C) Nothing changes, because the sodium-potassium pump moves the sodium across in place of the channels

Decide before you look. Answer on page 23.

05 2.5.A MEMBRANE TRANSPORT
Uphill, *for a price*

Sometimes a cell needs more of a substance than its surroundings have, or must push something out that is already more concentrated outside. Moving a substance **against** its gradient, from low to high concentration, is **active transport**. It always needs a protein, a pump, and a direct input of energy, usually from ATP.

The best known pump is the **sodium-potassium pump** (Na^+/K^+ ATPase). Each cycle it binds three Na^+ inside, takes a phosphate from ATP, changes shape, releases the Na^+ outside, binds two K^+, loses the phosphate, and releases the K^+ inside. Three positive charges out for two in: it builds the gradients and helps keep the inside negative.

Active transport is how root cells take in mineral ions from dilute soil water, and why so much of a cell's ATP, a third or more in a neuron, goes on pumping.

KEY POINTS

- Active transport: against the gradient, with a pump and energy (ATP).
- The Na^+/K^+ pump: 3 Na^+ out, 2 K^+ in, per ATP.
- Pumps make and keep gradients, and the membrane potential.

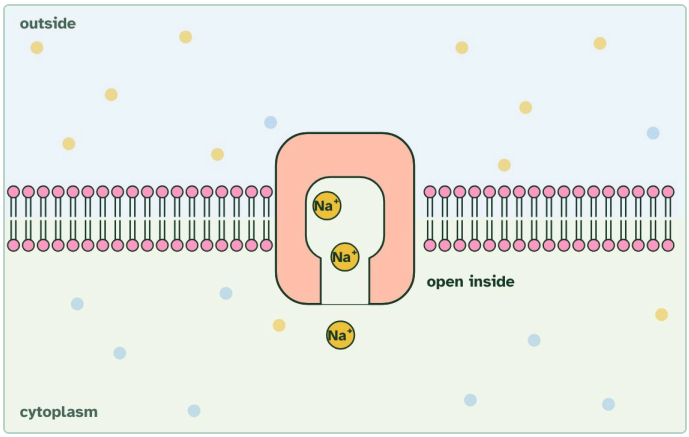
KEY TERMS

active transport
Movement of a substance across a membrane against its concentration gradient, using a pump protein and energy, usually from ATP.

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

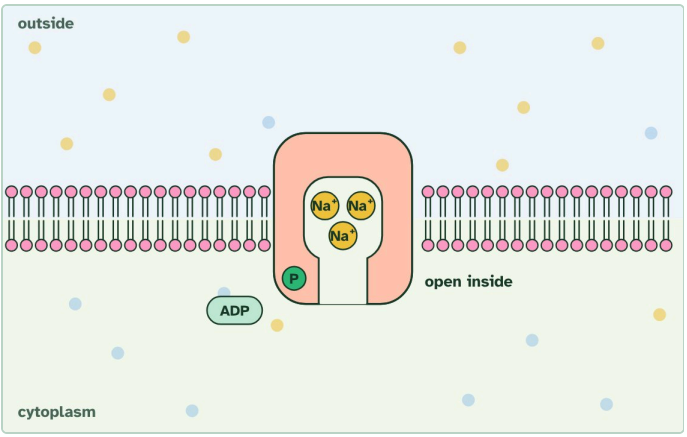
ANIMATION · THE SODIUM-POTASSIUM PUMP
7 MOMENTS

1 NA⁺ BIND



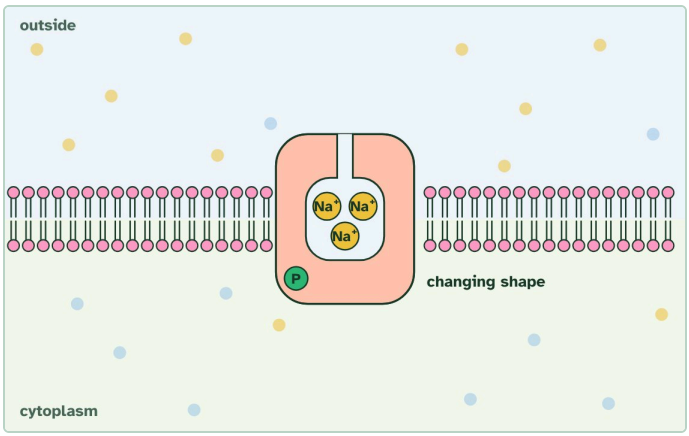
The pump is open to the **cytoplasm**. Three **Na⁺** ions diffuse in and bind to their sites inside it.

2 PHOSPHORYLATED



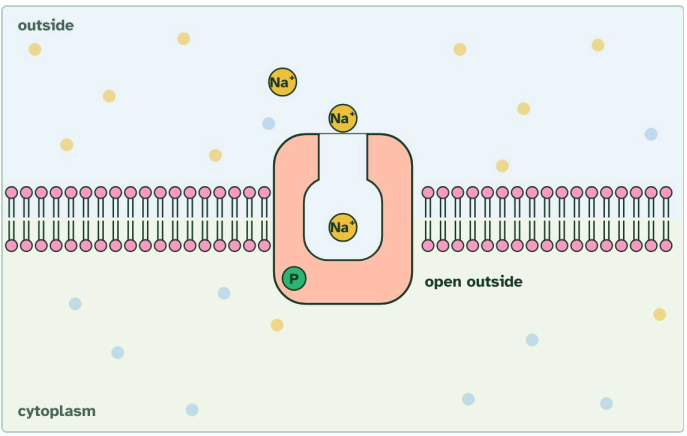
ATP gives the pump a phosphate group: the pump is **phosphorylated**, and ADP is left over.

3 SHAPE CHANGE



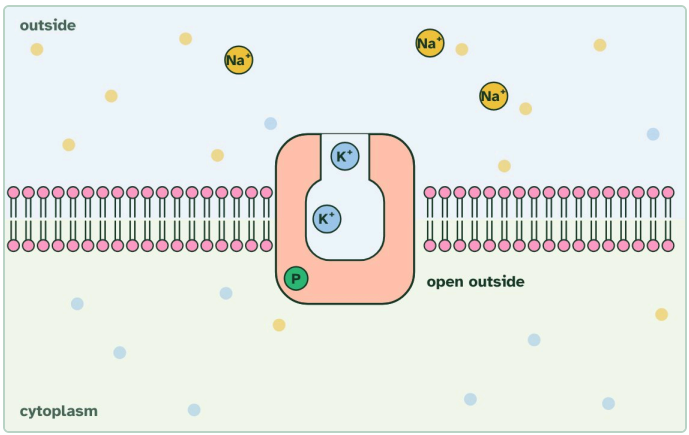
The phosphate makes the pump **change shape**. It closes on the cytoplasm side and opens to the outside.

4 NA⁺ OUT



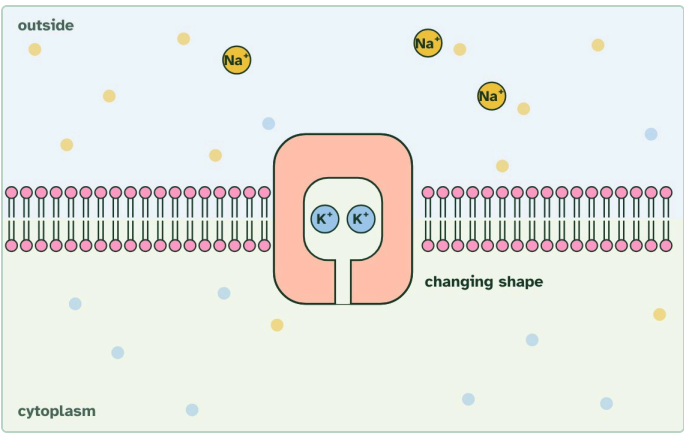
In this shape the sites no longer hold Na^+, so the three Na^+ are released **outside**, where Na^+ is already more concentrated.

5 K⁺ BIND



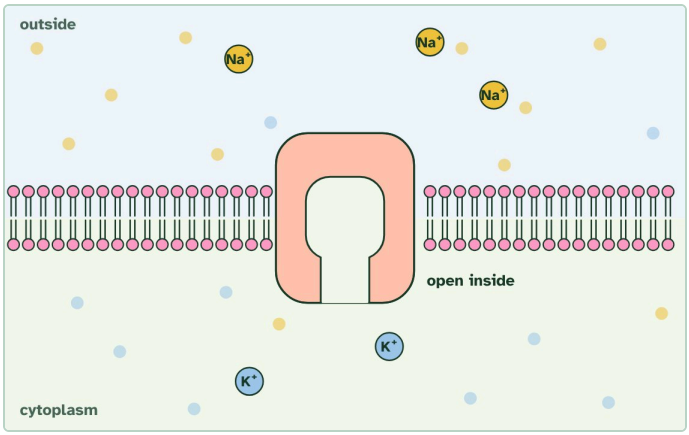
Two **K⁺** ions from outside bind to sites that suit this shape.

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/ap-biology-unit-2-membrane-transport#active

WATCH OUT

ATP does not push the ions. Its phosphate, attached to the pump, changes the pump's shape; the shape change moves the ions.

PREDICT

A drug stops a cell making ATP. Which kind of movement across its membrane stops first?

(A) Oxygen diffusing in through the phospholipid bilayer, because oxygen needs ATP to dissolve in the tails

(B) Water moving in through aquaporins, because the aquaporin channels close up when there is no ATP left

(C) Na^+ being pumped out by the sodium-potassium pump, because it uses ATP for every cycle

Decide before you look. Answer on page 23.

06 Riding *a gradient*

2.8.A MECHANISMS OF TRANSPORT

A gradient made by a pump is stored energy, like water behind a dam. Some carrier proteins use it. A **cotransporter** lets an ion flow back down its gradient and uses that flow to carry another substance with it, even against that substance's own gradient.

In the small intestine, the sodium-potassium pump on the blood side keeps Na^+ low inside the gut lining cells. On the gut side, a sodium-glucose cotransporter lets Na^+ in, and glucose comes with it, into a cell that already holds more glucose than the gut. The glucose then leaves on the blood side by facilitated diffusion.

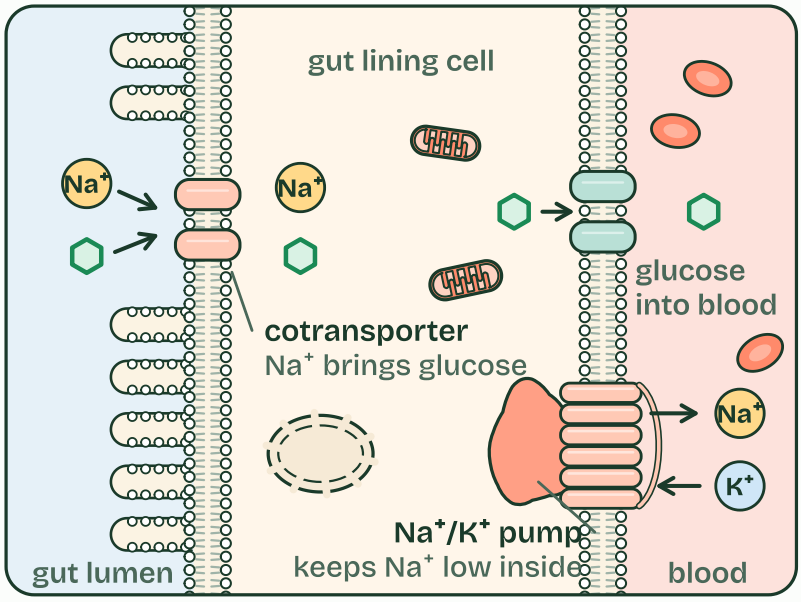
This is still active transport, because the glucose goes against its gradient. The ATP is spent by the pump, one step removed.

KEY POINTS

- A pump builds an ion gradient; a cotransporter uses it.
- Sodium-glucose cotransport: Na^+ down its gradient, glucose against its own.
- The energy comes from ATP, spent by the pump.

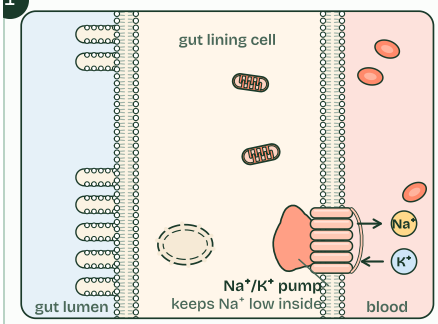
KEY TERMS

cotransporter
A carrier protein that moves two substances together, one down its gradient, which supplies the energy to move the other against its gradient.



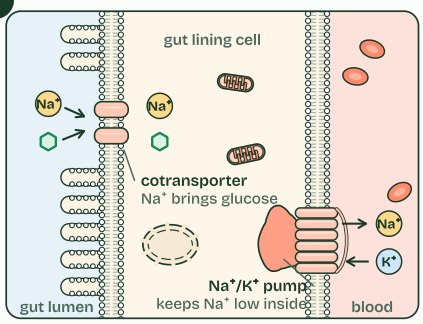
STEP BY STEP
3 STEPS

1



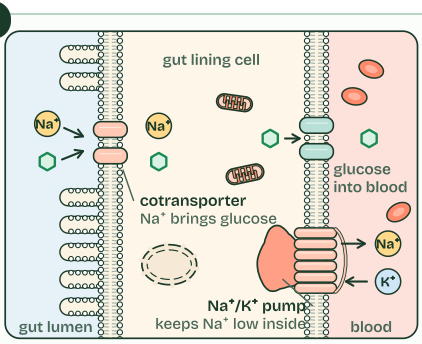
On the blood side, the **Na⁺/K⁺ pump** uses ATP and keeps Na⁺ low inside the cell.

2



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

3



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

WATCH OUT

The cotransporter itself uses no ATP. Stop the pump, though, and the Na⁺ gradient runs down and the glucose stops too.

PREDICT

Oral rehydration solution, for people losing water through diarrhea, contains salt and glucose together. Why glucose?

(A) The glucose gives the gut cells the ATP they need to pump water directly from the gut into the blood

(B) Glucose and Na
+ are taken in together by cotransport, and water follows the solutes in by osmosis

(C) Glucose makes the gut contents more concentrated, which draws water out of the blood into the gut

Decide before you look. Answer on page 23.

07 Moving it *in bulk*

2.5.B MEMBRANE TRANSPORT

Proteins, polysaccharides and whole cells are far too large for any channel or pump. Cells move them in and out wrapped in membrane, using the fluidity of the bilayer (the last guide). Both ways need energy.

In **endocytosis** the plasma membrane folds in around material outside the cell and pinches off as a vesicle inside. When the material is a large particle, such as a bacterium taken in by a white blood cell, it is called **phagocytosis**. In **exocytosis** a vesicle from inside the cell fuses with the plasma membrane and opens to the outside, releasing its contents: insulin from the pancreas, neurotransmitters at a synapse, mucus in the gut.

Each time a vesicle fuses, its membrane joins the plasma membrane; each time one forms, membrane is taken in. The two balance, and the membrane stays the same size.

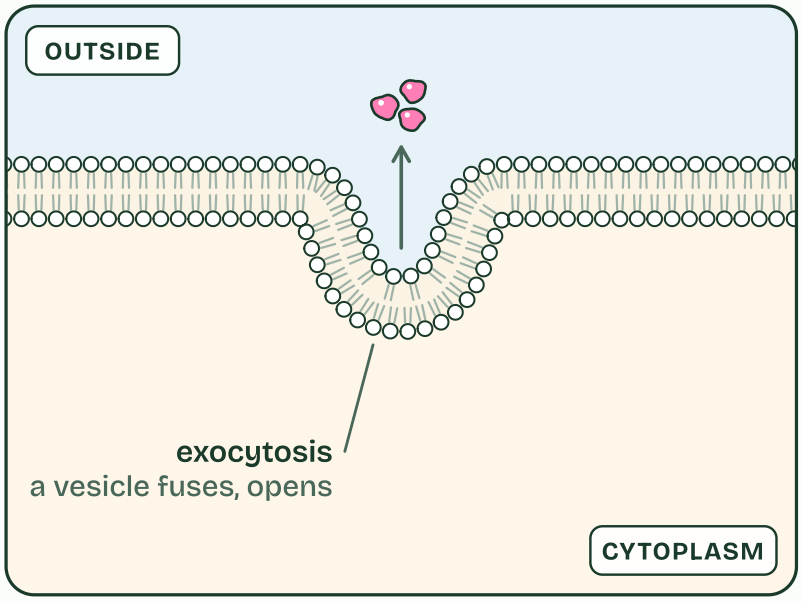
KEY POINTS

- Endocytosis: membrane folds in and pinches off a vesicle. Phagocytosis: large particles.
- Exocytosis: a vesicle fuses and releases its contents outside.
- Both need energy, and both depend on a fluid membrane.

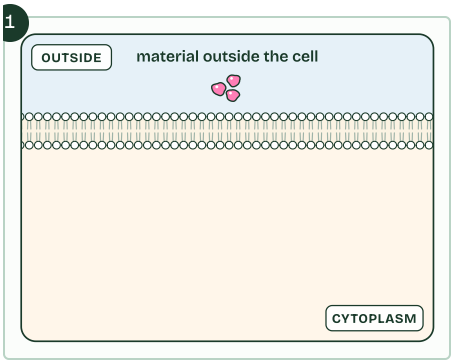
KEY TERMS

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

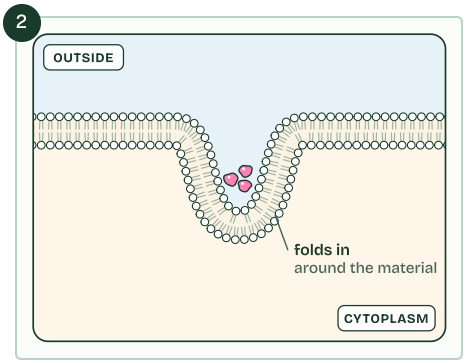
exocytosis
Releasing material from a cell when a vesicle fuses with the plasma membrane and opens to the outside.



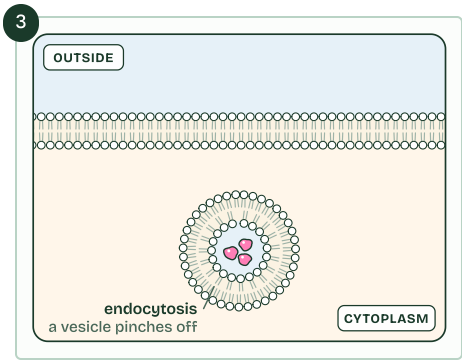
STEP BY STEP
4 STEPS



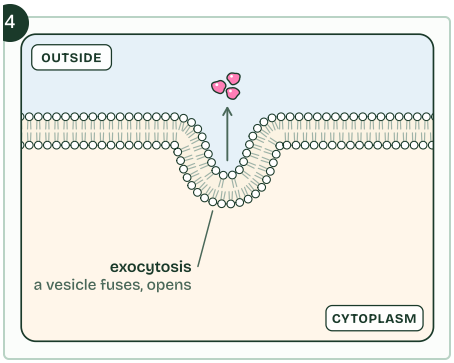
Material outside the cell, next to the plasma membrane.



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

Nothing in endocytosis crosses the membrane. The material is wrapped in it and stays inside a vesicle, separated from the cytoplasm.

PREDICT

A cell in the pancreas secretes insulin, a protein of 51 amino acids. How does insulin leave the cell?

(A) By diffusion through the phospholipid bilayer, because insulin is far more concentrated inside the cell

(B) Through a protein channel shaped for insulin, opened when blood glucose rises after a meal

(C) By exocytosis: vesicles of insulin fuse with the plasma membrane and release it outside the cell

Decide before you look. Answer on page 23.

08

2.8.A MECHANISMS OF TRANSPORT

Which way, and what it *costs*

Every way across a membrane answers three questions. Which way does the substance go, down its gradient or against it? Does it need a protein, and which kind? And does the cell spend energy?

Simple and facilitated diffusion go down the gradient and cost nothing; they differ only in whether a protein is needed. Active transport goes against the gradient and always needs both a pump and energy. Endocytosis and exocytosis move large amounts in vesicles and use energy too.

Use the table to place any example. A good exam answer names the mechanism and gives the reason: "facilitated diffusion, because K^+ is charged and moves down its gradient through a channel."

KEY POINTS

- Down the gradient, no energy: simple or facilitated diffusion.
- Against the gradient: active transport, with a pump and ATP.
- Large molecules: endocytosis and exocytosis, using energy.

WATCH OUT

Concentration is not the only thing that decides. An ion also feels the charge across the membrane, so a positive ion can be drawn into a negative cell.

PREDICT

A root hair cell takes in nitrate ions from soil water where nitrate is 100 times less concentrated than inside the cell. How?

(A) By simple diffusion through the bilayer, because nitrate is a small ion that passes between the lipids

(B) By facilitated diffusion through a channel, because channels let ions cross whichever way they need to

(C) By active transport, because nitrate is moving against its gradient, which needs a pump and energy

Decide before you look. Answer on page 23.

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 a substance across a membrane against its concentration gradient, using a pump protein and energy, usually from ATP.

aquaporins 03
A channel protein that lets water molecules through the membrane in single file, very fast.

carrier protein 02
A membrane protein that binds a particular molecule and changes shape to release it on the other side.

channel protein 02
A membrane protein with a hydrophilic pore through it, which lets one kind of ion or molecule diffuse across.

concentration gradient 01
A difference in the concentration of a substance between two regions, such as the two sides of a membrane.

cotransporter 06
A carrier protein that moves two substances together, one down its gradient, which supplies the energy to move the other against its gradient.

diffusion 01
The net movement of particles from a region where they are more concentrated to one where they are less, by their random motion.

endocytosis 07
Taking material into a cell by folding the plasma membrane around it and pinching off a vesicle.

exocytosis 07
Releasing material from a cell when a vesicle fuses with the plasma membrane and opens to the outside.

facilitated diffusion 02
Passive movement of a substance across a membrane down its concentration gradient, through a channel or carrier protein.

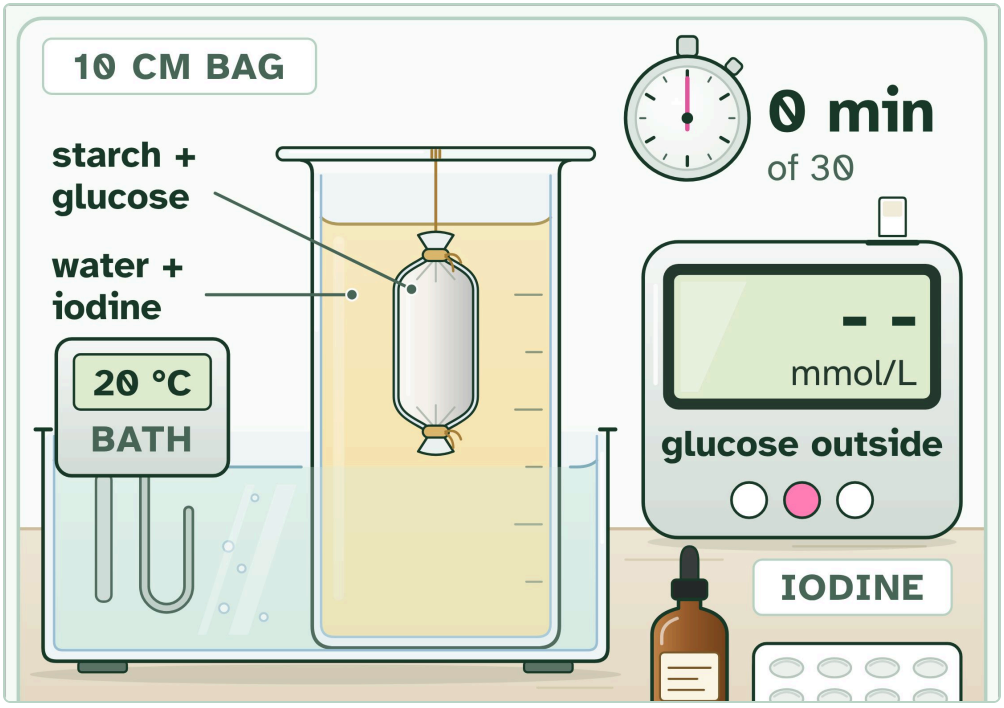
membrane potential 04
The difference in electrical charge between the inside and outside of a cell, made by unequal distribution of ions. Usually negative inside.

passive transport 01
Net movement of a substance across a membrane down its concentration gradient, with no direct input of energy from the cell.

sodium-potassium pump 05
A pump protein that uses one ATP to move three Na^+ ions out of a cell and two K^+ ions in, both against their gradients.

Dry lab: *What gets out of the bag*

A bag of dialysis tubing holds starch and glucose, and hangs in water with iodine in it. Sample the water for glucose as the minutes pass, watch which way the iodine goes, and find what speeds diffusion up.



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-membrane-transport#lab

Your question

Which substances cross dialysis tubing, and how do temperature and the area of the membrane affect how fast glucose diffuses out? Predict before you start: will doubling the length of the bag double the rate?

What you can change

The temperature of the water bath, from 10 to 40 °C, and the length of the bag, 5, 10 or 15 cm of the same tubing. Each run is one fresh bag, so three runs are three repeats.

What to record

The glucose in the water outside every 5 minutes for 30 minutes, the color inside the bag, and an iodine test of the water at the end. Graph glucose against time for each bag. The readings are modeled on real class results, with real scatter.

Find out

- **A control first.** A 10 cm bag at 20 °C. Watch the bag's color and the glucose outside. Then test the water for starch.
- **Area.** Bags of 5, 10 and 15 cm at 20 °C. Does three times the membrane give three times the rate at the start?
- **Temperature.** A 10 cm bag at 10, 20, 30 and 40 °C. How much faster does glucose leave in the warm?
- **Repeats.** At least two bags of each, because no two bags are quite the same.

Record

- The glucose outside every 5 minutes for each bag, and the bag's length and temperature.
- The rate over the first 5 minutes for each bag: the reading at 5 minutes divided by 5.
- A graph of glucose against time, one line per bag.
- What crossed the tubing and what did not, with the evidence for each.

Your question Which substances cross dialysis tubing, and how do temperature and the area of the membrane affect how fast glucose diffuses out? Predict before you start: will doubling the length of the bag double the rate?**What you can change**The temperature of the water bath, from 10 to 40 °C, and the length of the bag, 5, 10 or 15 cm of the same tubing. Each run is one fresh bag, so three runs are three repeats.**What to record**The glucose in the water outside every 5 minutes for 30 minutes, the color inside the bag, and an iodine test of the water at the end. Graph glucose against time for each bag. The readings are modeled on real class results, with real scatter.

Back to cells

How is dialysis tubing like the plasma membrane of a cell, and what can a real membrane do that tubing cannot? Use your results.

QUESTIONS ON THE LAB

QUESTION 1

The water outside never turns blue-black, but the inside of the bag does. What does that show about the iodine and the starch?

(A) Starch moved out of the bag and took the iodine back in with it, so the color only shows up inside the bag

(B) Iodine moved into the bag through the pores, and starch, far too large for them, stayed inside the bag

(C) Neither moved: the bag was blue-black from the start, and the water outside was only ever iodine

Answer on page 24.

QUESTION 2

The glucose outside levels off near 5 mmol/L, though the bag started with 55 mmol/L inside. Why does it stop there?

(A) The tubing's pores slowly clog with starch, so no more glucose can get out once about 5 mmol/L has left

(B) The glucose meter cannot read higher than 5 mmol/L, so higher values all show up as the same reading

(C) Glucose has spread into eleven times the volume, so both sides reach about 5 mmol/L and net movement stops

Answer on page 24.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on 2.5, 2.6, 2.8 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=2.5,2.6,2.8&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 Oxygen is at a higher concentration inside a leaf cell in sunlight than in the air spaces around it. Which way does it move, and what does it cost the cell?

B **Out of the cell, down its gradient, and the cell spends nothing on it because diffusion is passive**

Photosynthesis makes oxygen inside the cell, so the gradient runs outward and oxygen diffuses out, freely through the bilayer. At night, with no photosynthesis, the gradient reverses and oxygen diffuses in for respiration.

02 Glucose enters a red blood cell through a carrier protein. What happens to the rate of entry as the glucose outside rises higher and higher?

B **It rises, then levels off, because every carrier protein is busy and none is left to carry more**

A steeper gradient speeds entry at first, but there are only so many carriers and each takes time to change shape. Once all are working flat out, the rate stops rising. Simple diffusion has no such limit.

03 A frog's egg normally takes in little water. Scientists inject it with mRNA for an aquaporin and drop it in pure water. What happens?

A **It takes in water much faster than a normal egg, swells and bursts, because water now has a channel in**

This was the experiment that found aquaporins, in 1992. Eggs making the protein swelled and burst within minutes in dilute water; normal eggs barely changed. The protein was a water channel.

04 A toxin from pufferfish blocks the voltage-gated sodium channels of nerve cells. What happens to the nerves?

B **They cannot send impulses, because Na^+ cannot rush in when the charge across them changes**

An impulse depends on Na^+ flooding in through voltage-gated channels. Block them and the signal stops, which is why tetrodotoxin paralyzes. The pump keeps the gradient but is far too slow to carry a signal.

05 A drug stops a cell making ATP. Which kind of movement across its membrane stops first?

C **Na^+ being pumped out by the sodium-potassium pump, because it uses ATP for every cycle**

Only active transport uses ATP directly. Diffusion, facilitated or simple, carries on as long as there is a gradient, though the gradients slowly run down once the pumps stop.

06 Oral rehydration solution, for people losing water through diarrhea, contains salt and glucose together. Why glucose?

B **Glucose and Na^+ are taken in together by cotransport, and water follows the solutes in by osmosis**

The cotransporter takes in Na^+ and glucose together, so salt is absorbed far better with glucose than without it. Water follows the absorbed solutes by osmosis. This simple mixture has saved millions of lives.

07 A cell in the pancreas secretes insulin, a protein of 51 amino acids. How does insulin leave the cell?

C **By exocytosis: vesicles of insulin fuse with the plasma membrane and release it outside the cell**

Insulin is a protein, far too large and too polar for the bilayer or a channel. It is packed into vesicles by the Golgi, and when blood glucose rises the vesicles fuse with the membrane and release it.

08 A root hair cell takes in nitrate ions from soil water where nitrate is 100 times less concentrated than inside the cell. How?

C **By active transport, because nitrate is moving against its gradient, which needs a pump and energy**

Moving nitrate from 100 times lower outside to higher inside is against the gradient, so it must be active. Root cells are packed with mitochondria to supply the ATP, which is why waterlogged roots, short of oxygen, stop taking in minerals.

QUESTIONS ON THE DRY LAB

Q1 The water outside never turns blue-black, but the inside of the bag does. What does that show about the iodine and the starch?

B **Iodine moved into the bag through the pores, and starch, far too large for them, stayed inside the bag**

Iodine is small, so it diffuses in down its gradient and meets the starch, turning it blue-black. Starch is a huge polymer and cannot pass the pores, so none reaches the water outside: the iodine test of the water stays yellow-brown.

Q2 The glucose outside levels off near 5 mmol/L, though the bag started with 55 mmol/L inside. Why does it stop there?

C **Glucose has spread into eleven times the volume, so both sides reach about 5 mmol/L and net movement stops**

10 mL at 55 mmol/L shared between the 10 mL bag and 100 mL of water gives about 5 mmol/L everywhere. Once the two sides match there is no gradient: glucose still crosses both ways, but there is no net movement.

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.