

ESAT

Biology

Movement across membranes

Free lesson notes

Covers	B2.1
Format	Lesson, worked examples, self-check
Price	Free

About this lesson

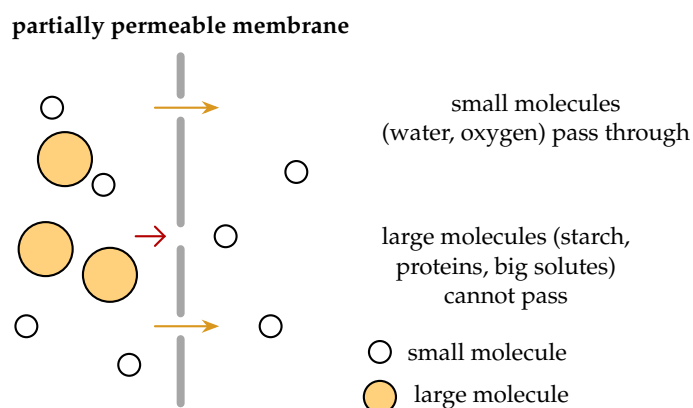
Every cell is a tiny chemical factory that has to take in raw materials (oxygen, glucose, ions, water) and get rid of waste (carbon dioxide, urea), all through its thin outer membrane. This lesson covers the three ways substances cross it: **diffusion**, **osmosis** (using the idea of *water potential*) and **active transport**. The ESAT examines them through definitions, through experiments such as potato cylinders in sugar solutions (with percentage changes and graphs), and through surface-area-to-volume calculations.

We start with why substances need to move at all, build up diffusion from the idea of random particle motion, develop osmosis as a special case, and finish with active transport and a comparison of all three. Cover each worked example and try it first. There is no calculator in the real ESAT, so the numbers are friendly. Finish with the self-check, then the practice set.

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1 Membranes and moving particles (B2.1)

A cell membrane is **partially permeable** (also called selectively permeable): it lets some substances through freely, restricts others and blocks the rest. Small molecules such as water, oxygen and carbon dioxide pass through easily; large molecules such as starch and proteins cannot.



All of the particles in a liquid or gas are in constant, random motion because they have kinetic energy. Particles bump into each other and the membrane, and any particle that happens to hit a gap and is small enough passes through. No energy has to be supplied for this: it is just the particles' own movement. That is why the first two processes in this lesson are called **passive**.

Cells are surrounded by a watery liquid and are full of watery cytoplasm. The substances being moved are the **solutes** dissolved in it (the particles) and the **solvent**, water.

Key ideas

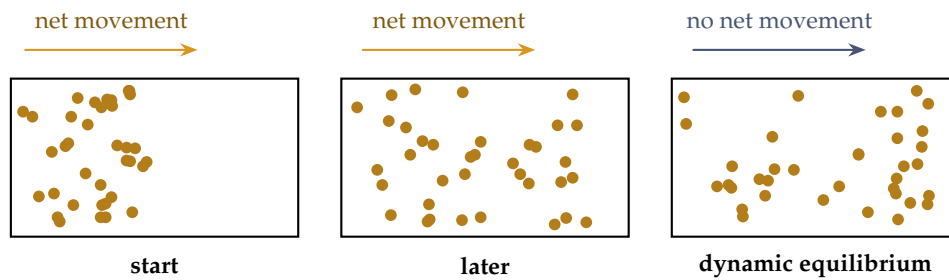
- Cell membranes are **partially permeable**: small molecules pass, large ones do not.
- Particles move randomly all the time. Diffusion and osmosis are **passive**: no energy from the cell is needed.

2 Diffusion (B2.1)

Diffusion is the **net movement of particles from a region of higher concentration to a region of lower concentration**, down a concentration gradient, as a result of their random movement.

Why is the movement "down the gradient"? Picture a box with a lot of particles on the left and few on the right. Every particle moves randomly. But there are more particles on the left, so more of them wander to the right than from right to

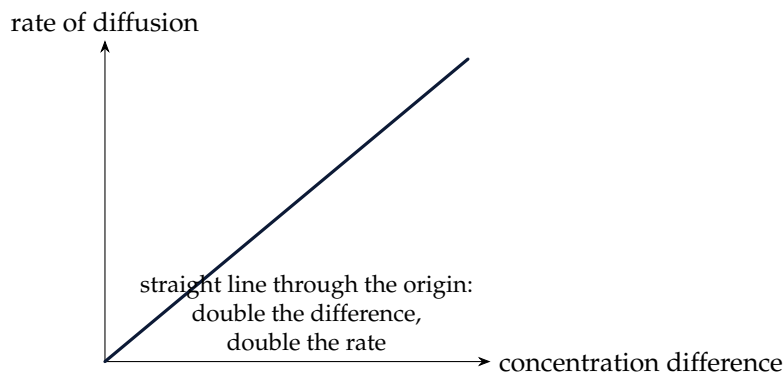
left: the *net* (overall) movement is rightwards. Eventually the particles are spread evenly. They keep moving, but the same number crosses each way (dynamic equilibrium), so there is no *net* movement.



Examples: oxygen diffuses from the air in the lungs (high concentration) into the blood (low), and carbon dioxide diffuses the other way; in a leaf, carbon dioxide diffuses into the cells that are using it up; urea made in liver cells diffuses out into the blood plasma.

What affects the rate of diffusion?

- **The concentration gradient.** The bigger the difference, the faster the net movement. The graph is a straight line through the origin: double the difference, double the rate.
- **Temperature.** Warmer particles have more kinetic energy and move faster.
- **Surface area** of the membrane. More membrane means more places to cross.
- **Distance** (thickness of the exchange surface). The shorter the distance, the faster the diffusion.



Worked example: a steeper gradient

The rate of diffusion of a gas into a cell is 6 units when the concentration difference is 4 units. What would the rate be if the difference were increased to 10 units (all else equal)?

Rate is proportional to the difference, so the rate is $6 \times \frac{10}{4} = 15$ units.

Common mistakes

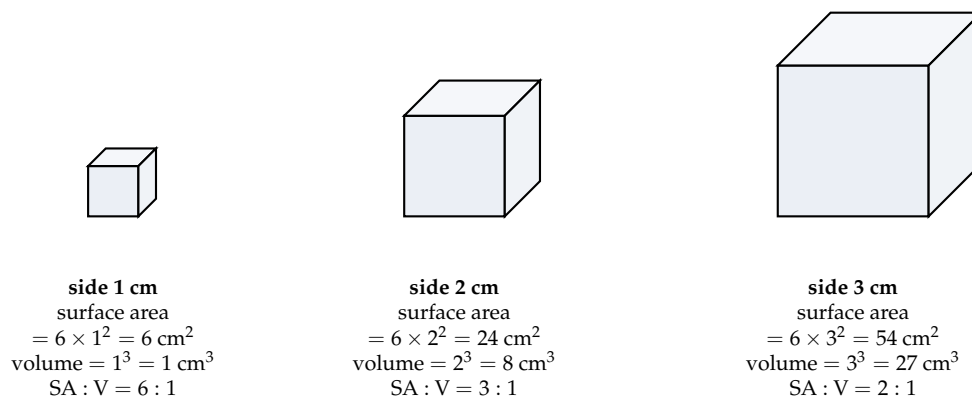
- Saying particles “want” to spread out. They move randomly; spreading is just the result of random motion and many more particles starting on one side.
- Forgetting the word *net*: particles move in both directions, but more move down the gradient.
- Saying diffusion needs energy from respiration. It does not; it is passive.

3 Surface area to volume ratio (B2.1)

Cells need materials in proportion to their *volume* (a bigger cell has more cytoplasm to supply), but materials can only enter through the *surface*. So what matters is the **surface area to volume ratio** (SA:V).

Take a cube of side L . Its surface has 6 faces, each of area L^2 , so the surface area is $6L^2$. Its volume is L^3 . So

$$\text{SA:V} = \frac{6L^2}{L^3} = \frac{6}{L}.$$



As the cube gets bigger, SA:V *falls*. A big cube has less surface for each unit of volume, so diffusion alone cannot supply the middle fast enough. This is why single-celled organisms (small, high SA:V) can rely on diffusion across their surface, but large organisms need **specialised exchange surfaces**: lungs with millions of tiny air sacs, a small intestine with villi, roots with root hair cells. These increase the surface area and are thin (a short diffusion distance) and often have a good blood supply to maintain a steep concentration gradient.

Worked example: splitting a cube

A cube of side 4 cm is cut into eight cubes of side 2 cm. How does the total surface area change?
Original: $6 \times 4^2 = 96 \text{ cm}^2$. Each small cube: $6 \times 2^2 = 24 \text{ cm}^2$, so eight give $8 \times 24 = 192 \text{ cm}^2$. The surface area doubles while the total volume ($4^3 = 64 = 8 \times 2^3$) is unchanged, so SA:V doubles (from 1.5 to 3).

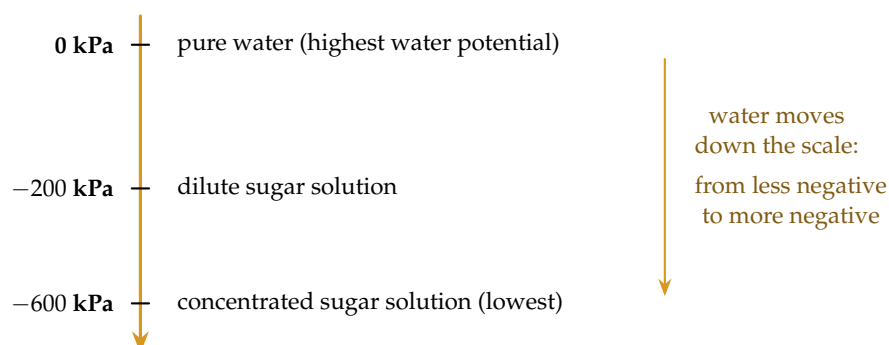
Common mistakes

- Writing the ratio upside down as V:SA. Always surface area first.
- Thinking a larger cell has a larger SA:V. Surface area grows with L^2 but volume with L^3 , so the ratio falls.
- Forgetting the six faces of a cube.

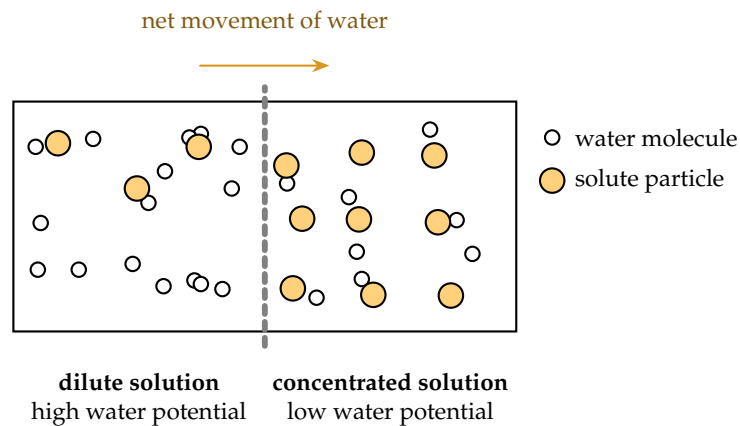
4 Osmosis and water potential (B2.1)

Osmosis is the **net movement of water molecules from a region of higher water potential to a region of lower water potential, through a partially permeable membrane**.

Water potential is a measure of how freely water can move, how “keen” water is to leave a solution. We give it a number in kilopascals (kPa). *Pure water has the highest water potential, and is defined as zero*. Dissolving a solute reduces the water potential, because the solute particles attract water molecules so they are less free to move. So every solution has a water potential below zero (negative), and the more concentrated the solution, the more negative it is.



Now put two solutions on either side of a partially permeable membrane that lets water but not solute through. The dilute side has more free water molecules, so more water molecules strike the membrane there and cross to the concentrated side than the other way. The net movement of water is from the dilute solution (higher water potential) to the concentrated solution (lower water potential).



Osmosis is a special case of diffusion: diffusion of water across a partially permeable membrane. Like diffusion it is passive. Water keeps moving until the water potentials are equal.

Worked example: which way does the water go?

Solution P has a water potential of -150 kPa and solution Q has -400 kPa, separated by a partially permeable membrane. In which direction does water move, and which solution is more concentrated?

-150 is higher (less negative) than -400 , so water moves from P to Q. Q has the lower water potential, so Q is the more concentrated solution.

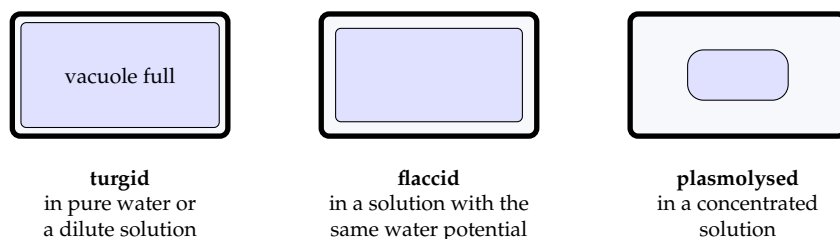
Common mistakes

- Saying water moves from “low concentration of water to high concentration”: it is the other way. Say *from higher to lower water potential*.
- Forgetting the membrane. Without a partially permeable membrane it is diffusion of everything, not osmosis.
- Thinking that a more negative value is a *higher* water potential. -600 is lower than -200 .

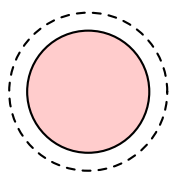
5 Osmosis in plant and animal cells (B2.1)

The cytoplasm of a cell contains dissolved substances, so a cell sits at some water potential. Put it in a different solution and water moves by osmosis across the membrane.

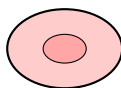
Plant cells. In pure water or a dilute solution, the water potential outside is higher than inside, so water enters and the vacuole swells and pushes the membrane against the cell wall. The cell becomes firm, or **turgid**. The strong wall stops it bursting. Turgid cells support soft plant stems and leaves. If the outside solution has the same water potential as the cell, there is no net movement and the cell is **flaccid** (soft). In a concentrated solution, water leaves the vacuole and cytoplasm, the cell shrinks and the membrane tears away from the wall: the cell is **plasmolysed**. A plant that loses too much water wilts.



Animal cells have no cell wall. In a solution that is too dilute (for example pure water) they gain water and may burst; in a solution that is too concentrated they lose water and shrivel. This is why the water potential of blood plasma must be controlled tightly.



in dilute solution
water enters by osmosis;
cell swells and may burst



**in a solution of the same
water potential**
no net movement: normal



in concentrated solution
water leaves by osmosis;
cell shrivels

Key ideas

- Plant cell in dilute solution: gains water, turgid, does not burst because of the cell wall. In concentrated solution: loses water, plasmolysed.
- Animal cell in dilute solution: gains water, may burst. In concentrated solution: loses water, shrivels.

Common mistakes

- Saying plant cells “burst”. The cell wall prevents this: they become turgid.
- Confusing flaccid (no net movement) and plasmolysed (membrane pulled away from the wall after water loss).
- Writing that water “enters because the cell is full of salt”. Say that the water potential is lower *inside* the cell than outside.

6 Investigating osmosis: potato cylinders (B2.1)

A classic experiment: cut identical cylinders of potato, measure the mass of each, place each in a sucrose solution of a different concentration (including pure water) for a set time, blot dry and weigh again. Because the cylinders did not all start with the same mass, we compare the **percentage change in mass**:

$$\% \text{ change} = \frac{\text{final mass} - \text{initial mass}}{\text{initial mass}} \times 100.$$

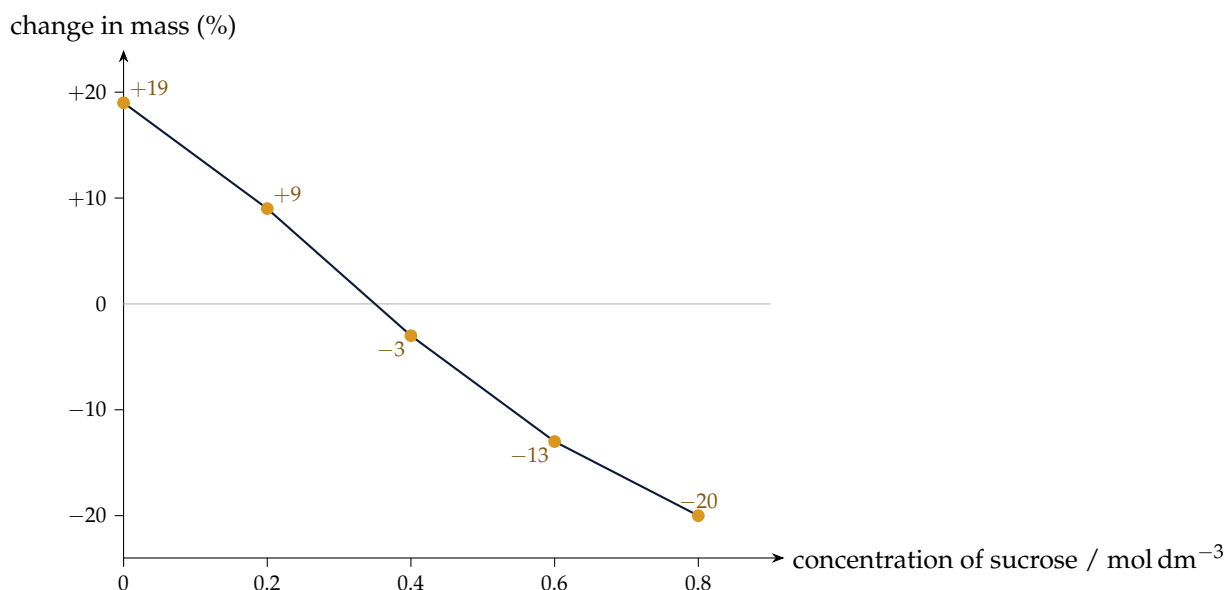
A gain gives a positive value, a loss a negative value. **Control variables** (the things kept the same): the size and type of the potato, the volume of solution, the temperature and the time. **Independent variable**: the concentration. **Dependent variable**: the percentage change in mass.

Worked example: percentage change

A potato cylinder has an initial mass of 5.0 g and a final mass of 4.6 g. Find the percentage change.

$\frac{4.6 - 5.0}{5.0} \times 100 = \frac{-0.4}{5.0} \times 100 = -8\%$. The cylinder lost water, so it was in a solution of lower water potential than the potato.

Plot the percentage change against the concentration. Where the line crosses zero, the cylinder neither gained nor lost mass: there was no net movement of water, so the solution has the *same water potential as the potato cells*. We read it off the graph, or by assuming a straight line between the two points either side of zero.



At 0.2 the change is +9% and at 0.4 it is -3%. The line falls 12 units over 0.2 of concentration, and it must fall 9 units to reach zero, so the zero is $\frac{9}{12} \times 0.2 = 0.15$ above 0.2, at 0.35 mol/dm³.

Worked example: reading the zero

A potato's percentage mass change is +6% in 0.1 mol/dm³ sucrose and -6% in 0.3 mol/dm³. Estimate the concentration with no net change.

The change falls 12 units over 0.2 of concentration, and zero is halfway between +6 and -6, so the zero is at 0.1 + 0.1 = 0.2 mol/dm³.

Diluting a stock solution. To make 100 cm³ of a 0.4 mol/dm³ solution from a 1.0 mol/dm³ stock, you need the fraction 0.4/1.0 = $\frac{2}{5}$ of stock: 40 cm³ stock + 60 cm³ water.

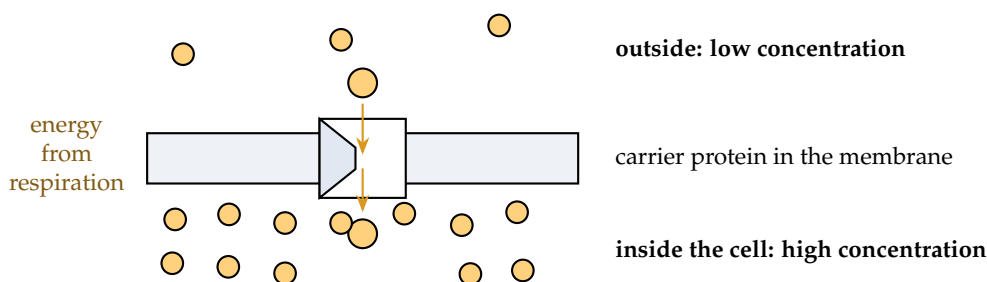
Common mistakes

- Using the *change in mass* in grams instead of the *percentage* change when the cylinders began with different masses.
- Forgetting to divide by the *initial* mass (not the final).
- Saying the potato "stops" gaining water at the zero point. Water still moves both ways; the net movement is zero.
- Not blotting the cylinders dry: surface water adds mass.

7 Active transport and comparing the processes (B2.1)

Sometimes a cell has to take in a substance that is *already more concentrated inside the cell than outside*. Diffusion would move it out, not in. For example, root hair cells take in mineral ions from soil water that has a lower concentration of ions than the cell sap, and cells lining the small intestine absorb glucose when the concentration in the gut is lower than in the blood.

Active transport is the movement of substances **from a region of lower concentration to a region of higher concentration (against the concentration gradient) using energy released by respiration**. Special **carrier proteins** in the membrane pick up the particle on one side and release it on the other, and the cell must supply energy to power them.



Evidence that a process is active transport: it works against the gradient, it *stops if respiration is stopped* (for example by a poison or lack of oxygen), and cells doing a lot of it contain many **mitochondria** to release the energy. A graph of uptake against oxygen concentration therefore rises as more oxygen supports respiration, and then levels off because another factor (such as the number of carrier proteins) is limiting.

	diffusion	osmosis	active transport
what moves	any small particle	water only	ions, glucose etc.
direction	high → low concentration	high → low water potential	low → high concentration
membrane needed?	not necessarily	partially permeable	yes (carrier proteins)
energy from respiration?	no	no	yes

Exam tip

If the question mentions “against a concentration gradient”, “respiration”, “mitochondria” or “carrier proteins”, the answer is active transport. If it mentions “water” and “partially permeable”, it is osmosis. For rates, check which factor is limiting.

Worked example: diffusion or active transport?

Root hair cells have 2 mM of potassium ions; the soil water has 0.2 mM. The cells take up potassium ions. Which process is it?

The ions move from 0.2 (low) to 2 (high): against the gradient, so the process is **active transport**, needing energy from respiration. Diffusion would move potassium *out*.

Common mistakes

- Saying active transport “creates energy”. It *uses* energy released by respiration.
- Describing active transport as moving “from high to low”.
- Calling osmosis active: it is passive.

Spec coverage (B2.1). This lesson covers diffusion, osmosis in terms of water potential, and active transport.

Check yourself

Try these without looking back, then compare with the answers on the next page.

1. Define diffusion.
2. Calculate the SA:V ratio of a cube of side 3 cm.
3. Water at -100 kPa is separated from a solution at -500 kPa by a partially permeable membrane. Which way does water move?
4. Why does a plant cell not burst in pure water but an animal cell may?
5. A potato cylinder goes from 4.0 g to 3.4 g. Find the percentage change.
6. Name two processes that need no energy from respiration and one that does.
7. Why do root hair cells contain many mitochondria?
8. How much water must be added to 25 cm^3 of 0.8 mol/dm^3 sucrose to make a 0.2 mol/dm^3 solution?

Answers to the self-check

1. The net movement of particles from a region of higher concentration to a region of lower concentration, down a concentration gradient (passive, because of random movement).
2. $SA = 6 \times 9 = 54$, $V = 27$; $SA:V = 54 : 27 = 2 : 1$.
3. From the -100 side to the -500 side (higher to lower water potential).
4. The plant cell has a cell wall, which resists the swelling and makes it turgid; animal cells have no wall.
5. $-0.6/4.0 \times 100 = -15\%$.
6. Diffusion and osmosis need none; active transport does.
7. They take up mineral ions by active transport, which needs energy released by respiration in the mitochondria.
8. Dilution by factor $0.8/0.2 = 4$, so the final volume is 100; add $100 - 25 = 75 \text{ cm}^3$ of water.

Next step

Heurisco's *ESAT Biology: Movement Across Membranes Practice Set* has twenty original exam-style questions on this lesson, with diagrams and potato-cylinder data, in order of difficulty, with a full worked solution and a note on the trap in each.