

Module 2: Foundations in Biology

Cell Membranes

Function of membranes

Cell membranes play different roles depending on whether they are on the outer surface of the cell (plasma membrane) or within cells:

Functions of the plasma membrane:

- Act as a **barrier** between the cell and the environment – they control what moves into and out of the cell. The plasma membrane is partially permeable so it lets some substance through but not others.
- **Cell recognition** – glycoproteins on the plasma membrane act as antigens, telling the immune system that the cell is not a foreign pathogen.
- **Cell communication** – receptors on the plasma membrane bind to hormones or other chemicals released by other cells.

Functions of intracellular membranes:

- **Compartmentalises the cell** – internal membranes act as a barrier between organelles and the cytoplasm, allowing them to function more efficiently by keeping enzymes and molecules in one place.
- Form **vesicles to transport substances** around the cell.
- **Control what moves into and out of organelles** – intracellular membranes are partially permeable.
- Act as the **site of chemical reactions** – for example, thylakoid membranes inside chloroplasts are where photosynthetic reactions take place.

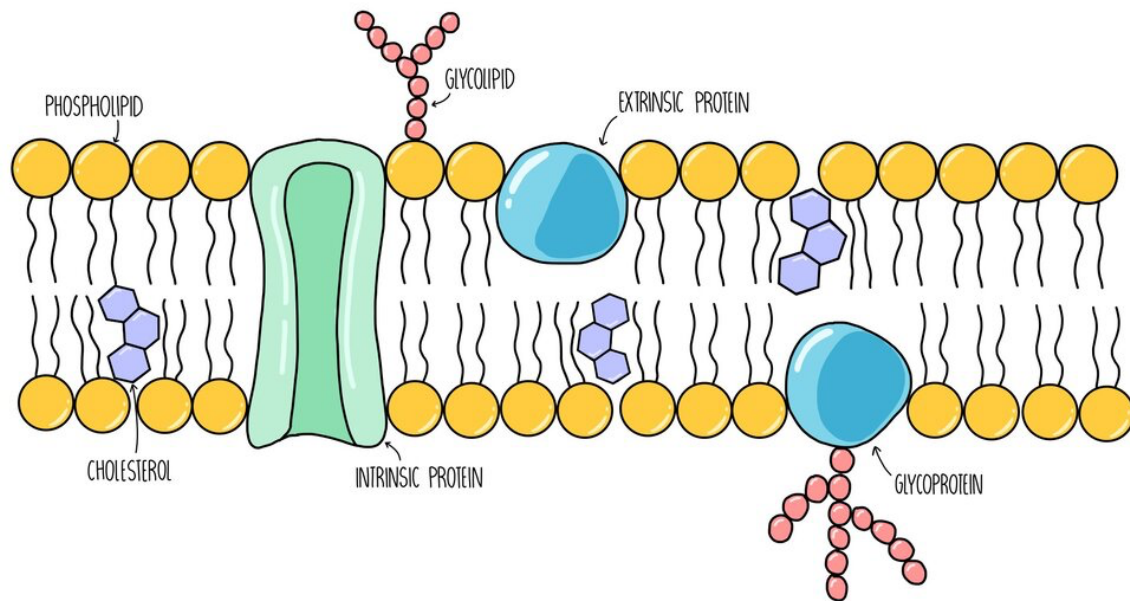
Fluid mosaic model

The structure of the plasma membrane is made up of a **bilayer of phospholipids** with **proteins** and **cholesterol** interspersed throughout the structure. The **fluid mosaic model** is used to describe the arrangement of molecules in the membrane - '**fluid**' because the **phospholipids are constantly moving around** and '**mosaic**' because protein molecules are **scattered** throughout the phospholipids like tiles in a mosaic.

We refer to this concept as a '**model**' because it is the **best representation** of membrane structure based on the **evidence which is currently available**. As we learn more about the structure of the plasma membrane, the fluid mosaic model may be updated.

Components of the plasma membrane

- **Phospholipids:** consist of a **hydrophilic** head group which faces the intracellular / extracellular fluid and two **hydrophobic** tails which point towards each other, away from water. They are the **main component** of the plasma membrane and form a **barrier** to anything which is not lipid-soluble (such as ions and glucose).
- **Glycoproteins:** these are **proteins** with **sugar** molecules attached. They act as **recognition sites** and **antigens** - antigens are like little 'flags' on the surface of our cells which allows our body to detect which cells are our own and which cells are foreign.
- **Glycolipids:** these are **phospholipids** with **sugar** molecules attached. They have a similar function to glycoproteins - they also act as **recognition sites** and **antigens**. They also **increase membrane stability** by forming **hydrogen bonds** with water molecules.
- **Cholesterol:** cholesterol is a **lipid** which slots in between the phospholipid tails, pushing them closer together. It regulates the **stability** and **fluidity** of the plasma membrane.
- **Intrinsic proteins:** these are proteins which **span both bilayers** of the plasma membrane. They act as **channels** or **carrier proteins** to transport water-soluble molecules.
- **Extrinsic proteins:** these are proteins which are found on the **surface** of the plasma membrane. They usually function as **enzymes** and catalyse chemical reactions inside the cell.



Cell communication and cell signalling

Cells communicate with each other using molecules such as **hormones** and **neurotransmitters**. Molecules are released from cells by exocytosis and **travel** (e.g. in the bloodstream) to the **target cells**. The target cells detect the molecule by having **complementary receptors** on their cell surface. For example, liver cells have insulin receptors on their plasma membrane which binds to insulin, triggering changes inside the cell which lower blood glucose levels.

Drugs also bind to cell membrane receptors, either triggering a response in the cell or blocking the receptor to prevent it from working. For example, heroin binds to opioid receptors in the brain, triggering processes which reduce pain and promote feelings of well-being.

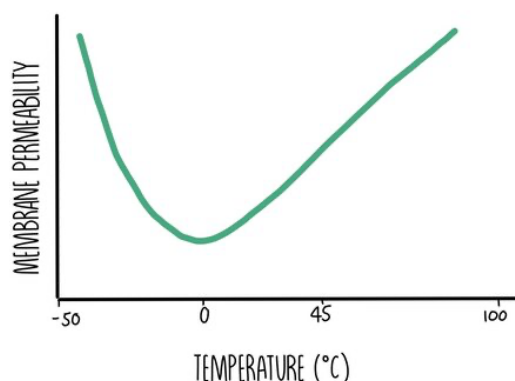
Investigating cell membrane permeability

The permeability of cell membranes is affected by things like **temperature**, **pH** and **ethanol**. You may be asked to describe an experiment to determine the effect of one of these factors on membrane permeability. These experiments using involve plant cells which contain a **coloured pigment**, such as beetroot, since we can measure the amount of membrane permeability depending on **how much pigment leaks out** of the cells and into the surrounding solution. The method for this type of experiment is outlined below:

- Prepare eight cylinders of beetroot of equal size. Make these samples as **similar as possible**, e.g. by cutting from the same part of each plant. **Rinse** each piece to remove any pigment released during cutting.
- If you are investigating the effect of temperature, prepare eight **water baths** of varying temperatures ranging from 0-70°C.
- Prepare a series of test tubes containing the **same volume of water** (e.g. 10 cm³). Place the tubes in different water for five minutes.
- Place a single sample of beetroot into each of the eight test tubes. Leave for 15 minutes.
- Use forceps to remove the pieces of beetroot from each tube. Keep the coloured liquid and transfer into a cuvette.
- Use a **colorimeter** to measure how much **light is absorbed** by each liquid. The darker the solution (i.e. the more permeable the membrane), the more light is absorbed.
- Draw a **graph plotting absorbance against temperature**.

Temperature and membrane permeability

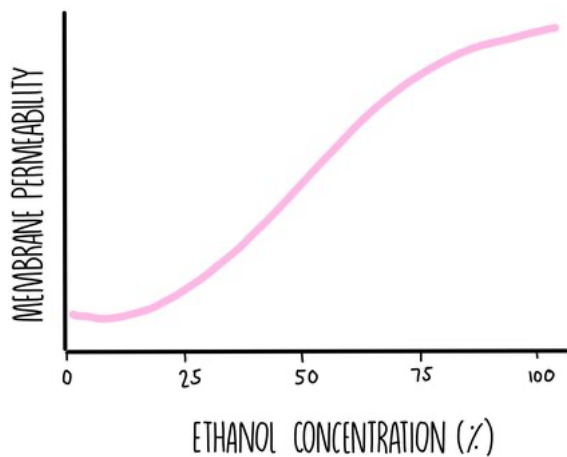
- At temperatures **below freezing**, the **permeability** of cell membranes **increases** since the **proteins** in the membrane unfold and become **deformed**. The molecules in the membrane have **low amounts of energy** so cannot move around much. The phospholipids become closely packed together which makes the membrane **rigid**. When temperatures fall low enough for **ice crystals** to form, these can **puncture** the membrane which increases its permeability when the cell membrane re-thaws, damaging the cell.
- Between temperatures of **0°C and 45°C**, membranes are **partially permeable**. As temperature increases, the components in the membrane gain kinetic energy and move around more. The **more fluid** the membrane is, the **more substances it allows through**.



- As temperatures **exceed 45°C**, **permeability increases rapidly** because **proteins** in the membrane become **denatured** and start to unravel. In addition, water inside the cell cytoplasm expands, putting pressure on the cell membrane and creating gaps within the bilayer.

Ethanol and membrane permeability

Ethanol is a non-polar solvent so it is able to **dissolve non-polar substances** such as **lipids**. This means that if you place a cell in ethanol, its membrane will become permeable and allow substances to leak into and out of the cell. **As the ethanol concentration increases, membrane permeability will increase.** If the ethanol concentration is high enough, enough phospholipids will dissolve to cause the plasma membrane to disintegrate completely which will kill the cell.



Transport across cell membranes

Molecules can make their way across the plasma membrane in one of three ways: **osmosis** (if the molecule is **water**), **diffusion** (if it is a molecule moving **down its concentration gradient**) or **active transport** (if it is a molecule moving **against its concentration gradient**). For **larger substances** to get into or out of the cell, such as proteins or carbohydrates, they will rely on processes called **endocytosis** and **exocytosis**.

Simple diffusion

Diffusion is the movement of molecules **down their concentration gradients**. When molecules move by simple diffusion, they pass **directly through the phospholipid bilayer**. It is a **passive** process which means that no energy is required. Oxygen and carbon dioxide move by simple diffusion when they pass from the alveoli into the bloodstream during gas exchange.

The rate of simple diffusion depends on:

- **The concentration gradient** – the steeper the gradient, the faster the rate of diffusion
- **The thickness of the exchange surface** – thicker exchange surfaces mean a longer diffusion distance
- **Surface area** – larger surface areas mean more space for diffusion to take place. Adaptations like microvilli in the small intestine increase surface area.

Investigating diffusion

The rate of simple diffusion can be investigated using the pH indicator **phenolphthalein**, which is **pink** in alkaline conditions and **colourless** in acids. You need to make up cubes of agar jelly containing phenolphthalein and dilute **sodium hydroxide** (an alkali). Place in a beaker containing dilute **hydrochloric acid**. The cubes will turn pink to colourless as the acid diffuses into the cubes and neutralises the sodium hydroxide. You can use this experimental set-up to see how the following factors affect the rate of diffusion:

- **Temperature** – repeat the experiment with several beakers, placing each in a water bath set to different temperatures. The agar cubes should be cut to exactly the same size. You'd expect to find that higher temperatures cause the cubes to lose their colour more quickly.
- **Surface area** – repeat using cubes cut to different sizes and calculate their surface area to volume ratio. Smaller cubes, with a larger surface area to volume ratio, will turn colourless quicker.
- **Concentration** – repeat the experiment with beakers containing different acid concentrations. Cut your agar cubes to exactly the same size and place in the separate beakers. The cubes in the highest concentration of hydrochloric acid will go colourless the fastest.

Facilitated diffusion

Facilitated diffusion involves the movement of molecules **down their concentration gradients**. It differs from simple diffusion in the fact that a **carrier protein** or a **channel protein** within the cell membrane helps them get from one side to the other. This is also a **passive** process. An example of facilitated diffusion is the movement of glucose molecules into liver cells through glucose transporter proteins embedded in the plasma membrane.

The rate of facilitated diffusion depends on:

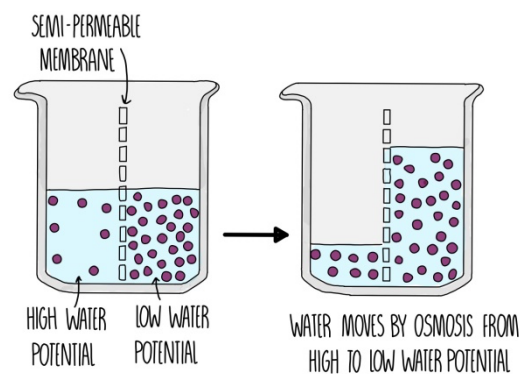
- **The concentration gradient** – the steeper the gradient, the faster the rate of diffusion
- **The number of channel/carrier proteins** – the more transport proteins, the faster substances can be moved across the membrane

Osmosis

Osmosis is the movement of **water** molecules **down its concentration gradient** across a **partially permeable membrane**. It is a **passive** process so does not require energy in the form of ATP. Osmosis is responsible for the movement of water molecules into the root hair cells of plants, for example.

You can think of it as how 'pure' the water is. Pure

water has the highest water potential – all other solutions will have lower water potentials in comparison, with the more solute dissolved in it, the lower the water potential. Two solutions with the same water potential are **isotonic**.

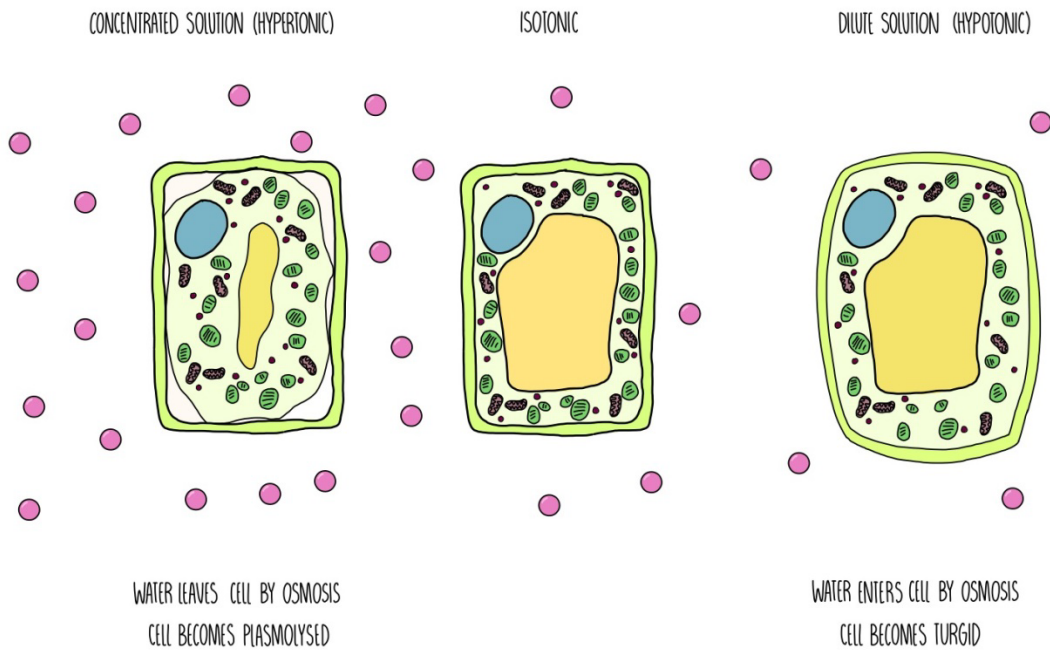


Rate of osmosis depends on:

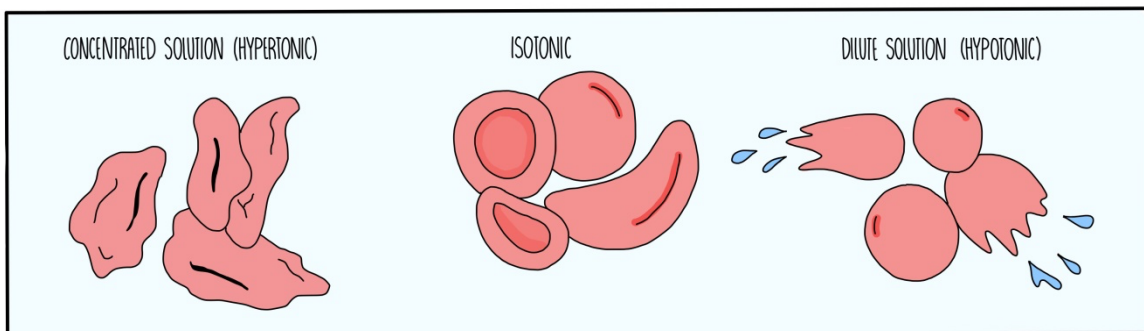
- **The water potential gradient** – the steeper the gradient, the faster the rate of osmosis
- **The surface area** – the larger the surface area, the more space there is for osmosis to take place
- **The thickness of the exchange surface** – thinner surfaces mean a shorter diffusion distance

Osmosis has different effects on plant cells and animal cells. When plant cells are placed in a hypertonic (concentrated) solution, water moves out of the cell by osmosis. The cell becomes **flaccid** and the cell membrane pulls away from the cell wall (**plasmolysis**). When they are placed in hypotonic (dilute) solution, water moves into the cell by osmosis. The vacuole swells and the

cytoplasm pushes against the cell wall. The cell becomes **turgid** and the cell wall protects it from bursting.



Animal cells **shrink** when they are placed in a hypertonic solution and **burst** when they are placed in a hypotonic solution, since they don't have a cell wall to maintain turgor pressure.



Determining the water potential of potato cells

You can set up an experiment to determine the water potential inside potato cells. If potato is placed in a solution of higher water potential, water will move into the cells and the potato gains mass. If it is placed in a solution of lower water potential, it will lose mass. When there is **no change in mass**, the solution and the potato's cytoplasm are **isotonic** and you have found the water potential inside the cells.

Method:

- Prepare cylinders of potato using a cork borer and cut into three.
- Measure the mass of the potato pieces using a mass balance.
- Prepare **serial dilutions** of sucrose solution. First, make a 2M solution with a volume of 10 cm³. Transfer half (5 cm³) to another test tube, with an equal volume of water. Repeat three more times so that you end up with solutions of 2M, 1M, 0.5M, 0.25M and 0.125M.
- Place the potato pieces in each solution and leave for 30 minutes.
- Remove from solution and dry with a paper towel.
- Record the mass of each potato piece and calculate the percentage change in mass.
- Draw a graph with percentage change in mass on the y-axis and concentration of sucrose solution on the x-axis. Read off the sucrose concentration where the change in mass = 0. Look up the water potential for this sucrose concentration – it's the same as the water potential of the potato cells.

Active transport

- Active transport moves molecules **against** their gradient, from low to high concentration.
- This involves a **carrier protein** which carries the molecule from one side of the membrane to the other.
- It is an **active** process and uses ATP to release energy.
- An example is the transport of glucose from the villi of the intestine into the bloodstream.
- **Cotransporters** are a special type of carrier protein which can bind to two molecules at a time. The concentration gradient of one molecule is used to transport the other molecule against its gradient.

Rate of active transport depends on:

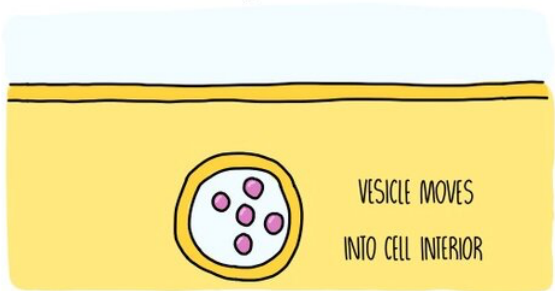
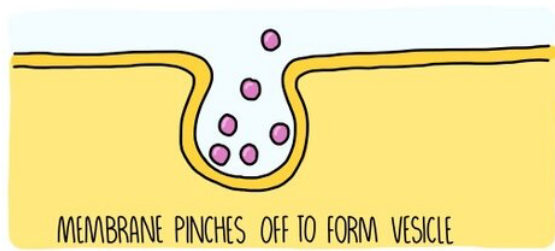
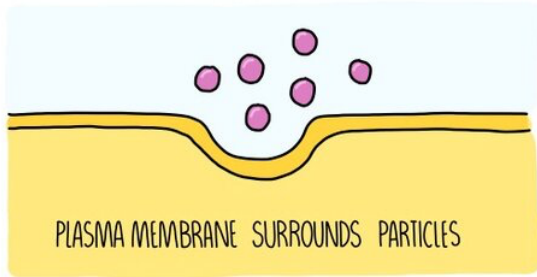
- **The number of carrier proteins in the membrane** – more proteins means faster rate of transport
- **The speed of each carrier protein** – the faster carrier proteins work, the faster the rate of active transport
- **The rate of respiration** – the faster respiration is taking place, the more ATP is generated. Inhibition of respiration will also inhibit active transport

Endocytosis and exocytosis

If substances are **too large** to cross the membrane, they enter the cell by endocytosis. The cell surrounds the substance and **folds its membrane around it**. The membrane then **pinches off** to **engulf** the substance, which causes a **vesicle** to form inside the cell containing the ingested substance. This is an **active** process so will require energy in the form of ATP. An example of endocytosis is when phagocytes carry out **phagocytosis**, in which the phagocyte engulfs a whole bacterium in order to destroy it.

When **large** substances need to leave the cell, such as hormones and digestive enzymes, they do so by exocytosis. These substances will be contained inside **vesicles** which move towards the plasma membrane and **fuse** with it. This causes the substances to either be **released outside of the cell** or they will be **inserted straight into the membrane** (for example, if the substance is a membrane protein). Exocytosis is an **active** process which requires ATP.

ENDOCYTOSIS



EXOCYTOSIS

