Biology Units 3 & 4

Chapter 1 — Assumed knowledge: cells, membranes and transport

Aboriginal and Torres Strait Islander content has been excluded as accuracy cannot be guaranteed, and it is better to be respectful than cover the entire curriculum inaccurately.

Significant effort has been made to ensure this content is legal. Please send any areas of concern to admin@vwx.au with appropriate document/legal references so errors can be verified and changes be made.

Contents

Chapter 1 Assumed knowledge: cells, membranes and transport — 1A Plasma membrane

Theory

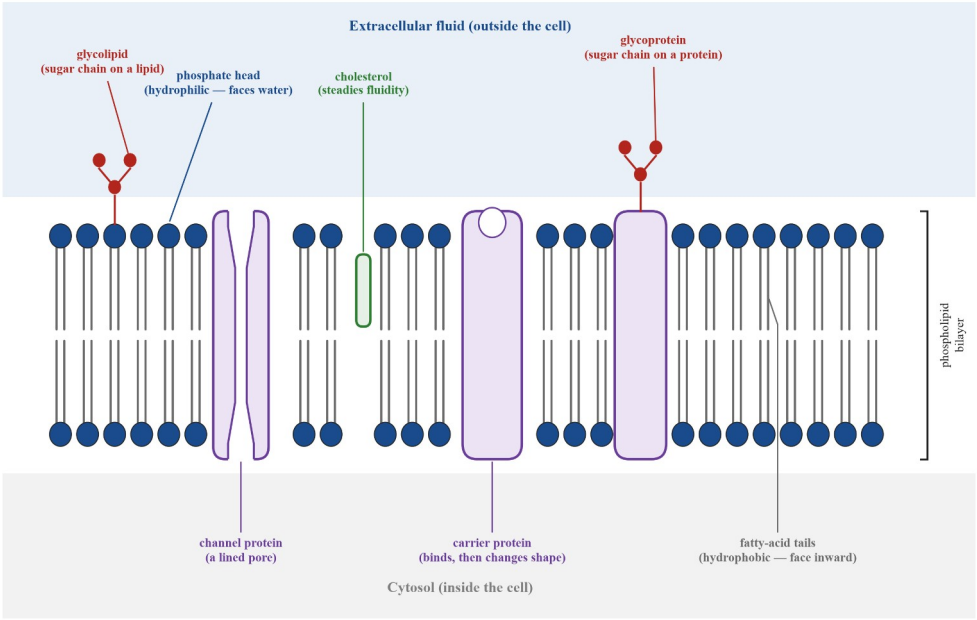
Assumed knowledge — Units 1 & 2 background, foundational for Units 3 & 4.

Every living cell is separated from its surroundings by a thin boundary called the **plasma membrane** (also called the cell membrane). This membrane holds the cell contents together, keeps the watery **cytosol** inside separate from the watery **extracellular fluid** outside, and — most importantly — controls which substances are allowed to pass between the two. Units 3 & 4 constantly rely on how substances cross membranes (into and out of cells and their compartments, and how the immune system reads what is on a cell's surface), so you need a secure picture of what the membrane is made of and why it behaves as it does.

The fluid mosaic model. The accepted description of membrane structure is the **fluid mosaic model**. The two words each describe a real feature:

- **Fluid** — the membrane is not a rigid, fixed sheet. Its molecules are held together only by weak attractions, so most of them can drift sideways and swap places, rather like people milling about in a crowd. The membrane behaves like a very thin, flexible, two-dimensional liquid.
- **Mosaic** — a mosaic is a picture built from many small pieces of different kinds. Seen from above, the membrane is a patchwork of different molecules — phospholipids, proteins, cholesterol and attached carbohydrates — scattered through and across the layer.

Put together, the model pictures a moving sheet of phospholipids with a mixture of other molecules set into it.

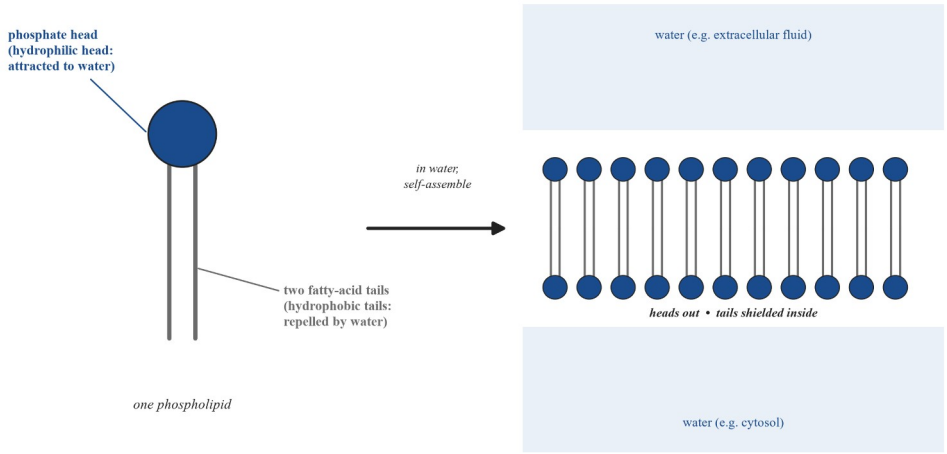


The phospholipid bilayer. The basic sheet of the membrane is built from **phospholipids**. A single phospholipid molecule has two very different ends:

- a **phosphate head**, which is **hydrophilic** ("water-loving") — it carries an electric charge, so it is attracted to water; and
- **two fatty-acid tails**, which are **hydrophobic** ("water-fearing") — they carry no charge and are pushed away from water.

A molecule that has one water-loving end and one water-fearing end will always try to arrange itself so that the heads sit in the water while the tails are tucked away from it. Because there is water on **both** sides of the membrane — extracellular fluid outside and cytosol inside — the phospholipids line up two rows deep, forming a **double layer**, or **bilayer**. The hydrophilic **heads point outward**, one row facing the extracellular fluid and one row facing the cytosol; the hydrophobic **tails point inward**, meeting in the middle where they are shielded from water on both sides. This

arrangement forms on its own, purely from the properties of the phospholipids, and it is what makes the membrane a stable barrier.



Other components set into the bilayer. The bilayer is the foundation, but several other kinds of molecule are embedded in it, and each has a job:

- **Cholesterol.** Cholesterol molecules sit tucked in among the fatty-acid tails. Cholesterol acts as a buffer for **fluidity**: it stops the membrane becoming too runny when conditions are warm, and stops it setting too stiff when conditions are cool. In this way it helps keep the membrane's flexibility — and therefore its barrier properties — fairly steady.
- **Membrane proteins.** Many proteins are embedded in the membrane, and some span right across the bilayer. The proteins that move specific substances from one side to the other are called **transport proteins**. "Transport protein" is the umbrella term, and there are **two kinds** of it:
    - a **channel protein** forms a lined **pore** — a water-filled tunnel through the membrane. Particles of the right size and charge can pass through the channel, which lets them avoid the oily interior that would otherwise block them.
    - a **carrier protein** works differently: it **binds** to a particular substance on one side, then **changes shape** to release that substance on the other side. Each carrier handles only its own particular substance.

  These proteins are how the membrane moves substances it cannot let through the bilayer directly. (Exactly how substances move, and why they move in a particular direction, is covered in a later subtopic.)
- **Glycoproteins and glycolipids.** On the **outer** surface of the membrane, short chains of carbohydrate (sugar) are attached to some molecules. A carbohydrate chain attached to a protein makes a **glycoprotein**; one attached to a lipid makes a **glycolipid**. These surface sugars act as **markers** — like name tags — that let cells **recognise** one another. They give each cell a chemical identity, so that the body can tell its own cells apart from foreign material.

A selectively permeable barrier. The whole point of the membrane is that it is **selectively permeable** (also called **semi-permeable**): it lets some substances cross while holding others back, rather than being either fully open or fully sealed. The reason lies in the structure just described. The oily, hydrophobic centre of the bilayer is the gatekeeper:

- **Small, non-polar (fat-soluble) molecules** — such as oxygen and carbon dioxide — slip between the phospholipids and cross the bilayer **readily**.
- **Large molecules and charged particles** — such as glucose, amino acids and ions like sodium — are repelled by, or too big for, the hydrophobic centre, so they **cannot cross the bilayer on their own**. They can only pass with the help of the channel and carrier proteins, each specific to a particular substance.
- **Water** is the important in-between case. A water molecule is **polar**, so the oily centre repels it — but it is also **very small**, small enough that some water molecules still slip between the phospholipids anyway. Water therefore does cross a bare bilayer, but only **slowly**. (Cells that must shift a lot of water quickly also carry channel proteins that let water through much faster.)

So **two** properties decide how readily a substance crosses the bilayer: **how small it is** and **how polar or charged it is**. The smaller and the less polar a substance is, the more easily it gets through.

Because different substances are treated differently, the cell can **regulate what enters and leaves** — taking in the materials it needs, keeping out or removing others, and holding useful substances inside. This control is what allows a cell to keep its internal conditions stable and different from its surroundings. Here the key point is simply that the membrane's structure makes it selective; the movement processes themselves are dealt with separately.

Worked examples

Example 1 — scaffolded

When a cell is broken open in water, its plasma membrane does not survive as flat sheets. Under the microscope the fragments are seen to curl up within moments and seal themselves into small **closed spheres**, each with a droplet of water trapped inside. Explain why the wall of such a sphere is **two molecules thick**, and why a fragment does not simply stay flat.

Working	Comment
A phospholipid has a **hydrophilic phosphate head** (attracted to water) and **two hydrophobic fatty-acid tails** (repelled by water).	Start from the molecule — everything the fragment does follows from these two opposite properties.
A fragment floating in water has **water on both of its faces**.	Find where the water is. This is what decides how many layers form.
A **single** layer could turn its heads towards the water on only **one** face, leaving the other row of tails exposed to water. Two rows solve this: **heads outward** into the water on each face, **tails meeting in the middle** — a wall two molecules thick.	Answer the "why two molecules thick" part directly, by ruling the single layer out.
A flat fragment still has an **exposed rim**, where the tails along the torn edge are in contact with water. Curling round until the edges join removes that rim, so **no tail anywhere is left touching water** — which is why the fragment closes into a sphere, trapping a droplet inside.	Answer the second part. The same property that builds the bilayer also drives it to seal into a closed compartment.

Example 2 — scaffolded

A protein that spans the plasma membrane is analysed. The middle section of the protein — the part lying inside the membrane — is built almost entirely from amino acids with **non-polar** side groups, while the sections sticking out at each end are built mostly from amino acids with **polar or charged** side groups. Explain how this arrangement suits the protein to its position, and predict what would happen if the whole protein were polar.

Working	Comment
The middle of the bilayer is a band of **hydrophobic fatty-acid tails**, while the two surfaces face **water** — extracellular fluid above, cytosol below.	Describe the environment the protein must sit in. It is not the same at the middle as at the two ends.
The protein's **non-polar middle** is hydrophobic, so it sits comfortably among the fatty-acid tails and is not pushed out of the oily core.	Match the non-polar band to the hydrophobic core.
The protein's **polar and charged ends** are hydrophilic, so they sit comfortably in the watery fluid on each surface.	Match the polar ends to the water on both faces.
Every part of the protein is therefore in the environment that suits it, so the protein is held **stably across the membrane**, in one orientation.	State the consequence — this is what "suits it to its position" means.
If the whole protein were polar, its middle would be	Answer the prediction separately, and give the reason

Working	Comment
repelled by the hydrophobic core. It could not stay buried in the bilayer and would be pushed out into the water on one side, sitting on the surface instead of spanning the membrane.	rather than just the outcome.

Example 3 — unscaffolded

In an investigation, a human cell and a mouse cell were fused together to make one cell with a single continuous plasma membrane. Before fusing, the surface proteins of the human cell had been tagged with a green marker and those of the mouse cell with a red marker. Immediately after fusion, green and red markers were still confined to separate halves of the joined cell. Forty minutes later they were evenly mixed over the whole surface. Explain what this result shows about the plasma membrane.

The result is direct evidence that the plasma membrane is **fluid**. The membrane is not a rigid sheet with its molecules locked in place: its phospholipids and many of its proteins are held together only by **weak attractions**, so they are free to **drift sideways** within the layer. Straight after fusion the tagged proteins had not yet had time to move, so each set stayed on its own half; over the next forty minutes they travelled laterally until they were spread evenly, which could only happen if the proteins were free to move within a single continuous sheet. The experiment also illustrates the **mosaic** half of the model, since the one membrane holds two different sets of proteins side by side. ∴ membrane molecules move sideways within one continuous sheet — the "fluid" of *fluid mosaic*.

Example 4 — unscaffolded

Living cells were treated with an enzyme that snips carbohydrate chains off the molecules they are attached to. The enzyme molecule is far too large to enter a cell. After the treatment, almost no carbohydrate could be detected on the cells. Explain what this result shows about where the membrane's carbohydrate chains lie, and why that location suits what they do.

Because the enzyme is too large to get inside, it can only have reached the **outside** of the cells — so the only carbohydrate it could possibly have removed is carbohydrate exposed on the **outer (extracellular) surface** of the plasma membrane. Since almost all of the cells' carbohydrate was in fact removed, essentially all of it must lie on that outer surface, attached to membrane proteins (making **glycoproteins**) and to membrane lipids (making **glycolipids**), with little or none on the cytosol face. This location is exactly what the job requires. These sugar chains act as **markers** that give the cell a chemical identity and let other cells **recognise** it, and a marker can only be read if it faces **outward**, into the extracellular fluid where other cells make contact. ∴ the carbohydrate chains sit on the outer surface because that is the only face on which a recognition marker would work.

Practice questions

Scaffolded

Q1. Define each of the following: (a) plasma membrane; (b) fluid mosaic model; (c) selectively permeable.

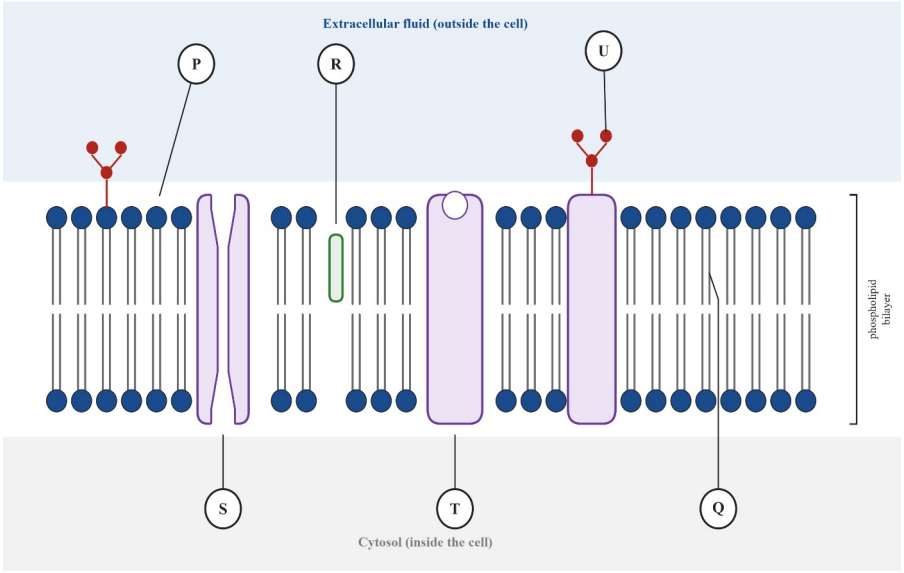
Q2. A phospholipid molecule has two distinct regions. (a) Name the two regions of a phospholipid. (b) State which region is hydrophilic and which is hydrophobic. (c) Describe how phospholipids are arranged in the membrane, and explain why they take up this arrangement.

Q3. Besides phospholipids, the membrane contains several other kinds of molecule. (a) State the role of cholesterol in the membrane. (b) State where the carbohydrate chains are found on the membrane. (c) Explain the role of glycoproteins and glycolipids.

Q4. Two kinds of transport protein are found in membranes. (a) Name the two kinds. (b) Describe how a channel protein allows a substance to cross the membrane. (c) Describe how a carrier protein moves a substance across the membrane.

Q5. The plasma membrane is selectively permeable. (a) Name one type of substance that can cross the phospholipid bilayer directly. (b) Name one type of substance that cannot cross the bilayer on its own. (c) Explain why these two types of substance are treated differently by the membrane.

Q6. *(Diagram interpretation.)* The diagram shows part of a plasma membrane with six structures labelled **P**–**U**.



(a) Identify the structures labelled **P** and **Q**.

(b) Identify the structure labelled **R** and state whereabouts in the bilayer it sits.

(c) Structures **S** and **T** are both proteins. Identify each, and state one difference you can **see between them in the diagram**.

(d) Identify the structure labelled **U** and state which of the two fluids shown in the diagram it projects into.

Unscaffolded

Q7. Distinguish between the terms **hydrophilic** and **hydrophobic** as they apply to a phospholipid. *(2 marks)*

Q8. *(Novel scenario.)* A nerve cell and a red blood cell taken from the same person have plasma membranes built from the same kind of phospholipid bilayer, yet the two membranes carry very different sets of membrane proteins. Using the fluid mosaic model, explain how this is possible, and state what it means for the substances each cell is able to move across its membrane. *(3 marks)*

Q9. Phospholipids shaken up in water arrange themselves into a bilayer. The same phospholipids stirred into an oily, water-free liquid do **not** form a bilayer at all. Explain this difference, referring to both parts of the phospholipid molecule. *(3 marks)*

Q10. *(Novel scenario.)* A living cell is pierced with a very fine glass needle. When the needle is withdrawn, the plasma membrane closes over the hole within seconds and the cell survives. State which feature of the fluid mosaic model this demonstrates, and explain how that feature allows the membrane to close the hole. *(2 marks)*

Q11. *(Novel scenario.)* Two proteins from the same membrane are studied. Protein 1 lets potassium ions flow straight through a water-filled opening that runs from one side of the membrane to the other. Protein 2 must attach to a glucose molecule and fold around it before the glucose can cross. Name the type of each protein, and state the feature you used to decide in each case. *(2 marks)*

Q12. A cell sits in a fluid containing oxygen, carbon dioxide, glucose and sodium ions. Explain how the selective permeability of its plasma membrane allows the cell to hold its internal conditions different from that surrounding fluid. *(3 marks)*

Q13. Oxygen crosses the plasma membrane easily, but a chloride ion cannot cross the bilayer on its own. With reference to the structure of the membrane, explain this difference. *(3 marks)*

Q14. *(Novel scenario.)* A patient receives a skin graft from an unrelated donor. Within days the patient's immune system attacks and destroys the grafted skin. Using what is found on the outer surface of a plasma membrane, explain how the patient's body could tell that the grafted cells were not its own. *(3 marks)*

Q15. *(Data interpretation.)* A researcher builds an artificial membrane made of a phospholipid bilayer **only** — no proteins are present. She measures whether each of several substances is able to pass through it. Her results are shown below.

Substance	Property of the substance	Passed through the bare bilayer?
Oxygen	small, non-polar	Yes — readily
Carbon dioxide	small, non-polar	Yes — readily
Water	small, polar	Yes — but only slowly
Glucose	large, polar	No
Sodium ion	small, charged	No

(a) State the **two** properties of a substance that, taken together, determine how readily it crosses the bare bilayer.

(b) Explain, using the structure of the membrane, why water crossed only slowly while glucose and sodium ions did not cross at all.

(c) State what would need to be added to this artificial membrane to allow glucose and sodium ions to cross, and name the two kinds of molecule involved. *(4 marks)*

Q16. *(Model evaluation.)* A student models the plasma membrane using a sheet of plastic food wrap floating on water, with small holes punched through it by a pin. State **one** way in which the model represents the plasma membrane well, and **two** important ways in which it does not, giving a reason in each case. *(3 marks)*

Q17. *(Research finding.)* In an investigation, cells were treated to **remove the cholesterol** from their plasma membranes. When these cholesterol-free cells were then warmed, their membranes became much more fluid and leaky than the membranes of untreated cells at the same temperature. Explain what this result shows about the normal role of cholesterol in the membrane. *(3 marks)*

Q18. The plasma membrane must act as a barrier and yet still allow the cell to exchange materials with its surroundings. Explain how the structure of the membrane allows it to do both. *(3 marks)*

Q19. *(Synthesis.)* A biotechnology team is building an artificial "cell" to carry a medicine through the bloodstream. At this stage its boundary is a phospholipid bilayer and **nothing else**. The medicine sealed inside is a **charged** molecule. The artificial cell must also take up **glucose** from the blood to keep working, and it must survive being stored at 4 °C and then warmed to 37 °C inside the body. (a) Explain why the bare bilayer will hold the charged medicine inside, but will also keep glucose out. (b) State what the team should build into the boundary so that glucose can enter, explain how it would move glucose across, and explain why this addition would not open the boundary to every other substance in the blood. (c) State what else the team should add so that the boundary keeps a steady fluidity at both 4 °C and 37 °C, and describe how it would act at each of those two temperatures. *(7 marks)*

Answers

Q1. (a) The thin boundary around a cell that separates the cytosol from the extracellular fluid and controls what passes between them. (b) The membrane described as a fluid (moving) phospholipid bilayer with a mosaic (patchwork) of proteins, cholesterol and carbohydrates set into it. (c) Letting some substances cross while holding others back — not fully open or fully sealed. **Q2.** (a) A phosphate head and two fatty-acid tails. (b) Head = hydrophilic; tails = hydrophobic. (c) A bilayer, heads facing the water on both sides and tails turned inward; because the heads are attracted to water and the tails are repelled by it. **Q3.** (a) It steadies the membrane's fluidity (stops it becoming too fluid or too stiff). (b) On the outer surface of the membrane. (c) They are surface carbohydrate markers that let cells recognise one another / act as cell identity tags. **Q4.** (a) Channel proteins and carrier proteins. (b) It forms a lined, water-filled pore through which suitable particles pass. (c) A carrier binds a specific substance and changes shape to move it across, rather than forming an open pore. **Q5.** (a) A small non-polar molecule such as oxygen (or carbon dioxide). (b) A charged ion such as sodium, or a large molecule such as glucose. (c) The hydrophobic centre lets small non-polar molecules through but repels/blocks charged and large ones, which need proteins. **Q6.** (a) P = phosphate (hydrophilic) head; Q = fatty-acid (hydrophobic) tails. (b) R = cholesterol; it sits in the oily interior of the bilayer, tucked in among the fatty-acid tails. (c) S = channel protein; T = carrier protein; in the diagram S is drawn with an opening running right through it from one surface to the other, whereas T is a closed body with only a small pocket opening on the outer side. (d) U = glycoprotein; it projects into the extracellular fluid. **Q7.** Hydrophilic = attracted to water (the phosphate head); hydrophobic = repelled by water (the fatty-acid tails). **Q8.** The proteins are a separate mosaic set into the bilayer, not part of it, so the same bilayer can carry a different set of proteins in each cell type; because transport proteins are specific, each cell can move only the substances its own proteins handle. **Q9.** In water the hydrophilic heads are drawn to the water and the hydrophobic tails are pushed out of it, so the only stable arrangement is heads-out, tails-in — a bilayer; in an oily, water-free liquid the tails already suit their surroundings and there is no water to hide them from, so nothing drives a bilayer to form. **Q10.** Fluidity — the phospholipids are held by weak attractions only, so they drift sideways into the gap and the bilayer flows back together. **Q11.** Protein 1 = channel protein, decided from the water-filled opening running right through the membrane; Protein 2 = carrier protein, decided from its binding the glucose and changing shape. **Q12.** Oxygen and carbon dioxide (small, non-polar) cross the bilayer freely, but glucose (large, polar) and sodium ions (charged) are blocked by the hydrophobic core and can pass only through specific transport proteins; controlling that traffic lets the cell hold internal concentrations different from the surrounding fluid. **Q13.** Oxygen is small and non-polar, so it passes through the hydrophobic centre; a chloride ion is charged and is repelled by the hydrophobic centre, so it cannot cross without a protein. **Q14.** The outer surface carries carbohydrate markers (glycoproteins and glycolipids) that give a cell its chemical identity; the unrelated donor's markers differ from the patient's own, and because they face outward the immune system can read them and recognise the grafted cells as non-self. **Q15.** (a) Its size and its polarity/charge — how small it is and how polar or charged it is. (b) Water is polar so the oily centre repels it, but it is small enough that some molecules still slip between the phospholipids, so it crosses slowly; glucose is large as well as polar and sodium ions are charged, so the centre blocks them completely. (c) Add transport proteins — channel proteins and carrier proteins — specific to glucose and sodium ions. **Q16.** Well: a very thin continuous sheet acting as a partly permeable barrier. Not well: the plastic is rigid, not fluid, so it could never reseal or let its parts drift; and the pin holes sort only by size, whereas real channel and carrier proteins are specific to particular substances. **Q17.** Without cholesterol the membrane became too fluid and leaky when warmed; this shows cholesterol normally restrains fluidity and keeps the membrane stable as temperature rises. **Q18.** The oily hydrophobic core blocks most substances (barrier), while transport proteins and the ability of small non-polar molecules to pass let selected substances through (exchange) — so the one structure does both. **Q19.** (a) The hydrophobic core repels the charged medicine, so it cannot get out, and blocks glucose, which is large and polar, so it cannot get in. (b) Build in a carrier protein specific to glucose: it binds glucose on the outside and changes shape to release it inside; because a transport protein binds only its own substance, this admits glucose alone. (c) Add cholesterol: at 37 °C it restrains the phospholipids and stops the boundary becoming too fluid; at 4 °C it holds them slightly apart and stops it setting too stiff.

Fully-worked solutions

Q1. (a) The **plasma membrane** is the thin boundary surrounding a cell. It separates the cell's **cytosol** from the **extracellular fluid** and **controls which substances pass** between them. (b) The **fluid mosaic model** describes the membrane as a **fluid** (freely moving) **phospholipid bilayer** in which a **mosaic** (patchwork) of proteins, cholesterol

molecules and surface carbohydrates is set. (c) **Selectively permeable** (semi-permeable) means the membrane **lets some substances cross but holds others back** — it is neither fully open nor fully sealed.

Q2. (a) A phospholipid has a **phosphate head** and **two fatty-acid tails**. (b) The **phosphate head is hydrophilic** (attracted to water); the **fatty-acid tails are hydrophobic** (repelled by water). (c) The phospholipids are arranged in a **bilayer** (two layers). The **hydrophilic heads face outward** into the water on both sides — the extracellular fluid and the cytosol — while the **hydrophobic tails point inward**, meeting in the middle away from water. They take up this arrangement **because their heads are attracted to the water on each side and their tails are repelled by water**, so the only stable arrangement is heads-out, tails-in.

Q3. (a) **Cholesterol** helps **maintain the membrane's fluidity**: it keeps the membrane from becoming too fluid when warm and too stiff when cool, steadying its flexibility. (b) The carbohydrate chains are found on the **outer (extracellular) surface** of the membrane. (c) **Glycoproteins** (sugar on a protein) and **glycolipids** (sugar on a lipid) act as **surface markers**. They give the cell a chemical identity and allow **cell recognition** — letting cells identify one another and letting the body tell its own cells from foreign material.

Q4. (a) **Channel proteins** and **carrier proteins**. (b) A **channel protein** forms a **lined, water-filled pore** that passes right through the membrane; a particle of the right size and charge **moves through this pore**, avoiding the oily interior that would otherwise block it. (c) A **carrier protein** does **not** form an open pore. Instead it **binds** a specific substance on one side and then **changes shape** to carry that substance across and release it on the other side — so a carrier moves one particular substance at a time by changing shape, whereas a channel is simply an open passage.

Q5. (a) A **small, non-polar molecule** such as **oxygen** (or carbon dioxide). (b) A **charged ion** such as **sodium**, or a **large molecule** such as **glucose**. (c) The difference comes from the **hydrophobic (oily) centre** of the bilayer. **Small, non-polar molecules dissolve in and slip through** this centre, so they cross directly. **Charged and large molecules are repelled by, or too big for**, the hydrophobic centre, so they cannot cross on their own and instead require a specific **transport protein**.

Q6. (a) **P** is a **phosphate head** (the hydrophilic head of a phospholipid); **Q** is the **fatty-acid tails** (the hydrophobic tails). (b) **R** is **cholesterol**. It sits **inside the bilayer, in the oily interior** — tucked in among the **fatty-acid tails**, between the phospholipids, rather than at either watery surface. (c) **S** is a **channel protein** and **T** is a **carrier protein**. The difference visible **in the diagram** is that **S is drawn with an opening running right through it**, from the extracellular fluid to the cytosol — its outline is broken at both membrane surfaces — whereas **T is drawn as a closed body** with only a **small pocket opening on the outer side**, so there is no route straight through it. (d) **U** is a **glycoprotein** — a carbohydrate chain attached to a protein. Of the two fluids shown, it projects into the **extracellular fluid**, the fluid outside the cell, which is where a cell-recognition marker has to face in order to be read.

Q7. Hydrophilic means **attracted to water**; in a phospholipid this describes the **phosphate head**, which carries a charge and mixes with water. **Hydrophobic** means **repelled by water**; this describes the **two fatty-acid tails**, which carry no charge and are pushed away from water. *(1 mark for each term correctly explained and linked to the correct part of the phospholipid.)*

Q8. In the **fluid mosaic model** the phospholipid **bilayer** is the foundation and the other molecules form a **mosaic set into it**. The bilayer is built from the same kind of amphipathic phospholipid in every cell, so it is **identical in the two cells** and contributes the same basic barrier. The proteins, however, are **separate molecules embedded in** that bilayer rather than part of it, so the **same bilayer can be fitted with a different set of proteins** in each cell type — which is how a nerve cell and a red blood cell can share an identical bilayer yet carry very different membrane proteins. Because **transport proteins are specific**, each one moving only its own substance, the set of proteins a cell carries decides **which substances that cell can move across its membrane**: each cell can move the substances its own proteins handle and no others, even though the bilayer beneath them is the same. *(1 mark: the phospholipid bilayer is the common foundation, the same in both cells; 1 mark: proteins form a mosaic embedded in it, so the set can differ from cell type to cell type; 1 mark: transport proteins are specific, so each cell can move only the substances its own proteins handle.)*

Q9. A phospholipid has a **hydrophilic phosphate head** (attracted to water) and **two hydrophobic fatty-acid tails** (repelled by water). **In water** these two properties pull in opposite directions, and the only arrangement that satisfies both is one in which the **heads face the water** while the **tails are tucked away from it**; with water on both sides, that arrangement is a **bilayer**. The bilayer therefore assembles on its own, driven by the tails being pushed out of the water.

In an oily, water-free liquid there is no water at all. The hydrophobic tails **mix freely with the oil**, which already suits them, and with no water present there is nothing to draw the heads to a surface or to push the tails together. The driving force that builds a bilayer is simply absent, so the phospholipids disperse through the oil instead of lining up. *(1 mark: head hydrophilic, tails hydrophobic; 1 mark: in water the heads face the water and the tails are driven out of it, giving a bilayer; 1 mark: in oil there is no water, the tails already suit their surroundings, so there is no driving force and no bilayer.)*

Q10. The feature demonstrated is that the membrane is **fluid**. In the fluid mosaic model the phospholipids are held to one another only by **weak attractions** rather than fixed bonds, so they are free to **drift sideways within the layer** instead of being locked in place. When the needle is withdrawn, the phospholipids around the hole simply **flow sideways into the gap** until the sheet is continuous again, with the heads once more facing the water on each side. The membrane can close the hole because it can **flow**; a rigid sheet, whose molecules could not move, would have been left with a permanent puncture. *(1 mark: identifies fluidity — the phospholipids can move sideways; 1 mark: explains that they drift into the gap so the bilayer flows back together and reseals.)*

Q11. Protein 1 is a channel protein. The feature used to decide this is that it offers a **water-filled opening running right through the membrane**, from one side to the other, and the potassium ions pass **straight through** it — a continuous open pore is exactly what defines a channel, and the protein itself does not have to move. **Protein 2 is a carrier protein.** The feature used here is that it must **attach to (bind) the glucose molecule and fold around it** before the glucose can cross — that is, it **changes shape** to carry its substance across rather than providing an open passage. *(1 mark for each protein correctly named together with the feature used to decide it.)*

Q12. The four substances are not all treated the same way, and that is what **selective permeability** means. **Oxygen and carbon dioxide** are **small and non-polar**, so they dissolve in and slip through the **hydrophobic (oily) centre** of the bilayer and move freely in both directions. **Glucose** is **large and polar** and a **sodium ion** is **charged**, so both are **repelled by, or too big for**, that same hydrophobic centre and **cannot cross the bilayer on their own**; they can enter or leave only through a **transport protein specific to them**. Because those proteins are specific, and the cell has only the ones it carries, the cell **controls the entry and exit** of glucose and sodium ions. It can therefore hold their concentrations inside the cell at levels quite **different from the surrounding fluid**, which is what it means to keep stable internal conditions. *(1 mark: oxygen and carbon dioxide are small and non-polar so cross the bilayer freely; 1 mark: glucose is large/polar and sodium is charged, so the hydrophobic centre blocks them and they need specific transport proteins; 1 mark: controlling that traffic lets the cell hold internal concentrations different from the surrounding fluid.)*

Q13. The difference is due to the **hydrophobic (oily) centre** of the bilayer. **Oxygen** is a **small, non-polar** molecule, so it **dissolves in and slips through** this hydrophobic centre and crosses the bilayer directly. A **chloride ion** is **charged**, so it is **repelled by the hydrophobic centre** and cannot pass through the oily core. To cross, a chloride ion would need a **channel or carrier protein** specific to it. *(1 mark: oxygen small/non-polar so passes the hydrophobic core; 1 mark: chloride is charged so is repelled/blocked by the core; 1 mark: it requires a transport protein.)*

Q14. The **outer (extracellular) surface** of a plasma membrane carries short **carbohydrate chains** attached to membrane proteins (making **glycoproteins**) and to membrane lipids (making **glycolipids**). These sugar chains act as **markers** that give each cell a **chemical identity**. The pattern of markers is **not the same in unrelated people**, so the grafted skin cells carry a set of surface markers **different from** the patient's own cells. Because the markers face **outward**, into the extracellular fluid, they are the part of the cell the patient's immune cells make contact with and can read; on reading markers that do not match the body's own, the immune system identifies the grafted cells as **foreign (non-self)** rather than self, and attacks and destroys them. *(1 mark: the outer surface carries carbohydrate markers — glycoproteins and glycolipids — giving the cell a chemical identity; 1 mark: the unrelated donor's markers differ from the patient's own; 1 mark: because they face outward they can be read, so the immune system recognises the cells as non-self and attacks them.)*

Q15. (a) Two properties decide it, taken together: **how small the substance is** and **how polar or charged it is**. Together they account for the whole table — oxygen and carbon dioxide are **small and non-polar** and cross readily; water is **small but polar** and crosses only slowly; glucose is **large and polar** and sodium is **charged**, and neither crosses at all. (b) The centre of the bilayer is a band of **hydrophobic fatty-acid tails**. **Water is polar**, so this oily centre **repels** it — but a water molecule is also **very small**, small enough that some molecules still **slip between the phospholipids** anyway; the repulsion slows water down without stopping it, so it crosses **slowly**. **Glucose** is **large as well as polar**, and a **sodium ion** carries a **charge**, so for these two the hydrophobic centre is a complete obstacle —

too big for it, too strongly repelled by it, or both — and they do not cross the bare bilayer at all. (c) The membrane would need **transport proteins** specific to glucose and to sodium ions; the two kinds of molecule involved are **channel proteins** and **carrier proteins**. *(a: 1 mark — both size and polarity/charge named; b: 1 mark — water is polar so is repelled, but small enough to slip between the phospholipids, hence slow; 1 mark — glucose is large and polar and sodium is charged, so the hydrophobic centre blocks them completely; c: 1 mark — add transport proteins, named as channel proteins and carrier proteins.)*

Q16. One way the model works well. Food wrap is an **extremely thin, continuous sheet** that forms a **barrier** between what lies above it and what lies below, and the pin holes let some material through while the rest of the sheet holds material back. That captures the membrane's basic job — a very thin boundary that is **partly, not fully, permeable**. **First important limitation: the model is not fluid.** The plastic is a **solid sheet** whose molecules are fixed in place, whereas a real membrane is a **fluid** phospholipid bilayer whose molecules are held by weak attractions and can drift sideways. A real membrane can flow, bend and **reseal** a puncture; the food wrap keeps every hole permanently. **Second important limitation: the holes are not selective.** A pin hole is just a **gap**, so the only thing that decides passage is **size** — anything small enough gets through. Real crossing points are **channel and carrier proteins**, each **specific to a particular substance**, so a real membrane can admit one substance and refuse another of the same size. (The model is also not a **mosaic**: it is one uniform material, with no proteins, cholesterol or surface carbohydrates set into it.) *(1 mark: one valid strength with a reason — a very thin sheet acting as a partly permeable barrier; 1 mark: first limitation with a reason — the plastic is rigid, not fluid, so it cannot flow or reseal; 1 mark: second limitation with a reason — pin holes sort by size alone, whereas transport proteins are specific / the model has no mosaic of other molecules.)*

Q17. The result shows that cholesterol normally **restrains the fluidity** of the membrane. When cholesterol was **present** (untreated cells), the membrane stayed reasonably stable when warmed; when cholesterol was **removed**, warming made the membrane **much more fluid and leaky**. This means cholesterol normally **buffers the membrane against becoming too fluid** as temperature rises, helping keep the membrane's structure and barrier function **stable**. *(1 mark: cholesterol restrains/buffers fluidity; 1 mark: without it the membrane becomes too fluid/leaky when warm; 1 mark: so cholesterol keeps the membrane stable across temperature.)*

Q18. The membrane does both because of its structure. Its **hydrophobic core** (the fatty-acid tails) acts as a **barrier**, blocking most substances — in particular large and charged particles — from simply passing through. At the same time, **small non-polar molecules can cross the bilayer directly**, and **channel and carrier proteins** provide specific routes for particular substances the bilayer would otherwise block. So the same structure that seals the cell off also provides **selected routes for exchange**, making the membrane a barrier that still allows controlled exchange. *(1 mark: hydrophobic core acts as a barrier; 1 mark: small non-polar molecules cross and/or proteins provide routes; 1 mark: therefore the structure is both a barrier and selectively permeable.)*

Q19. (a) The middle of the bilayer is a band of **hydrophobic fatty-acid tails** — an oily layer that repels anything charged or strongly polar. The medicine is a **charged** molecule, so when it reaches the boundary from the inside it is **repelled by that hydrophobic core** and cannot pass through it; it is held inside. **Glucose** meets the same obstacle from the outside: it is a **large, polar** molecule, so it is both **too big for** and **repelled by** the core and cannot cross either. One and the same feature — the oily centre — traps the medicine in and keeps the glucose out. (b) The team should build a **transport protein specific to glucose** into the boundary — a **carrier protein**. It **binds a glucose molecule** at its site on the outer face, then **changes shape** so that the glucose is released on the inner face, so the glucose crosses without ever passing through the oily core. This would **not** open the boundary to everything else in the blood, because a transport protein is **specific**: its binding site fits **only glucose**, so any other substance is not bound and is not carried. Everything else still meets the bare bilayer, which goes on blocking it — the boundary gains **one controlled route**, not a general leak. (c) The team should also add **cholesterol** among the fatty-acid tails, because cholesterol acts as a **buffer for fluidity**. At **37 °C** the phospholipids would otherwise move a great deal and the boundary would become too fluid and leaky, so cholesterol **restrains the phospholipids** and holds the fluidity down. At **4 °C** they would otherwise pack tightly together and the boundary would set too stiff, so cholesterol **keeps them slightly apart** and stops it becoming rigid. Acting in opposite ways at the two temperatures, cholesterol keeps the boundary's fluidity roughly **steady** right across the storage-to-body range. *(a: 2 marks — the hydrophobic core repels the charged medicine so it cannot leave; glucose is large and polar so the same core blocks it from entering; b: 3 marks — add a transport protein specific to glucose (a carrier); it binds glucose and changes shape to release it on the other side; transport proteins are specific, so the rest of the boundary stays a barrier; c: 2 marks — add cholesterol as a fluidity buffer; at 37 °C it restrains the phospholipids and at 4 °C it keeps them slightly apart.)*

Chapter 1 Assumed knowledge: cells, membranes and transport — 1B Cell types and cell organelles

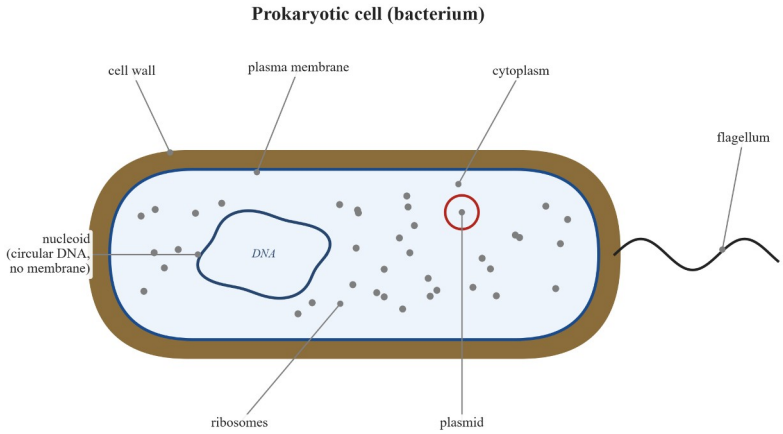
Theory

Assumed knowledge — Units 1 & 2 background, foundational for Units 3 & 4.

The cell is the basic unit of life: every living thing is made of one or more cells. Although cells come in an enormous variety of shapes and sizes, they fall into just **two fundamental types** — **prokaryotic** and **eukaryotic** — and within a eukaryotic cell the work of life is shared out among small specialised structures called **organelles**. This subtopic sets out the two cell types, the structure and function of the main organelles, and the differences between plant and animal cells. You will rely on all of this when you study how proteins are made, how cells obtain energy, and how the immune system works later in the course.

Two terms to fix first. An **organelle** is a specialised structure inside a cell that carries out a particular function; many (but not all) organelles are enclosed by their own membrane. The **cytoplasm** is everything inside the plasma membrane apart from the nucleus — it includes the organelles and the fluid around them. That fluid is the **cytosol**: the watery, jelly-like solution in which the organelles are suspended and in which many of the cell's chemical reactions take place.

Prokaryotic and eukaryotic cells. The single most important difference between the two cell types is the nucleus. A **eukaryotic cell** keeps its DNA inside a **membrane-bound nucleus**, and it contains many other **membrane-bound organelles** (such as mitochondria and the endoplasmic reticulum). A **prokaryotic cell** has **no membrane-bound nucleus** — its DNA lies free in the cytoplasm in a region called the **nucleoid** — and it has **no membrane-bound organelles** at all. Prokaryotic cells are also much smaller and structurally simpler. Bacteria are prokaryotes; animals, plants, fungi and protists are all made of eukaryotic cells.

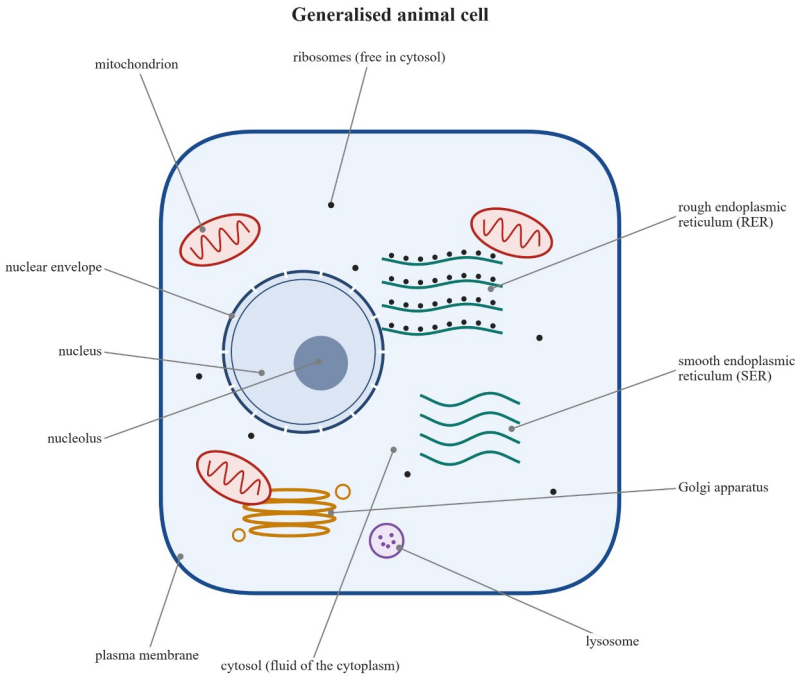


A prokaryotic cell still has a **plasma membrane**, a **cell wall**, **cytoplasm** and **ribosomes**, and often a small extra loop of DNA called a **plasmid** and a whip-like **flagellum** for movement. What it lacks is the internal membrane-bound compartments that organise a eukaryotic cell. The table below summarises the comparison.

Feature	Prokaryotic cell	Eukaryotic cell
Nucleus	No membrane-bound nucleus; DNA lies free in a region called the nucleoid	DNA enclosed in a membrane-bound nucleus
DNA arrangement	Usually one circular chromosome, plus small circular plasmids	Several linear chromosomes
Membrane-bound organelles	Absent (no mitochondria, ER, Golgi, etc.)	Present (mitochondria, ER, Golgi, etc.)
Ribosomes	Present (smaller)	Present (larger)

Feature	Prokaryotic cell	Eukaryotic cell
Typical size	Small, about 1–10 µm	Larger, about 10–100 µm
Cell wall	Usually present (not made of cellulose)	Present in plants and fungi; absent in animals
Examples	Bacteria (and archaea)	Animal, plant, fungal and protist cells

The organelles of a eukaryotic cell. The diagram below shows a generalised **animal cell** with its main organelles. Each organelle has a structure suited to a specific function; study the diagram alongside the descriptions that follow.



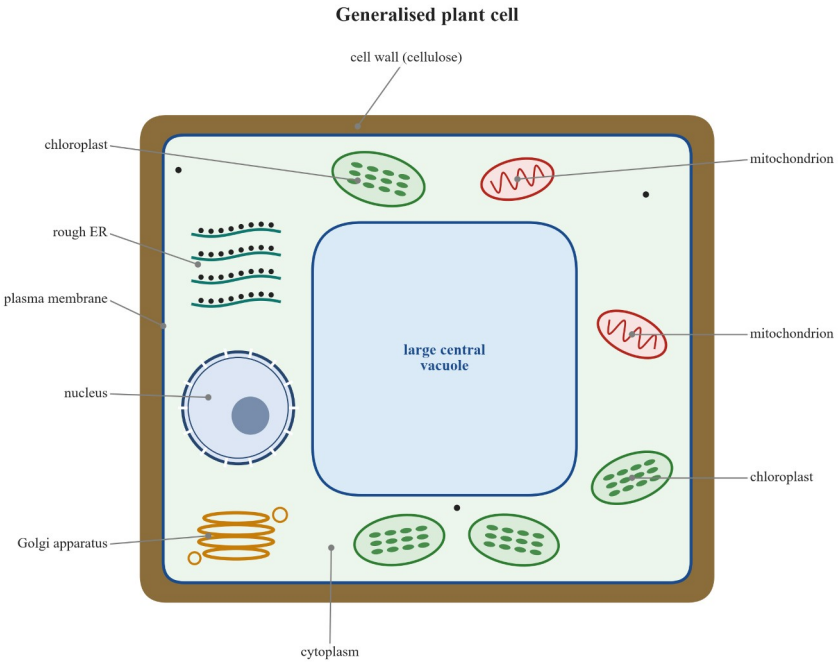
Organelle	Structure	Function
Plasma membrane	A thin membrane forming the outer boundary of the cell	Controls which substances enter and leave the cell (it is selectively permeable)
Nucleus	A large organelle enclosed by a double membrane (the nuclear envelope) with nuclear pores; holds the DNA	Stores the cell's DNA and controls the cell's activities by controlling which proteins are made
Nucleolus	A dense region inside the nucleus	Where ribosomes are made (assembled)
Ribosomes	Very small structures (not membrane-bound) made of RNA and protein; free in the cytosol or attached to the rough ER	The site of protein synthesis — joining amino acids into polypeptides
Rough endoplasmic reticulum (RER)	A network of flattened membrane sacs studded with ribosomes	Makes and folds proteins, especially proteins that will be secreted from the cell or built into membranes
Smooth endoplasmic reticulum (SER)	A network of membrane tubes with no ribosomes	Makes lipids (fats and steroids)
Golgi apparatus	A stack of flattened membrane sacs	Modifies, sorts and packages proteins and other molecules into membrane-bound vesicles

Organelle	Structure	Function
Mitochondrion	A rod-shaped organelle with a double membrane; the inner membrane is folded into cristae	The site of aerobic cellular respiration, which releases energy from glucose as ATP
Chloroplast	A double-membraned organelle containing the green pigment chlorophyll in stacked membranes (grana)	The site of photosynthesis, which uses light energy to make glucose
Vacuole	A fluid-filled sac bounded by a membrane	Stores water, dissolved substances and wastes; in plants a large central vacuole also keeps the cell firm
Lysosome	A small membrane-bound sac containing digestive enzymes	Breaks down worn-out organelles, wastes and materials taken into the cell
Cell wall	A rigid layer outside the plasma membrane, made of cellulose in plants	Supports and protects the cell and gives it a fixed shape

A few of these deserve a closer look. The **mitochondrion** is often called the cell's powerhouse: its folded inner membrane (the cristae) gives a large surface area for the reactions that make ATP, the cell's usable energy supply. Cells that do a lot of work — such as muscle cells — contain very many mitochondria. **Ribosomes** are found in *both* prokaryotic and eukaryotic cells, because every cell must make proteins — unlike the membrane-bound organelles (the nucleus, ER, Golgi, mitochondria and chloroplasts), which are found only in eukaryotic cells. The **rough ER** is "rough" precisely because it is covered in ribosomes, whereas the **smooth ER** has none — that difference in appearance is the easiest way to tell the two apart. Note that **mitochondria are present in plant cells as well as animal cells**: plants respire just as animals do, so they need mitochondria; they simply have chloroplasts as well.

Why membranes matter. The membrane around an organelle does more than hold it together: it keeps that organelle's contents separate from the rest of the cytosol, so a single cell can run many different processes side by side without them interfering with one another. The digestive enzymes of a **lysosome**, for example, stay sealed inside it, where they break down the material delivered to them rather than the cell's own cytosol and organelles.

Plant cells and animal cells. Both plant and animal cells are eukaryotic, so both have a plasma membrane, a nucleus, mitochondria, ribosomes, rough and smooth ER, a Golgi apparatus and cytosol. The diagram below shows a generalised **plant cell**.



Three structures are found in a plant cell but **not** in a typical animal cell:

- a **cell wall** made of cellulose, outside the plasma membrane, which supports the cell and gives it its shape;
- **chloroplasts**, which carry out photosynthesis;
- one **large central vacuole**, which stores water and keeps the cell firm (turgid).

A typical animal cell has none of these three, but it often contains **lysosomes** and only small vacuoles. The table below sets the two cell types side by side.

Structure	Animal cell	Plant cell
Plasma membrane	present	present
Nucleus, ribosomes, ER, Golgi	present	present
Mitochondria	present	present
Cell wall	absent	present (cellulose)
Chloroplasts	absent	present
Large central vacuole	absent (small vacuoles only)	present
Lysosomes	usually present	rare

Reading a cell. Because organelles do particular jobs, the mix of organelles in a cell tells you what the cell is specialised to do. A cell packed with **mitochondria** must need a lot of ATP, so it is doing energy-demanding work; a cell with extensive **rough ER** and many ribosomes must be making a lot of protein, so it is likely a secretory cell. Learning to reason from structure to function in this way is a skill you will use throughout the course.

Worked examples

Example 1 — scaffolded

An organelle in a human cell has a double membrane, the inner membrane being folded into structures called cristae, and it is the main site where ATP is produced. (a) Name the organelle. (b) Name the process it carries out. (c) State whether this organelle is also found in plant cells.

Working	Comment
A double membrane with a folded inner membrane (cristae) that produces ATP identifies this as a **mitochondrion**.	The folded inner membrane increases the surface area available for the reactions that release energy.
The process that releases energy from glucose as ATP, using oxygen, is **aerobic cellular respiration**.	Name the process; ATP is the cell's usable energy currency.
Mitochondria are found in **plant cells as well as animal cells**.	Common error: assuming only animals respire. Plant cells respire too, so they also contain mitochondria.
Answer: (a) mitochondrion; (b) aerobic cellular respiration; (c) yes — plant cells have mitochondria too.	

Example 2 — scaffolded

A cell is about 2 μm long. It has no membrane-bound nucleus — its DNA lies free in the cytoplasm as a single circular chromosome. It has ribosomes, a plasma membrane and a cell wall, but no mitochondria and no chloroplasts. (a) State whether the cell is prokaryotic or eukaryotic. (b) Name the region where its DNA is located. (c) Name a group of organisms this cell could belong to.

Working	Comment
No membrane-bound nucleus, no membrane-bound organelles and a very small size (2 μm) all point to a **prokaryotic** cell.	The defining feature of a prokaryote is the absence of a membrane-bound nucleus.
The DNA lies free in a region of the cytoplasm called the **nucleoid**.	The nucleoid is not a nucleus — it has no surrounding membrane.
A cell like this belongs to the **bacteria** (prokaryotes also include the archaea).	Bacteria are the everyday example of prokaryotic organisms.
Answer: (a) prokaryotic; (b) the nucleoid; (c) bacteria.	

Example 3 — unscaffolded

A cell viewed under a microscope has a rigid outer wall, several green chloroplasts and a single large fluid-filled sac that takes up most of the cell's volume. Identify whether it is a plant cell or an animal cell, and justify your answer by referring to THREE structures.

This is a **plant cell**. Three structures identify it. First, the rigid outer wall is a **cell wall** (made of cellulose), which supports the cell; a typical animal cell has no cell wall. Second, the green **chloroplasts** are the site of photosynthesis and are found only in plant cells (and algae), never in animal cells. Third, the single large fluid-filled sac is a **large central vacuole**, which stores water and keeps the cell firm; animal cells have only small vacuoles, if any. Because all three structures are present in plant cells and absent from animal cells, ∴ the cell is a plant cell.

Example 4 — unscaffolded

An animal cell is found to contain unusually large numbers of mitochondria together with an extensive network of rough endoplasmic reticulum. Suggest, with reasons, the kind of work this cell is specialised to do.

The large number of **mitochondria** shows that the cell carries out a great deal of aerobic cellular respiration, producing large amounts of **ATP**; this points to energy-demanding work, such as a lot of movement or the active pumping of substances. The extensive **rough endoplasmic reticulum**, studded with ribosomes, shows that the cell makes large amounts of **protein**, especially protein to be exported from the cell; this points to a **secretory cell**, such as a gland cell that releases enzymes or hormones. Taken together, ∴ this cell is most likely specialised for energy-intensive protein secretion — for example, a gland cell that manufactures and secretes protein products and needs plentiful ATP to do so.

Practice questions

Scaffolded

Q1. Define each of the following terms: (a) organelle; (b) cytosol; (c) prokaryotic cell.

Q2. The nucleus controls a eukaryotic cell. (a) Name the molecule stored in the nucleus that carries the cell's genetic instructions. (b) Name the double membrane that surrounds the nucleus. (c) Name the structure inside the nucleus where ribosomes are made.

Q3. For each function below, name the organelle responsible: (a) the site of photosynthesis; (b) the site of protein synthesis; (c) modifies, sorts and packages molecules into vesicles.

Q4. Cells are described as prokaryotic or eukaryotic. (a) State the key difference between the two in terms of where the DNA is located. (b) State one difference in their typical size. (c) Give one example of an organism made of prokaryotic cells and one made of eukaryotic cells.

Q5. Plant cells and animal cells have some differences. (a) Name three structures found in a plant cell but not in a typical animal cell. (b) Name two structures found in both plant and animal cells. (c) State the function of the large central vacuole.

Q6. Mitochondria and chloroplasts are both energy-related organelles. (a) State the function of a mitochondrion. (b) State the function of a chloroplast. (c) State which of these two organelles is found in a typical animal cell.

Unscaffolded

Q7. Distinguish between prokaryotic and eukaryotic cells, referring to the nucleus and to membrane-bound organelles. *(2 marks)*

Q8. Describe the structure and function of the rough endoplasmic reticulum. *(2 marks)*

Q9. Most of the organelles of a eukaryotic cell are enclosed by their own membrane. Explain one advantage this gives the cell, using the lysosome as an example. *(2 marks)*

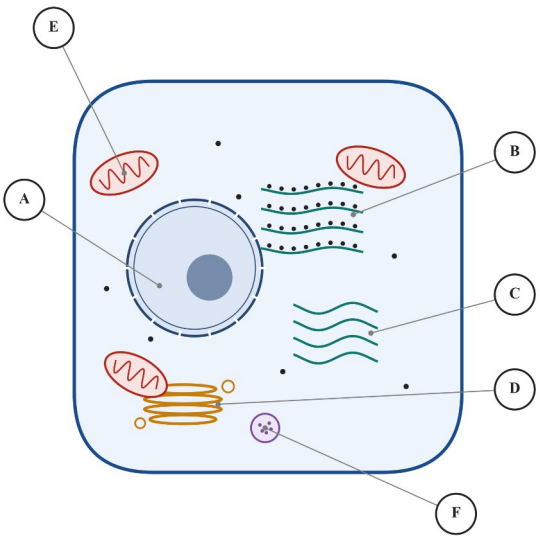
Q10. Explain the difference between the terms *cytoplasm* and *cytosol*. *(2 marks)*

Q11. For each of the following functions, identify the organelle responsible: (a) contains digestive enzymes that break down worn-out organelles and wastes; (b) makes lipids; (c) the site of aerobic cellular respiration; (d) controls the cell's activities and stores its DNA. *(4 marks)*

Q12. Organelles can be grouped according to the membrane that encloses them. (a) Name one organelle of a eukaryotic cell that is not enclosed by any membrane. (b) Name one organelle that is enclosed by a single membrane. (c) Name one organelle that is enclosed by two membranes. *(3 marks)*

Q13. *(Stimulus.)* The diagram below shows an animal cell as seen under an electron microscope, with six structures labelled A–F.

Cell Q — as seen under an electron microscope

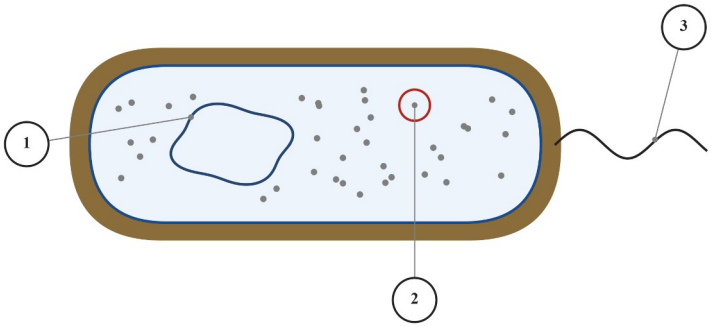


(a) Name the organelle labelled at each of A, B, C, D, E and F.

(b) Structures B and C are both networks of membranes. State one way you could tell them apart from the diagram. *(7 marks)*

Q14. *(Stimulus.)* The diagram shows a bacterial cell, Cell S, with three structures labelled 1, 2 and 3.

Cell S



(a) Name the structure labelled at each of 1, 2 and 3.

(b) State one difference between the DNA of Cell S and the DNA of a human cell, other than where in the cell the DNA is found. *(4 marks)*

Q15. Explain why a typical plant cell contains both chloroplasts and mitochondria, whereas a typical animal cell contains mitochondria but no chloroplasts. *(3 marks)*

Q16. A biologist compares a bacterial cell with a human cheek cell. (a) State two structures found in both cells. (b) State two structures found in the human cell but not in the bacterial cell. *(4 marks)*

Q17. Describe the function of the plasma membrane. *(2 marks)*

Q18. *(Stimulus — data.)* The table gives some features observed in three cells, X, Y and Z.

Feature	Cell X	Cell Y	Cell Z
Membrane-bound nucleus	present	absent	present
Cell wall	present	present	absent

Feature	Cell X	Cell Y	Cell Z
Chloroplasts	present	absent	absent
Large central vacuole	present	absent	absent
Approximate size	50 µm	2 µm	30 µm

(a) Identify each of Cell X, Cell Y and Cell Z as a plant cell, an animal cell or a prokaryotic cell.

(b) Cell X and Cell Y both have a cell wall. Explain why the presence of a cell wall on its own does not show that a cell is a plant cell. *(4 marks)*

Q19. Describe the internal structure of a chloroplast, and explain how that structure suits it to photosynthesis. *(2 marks)*

Q20. *(Synthesis.)* A biologist examines cells taken from a mould growing on damp bread. Every cell has a cell wall, a membrane-bound nucleus, mitochondria, ribosomes, an endoplasmic reticulum and a Golgi apparatus, but no chloroplasts. (a) State whether the organism is prokaryotic or eukaryotic, and justify your answer. (b) The biologist concludes that these cells are neither plant cells nor typical animal cells. State one feature from the list that rules out an animal cell, and one feature that rules out a plant cell. (c) Predict two processes these cells can carry out, and link each process to the organelle that performs it. *(6 marks)*

Answers

Q1. (a) A specialised structure within a cell that carries out a particular function (many are membrane-bound). (b) The watery, jelly-like fluid of the cytoplasm in which the organelles are suspended. (c) A cell with no membrane-bound nucleus and no membrane-bound organelles (e.g. a bacterium). **Q2.** (a) DNA. (b) The nuclear envelope. (c) The nucleolus. **Q3.** (a) Chloroplast. (b) Ribosome. (c) Golgi apparatus. **Q4.** (a) Prokaryotes have no membrane-bound nucleus (DNA free in the nucleoid); eukaryotes keep DNA in a membrane-bound nucleus. (b) Prokaryotes are smaller (about 1–10 μm) than eukaryotes (about 10–100 μm). (c) Prokaryotic — a bacterium; eukaryotic — a plant or an animal. **Q5.** (a) Cell wall, chloroplasts, large central vacuole. (b) Any two of: plasma membrane, nucleus, mitochondria, ribosomes, ER, Golgi apparatus. (c) Stores water and dissolved substances and keeps the cell firm (turgid). **Q6.** (a) The site of aerobic cellular respiration, producing ATP. (b) The site of photosynthesis, making glucose using light energy. (c) The mitochondrion. **Q7.** Prokaryotic cells have no membrane-bound nucleus and no membrane-bound organelles; eukaryotic cells have a membrane-bound nucleus and membrane-bound organelles. **Q8.** A network of membrane sacs studded with ribosomes; it makes (and folds) proteins, especially proteins for export or for membranes. **Q9.** The membrane keeps each organelle's contents separate from the cytosol, so many different processes can go on at once without interfering; a lysosome's membrane seals its digestive enzymes inside, so they break down only the material delivered to them and not the rest of the cell. **Q10.** Cytoplasm = everything inside the plasma membrane except the nucleus (organelles + fluid); cytosol = only the fluid part of the cytoplasm. **Q11.** (a) Lysosome. (b) Smooth endoplasmic reticulum. (c) Mitochondrion. (d) Nucleus. **Q12.** (a) Ribosome (the nucleolus is also unbounded). (b) Any one of: lysosome, vacuole, Golgi apparatus, endoplasmic reticulum. (c) Any one of: nucleus, mitochondrion, chloroplast. **Q13.** (a) A = nucleus, B = rough endoplasmic reticulum, C = smooth endoplasmic reticulum, D = Golgi apparatus, E = mitochondrion, F = lysosome. (b) B (rough ER) has ribosomes (dots) on its membranes; C (smooth ER) does not. **Q14.** (a) 1 = the nucleoid (the region holding the cell's circular chromosome; accept *circular chromosome* / *bacterial DNA*); 2 = a plasmid; 3 = the flagellum. (b) Cell S has a single circular chromosome, whereas a human cell has several linear chromosomes; accept also that Cell S carries plasmids (extra small loops of DNA) and a human cell does not. **Q15.** Plants photosynthesise (needing chloroplasts) and respire (needing mitochondria); animals do not photosynthesise, so they have no chloroplasts, but they respire, so they have mitochondria. **Q16.** (a) Any two of: plasma membrane, ribosomes, cytoplasm/cytosol, DNA. (b) Any two of: a membrane-bound nucleus, mitochondria, endoplasmic reticulum, Golgi apparatus. **Q17.** It forms the outer boundary of the cell and controls which substances enter and leave (it is selectively permeable). **Q18.** (a) Cell X = plant cell; Cell Y = prokaryotic cell; Cell Z = animal cell. (b) A cell wall is not unique to plants — prokaryotes such as Cell Y have one too — so chloroplasts, a large central vacuole and a membrane-bound nucleus are needed to identify a plant cell. **Q19.** Its membranes are stacked into grana that hold chlorophyll; the stacks give a large area of chlorophyll to absorb the light energy that drives photosynthesis. **Q20.** (a) Eukaryotic — the cells have a membrane-bound nucleus and membrane-bound organelles (mitochondria, ER, Golgi). (b) The cell wall rules out an animal cell; the absence of chloroplasts rules out a plant cell. (c) Any two, e.g. aerobic cellular respiration (mitochondria) and protein synthesis (ribosomes).

Fully-worked solutions

Q1. (a) An **organelle** is a specialised structure inside a cell that carries out a particular function; many organelles are surrounded by their own membrane. (b) The **cytosol** is the watery, jelly-like fluid of the cytoplasm in which the organelles are suspended and in which many of the cell's chemical reactions take place. (c) A **prokaryotic cell** is a cell that has **no membrane-bound nucleus** (its DNA lies free in the cytoplasm) and **no membrane-bound organelles** — for example, a bacterium.

Q2. (a) The molecule is **DNA** (deoxyribonucleic acid), which carries the cell's genetic instructions. (b) The double membrane around the nucleus is the **nuclear envelope**. (c) Ribosomes are made in the **nucleolus**, a dense region inside the nucleus.

Q3. (a) Photosynthesis occurs in the **chloroplast**. (b) Protein synthesis occurs at the **ribosome**. (c) The **Golgi apparatus** modifies, sorts and packages molecules into vesicles.

Q4. (a) In a **prokaryotic** cell the DNA lies **free in the cytoplasm** in a region called the nucleoid, with no surrounding membrane; in a **eukaryotic** cell the DNA is enclosed in a **membrane-bound nucleus**. (b) Prokaryotic cells are

smaller (about 1–10 μm) than eukaryotic cells (about 10–100 μm). (c) An organism made of prokaryotic cells is a **bacterium**; an organism made of eukaryotic cells is a **plant** (or an animal, fungus or protist).

Q5. (a) Three structures found in a plant cell but not a typical animal cell are the **cell wall**, **chloroplasts** and the **large central vacuole**. (b) Two structures found in both are any two of: the **plasma membrane**, the **nucleus**, **mitochondria**, **ribosomes**, the **endoplasmic reticulum** and the **Golgi apparatus**. (c) The large central vacuole **stores water and dissolved substances (and wastes) and keeps the cell firm (turgid)**, helping to support the plant.

Q6. (a) The **mitochondrion** is the site of **aerobic cellular respiration**, which releases energy from glucose as **ATP**. (b) The **chloroplast** is the site of **photosynthesis**, which uses **light energy** to make **glucose**. (c) Of the two, only the **mitochondrion** is found in a typical animal cell (animal cells do not have chloroplasts).

Q7. A **prokaryotic** cell has **no membrane-bound nucleus** — its DNA lies free in the cytoplasm in the nucleoid — and it has **no membrane-bound organelles**. A **eukaryotic** cell keeps its DNA inside a **membrane-bound nucleus** and contains many **membrane-bound organelles** (such as mitochondria, ER and the Golgi apparatus). *(1 mark: nucleus difference; 1 mark: membrane-bound organelles difference.)*

Q8. Structure: the rough endoplasmic reticulum is a **network of flattened membrane sacs** covered on its surface with **ribosomes** (which give it its rough appearance). **Function:** it **makes and folds proteins**, especially proteins that will be **secreted from the cell** or built into membranes. *(1 mark: membrane network with attached ribosomes; 1 mark: makes proteins.)*

Q9. Enclosing an organelle in its own membrane **separates that organelle's contents from the cytosol**, so the cell is divided into compartments and **many different processes can go on at the same time** without interfering with one another. The **lysosome** shows why this matters: it is filled with **digestive enzymes**, and its membrane keeps those enzymes sealed inside, so they break down only the worn-out organelles and wastes delivered to them — free in the cytosol, the same enzymes would digest the cell's own structures. *(1 mark: the membrane separates the contents from the rest of the cell / creates separate compartments; 1 mark: the lysosome example, enzymes kept away from the rest of the cell.)*

Q10. The **cytoplasm** is **everything inside the plasma membrane except the nucleus** — this includes all the organelles together with the fluid around them. The **cytosol** is **only the fluid part** of the cytoplasm — the watery solution in which the organelles are suspended. In other words, the cytosol is one component of the cytoplasm; the cytoplasm is the cytosol plus the organelles it contains. *(1 mark each for a correct meaning of the two terms.)*

Q11. (a) Digestive enzymes that break down worn-out organelles and wastes are contained in the **lysosome**. (b) Lipids are made by the **smooth endoplasmic reticulum**. (c) The site of aerobic cellular respiration is the **mitochondrion**. (d) The organelle that controls the cell's activities and stores its DNA is the **nucleus**. *(1 mark each.)*

Q12. (a) **Ribosomes** are not enclosed by a membrane — they are very small structures made of RNA and protein, sitting free in the cytosol or attached to the rough ER. (The nucleolus, a dense region inside the nucleus, is likewise not membrane-bound.) (b) Organelles bounded by a **single** membrane include the **lysosome**, the **vacuole**, the **Golgi apparatus** and the **endoplasmic reticulum**. (c) Organelles bounded by **two** membranes include the **nucleus** (its double membrane is the nuclear envelope), the **mitochondrion** and the **chloroplast**. *(1 mark each; any one correct organelle per part.)*

Q13. (a) The labelled structures are: **A = nucleus**, **B = rough endoplasmic reticulum**, **C = smooth endoplasmic reticulum**, **D = Golgi apparatus**, **E = mitochondrion**, **F = lysosome**. (b) B and C can be told apart because **B (rough ER) has ribosomes attached to its membranes** (shown as small dots), whereas **C (smooth ER) has no ribosomes** on its membranes. *(1 mark for each of the six organelles correctly named; 1 mark for the rough-vs-smooth distinction.)*

Q14. (a) From the diagram: **1 = the nucleoid** — the region of the cytoplasm that holds the cell's circular chromosome, with no membrane around it; **2 = a plasmid**, a small extra loop of DNA separate from the main chromosome; **3 = the flagellum**, the whip-like structure that drives the cell along. (b) Apart from where it lies, the DNA of Cell S is **a single circular chromosome**, whereas a human (eukaryotic) cell carries **several linear chromosomes**. A second acceptable difference is that Cell S also carries **plasmids** — small extra loops of DNA — which a human cell does not. *(1 mark each for the three structures, accepting "circular chromosome" or "bacterial DNA" for 1; 1 mark for one correct difference in the DNA itself — either circular/single versus linear/several, or the presence of plasmids.)*

Q15. A typical **plant cell** must be able to **photosynthesise**, which requires **chloroplasts**, and it must also **respire** to release usable energy, which requires **mitochondria** — so it has both. A typical **animal cell cannot photosynthesise**, so it has **no chloroplasts**, but it still needs to **respire**, so it does have **mitochondria**. In short, chloroplasts are only needed by cells that photosynthesise, whereas mitochondria are needed by almost every eukaryotic cell because all of them respire. *(1 mark: plants need chloroplasts for photosynthesis; 1 mark: both cell types respire, so both have mitochondria; 1 mark: animals do not photosynthesise, so lack chloroplasts.)*

Q16. (a) Two structures found in **both** a bacterial cell and a human cheek cell are any two of: the **plasma membrane**, **ribosomes**, **cytoplasm/cytosol**, and **DNA** (every cell has these). (b) Two structures found in the **human cell but not the bacterial cell** are any two of: a **membrane-bound nucleus**, **mitochondria**, the **endoplasmic reticulum**, and the **Golgi apparatus** — these are all features a eukaryotic cell has but a prokaryotic cell lacks. (Note the human cell also lacks a cell wall, which the bacterium has.) *(2 marks: two correct shared structures; 2 marks: two correct eukaryote-only structures.)*

Q17. The **plasma membrane** forms the **outer boundary of the cell**, separating the cell contents from the surroundings. Its function is to **control which substances enter and leave the cell** — it is **selectively permeable**, meaning it allows some substances through while keeping others out, and so it regulates the cell's internal environment. *(1 mark: boundary of the cell; 1 mark: controls entry/exit / selectively permeable.)*

Q18. (a) **Cell X = plant cell** (it has a membrane-bound nucleus, a cell wall, chloroplasts and a large central vacuole). **Cell Y = prokaryotic cell** (it has no membrane-bound nucleus and is very small). **Cell Z = animal cell** (it has a membrane-bound nucleus but no cell wall, no chloroplasts and no large central vacuole). (b) A **cell wall is not unique to plant cells**: Cell Y has one and yet it is prokaryotic, and fungi have cell walls too — a bacterial wall is not even made of cellulose, as a plant wall is. A cell wall on its own therefore shows only that the cell is **not** a typical animal cell. To identify Cell X as a plant cell you must use the features in the table that plants alone have — its **chloroplasts** and its **large central vacuole** — together with the **membrane-bound nucleus** that makes it eukaryotic. *(1 mark each for X, Y and Z; 1 mark for explaining that a cell wall is not restricted to plant cells and so cannot identify one on its own.)*

Q19. A chloroplast is bounded by a **double membrane**, and inside it a further system of membranes is **stacked into grana**. It is these internal membranes that carry the green pigment **chlorophyll**. Stacking packs a **large area of chlorophyll** into a small organelle, so the chloroplast can absorb a great deal of **light energy** — and it is that light energy which drives **photosynthesis**, the making of glucose. *(1 mark: internal membranes stacked into grana, carrying chlorophyll; 1 mark: the large area of chlorophyll absorbs the light energy that drives photosynthesis.)*

Q20. (a) The organism is **eukaryotic**, because every cell has a **membrane-bound nucleus** and several **membrane-bound organelles** (mitochondria, endoplasmic reticulum, Golgi apparatus) — a prokaryotic cell has neither, keeping its DNA free in the cytoplasm. (b) The **cell wall rules out a typical animal cell**, because animal cells have no cell wall at all. The **absence of chloroplasts rules out a plant cell**, because a typical plant cell contains chloroplasts for photosynthesis. (These cells are in fact fungal: fungi have cell walls but cannot photosynthesise.) (c) Two processes and their organelles: the cells can carry out **aerobic cellular respiration**, which takes place in the **mitochondria** (releasing energy from glucose as ATP); and they can carry out **protein synthesis**, which takes place at the **ribosomes** (joining amino acids into polypeptides). They cannot photosynthesise, having no chloroplasts. ∴ this is a walled, non-photosynthetic eukaryotic organism that is neither a plant nor an animal. *(a: 2 marks — eukaryotic, justified by the nucleus/membrane-bound organelles; b: 2 marks — one feature ruling out an animal cell, one ruling out a plant cell; c: 2 marks — two processes each correctly linked to its organelle.)*

Chapter 1 Assumed knowledge: cells, membranes and transport — 1C Membrane transport

Theory

Assumed knowledge — Units 1 & 2 background, foundational for Units 3 & 4.

Every cell is surrounded by a **plasma (cell) membrane** built from a **phospholipid bilayer** — a double layer of phospholipid molecules with their water-attracting (hydrophilic) heads facing the watery fluid on each side and their water-repelling (hydrophobic) fatty-acid tails packed together in the oily middle. This oily core is what makes the membrane **selectively permeable** (also called partially permeable): it lets some substances cross easily while holding others back. Whether a substance can cross the membrane, and how, depends on its **size**, its **electrical charge**, and whether it is **polar** (water-loving) or **non-polar** (fat-loving).

Two questions decide how any substance crosses the membrane. **First, which way does it move?** A substance moving **down** its concentration gradient — from where it is more concentrated to where it is less concentrated — needs no energy from the cell; this is **passive transport**. A substance moving **against** its gradient — from low to high concentration — needs an input of energy (as **ATP**); this is **active transport**. **Second, can it get through the bilayer on its own?** Small non-polar molecules can slip directly between the phospholipids, but ions and large polar molecules need a **transport protein** to ferry them across.

Diffusion and the concentration gradient. Particles in a liquid or gas are always moving randomly. **Diffusion** is the **net movement of particles from a region of high concentration to a region of low concentration** — down the concentration gradient — until they are evenly spread. Once evenly spread the particles keep moving, but there is no *net* movement in either direction: the system is at **dynamic equilibrium**. Diffusion is passive, driven by the random motion of the particles themselves, so it needs no energy from the cell. The **steeper the concentration gradient** — the bigger the difference between the two sides — the **faster the net rate of diffusion**.

1. Simple diffusion. In **simple diffusion** a substance passes **directly through the phospholipid bilayer**, between and through the phospholipid molecules, with no help from a protein. Only substances that dissolve in the oily core can do this: **small, non-polar (lipid-soluble) molecules** such as oxygen (O2) and carbon dioxide (CO2), and a few small uncharged molecules. They move down their concentration gradient — for example, oxygen diffuses from the blood (high O2) into a respiring cell (low O2), while carbon dioxide diffuses the other way.

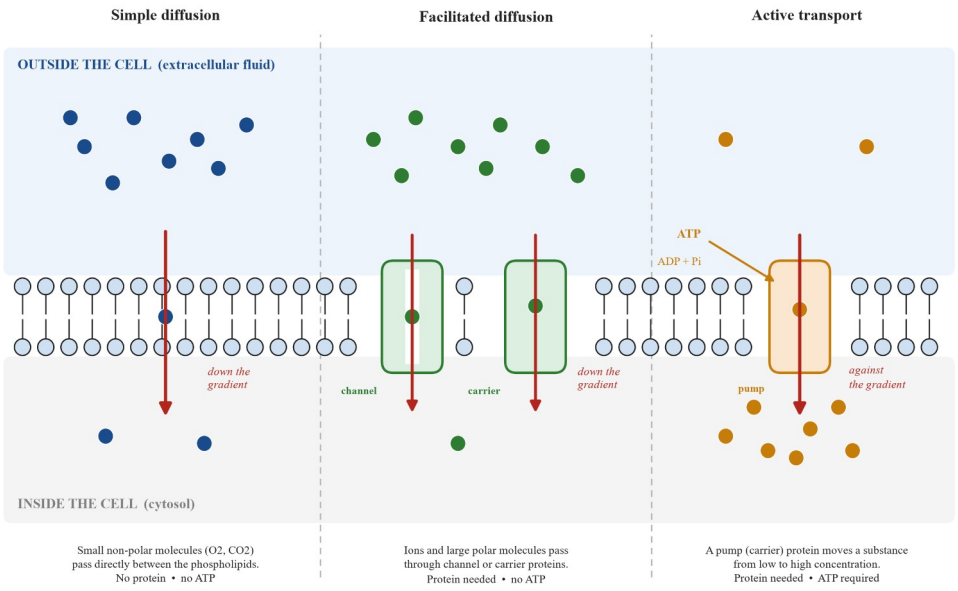
2. Facilitated diffusion. Many vital substances — **ions** (such as sodium, potassium and chloride) and **large or polar molecules** (such as glucose and amino acids) — are repelled by the hydrophobic core and cannot cross the bilayer alone. They cross by **facilitated diffusion**: still passive (down the gradient, no ATP), but with the help of a **transport protein** spanning the membrane. There are two kinds:

- **Channel proteins** form a water-filled pore through the membrane. Ions and water molecules pass straight through, but only if they match the **size and charge** of the pore — anything else is excluded, so each channel is specific to a few kinds of particle. Some channels are "gated" and open or close in response to a signal.
- **Carrier proteins** bind the specific substance on one side, change shape, and release it on the other side. Each carrier is specific to the substance it moves (a glucose carrier moves only glucose, for example).

Because facilitated diffusion moves substances **down** their gradient, it needs **no ATP** — the protein simply provides a route across the membrane. A membrane holds only a **limited number** of each transport protein, so as the outside concentration rises more and more of them are in use, until every one is working at full capacity; beyond that point the rate of facilitated diffusion **levels off** and cannot rise further. Simple diffusion has no such limit, because the substance passes through the bilayer itself.

3. Osmosis. Osmosis is a special case of diffusion that applies to **water**. It is the **net movement of water molecules across a selectively permeable membrane, from a region of higher free-water concentration (a dilute, low-solute solution) to a region of lower free-water concentration (a concentrated, high-solute solution)** — that is, **down the water potential gradient**. Adding solute lowers the water potential of a solution, so water always moves by osmosis **towards the more concentrated solution** until the concentrations balance or another force stops it. Osmosis is passive; water crosses partly through the bilayer and mostly through special water-channel proteins.

4. Active transport. Sometimes a cell must move a substance **against its concentration gradient** — from where it is less concentrated to where it is more concentrated — for example, a root hair cell absorbing mineral ions from very dilute soil water, or a nerve cell pumping sodium out and potassium in. This is **active transport**. Because it works "uphill" against the gradient, it **requires energy** supplied by **ATP**, and it uses a specific **carrier protein** (often called a **pump**). The pump binds the substance, and energy released from ATP changes the pump's shape so that the substance is carried across and released on the high-concentration side. If a cell's ATP supply is cut off (for instance, by a lack of oxygen or a metabolic poison), active transport stops — but passive transport continues, because it does not depend on the cell's energy.



5. Bulk transport. Some materials are far too large to cross the membrane or fit through a transport protein — whole bacteria, cell debris, or large amounts of fluid and dissolved material. These are moved in bulk, wrapped in a piece of membrane called a **vesicle**. Bulk transport always **requires ATP**.

- **Endocytosis** brings material **into** the cell. A region of the plasma membrane folds inwards around the material and pinches off to form a vesicle inside the cell. There are two types:
    - **Phagocytosis** ("cell eating") — the cell engulfs a **large solid particle** (such as a bacterium or a piece of debris) in a large vesicle. White blood cells use phagocytosis to destroy pathogens.
    - **Pinocytosis** ("cell drinking") — the cell takes in **extracellular fluid and its dissolved solutes** in small vesicles.
- **Exocytosis** moves material **out of** the cell. A vesicle inside the cell — often carrying a product such as an enzyme, a hormone or a neurotransmitter, or a waste — moves to the plasma membrane, **fuses** with it, and releases its contents outside the cell. Exocytosis is how cells **secrete** substances.

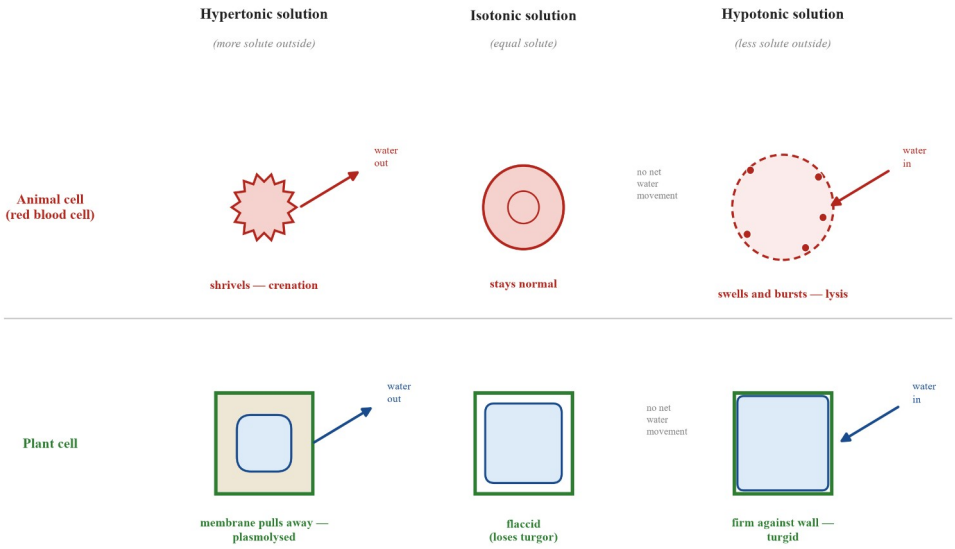
Tonicity — the effect of a solution on a cell. Because a cell is wrapped in a selectively permeable membrane, the concentration of the surrounding solution decides which way water moves by osmosis, and therefore whether the cell swells, shrinks or stays the same. **Tonicity** describes the solute concentration of a solution **compared with the inside of the cell**:

- A **hypertonic** solution has a **higher** solute concentration than the cell (a lower water potential), so water moves **out** of the cell.
- A **hypotonic** solution has a **lower** solute concentration than the cell (a higher water potential), so water moves **into** the cell.
- An **isotonic** solution has the **same** solute concentration as the cell, so there is **no net movement** of water (water enters and leaves at equal rates).

The consequences differ for animal and plant cells, because a **plant cell has a strong cell wall** outside its membrane while an **animal cell does not**:

Solution	Animal cell (e.g. red blood cell)	Plant cell
Hypertonic (water leaves)	Shrinks and shrivels — **crenation**	Membrane pulls away from the cell wall — **plasmolysis**; the cell is flaccid
Isotonic (no net movement)	Stays normal	**Flaccid** (soft; the cell has lost turgor)
Hypotonic (water enters)	Swells and bursts — **lysis**	Swells; the cell wall resists, building up pressure — the cell becomes **turgid** (firm)

An animal cell in a hypotonic solution keeps taking in water until it **bursts (lysis)**, because nothing resists the swelling. A plant cell in the same solution also takes in water, but its rigid **cell wall** pushes back, creating **turgor pressure** that stops the cell bursting and keeps the plant firm and upright. This is why healthy plant cells are usually in a slightly hypotonic environment and are turgid.



Worked examples

Example 1 — scaffolded

Carbon dioxide is made inside a respiring muscle cell and passes out into the blood, where its concentration is lower. Name the type of membrane transport involved and justify your answer in terms of the gradient, the molecule, and energy.

Working	Comment
CO_2 moves from a high concentration (inside the cell) to a low concentration (in the blood) — **down its concentration gradient**.	Establish the direction first: down-gradient means the process is passive.
CO_2 is a **small, non-polar molecule**, so it can dissolve in and pass **directly through the phospholipid bilayer**, with no transport protein.	Link the molecule's size and polarity to whether a protein is needed.
Moving down the gradient releases energy, so **no ATP** is used from the cell.	Passive transport never uses the cell's ATP.
The transport is **simple diffusion**.	State the specific mode, not just "passive".

Example 2 — scaffolded

A red blood cell is placed in a concentrated salt solution that is hypertonic to the cell's contents. Predict the direction of net water movement and the effect on the cell, and explain your reasoning.

Working	Comment
The solution is **hypertonic** — it has a higher solute concentration (lower water potential) than the inside of the cell.	Compare solute concentrations to find the water-potential gradient.
Water moves by **osmosis** from the higher free-water region (inside the cell) to the lower free-water region (the solution), so water moves **out of the cell**.	Water moves down the water-potential gradient, towards the more concentrated solution.
Losing water, the red blood cell **shrinks and shrivels**.	Give the outcome for an animal cell.
This shrivelling of an animal cell is called **crenation**.	Use the correct term; an animal cell has no wall to hold its shape.

Example 3 — unscaffolded

A cell lining an airway moves chloride ions out of its cytosol into the thin layer of fluid on its surface through a chloride channel protein. Chloride is more concentrated inside the cell than in the surface fluid, and the channel will not pass glucose molecules or sodium ions. Name the type of transport involved, and explain why the ions need the channel and why the channel moves only chloride.

The chloride ions move from the cytosol, where they are more concentrated, to the surface fluid, where they are less concentrated — **down their concentration gradient** — so the movement is **passive** and uses **no ATP**. A chloride ion is **charged (hydrophilic)**, so it is repelled by the hydrophobic fatty-acid tails in the middle of the bilayer and cannot slip between the phospholipids on its own; it needs a **transport protein**. A **channel protein** solves this by forming a **water-filled pore** through the membrane, giving the ion a hydrophilic route from one side to the other. The channel is also **specific**: only particles that match the **size and charge** of its pore can pass, so a much larger, uncharged glucose molecule and a differently sized, positively charged sodium ion are both excluded. ∴ the chloride leaves by **facilitated diffusion** through a specific channel protein, driven by the concentration gradient and needing no energy from the cell.

Example 4 — unscaffolded

A cell in the pancreas makes the protein-digesting enzyme trypsin and releases it into a duct outside the cell. Trypsin is a large protein and cannot pass through the membrane or a transport protein. Describe how the cell releases the enzyme.

The enzyme is released by **exocytosis**, a form of bulk transport used for large materials. Inside the cell, the trypsin is packaged into a membrane-bound **vesicle**. The vesicle moves to the **plasma membrane** and **fuses** with it; as the vesicle membrane joins the plasma membrane, the trypsin is released into the fluid **outside the cell**. Because the vesicle must be moved to the membrane and made to fuse with it, the process **requires ATP**. ∴ the large enzyme leaves the cell by exocytosis — a vesicle fuses with the plasma membrane and empties its contents outside.

Practice questions

Scaffolded

Q1. Define each of the following terms: (a) diffusion; (b) osmosis; (c) active transport.

Q2. Two types of passive transport move substances across a membrane. (a) State whether passive transport requires energy (ATP) from the cell. (b) Explain why oxygen can cross the membrane by simple diffusion but glucose cannot. (c) State the direction of movement (relative to the concentration gradient) in all passive transport.

Q3. Facilitated diffusion uses transport proteins. (a) Name the two types of transport protein involved in facilitated diffusion. (b) Describe how a carrier protein moves a molecule across the membrane. (c) State one substance that crosses the membrane through a channel protein.

Q4. Active transport moves substances across the membrane. (a) State the direction of movement relative to the concentration gradient. (b) Name the molecule that supplies the energy for active transport. (c) Give one example of a substance moved by active transport, in a named type of cell.

Q5. The tonicity of a solution affects the movement of water into and out of a cell. (a) Define the term hypertonic. (b) State what happens to a red blood cell placed in a hypotonic solution. (c) State what happens to a plant cell placed in a hypotonic solution.

Q6. Large materials are moved across the membrane by bulk transport. (a) Distinguish between endocytosis and exocytosis in terms of the direction of movement. (b) Distinguish between phagocytosis and pinocytosis. (c) State whether bulk transport requires energy.

Unscaffolded

Q7. For each of the following, name the type of membrane transport and justify your choice by referring to the concentration gradient and whether energy is needed: (a) oxygen entering a red blood cell in the lungs; (b) glucose entering a cell down its concentration gradient through a membrane protein; (c) calcium ions being moved out of a muscle cell into a region where calcium is already more concentrated. *(6 marks)*

Q8. Oxygen enters a muscle cell from the blood by simple diffusion. (a) State what determines the rate at which oxygen diffuses into the cell. (b) Explain the effect on this rate of an increase in the oxygen concentration of the blood. (c) Explain the effect on this rate of the muscle cell starting to respire more rapidly. *(3 marks)*

Q9. Both facilitated diffusion and active transport can use carrier proteins to move substances across a membrane. Explain **two** differences between them. *(4 marks)*

Q10. *(Data interpretation.)* Substances R and S both enter the same cell without using ATP. The rate of uptake of each was measured at four different external concentrations.

External concentration (mmol/L)	Uptake of R (relative units)	Uptake of S (relative units)
1	4	12
2	8	22
4	16	30
8	32	30

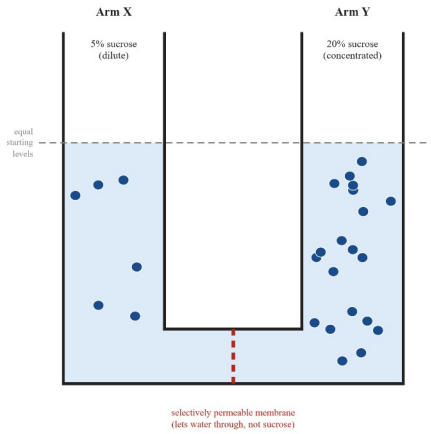
(a) State which substance crosses the membrane through a transport protein, and justify your answer using the data.

(b) Explain why the rate of uptake of that substance stops rising. *(3 marks)*

Q11. A red blood cell is placed in distilled (pure) water. A plant cell is placed in a solution that is isotonic to its cytosol. (a) Predict and explain what happens to the red blood cell. (b) Predict and explain what happens to the plant cell, and name the condition it is left in. (c) Name the process by which water crosses the membrane in each case. *(4 marks)*

Q12. A plant cell is placed in a strongly hypertonic solution. (a) Predict what happens to the cell, and name this condition. (b) Explain, in terms of water movement, why it happens. (c) A plant cell and an animal cell are both placed in a hypotonic solution. Explain why the plant cell does not burst but the animal cell may. *(5 marks)*

Q13. *(Stimulus.)* The diagram shows a U-tube with a selectively permeable membrane at its base that lets water through but not sucrose. Arm X contains 5% sucrose and arm Y contains 20% sucrose. The liquid starts at the same level in both arms.



(a) State the direction of net water movement across the membrane.
(b) Predict which arm's liquid level rises, and explain why in terms of osmosis.
(c) Explain what happens to the sucrose concentrations in the two arms as the process continues. *(4 marks)*

Q14. *(Data interpretation.)* Identical cylinders of potato were weighed, placed in sucrose solutions of different concentration for two hours, then reweighed. The table shows the percentage change in mass.

Sucrose concentration (M)	Change in mass (%)
0.0	+14
0.2	+6
0.3	0
0.4	−7
0.6	−16

(a) Explain why the cylinders in 0.0 M and 0.2 M sucrose gained mass.
(b) Explain why the cylinders in 0.4 M and 0.6 M sucrose lost mass.
(c) Estimate the sucrose concentration that is isotonic to the potato cells, and justify your answer using the data. *(4 marks)*

Q15. *(Stimulus.)* A macrophage (a type of white blood cell) detects a bacterium in the tissue fluid. The macrophage flows around the bacterium, encloses it in a large vesicle drawn into the cell, and later destroys it. (a) Name the type of transport the macrophage uses to take in the bacterium, and the specific term for engulfing a large solid particle. (b) Describe how the bacterium is brought into the cell. (c) Explain why this process requires ATP. *(4 marks)*

Q16. *(Stimulus / data.)* A gland cell secretes a hormone by packaging it into vesicles that fuse with the plasma membrane. In an experiment, a drug that blocks ATP production was added to the cells. The results were:

Condition	Hormone secreted (units/hour)
Normal cells	48
Cells + ATP-blocking drug	5

(a) Name the process by which the hormone is released from the cell.
(b) Suggest why a small amount of hormone was still secreted by the cells treated with the drug.
(c) Using the data, explain the effect of the ATP-blocking drug and what it shows about the process. *(4 marks)*

Q17. A U-tube divided by an artificial selectively permeable membrane, like the one in Question 13, is often used as a model of osmosis across a cell membrane. Explain one way in which the model represents osmosis in a living cell well, and one way in which it is misleading. *(3 marks)*

Q18. *(Data interpretation.)* A cell takes up two substances, P and Q. The rate of uptake of each was measured at normal oxygen levels and again after a poison stopped the cell making ATP.

Substance	Uptake, normal (relative units)	Uptake, no ATP (relative units)
P	20	20
Q	18	2

(a) State which substance is moved by active transport, and justify your answer using the data.

(b) State which substance is moved by a passive process, and justify your answer.

(c) Explain why stopping ATP production affects the two substances differently. *(4 marks)*

Q19. *(Synthesis.)* A root hair cell absorbs both water and mineral ions from the soil. The soil water is more dilute (has less solute) than the cytosol of the root hair cell, but individual mineral ions such as nitrate are more concentrated inside the cell than in the soil. (a) Explain how water enters the root hair cell, and name the process. (b) Explain how nitrate ions are absorbed, and why the cell must use ATP to do this. (c) Root hair cells are long and narrow, so each cell has a large surface area in contact with the soil water. Explain how this shape helps the cell absorb water and mineral ions. (d) After a paddock is over-fertilised, the soil water becomes hypertonic to the root hair cells. Predict and explain the effect on the root hair cells. *(8 marks)*

Answers

Q1. (a) The net movement of particles from a high to a low concentration (down the gradient) until evenly spread. (b) The net movement of water across a selectively permeable membrane from a dilute (high free-water) to a concentrated (low free-water) region, down the water-potential gradient. (c) The movement of a substance against its concentration gradient, using a carrier protein and energy from ATP. **Q2.** (a) No. (b) Oxygen is small and non-polar, so it crosses the bilayer directly; glucose is large and polar, so it cannot cross the oily core and needs a carrier protein. (c) Down the gradient (high → low). **Q3.** (a) Channel proteins and carrier proteins. (b) It binds the molecule on one side, changes shape, and releases it on the other side. (c) Any suitable ion (e.g. sodium, potassium or chloride) — or water. **Q4.** (a) Against the gradient (low → high). (b) ATP. (c) e.g. nitrate/potassium ions into a root hair cell, or sodium and potassium by the pump in a nerve cell. **Q5.** (a) A solution with a higher solute concentration than the cell. (b) It swells and bursts (lysis). (c) It swells and becomes turgid (the cell wall stops it bursting). **Q6.** (a) Endocytosis brings material into the cell; exocytosis moves material out. (b) Phagocytosis engulfs a large solid particle; pinocytosis takes in fluid and dissolved solutes. (c) Yes. **Q7.** (a) Simple diffusion — O2 moves down its gradient, is small and non-polar, no ATP. (b) Facilitated diffusion — glucose moves down its gradient through a protein, no ATP. (c) Active transport — calcium moves against its gradient, so ATP is needed. **Q8.** (a) The steepness of the concentration gradient across the membrane. (b) The gradient becomes steeper, so oxygen diffuses in faster. (c) Respiration uses oxygen inside the cell, lowering the internal concentration and steepening the gradient, so oxygen diffuses in faster. **Q9.** (1) Energy — facilitated diffusion uses no ATP, active transport uses ATP. (2) Direction — facilitated diffusion moves substances down the gradient, active transport against it. **Q10.** (a) S — its uptake levels off at 30 units above 4 mmol/L, while R's keeps rising in proportion to the concentration. (b) The membrane holds a limited number of transport proteins; once they are all working at full capacity (saturated), raising the concentration cannot raise the rate. **Q11.** (a) Water enters (pure water is hypotonic to the cell) and the cell swells and bursts — lysis. (b) There is no net movement of water, so no turgor pressure builds up against the wall and the cell stays soft — flaccid. (c) Osmosis (in the isotonic solution water still crosses both ways, but at equal rates). **Q12.** (a) The cell loses water and the membrane pulls away from the wall — plasmolysis. (b) The solution is hypertonic (lower water potential), so water leaves the cell by osmosis. (c) The plant's rigid cell wall resists the swelling and stops the cell bursting; the animal cell has no wall, so it bursts. **Q13.** (a) From arm X to arm Y. (b) Arm Y's level rises, because water moves by osmosis into the more concentrated (20%) solution. (c) Arm X becomes more concentrated and arm Y becomes more dilute, so the two concentrations move closer together and the net movement slows. **Q14.** (a) 0.0 M and 0.2 M are hypotonic to the cells, so water entered by osmosis and the mass rose. (b) 0.4 M and 0.6 M are hypertonic, so water left by osmosis and the mass fell. (c) About 0.3 M — the mass change is 0, so there was no net water movement (isotonic). **Q15.** (a) Endocytosis; phagocytosis. (b) The membrane flows around and encloses the bacterium, pinching off a vesicle inside the cell. (c) ATP is needed to move the membrane and form the vesicle. **Q16.** (a) Exocytosis. (b) Vesicles that had already reached the membrane when the drug acted could still fuse and release their hormone (and the ATP already in the cell was not used up instantly). (c) Secretion fell from 48 to 5 units/h; without ATP, exocytosis nearly stops, showing it requires ATP. **Q17.** Good: a partially permeable barrier separates a dilute from a concentrated solution and water moves passively down the water-potential gradient, as it does across a plasma membrane. Misleading: the artificial membrane holds no transport proteins, so it cannot show water channels, facilitated diffusion or active transport, and the closed tube can only raise a liquid level, not swell, burst or plasmolyse as a cell does. **Q18.** (a) Q — its uptake collapsed (18 → 2) when ATP was blocked, so it needs ATP (active transport). (b) P — its uptake was unchanged (20 → 20) without ATP, so it is passive. (c) Active transport needs ATP, so Q's uptake falls; passive transport does not use ATP, so P's uptake is unaffected. **Q19.** (a) Osmosis — water moves from the dilute soil (higher water potential) into the cytosol (lower water potential). (b) By active transport using a pump (carrier) protein; ATP is needed because the ions move against their gradient (dilute soil → concentrated cell). (c) The large membrane surface area in contact with the soil gives more area for osmosis and more transport proteins for ion uptake, so absorption is faster. (d) Water leaves the cells by osmosis (the soil is now hypertonic); the cells lose turgor and may plasmolyse, and the plant wilts.

Fully-worked solutions

Q1. (a) **Diffusion** is the **net movement of particles from a region of high concentration to a region of low concentration** (down the concentration gradient) until they are evenly spread; it is passive and needs no energy. (b) **Osmosis** is the **net movement of water molecules across a selectively permeable membrane from a region of higher free-water concentration (dilute) to a region of lower free-water concentration (concentrated)** — down

the water-potential gradient. (c) **Active transport** is the movement of a substance **against its concentration gradient** (from low to high concentration), using a **carrier (pump) protein** and **energy from ATP**.

Q2. (a) **No** — passive transport does not require any ATP from the cell. (b) **Oxygen** is a **small, non-polar molecule**, so it can dissolve in the oily core of the bilayer and pass **directly through** it. **Glucose** is a **large, polar molecule**, so it is repelled by the hydrophobic core and cannot cross on its own; it needs a **carrier protein** (facilitated diffusion). (c) In all passive transport, substances move **down the concentration gradient** — from high to low concentration.

Q3. (a) **Channel proteins** and **carrier proteins**. (b) A **carrier protein binds** the specific molecule on one side of the membrane, then **changes shape**, moving the molecule across and **releasing it on the other side**; it then returns to its original shape. (c) Any ion that fits a channel, for example **sodium, potassium or chloride ions** (water also crosses through water channels).

Q4. (a) **Against the concentration gradient** — from low to high concentration. (b) **ATP**. (c) Any valid example, e.g. **nitrate or potassium ions actively absorbed into a root hair cell**, or **sodium and potassium moved by the pump protein in a nerve cell**.

Q5. (a) A **hypertonic** solution has a **higher solute concentration than the cell** (a lower water potential), so water moves out of the cell. (b) In a **hypotonic** solution water moves **into** the red blood cell, which **swells and bursts — lysis** (there is no wall to resist it). (c) In a hypotonic solution water moves **into** the plant cell, which swells until the **cell wall resists** and the cell becomes **turgid** (firm); it does not burst.

Q6. (a) **Endocytosis** moves material **into** the cell (the membrane folds in to form a vesicle); **exocytosis** moves material **out of** the cell (a vesicle fuses with the membrane and releases its contents). (b) **Phagocytosis** is the engulfing of a **large solid particle** (such as a bacterium) in a large vesicle; **pinocytosis** is the taking in of **extracellular fluid and dissolved solutes** in small vesicles. (c) **Yes** — bulk transport (both endocytosis and exocytosis) requires **ATP**.

Q7. (a) **Simple diffusion.** Oxygen moves from a high concentration in the lungs to a low concentration in the red blood cell — **down its gradient** — and, being **small and non-polar**, it crosses the bilayer directly; **no ATP** is used. (b) **Facilitated diffusion.** Glucose moves **down its concentration gradient**, but because it is **large and polar** it must pass through a **transport (carrier) protein**; it is still passive, so **no ATP** is used. (c) **Active transport.** The calcium ions move **against their concentration gradient** (into a region where calcium is already more concentrated), which cannot occur by diffusion, so a **pump protein and ATP** are required. *(2 marks each: correct mode + a justification that names the gradient direction and the energy requirement.)*

Q8. (a) The rate of simple diffusion is set by the **steepness of the concentration gradient** across the membrane — that is, by how much higher the oxygen concentration is in the blood than in the cytosol. (b) Raising the oxygen concentration of the blood makes that difference **larger**, so the gradient is **steeper** and oxygen **diffuses into the cell faster**. (c) A muscle cell that respires more rapidly **uses up oxygen inside the cell**, which **lowers the internal concentration**; the difference across the membrane is again **larger**, so the gradient steepens and oxygen **enters faster**. (The diffusion itself is still passive — a steeper gradient simply makes the random movement of the particles produce a larger net inward flow.) *(1 mark each for a, b and c.)*

Q9. First difference — energy. Facilitated diffusion is **passive** and uses **no ATP**, whereas active transport uses **ATP** to power the carrier. **Second difference — direction.** Facilitated diffusion moves substances **down** the concentration gradient (from high to low), whereas active transport moves them **against** the gradient (from low to high). (Both are similar in using a specific protein, but these two features set them apart.) *(2 marks per difference: the feature named for both processes — a one-sided answer is capped.)*

Q10. (a) **Substance S** crosses through a **transport protein**. The uptake of **R** is **directly proportional** to the external concentration (4, 8, 16 and 32 units as the concentration rises 1 → 2 → 4 → 8 mmol/L), which is what happens when a substance passes straight through the bilayer. The uptake of **S** rises at first but then **levels off at 30 units**: it is the same at 8 mmol/L as at 4 mmol/L even though the concentration has doubled. (b) A membrane contains only a **limited number** of the transport protein that carries S. As the outside concentration rises, **more and more of those proteins are occupied**, and once **every one is working at full capacity (saturated)** no further rise in concentration can increase the rate, so the uptake of S **plateaus**. R has no such ceiling because it does not depend on a protein. *(1 mark: S identified and justified from the levelling-off in the data; 2 marks: a limited number of transport proteins, all saturated, so the rate cannot rise further.)*

Q11. (a) Distilled water is **hypotonic** to the red blood cell (the cytosol holds far more solute), so water moves **into** the cell by osmosis, down the water-potential gradient. The cell **swells and bursts — lysis** — because an animal cell has no wall to resist the swelling. (b) The solution is **isotonic**: it has the **same solute concentration** as the cytosol, so the water potentials on the two sides are equal and there is **no net movement of water**. The plant cell therefore gains no extra water, no **turgor pressure** builds up against the cell wall, and the cell is left **flaccid** (soft rather than firm). (c) In both cases water crosses the membrane by **osmosis**; in the isotonic solution water molecules still cross in **both directions**, but at **equal rates**, so there is no net change. *(1 mark: water enters and the red blood cell lyses; 1 mark: equal water potentials, so no net water movement; 1 mark: flaccid named; 1 mark: osmosis, water still crossing both ways in the isotonic case.)*

Q12. (a) Water moves **out** of the cell and the membrane **pulls away from the cell wall** — the cell is **plasmolysed** (plasmolysis). (b) The solution is **hypertonic** — it has a higher solute concentration (lower water potential) than the cell — so water moves **out of the cell by osmosis**, down the water-potential gradient; as the cytoplasm and vacuole lose water and shrink, the membrane is pulled inwards away from the rigid wall. (c) In a hypotonic solution both cells take in water and swell. The **plant cell has a strong, rigid cell wall**: as it swells, the wall pushes back and builds up **turgor pressure**, which stops any more water entering and prevents bursting. The **animal cell has no wall**, so nothing resists the swelling and it keeps taking in water until it **bursts (lysis)**. *(a: 1 mark; b: 2 marks — hypertonic/water out by osmosis + membrane pulls off wall; c: 2 marks — plant wall resists / turgor vs no wall in animal cell.)*

Q13. (a) Net water moves **from arm X to arm Y** (from the dilute side to the concentrated side). (b) The level in **arm Y rises** (and the level in arm X falls). Arm Y's 20% sucrose is **more concentrated** (lower water potential) than arm X's 5% sucrose, so water moves by **osmosis through the membrane into arm Y**; because the sucrose cannot cross the membrane, the extra water raises the level in arm Y. (c) As water leaves arm X, the sucrose there becomes **more concentrated**; as water enters arm Y, its sucrose becomes **more dilute**. The two concentrations therefore move **closer together**, so the water-potential difference shrinks and the net movement **slows down**. *(1 mark: X → Y; 1 mark: Y rises; 1 mark: osmosis into the more concentrated solution; 1 mark: concentrations converge / movement slows.)*

Q14. (a) In 0.0 M and 0.2 M sucrose the external solution is **hypotonic** to the potato cells (it has less solute than the cells), so water moved **into** the cells by osmosis and the cylinders **gained mass**. (b) In 0.4 M and 0.6 M sucrose the external solution is **hypertonic** (more solute than the cells), so water moved **out** of the cells by osmosis and the cylinders **lost mass**. (c) The isotonic concentration is about **0.3 M**, because at 0.3 M the change in mass is **0** — there was **no net movement of water**, which means the external solution had the **same solute concentration as the cells**. *(1 mark each for a and b with the osmosis reasoning; 2 marks: 0.3 M identified and justified by the zero mass change.)*

Q15. (a) The macrophage uses **endocytosis**; the specific term for engulfing a large solid particle is **phagocytosis**. (b) The macrophage's **plasma membrane flows around and encloses** the bacterium; the membrane then **pinches off** to form a large **vesicle** containing the bacterium **inside** the cell. (c) The process **requires ATP** because the cell must actively **move the membrane and cytoskeleton** to wrap around the bacterium and form the vesicle — this is active work by the cell, not a passive down-gradient movement. *(1 mark: endocytosis + phagocytosis; 2 marks: membrane surrounds and encloses the particle in a vesicle; 1 mark: ATP needed because the cell does work to move the membrane.)*

Q16. (a) The hormone is released by **exocytosis**. (b) A small amount is still released because the **vesicles that had already reached the plasma membrane** when the drug took effect can still **fuse** with it and empty their contents, and the **ATP already present in the cell** is not used up the instant the drug is added. (c) With the ATP-blocking drug, secretion **fell sharply from 48 to 5 units/hour** — a fall of about 90%. This shows that exocytosis **depends on ATP**: without ATP the cell cannot move the vesicles to the membrane or make them fuse, so almost no hormone is released. *(1 mark: exocytosis; 1 mark: vesicles already at the membrane / ATP already in the cell; 2 marks: uses the data (48 → 5) to conclude exocytosis requires ATP.)*

Q17. What the model represents well: in the U-tube an **artificial selectively permeable membrane** separates a **dilute** solution from a **concentrated** one, and water moves **across it towards the concentrated side** — down the water-potential gradient, passively and with no energy input — while the solute cannot follow. That is exactly the movement that occurs across a plasma membrane, so the model shows both the **direction** and the **driving force** of osmosis correctly. **What is misleading:** the artificial membrane is an **inert filter with no proteins in it**, whereas a plasma membrane is studded with **water channels** that make osmosis much faster and with **carrier and pump proteins** that also move solutes by facilitated diffusion and active transport — so a living cell can change the

concentrations on either side, while the U-tube cannot. The U-tube is also a **closed two-compartment system** whose only response is a **rising column of liquid**, whereas a cell is bounded by a flexible membrane (and, in plants, a cell wall) and responds by **swelling, bursting or plasmolysing**. *(1 mark: a valid strength — passive water movement down the gradient across a partially permeable barrier; 2 marks: a valid limitation, developed — no transport proteins / not a living, changing system.)*

Q18. (a) **Substance Q** is moved by **active transport**. When ATP production was stopped, Q's uptake **fell from 18 to 2** — an almost complete stop — which shows its uptake **depends on ATP**, the hallmark of active transport. (b) **Substance P** is moved by a **passive process**. Its uptake was **unchanged (20 → 20)** when ATP was blocked, so it does **not depend on the cell's energy** and must be moving **down its gradient**. (c) **Active transport requires ATP** to power its pump protein, so blocking ATP stops Q's uptake; a **passive process does not use ATP**, so blocking ATP has **no effect** on P. *(1 mark: Q active with data; 1 mark: P passive with data; 2 marks: explanation linking ATP dependence to the different effects.)*

Q19. (a) Water enters the root hair cell by **osmosis**. The **soil water is more dilute** (higher water potential) than the cell's cytosol (lower water potential, because it holds more solute), so water moves down the water-potential gradient **from the soil into the cell** across the selectively permeable membrane. (b) The **nitrate ions are more concentrated inside the cell than in the soil**, so absorbing more of them means moving them **against their concentration gradient**. This cannot happen by diffusion, so the cell uses **active transport**: a **carrier (pump) protein** binds each ion, and **energy from ATP** changes the pump's shape to carry the ion into the cell. ATP is required precisely because the movement is "uphill" against the gradient. (c) The long, narrow shape gives the root hair cell a **very large area of plasma membrane** in contact with the soil water. A larger membrane area means a **greater area across which water can move by osmosis** and a **larger number of channel and pump proteins** exposed to the soil solution, so both water and mineral ions are absorbed **faster**. The extension also pushes **between the soil particles**, putting the cell in contact with a **larger volume of soil water** and so with more of the available ions. (d) The soil is now **hypertonic** to the root hair cells (more solute outside than inside), so water moves **out of the cells by osmosis**. The cells **lose water and turgor**, becoming flaccid and, if enough water leaves, **plasmolysed** (the membrane pulls away from the wall); the plant can no longer take up water and **wilts**. ∴ the cell relies on osmosis for water and active transport for ions, and it fails when the surrounding soil becomes hypertonic. *(a: 2 marks — osmosis, soil dilute → cell, down the water-potential gradient; b: 2 marks — active transport against the gradient, ATP powers the pump; c: 2 marks — large membrane surface area / more transport proteins in contact with the soil, so faster uptake of water and ions; d: 2 marks — hypertonic soil, water leaves by osmosis, cells lose turgor / plasmolyse and the plant wilts.)*