



Cells (Form and function) revision notes

Cells (Form and function) is about how the structure of a cell suits its function: how membranes are built and control what crosses them, how organelles divide a cell into compartments, and how cells specialize in size, shape and contents.

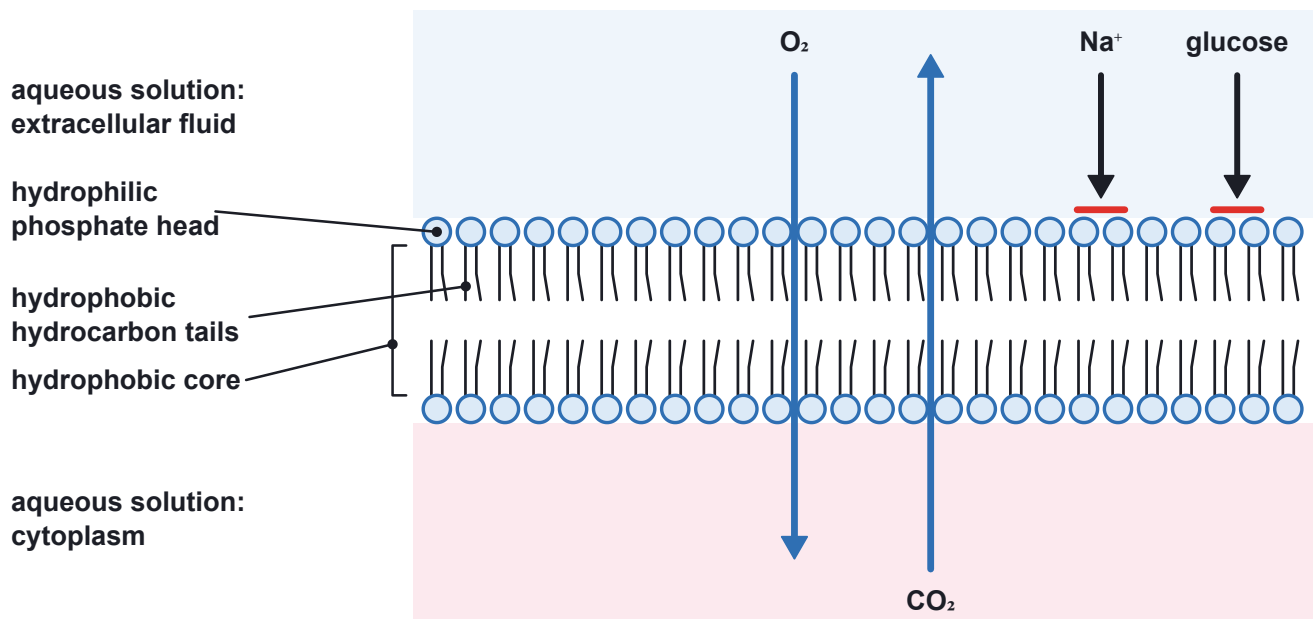
For IB Diploma Biology SL undefined. **HL only** is additional higher level content, for HL students only.

1 Membranes and membrane transport Spec B2.1

Lipid bilayers, barriers and simple diffusion Spec B2.1.1-B2.1.3

A phospholipid is **amphipathic**: it has a hydrophilic (water-attracting) phosphate head and two hydrophobic (water-repelling) hydrocarbon tails. Other membrane lipids, such as cholesterol and glycolipids, are also amphipathic.

In water, phospholipids naturally arrange themselves into a **lipid bilayer**. The heads face outwards into the water on both sides and the tails point inwards, away from the water. The bilayer forms continuous sheets, which close up so that no tails are left exposed at an edge. No energy input is needed. This bilayer is the basis of every cell membrane.



O_2 and CO_2 diffuse between the phospholipids;
 Na^+ and glucose cannot enter the hydrophobic core

[\(opens full size in a new tab\)](#)

Small non-polar O_2 and CO_2 cross the **hydrophobic core**; ions such as Na^+ and polar molecules such as glucose cannot.

Bilayers as barriers

The hydrocarbon chains that form the core of the membrane are non-polar. Hydrophilic particles cannot easily enter this region, so the core has **low permeability** to large molecules and to hydrophilic particles,

including ions (such as Na^+ and Cl^-) and polar molecules (such as glucose). Membranes are therefore effective barriers between two aqueous solutions, such as the cytoplasm and tissue fluid.

Permeability of a lipid bilayer without membrane proteins		
Particle	Example	Crosses the hydrophobic core?
Small non-polar molecule	O_2 , CO_2	Yes, readily
Small polar molecule	H_2O	Slowly
Large polar molecule	Glucose	Hardly at all
Ion	Na^+ , K^+ , Cl^-	Hardly at all (charged)

Simple diffusion

Simple diffusion is the net movement of particles from a region of higher concentration to a region of lower concentration, caused by their random movement. It is passive: no energy from ATP is used. Oxygen and carbon dioxide are small and non-polar, so they diffuse directly between the phospholipids. In a respiring cell oxygen is used up, so it diffuses in; carbon dioxide is produced, so it diffuses out.

Common mistake: Particles do not move because of the gradient. They move randomly in all directions, but more cross from the side with the higher concentration, so the net movement is down the gradient.

Osmosis, channel proteins and pump proteins Spec B2.1.5-B2.1.8

Osmosis

Osmosis is the net movement of water molecules across a partially permeable membrane from a region of lower solute concentration to a region of higher solute concentration.

1. Water molecules move randomly and cross the membrane in both directions.
2. The membrane is impermeable to the solute, so solute particles stay on their own side.
3. On the side with the higher solute concentration, solute particles take up part of the solution, so the concentration of water molecules free to move across the membrane is lower there.
4. More water molecules therefore cross from the side with the lower solute concentration than move back, giving a net movement of water towards the higher solute concentration.
5. Osmosis is passive and continues while the difference in solute concentration remains.

Water is polar, so it crosses the lipid bilayer only slowly. **Aquaporins** are integral channel proteins that let water molecules pass through in single file, increasing the permeability of the membrane to water many times over. The pore is too narrow for most solutes, and charges inside it repel ions, so only water passes. Cells that move large volumes of water, such as kidney collecting duct cells and root cells, have many aquaporins.

Channel proteins and facilitated diffusion

Facilitated diffusion is passive diffusion of particles through a membrane protein. A **channel protein** is an integral protein with a hydrophilic pore through the membrane. The diameter of the pore and the charges lining it allow only specific ions (for example K^+) to pass. Many channels are gated: ions diffuse through when the channel is open but not when it is closed, so the cell can control permeability.

Pump proteins and active transport

Active transport is the movement of particles across a membrane against a concentration gradient, using energy from ATP. Pump proteins bind a specific particle on one side, use energy from ATP to change shape, and release the particle on the other side. Pumps move particles in one direction only, so they can build up concentration gradients.

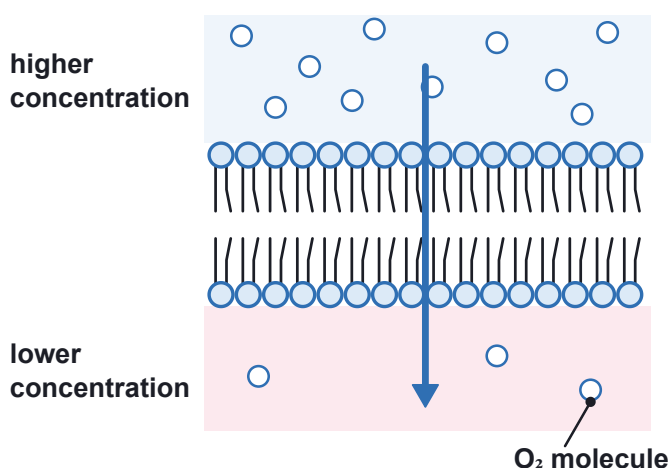
Comparing transport across membranes			
Feature	Simple diffusion	Facilitated diffusion	Active transport
Direction	Down the concentration gradient	Down the concentration gradient	Against the concentration gradient
Energy from ATP	No	No	Yes
Membrane protein	None (between phospholipids)	Channel protein	Pump protein
Selective?	No: depends only on size and polarity	Yes: specific ions	Yes: specific particles
Example	O ₂ and CO ₂	K ⁺ through a potassium channel	Mineral ions into root hair cells

Selectivity in membrane permeability

Facilitated diffusion and active transport give membranes **selective permeability**: the channel and pump proteins present decide which ions and molecules can cross. Permeability by simple diffusion is not selective. It depends only on the size of a particle and whether it is hydrophilic or hydrophobic.

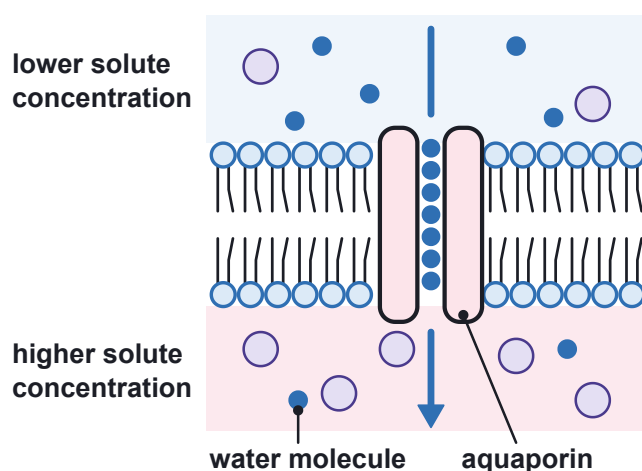
1 Simple diffusion

passive



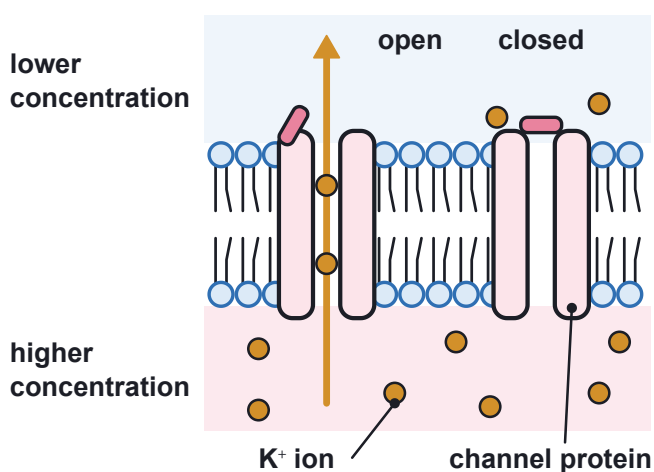
2 Osmosis (aquaporin)

passive



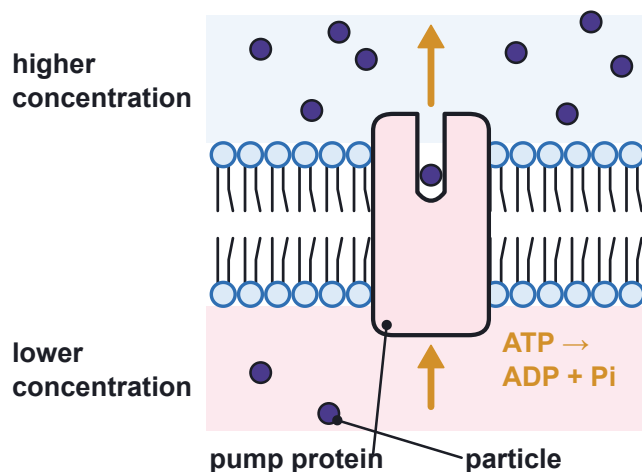
3 Facilitated diffusion

passive



4 Active transport

active



[\(opens full size in a new tab\)](#)

Diffusion, osmosis and facilitated diffusion are **passive**; pump proteins use ATP for **active transport** against the gradient.

Exam tip: Linking question: what processes depend on active transport? Think of mineral ion uptake by roots, nerve impulses and the absorption of glucose in the gut.

Membrane proteins, glycoproteins and the fluid mosaic model Spec B2.1.4, B2.1.9, B2.1.10

Integral and peripheral proteins

Membrane proteins have diverse structures, locations and functions. **Integral proteins** are embedded in one or both of the lipid layers. Those that span both layers have hydrophobic regions in contact with the hydrocarbon core and hydrophilic regions facing the water on each side. **Peripheral proteins** are attached to one or other surface of the bilayer, often bound to an integral protein, and do not enter the hydrophobic core.

- Transport: channels and pumps (integral proteins).
- Receptors: bind signalling chemicals such as hormones or neurotransmitters.
- Enzymes: catalyse reactions at the membrane surface.
- Cell adhesion: bind cells to each other.
- Cell recognition: identify a cell to other cells.

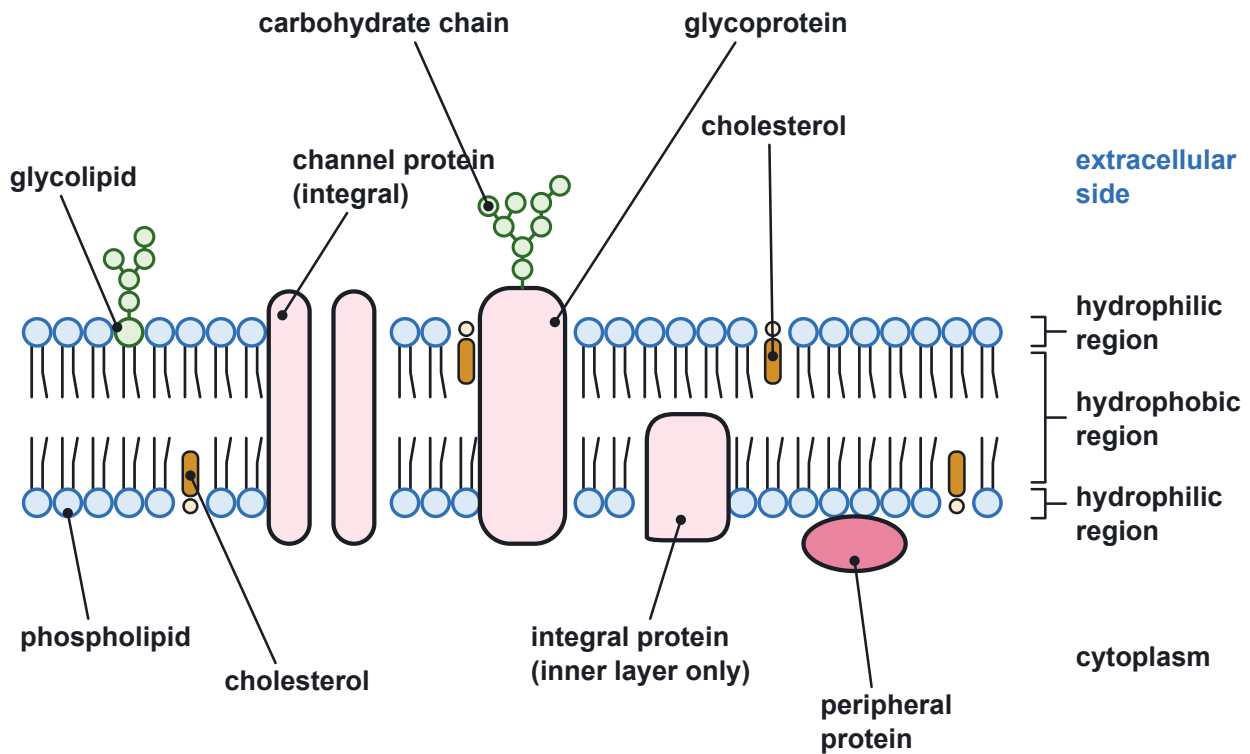
Glycoproteins and glycolipids

Glycoproteins are proteins with carbohydrate chains attached, and **glycolipids** are lipids with carbohydrate chains attached. In the plasma membrane the carbohydrate is always on the **extracellular side**, where it forms a sugary coat on the cell surface.

- Cell recognition: the carbohydrate chains act as markers, so other cells, such as cells of the immune system, can recognise a cell as self or non-self.
- Cell adhesion: carbohydrate chains help cells attach to each other to form tissues.

The fluid mosaic model

The membrane is described as **fluid** because phospholipids and many proteins can move sideways within each layer, and **mosaic** because proteins are scattered through the bilayer like tiles in a mosaic.



[\(opens full size in a new tab\)](#)

The fluid mosaic model: carbohydrate chains only on the **extracellular side**, cholesterol among the tails in the **hydrophobic region**.

Exam tip: In a drawing, put carbohydrate chains only on the outside, draw cholesterol among the tails, and label the hydrophilic and hydrophobic regions, not just the heads and tails.

Quick check

1. Which part of a phospholipid is hydrophobic?
2. Name the channel protein that lets water cross membranes rapidly.
3. What does a pump protein use to move particles against a concentration gradient?
4. On which side of the plasma membrane are the carbohydrate chains of glycoproteins?

2 Organelles and compartmentalization Spec B2.2

Organelles, the nucleus and compartments Spec B2.2.1-B2.2.3

Organelles are discrete subunits of cells that are adapted to perform specific functions. Nuclei, mitochondria, chloroplasts, the endoplasmic reticulum, the Golgi apparatus, vesicles, ribosomes and the plasma membrane are all organelles.

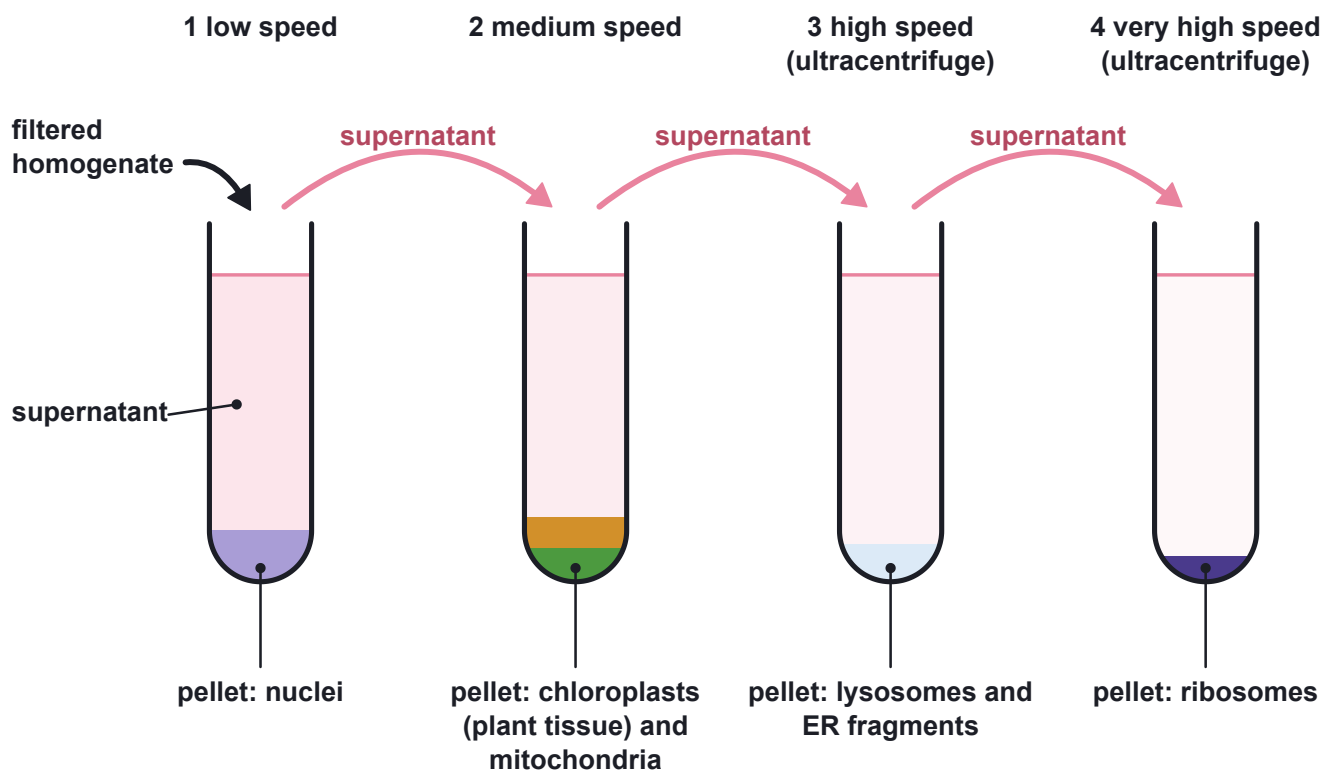
The cell wall, the cytoskeleton and the cytoplasm are **not considered organelles**. The wall lies outside the plasma membrane, the cytoskeleton is a network running through the whole cell, and the cytoplasm is the medium in which the organelles sit.

Cell fractionation

Progress in science often follows the development of new techniques. The functions of individual organelles could only be studied once **ultracentrifuges** had been invented and methods of using them for **cell fractionation** had been developed.

1. Tissue is cut up and homogenised (blended) in a cold, isotonic, buffered solution to break the cells open.
2. The homogenate is filtered to remove large debris.
3. It is spun in a centrifuge at low speed. The largest, densest organelles (nuclei) form a pellet at the bottom of the tube.
4. The liquid above the pellet (the supernatant) is spun at a higher speed to pellet chloroplasts (from plant tissue) and then mitochondria, then at even higher speeds in an ultracentrifuge for smaller parts such as fragments of ER and ribosomes.
5. Each pellet is resuspended and tested, for example by measuring the activity of enzymes, to find out what that organelle does.

Practical skill: Cold slows enzymes that would digest the organelles, an isotonic solution stops organelles gaining or losing water by osmosis, and a buffer keeps the pH constant so proteins are not denatured.



[\(opens full size in a new tab\)](#)

Differential centrifugation: each faster spin pellets **smaller, less dense** organelles from the supernatant.

Separating the nucleus from the cytoplasm

In eukaryotes, **transcription** happens in the nucleus and **translation** happens at ribosomes in the cytoplasm. Because they are in separate compartments, **post-transcriptional modification** of mRNA (such as removing introns) can happen before the mRNA meets ribosomes. Prokaryotes have no nucleus, so mRNA may meet ribosomes immediately and translation can begin before transcription has finished.

Compartments in the cytoplasm

- Enzymes and their substrates (metabolites) can be concentrated in a small volume, so reactions are faster.
- Incompatible biochemical processes are kept apart, for example digestion of molecules and their synthesis.
- Conditions such as pH can be kept different in each compartment.

Lysosomes are vesicles containing hydrolytic enzymes that work best at acid pH. If these enzymes were free in the cytoplasm they would digest the cell's own molecules. **Phagocytic vacuoles** form when a cell such as a white blood cell engulfs a bacterium by endocytosis. Lysosomes then fuse with the vacuole, so the bacterium is digested inside a closed compartment.

Exam tip: Linking question: what separation techniques are used by biologists? Centrifugation separates cell parts by size and density; compare chromatography and gel electrophoresis, which separate molecules.

Quick check

- 1 . Name two structures that are not considered organelles.
- 2 . In cell fractionation, which organelles form a pellet first, at the lowest speed?
- 3 . Why must the hydrolytic enzymes of lysosomes be kept in a compartment?

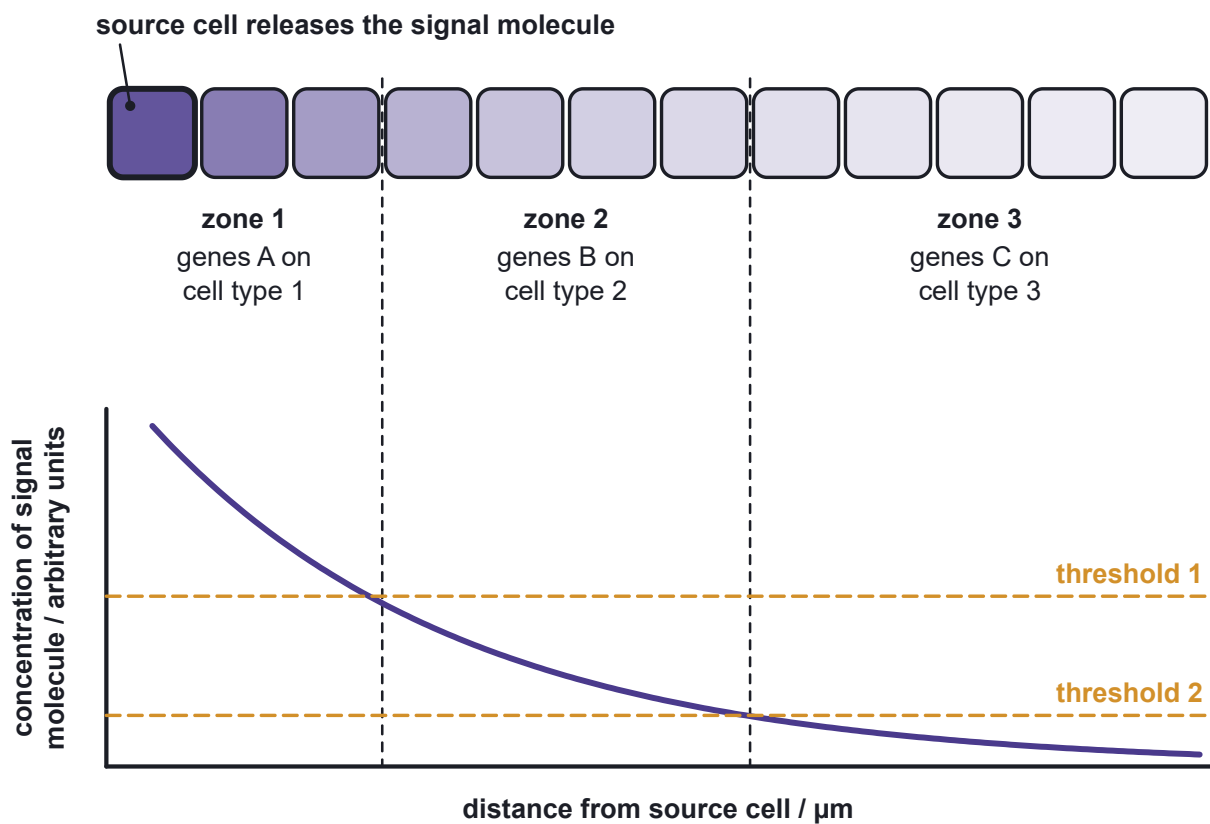
3 Cell specialization Spec B2.3

Differentiation and stem cells Spec B2.3.1-B2.3.4

From zygote to specialized cells

Fertilization produces a **zygote**, which divides by mitosis to form an embryo of unspecialized cells. These cells then develop into specialized cells by **differentiation**: each cell type expresses a different set of genes, so it makes different proteins and develops a different structure and function. All the cells still contain the same genes.

In an early-stage embryo, certain cells release signal molecules (morphogens). These diffuse away from their source, forming a **concentration gradient** across the embryo. The concentration a cell receives depends on its position, and this determines which genes it expresses. Cells in different positions therefore follow different developmental pathways, which is how body axes such as head-to-tail are set up.



[\(opens full size in a new tab\)](#)

A **concentration gradient** of signal molecule tells each cell its position, so different genes are expressed in each zone (illustrative).

Properties of stem cells

Stem cells have two properties: they can **divide endlessly**, and they can **differentiate along different pathways** to become different cell types.

Stem cell niches in adult humans

A stem cell niche is a location in the body where stem cells are found. Conditions in the niche can either maintain the stem cells or promote their proliferation and differentiation, depending on the body's needs.

Two stem cell niches in adult humans

Niche	Stem cells	Function
Bone marrow	Blood-forming (haematopoietic) stem cells	Produce red blood cells, white blood cells and platelets throughout life
Hair follicles	Stem cells in a region of the follicle called the bulge	Regenerate the hair follicle in each growth cycle and help repair the skin after wounding

Totipotent, pluripotent and multipotent stem cells

Potency of stem cells

Type	Can form	Example
Totipotent	Any type of cell, including the placenta and other tissues outside the embryo; can form a whole organism	The zygote and cells of the very early embryo
Pluripotent	Any type of cell in the body, but not a whole organism	Embryonic stem cells, from the embryo a few days after fertilization
Multipotent	A limited range of related cell types	Adult stem cells, such as those in bone marrow, which form the different types of blood cell

Common mistake: Differentiated cells do not lose genes. Differentiation changes which genes are expressed, not which genes are present.

Cell size and surface area-to-volume ratio Spec B2.3.5, B2.3.6

Cell size as an aspect of specialization

Human cells vary greatly in size, and the size of each type suits its function.

Approximate sizes of some human cells

Cell	Approximate size	Link to function
Sperm (male gamete)	Head about 5 μm long; whole cell about 50–60 μm long	Small and streamlined, with little cytoplasm, so it can swim to the egg
Egg (female gamete)	About 110 μm (0.1 mm) in diameter, at the limit of what the naked eye can see	Large, with cytoplasm and nutrients for the early embryo
Red blood cell	About 7–8 μm in diameter	Small and flexible, so it can squeeze through narrow capillaries
White blood cells	About 7–20 μm in diameter, from small lymphocytes (similar to a red blood cell) to monocytes	Most are larger than red blood cells; phagocytes are large enough to engulf bacteria
Neuron	Cell body up to about 100 μm across; axons up to about 1 m long	Long axons carry impulses over long distances, such as from the spinal cord to the foot
Striated muscle fibre	Up to about 100 μm wide and many centimetres long	Long fibres contract along their whole length

Surface area-to-volume ratio

A cell exchanges materials such as oxygen, nutrients and waste across its surface, so the rate of exchange depends on its **surface area**. The need for exchange depends on how much cytoplasm is carrying out metabolism, which is the cell's **volume**.

As a cell gets larger, its volume increases faster than its surface area. For a cube of side length L , surface area = $6L^2$ but volume = L^3 , so the **surface area-to-volume ratio** ($6 \div L$) falls as L increases. A large cell may not be able to exchange materials fast enough to meet its needs, and the distance from the surface to the centre becomes long for diffusion. This constrains cell size.

surface area-to-volume ratio = surface area $\div$ volume

Calculating SA:V

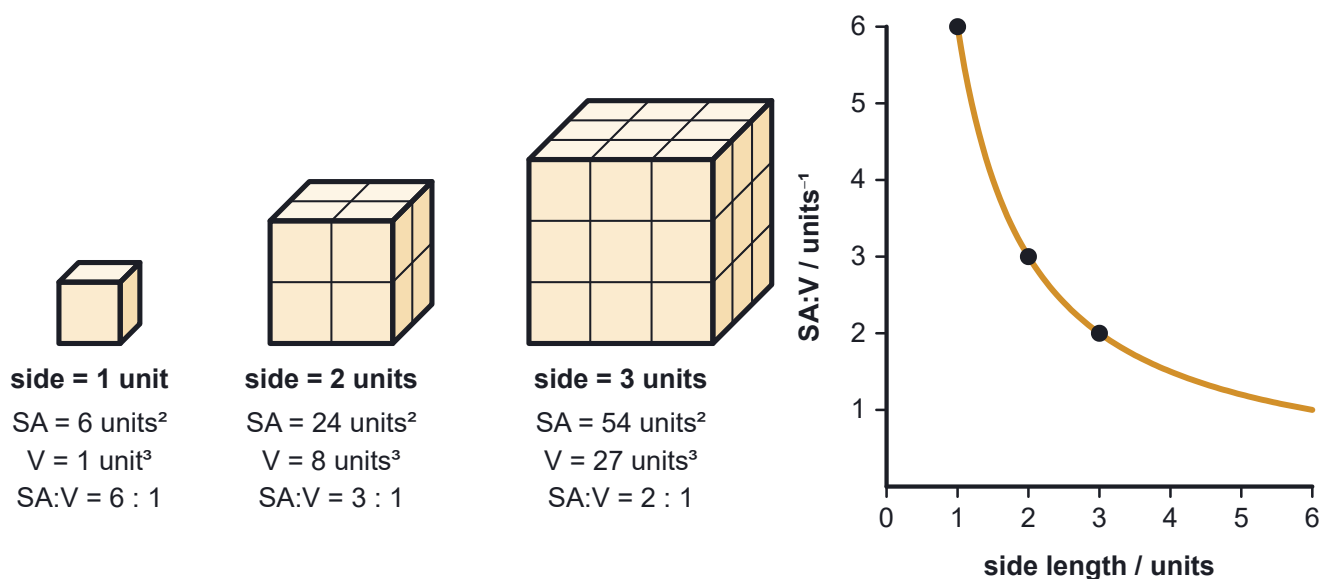
Model two cells as cubes with sides of $10\text{ }\mu\text{m}$ and $20\text{ }\mu\text{m}$. Calculate the surface area-to-volume ratio of each and state the effect of doubling the side length.

1. $10\text{ }\mu\text{m}$ cube: surface area = $6 \times 10^2 = 600\text{ }\mu\text{m}^2$; volume = $10^3 = 1000\text{ }\mu\text{m}^3$
2. SA:V = $600 \div 1000 = 0.6\text{ }\mu\text{m}^{-1}$ (0.6 : 1)
3. $20\text{ }\mu\text{m}$ cube: surface area = $6 \times 20^2 = 2400\text{ }\mu\text{m}^2$; volume = $20^3 = 8000\text{ }\mu\text{m}^3$
4. SA:V = $2400 \div 8000 = 0.3\text{ }\mu\text{m}^{-1}$ (0.3 : 1)

Answer: Doubling the side length multiplies surface area by 4 but volume by 8, so SA:V halves, from 0.6 to $0.3\text{ }\mu\text{m}^{-1}$.

Maths skill: Give SA:V in μm^{-1} (or cm^{-1}) or as a ratio such as 0.6 : 1. Work out surface area (squared units) and volume (cubed units) separately before dividing.

Practical skill: Model SA:V with agar cubes of different side lengths containing an indicator, placed in acid. The percentage of each cube's volume that changes colour in a fixed time shows how exchange falls behind as cubes get larger. Models are simplified: cubes are simpler than real cells, but scale factors work in the same way.



[\(opens full size in a new tab\)](#)

As side length increases, volume grows faster than surface area, so the **SA:V ratio falls**.

Exam tip: Linking question: what are the advantages of small size and large size in biological systems? Small cells exchange materials quickly; large organisms need extra adaptations such as lungs and a circulatory system.

Quick check

1. State the two properties of stem cells.
2. Name two stem cell niches in adult humans.
3. What type of stem cell is found in adult bone marrow?
4. What happens to the SA:V of a cube when its side length doubles?

Quick check answers

Membranes and membrane transport

1. The two hydrocarbon (fatty acid) tails.
2. Aquaporin.
3. Energy from ATP.
4. The extracellular side.

Organelles and compartmentalization

1. Any two of: the cell wall, the cytoskeleton, the cytoplasm.
2. Nuclei.
3. So they do not digest the cell's own molecules, and so they can be concentrated at their acid optimum pH.

Cell specialization

1. They can divide endlessly and differentiate along different pathways.
2. Bone marrow and hair follicles.
3. Multipotent.
4. It halves.