Exam Papers Practice

Membranes & Membrane Transport

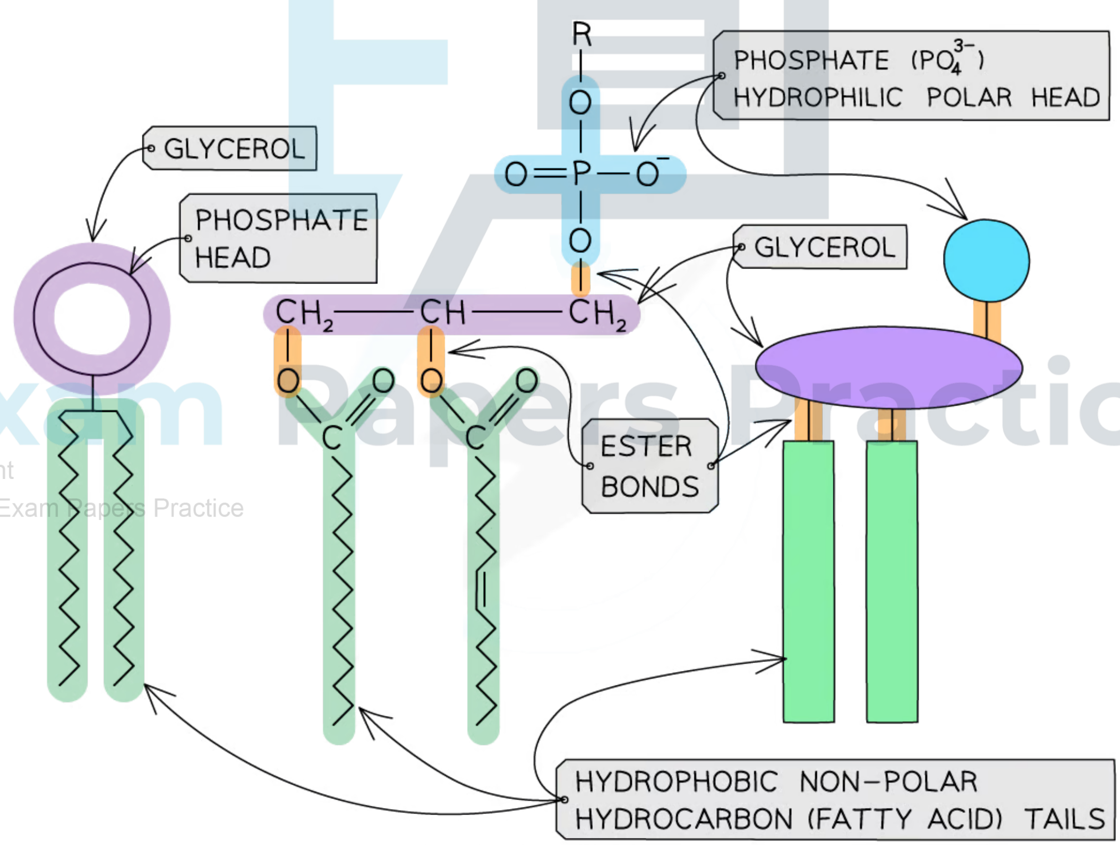
IB Biology - Revision Notes

Lipid Bilayers

Lipid Bilayers: Basis of Cell Membranes

- Phospholipids form the basic structure of cell membranes, which are formed from phospholipid bilayers
- They are formed by a hydrophilic **phosphate head** bonding with two hydrophobic **hydrocarbon (fatty acid) tails**
- As phospholipids have a **hydrophobic** and **hydrophilic** part they are known as **amphipathic**
  - The **phosphate head** of a phospholipid is **polar** and therefore **soluble** in water (hydrophilic)
  - The **fatty acid tail** of a phospholipid is **nonpolar** and therefore **insoluble** in water (hydrophobic)

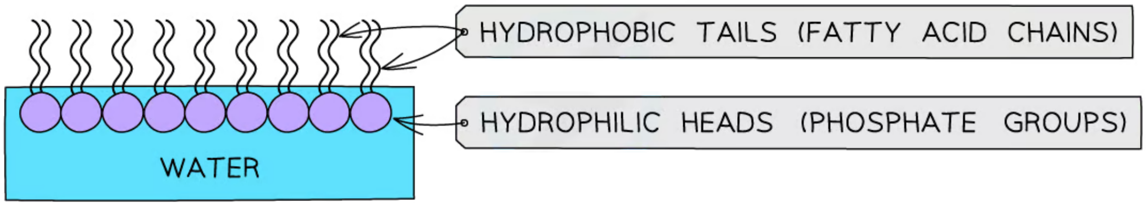
Phospholipid structure diagram



Phospholipids consist of a molecule of glycerol, two fatty acid tails, and a phosphate group

- When phospholipids are placed in water the hydrophilic phosphate heads orient **towards the water** and the hydrophobic hydrocarbon tails orient **away from the water**
  - This forms a **phospholipid monolayer**

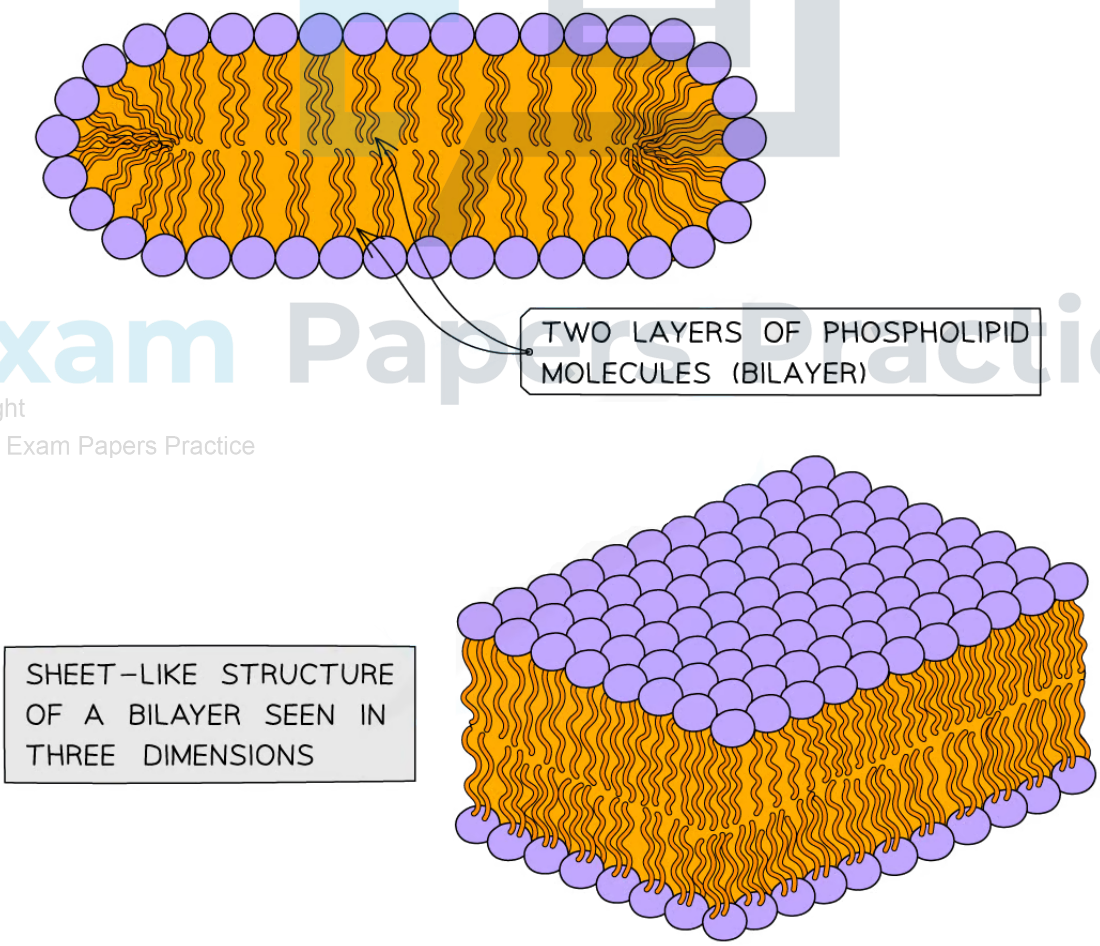
Phospholipid monolayer diagram



Phospholipids can form a monolayer in water

- When there is a sufficient concentration of phospholipids present then two-layered structures may form
- These sheets are called **phospholipid bilayers**

Phospholipid bilayer diagram



A phospholipid bilayer is composed of two layers of phospholipids; their hydrophobic tails facing inwards and hydrophilic heads outwards

Lipid Bilayers: Barriers

- The phospholipid bilayer has two regions - a **hydrophobic core** and a **hydrophilic outer layer**
- The hydrophobic regions are attracted to each other and the hydrophilic regions are attracted to water in the cytoplasm or the extracellular fluid
- These properties allow the bilayer to form a **barrier**
    - **Large molecules** cannot pass through the barrier as the hydrophobic region is tightly packed and has low permeability to larger molecules
    - **Polar molecules** and **ions** cannot pass through the hydrophobic tails of the phospholipid structure
        - The hydrophilic nature of these molecules and ions means that they will not interact with the hydrophobic fatty acid tails of the phospholipids
- The bilayer forms an effective barrier so that it is able to control which molecules pass through and out of the cell

Membrane Proteins

Membrane Proteins

- The phospholipid bilayer carries out the main function of the plasma membrane, providing a barrier to the movement of some substances into and out of the cell
- Additional functions are carried out by **proteins** in the membrane
- These proteins are grouped into two categories:
  - **Integral**
    - These are partially **hydrophobic**, i.e. they are amphipathic
    - They are **embedded** in the phospholipid bilayer
    - They can be embedded across **both layers** or just **one layer**
  - **Peripheral**
    - These are **hydrophilic** proteins
    - They are **attached** to either the surface of integral proteins, or to the plasma membrane via a hydrocarbon chain
    - They can be **inside** or **outside** the cell
- The protein content of membranes can vary depending on the function of the cell
  - E.g. membranes of the mitochondria and chloroplasts have the highest protein content with their many electron carriers

Membrane protein functions

- Membrane proteins carry out many functions: transport, receptors, cell adhesion, cell-to-cell recognition and immobilized enzymes

Transport

- Transport proteins **allow ions and polar molecules to travel across the membrane**
- There are two types:
  - **Channel** proteins
    - These form holes, or pores, through which molecules can travel
  - **Carrier** proteins
    - Carrier proteins **change shape** to transport a substance across the membrane, e.g. protein pumps and electron carriers
- Each transport protein is **specific to a particular ion or molecule**
- Transport proteins allow the cell to **control** which substances enter or leave

Receptors

- Receptors are for the binding of peptide hormones, e.g. insulin, neurotransmitters or antibodies
- The binding generates a signal that triggers a series of reactions inside the cell

Immobilised enzymes

- Immobilized enzymes are integral proteins with the active site exposed on the surface of the membrane
- They can be inside or outside the cell

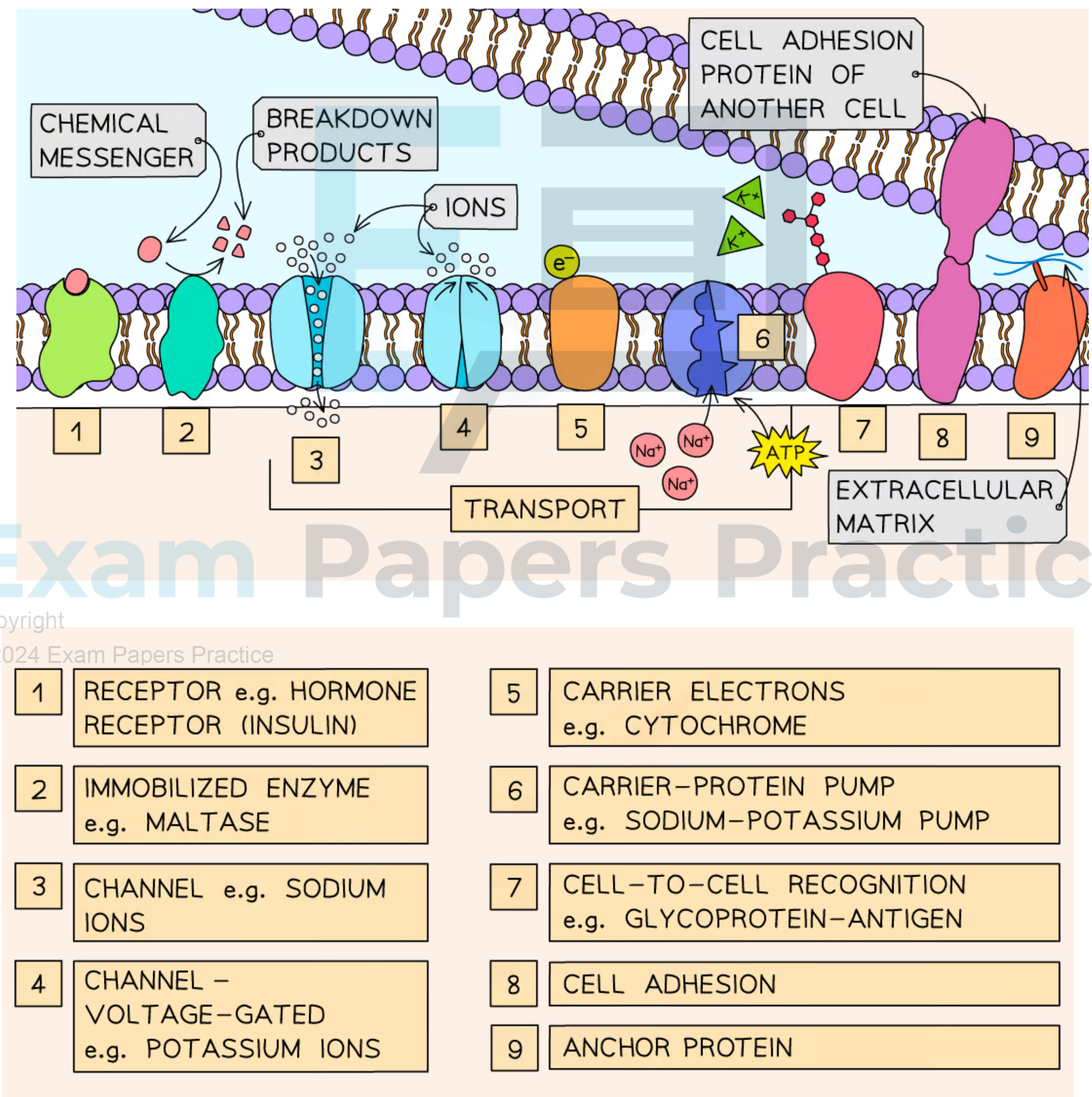
Cell adhesion

- Cell adhesion allows cells to attach to neighbouring cells within a tissue

Cell-to-cell recognition

- Glycoproteins act as cell markers, or antigens, for cell-to-cell recognition
- E.g. the ABO blood group antigens are glycolipids and glycoproteins that differ slightly in their carbohydrate chains

Plasma membrane proteins diagram



Membrane proteins have multiple functions

Exam Tip

As you go through the biology course you will learn specific examples of how membrane proteins are used; making links between the content here and other sections of the course will make it easier to learn examples of membrane proteins

Membrane Transport

Simple Diffusion

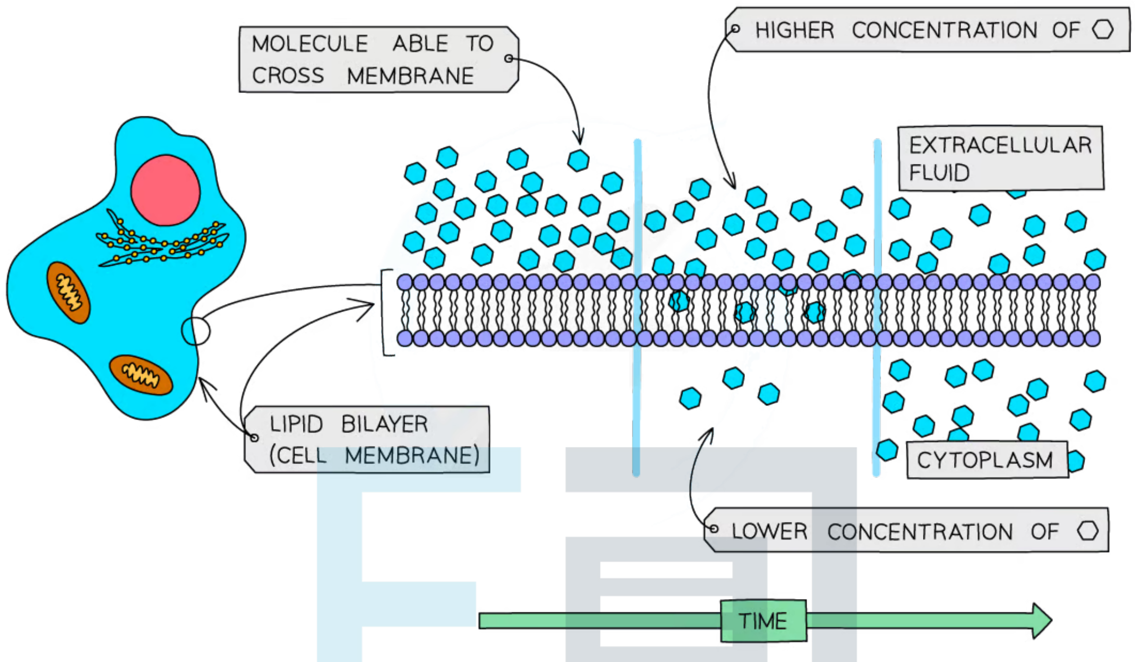
- Simple diffusion is a type of **membrane transport** that involves particles passing directly between the phospholipids in **the plasma membrane**
- It can be defined as:

The net movement, as a result of the random motion of molecules or ions, of a substance from a region of higher concentration to a region of lower concentration

- The random movement is caused by the **kinetic energy** of the molecules or ions
- The molecules or ions are said to move **down a concentration gradient**
- If diffusion takes place for a long enough time period, molecules eventually reach **equilibrium**, where they are **evenly distributed** on either side of a membrane

- Examples of molecules that move by simple diffusion include
  - **Oxygen**
    - Oxygen diffuses into cells from the surrounding capillaries
    - Respiration uses up oxygen, resulting in a low concentration inside cells and so generating a concentration gradient
  - **Carbon dioxide**
    - Carbon dioxide diffuses out of cells and into the surrounding capillaries
    - Respiration produces carbon dioxide as a product, resulting in a high concentration inside cells and so generating a concentration gradient

Simple diffusion diagram



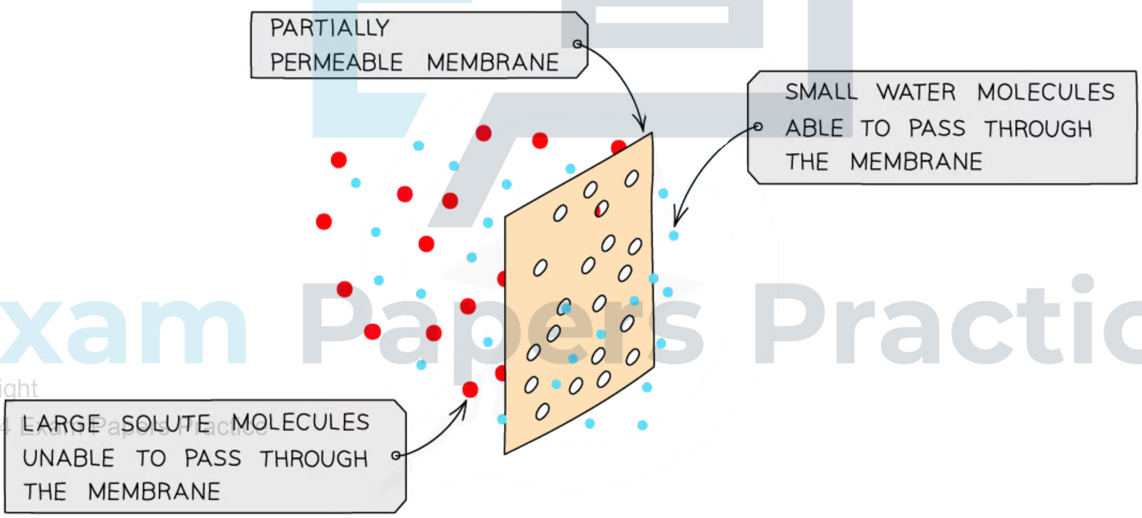
Simple diffusion involves the movement of molecules directly between the phospholipids of a cell membrane

- The **rate** at which a substance diffuses across a membrane depends on several factors:
  - **'Steepness' of the concentration gradient**
    - The greater the difference in concentration across a membrane, the higher the rate of diffusion
  - **Temperature**
    - The higher the temperature the higher the rate of diffusion
    - The molecules have more kinetic energy at high temperatures, so random movement of molecules is faster
  - **Surface area**
    - The greater the surface area the higher the rate of diffusion
  - **Properties of the molecules or ions**
    - **Large molecules** diffuse more slowly as they require more energy to move
    - **Uncharged** molecules, e.g. oxygen, diffuse faster as they move directly across the phospholipid bilayer
    - **Non-polar** molecules diffuse more quickly as they are soluble in the non-polar phospholipid bilayer
- Although polar molecules cannot easily pass through the hydrophobic part of the membrane, **smaller polar** molecules (e.g. urea) can diffuse at low rates

Osmosis

- Osmosis can be defined as:
  The diffusion of water molecules, from a dilute solution to a solution with a higher solute concentration, across a partially permeable membrane
- In doing this, water is moving down its **concentration gradient**, and so osmosis can be said to be a **type of diffusion**
  - A dilute solution has a high concentration of water molecules and a concentrated solution has a low concentration of water molecules
- As with facilitated diffusion, osmosis occurs as the result of the **random movement** of molecules, so is technically the **net** movement of water
- While water can move directly in between the phospholipids, channel proteins called **aquaporins** allow water to pass through membranes more freely
  - Water is unusual for a polar molecule in its ability to pass directly across cell membranes

Movement of water molecules diagram

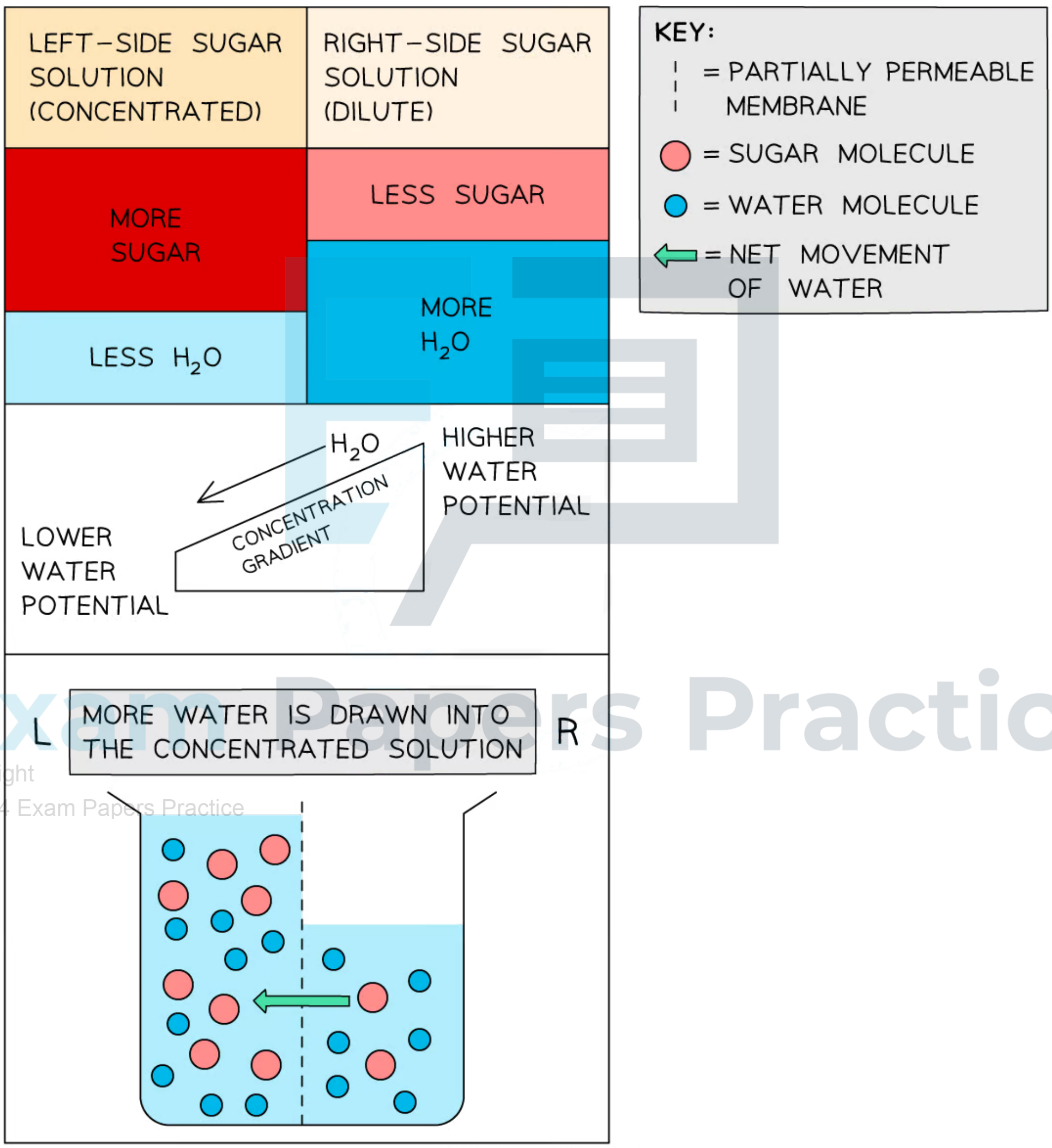


Water molecules can cross partially permeable membranes

- Osmosis can also be described as the net movement of water molecules from a region of **higher water potential** to a region of **lower water potential**, through a partially permeable membrane

- Water potential describes the tendency of water to move; this term is used to avoid confusion between water concentration and solute concentration of a solution

Osmosis diagram



Osmosis is the movement of water molecules from a dilute to a concentrated solution across a partially permeable membrane

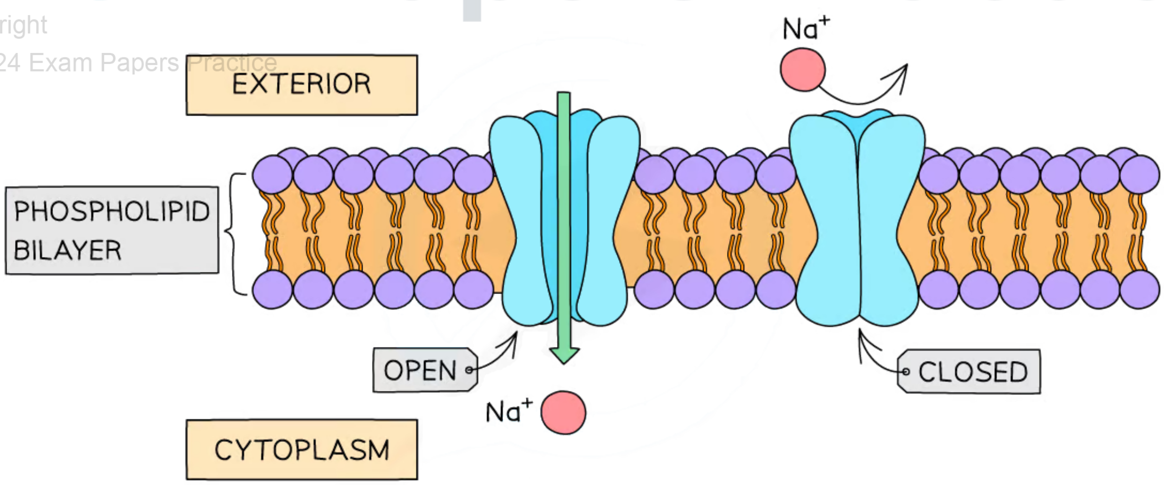
Facilitated Diffusion

- Some substances cannot diffuse through the phospholipid bilayer of cell membranes, e.g.:
  - **Large** molecules
  - **Polar** molecules
  - **Ions**
- These substances can only cross the phospholipid bilayer with the help of transport proteins
- This form of diffusion is known as **facilitated diffusion**
- There are two types of proteins that enable facilitated diffusion:
  - **Channel proteins**
  - **Carrier proteins**
- Transport proteins are **highly specific**, meaning that they only allow one type of molecule or ion to pass through
- During facilitated diffusion the net diffusion of molecules or ions into or out of a cell will occur **down a concentration gradient**
  - Facilitated diffusion is a **passive** form of transport; it does not require energy
  - The direction of movement of molecules through a transport protein depends on their **relative concentration** on each side of the membrane

Channel proteins

- Channel proteins are **pores** that allow the passage of specific substances across a membrane
- They allow **charged substances** (eg. ions) to diffuse through the cell membrane
- Some channel proteins are **gated**, meaning that part of the channel protein on the inside surface of the membrane can move in order to close or open the pore
  - This allows the channel protein to **control** the exchange of ions

Channel protein diagram

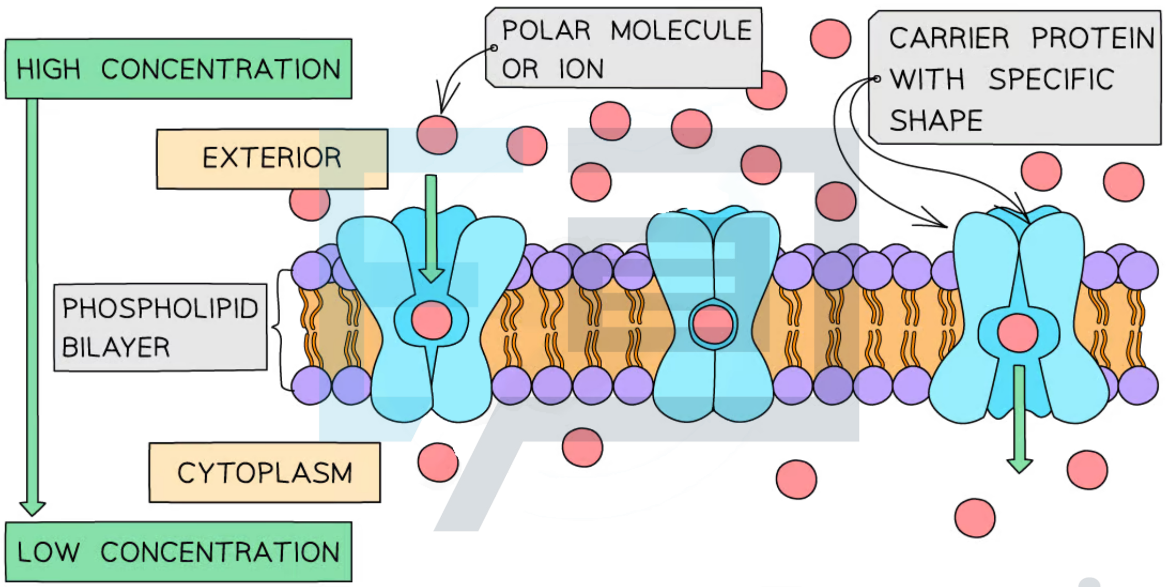


Channel proteins are membrane pores; some channel proteins can open and close

Carrier proteins

- Unlike channel proteins, which have a fixed shape, **carrier proteins can switch between two shapes**
  - The substance to be transported attaches to a binding site, causing a shape change in the carrier protein
  - Initially the binding site of the carrier protein is open to one side of the membrane
  - When the carrier protein switches shape it opens to the other side of the membrane

Carrier protein diagram



Carrier proteins change shape to carry substances across cell membranes

Exam Tip

Remember that the movement of molecules from **high concentration to low concentration** is diffusion; this movement is **passive** and requires no energy

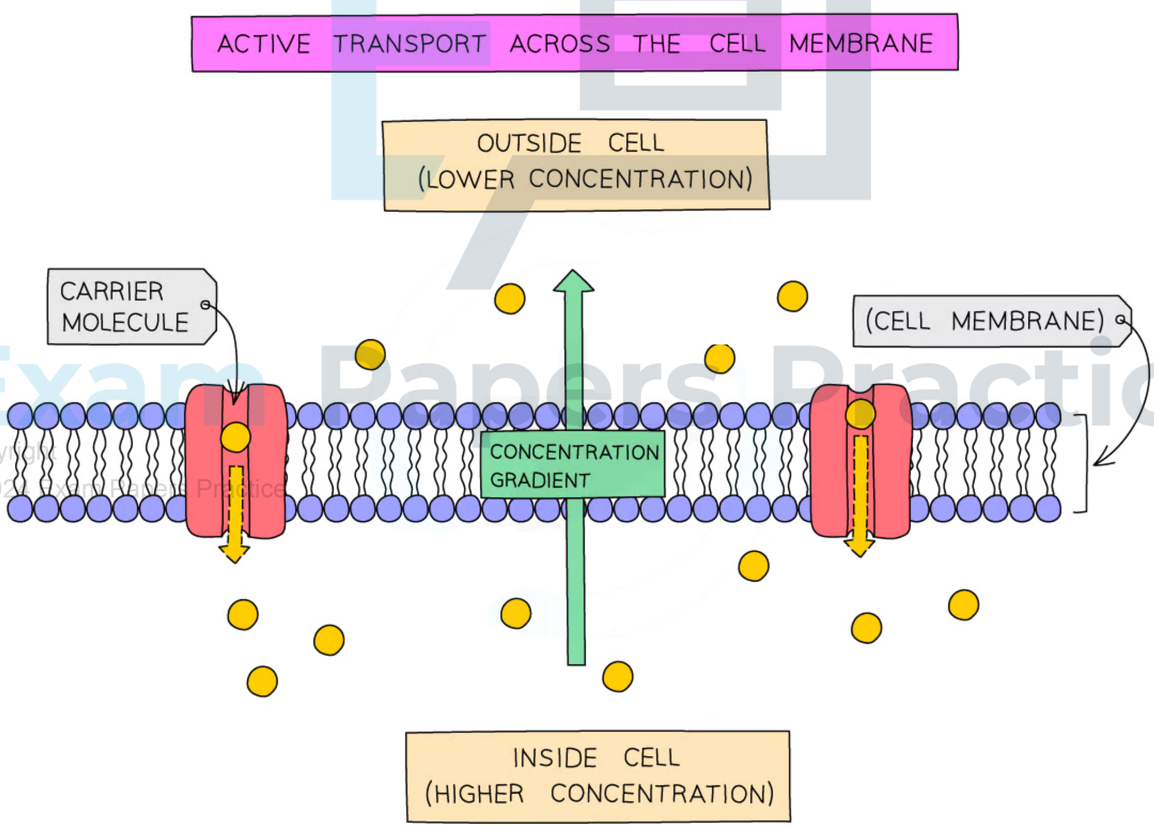
- If this movement requires the aid of a protein then it is facilitated diffusion
- If it involves the movement of water across a partially permeable membrane it is osmosis.

Active Transport

- Active transport can be defined as:
  The movement of molecules and ions across a cell membrane, from a region of lower concentration to a region of higher concentration, using energy from respiration

- Active transport occurs **against**, or **up**, a **concentration gradient**
- Active transport requires **carrier proteins**
  - Carrier proteins in active transport are sometimes known as **pumps**
  - Although facilitated diffusion also uses carrier proteins, active transport is different as it requires **energy**
- Energy is required to allow the carrier protein to **change shape**, allowing it to transfer the molecules or ions across the cell membrane
  - The energy required is provided by **ATP** (adenosine triphosphate), produced during **respiration**.
  - The ATP is **hydrolysed** to release energy

Active transport diagram



Active transport is the transport of substances across cell membranes from low to high concentration

Selective Permeability

- **Facilitated diffusion** and **active transport** are mechanisms that allow cell membranes to be **selectively permeable**
  - Selective permeability is the ability of the membrane to **differentiate** between different types of molecules, only allowing some molecules through while blocking others
- **Simple diffusion** provides less control for cell membranes, as it is dependent only on the size and hydrophobic or hydrophilic nature of the molecules diffusing
  - Simple diffusion provides no ability for membranes to be selective with regard to **small, polar molecules**
    - Small, non-polar molecules can diffuse across the membrane with ease so this is not selective
  - Simple diffusion does allow for selective permeability with regard to **large** or **polar molecules**
    - Large or polar molecules cannot cross the phospholipid bilayer without transport proteins

Glycolipids & Glycoproteins

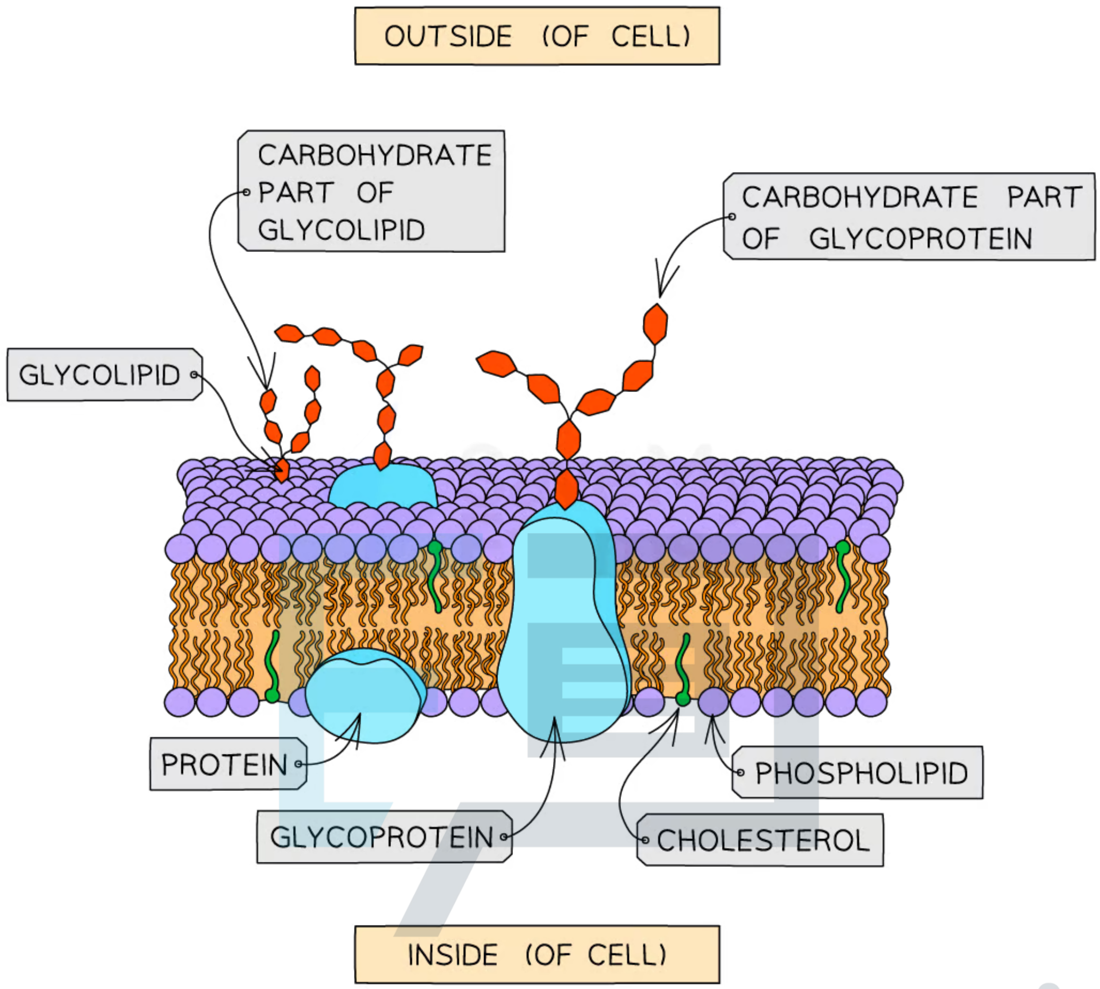
Glycoproteins & Glycolipids

- **Glycoproteins** are cell membrane **proteins** that have a **carbohydrate** chain attached on the **extracellular** side
  - Extracellular = outside cells
- **Glycolipids** are **lipids** with **carbohydrate chains** attached, also located on the outer surface of cell membranes

The function of glycoproteins and glycolipids

- The carbohydrate chain enables them to act as **receptor molecules**
  - This allows them to **bind** with substances at the cell surface
  - Receptor types include:
    - **Signalling receptors which bind to hormones and neurotransmitters**
    - Receptors involved in endocytosis
    - Receptors involved in **cell adhesion** and **stabilisation**
      - Cell adhesion allows cells to attach to each other to form tissues
- Some act as cell markers, or antigens, for **cell identification**
  - E.g. this allows the immune system to determine whether or not a cell belongs in the body, or whether it is a pathogen

Glycoproteins and glycolipids diagram



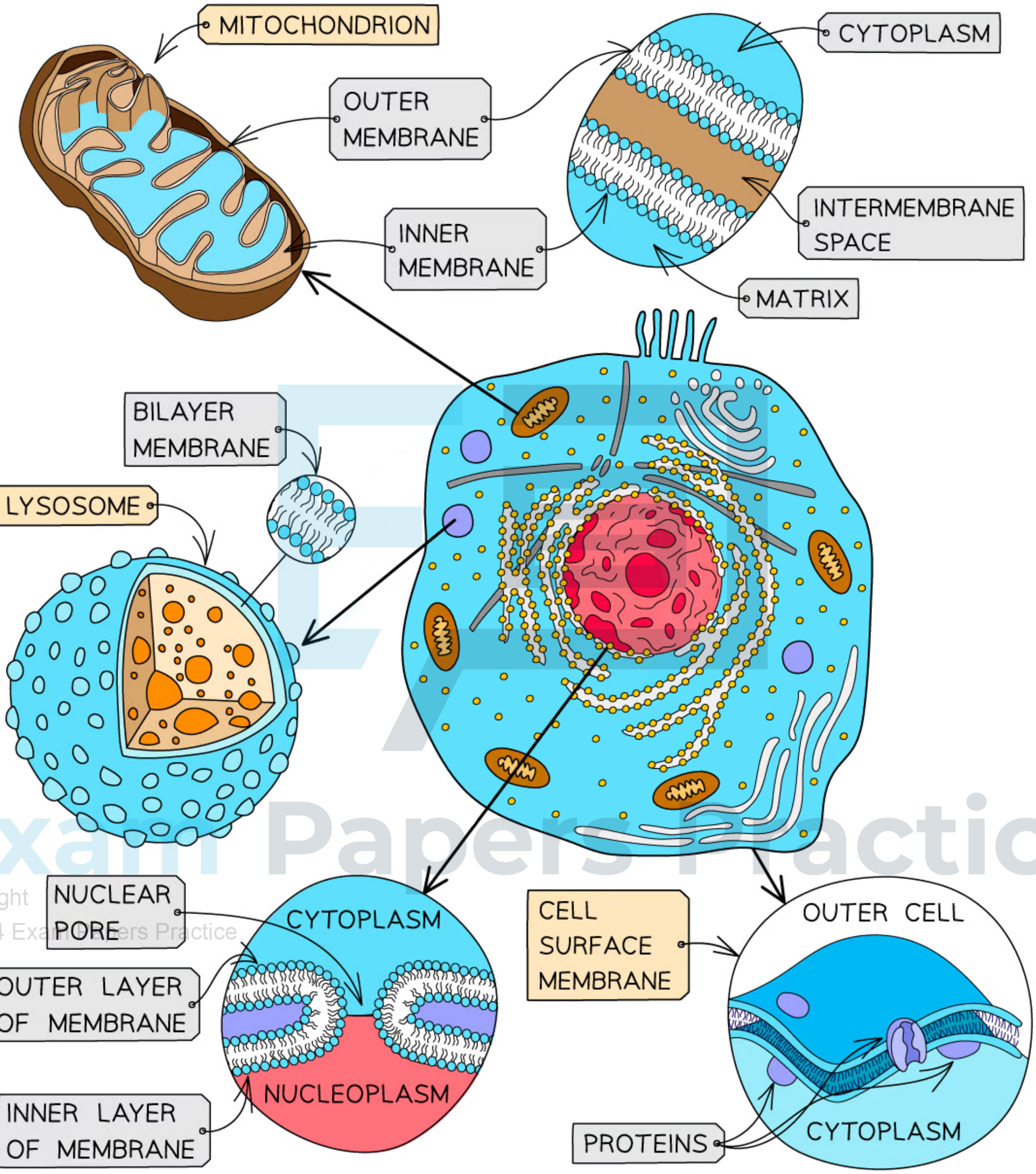
Glycoproteins are carbohydrate chains attached to membrane proteins and glycolipids are carbohydrate chains attached to the lipid element of the cell membrane

The Fluid Mosaic Model: Skills

The Fluid Mosaic Model

Membranes

- Membranes form partially permeable **barriers** between the cell and its environment, between cytoplasm and organelles and also within organelles
- Substances can cross membranes by **diffusion, facilitated diffusion**, **osmosis** and **active transport**
- Membranes play a role in **cell signalling** by acting as an **interface** for **communication between cells**

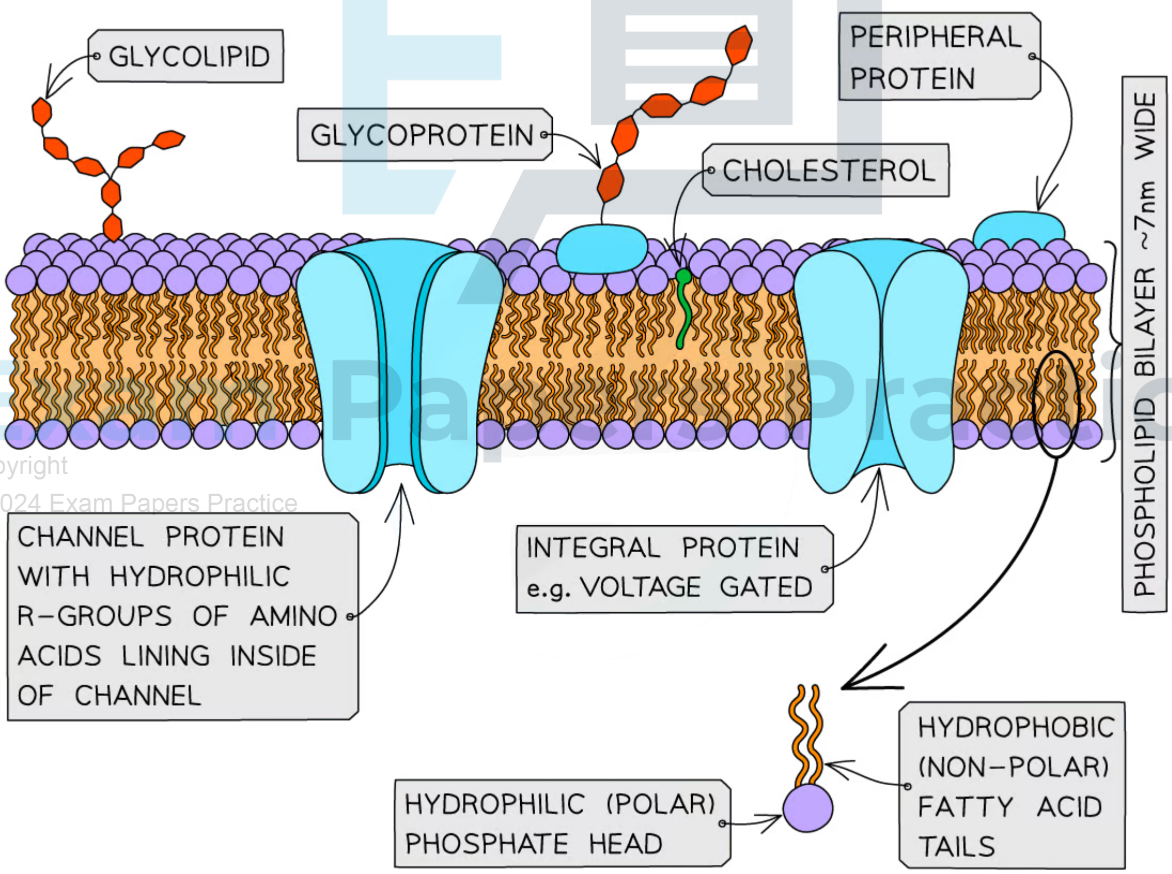


Membranes formed from phospholipid bilayers help to compartmentalise different regions within the cell, as well as forming the cell surface membrane

Fluid mosaic model

- The **fluid mosaic model** of membranes was first outlined in 1972 by **Singer and Nicolson** and it explains how biological molecules are arranged to form cell membranes
- The fluid mosaic model also helps to explain:
  - **Passive and active movement between cells and their surroundings**
  - **Cell-to-cell interactions**
  - **Cell signalling**
- The fluid mosaic model describes cell membranes as **'fluid'** because:
  - The **phospholipids** and **proteins** can **move around** within their own layers
- The fluid mosaic model describes cell membranes as **'mosaics'** because:
  - The **scattered pattern** produced by the **proteins** within the phospholipid bilayer looks somewhat like a mosaic when viewed from above
- The **fluid mosaic model** of membranes includes four main components:
  - Phospholipids
  - Cholesterol
  - Glycoproteins and glycolipids
  - Integral and peripheral proteins

The fluid mosaic model diagram



The distribution of the proteins within the membrane gives a mosaic appearance and the structure of the proteins determines their position in the membrane

Exam Tip

You should be able to draw a two-dimensional diagram of the fluid mosaic model of membrane structure.

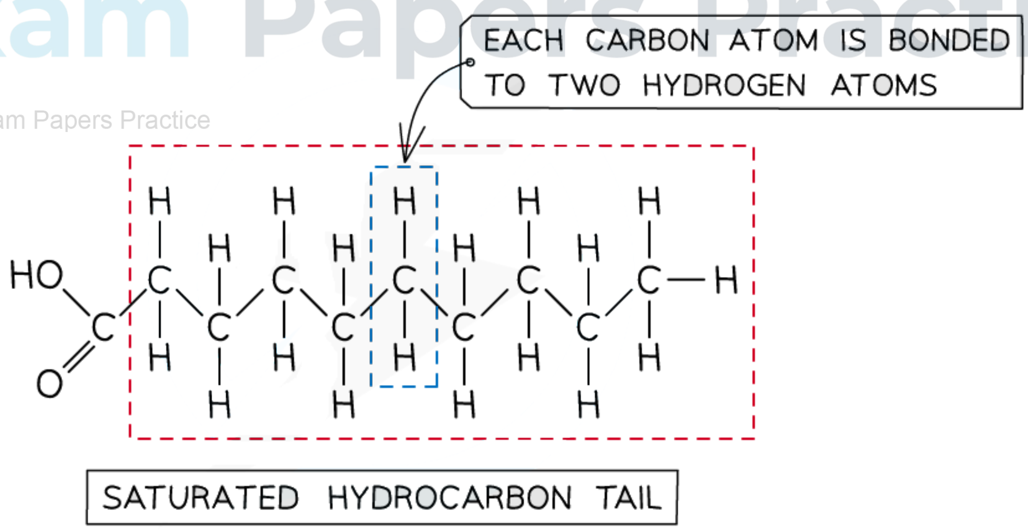
You should show and **label** the following:

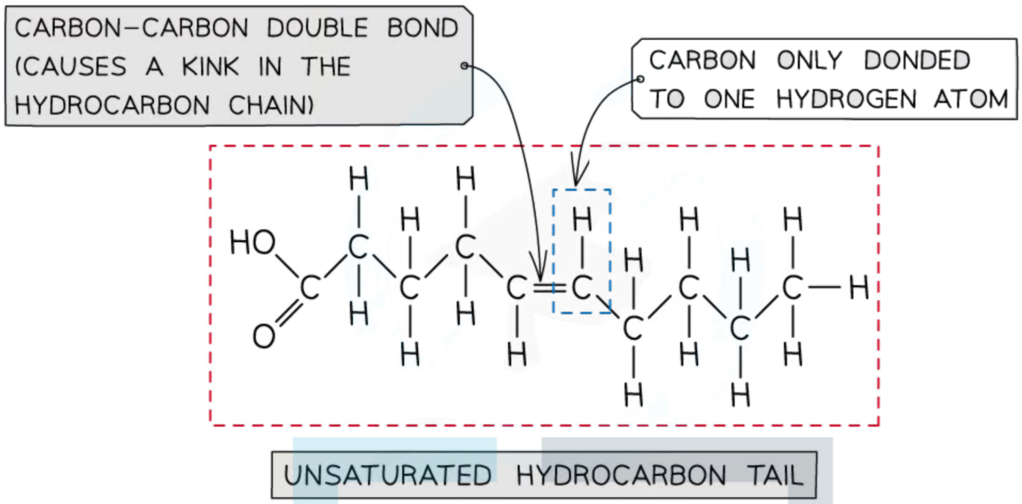
- The **phospholipid bilayer**, making it clear which part is the phosphate head and which parts are the hydrocarbon tails
- **Integral proteins**, e.g. channel/carrier
- **Peripheral proteins** that **do not** extend into the hydrophobic region
- **Glycoproteins** with a carbohydrate attached
- **Cholesterol**, with the OH group next to the phosphate heads and the rest positioned next to the tails

Membrane Fluidity (HL)

Fatty Acid Composition

- Phospholipids contain glycerol, a phosphate group, and two **fatty acid chains**
- Fatty acids can vary in two ways:
  - **Length** of the hydrocarbon chain
  - The fatty acid chain may be **saturated** or **unsaturated**
- **Saturated fatty acids**
  - Every carbon atom is bonded to 4 other atoms, meaning that each carbon in the chain is linked to 2 hydrogen atoms
    - The chain can be said to be 'saturated' with hydrogens; it contains as many hydrogen atoms as it possibly can
  - Saturated fatty acids are **straight**, allowing the molecules to **pack together tightly**
  - They therefore have **higher melting points**, so their presence in cell membranes allow membranes to **maintain stability** at higher temperatures
- **Unsaturated fatty acids**
  - Contain one or more double bonds between carbon atoms
    - One double bond - mono-unsaturated
    - More than one double bond = polyunsaturated
  - Unsaturated fatty acids have **bends**, or kinks, in the chain, meaning that they **cannot pack together so tightly**
  - Unsaturated fatty acids have **lower melting points** so they allow membranes to be **fluid and flexible**





Fatty acids can be saturated (top) or unsaturated (bottom); this affects the shape, and therefore the properties of the fatty acid

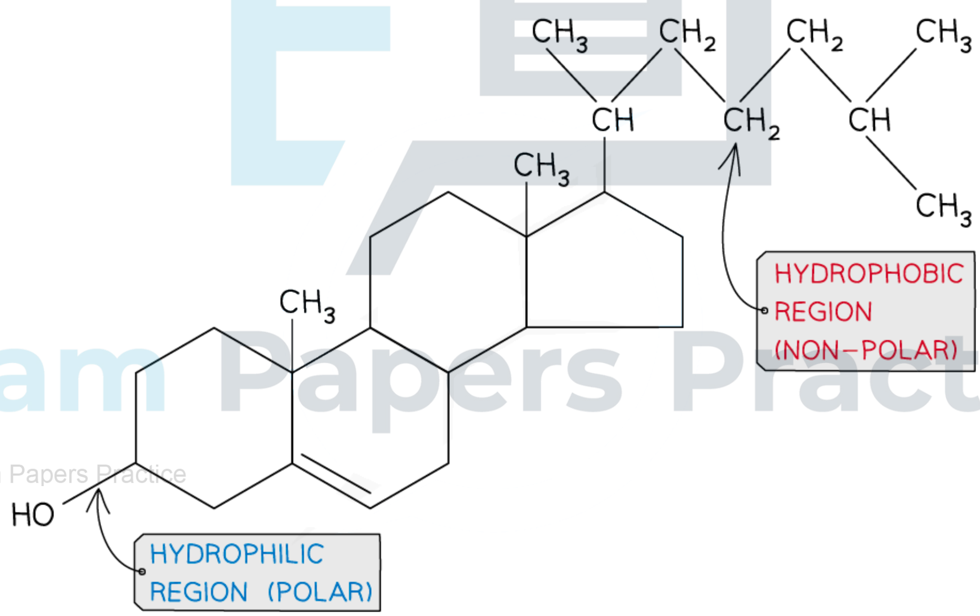
Fatty acids & regulating membrane fluidity

- **Bacteria** do not regulate their internal temperature, so their cell membranes are subject to temperature change
  - This means that they require mechanisms to overcome temperature fluctuations
  - Some bacteria species produce enzymes called **fatty acid desaturases** which **increase the number of double bonds** within a fatty acid as part of the membrane; this helps to **maintain membrane fluidity**, particularly during exposure to colder temperatures
- **Deep-sea marine organisms** have to contend with extreme temperatures
  - Correlations have been found between sea temperature and membrane-fluidising lipid components, such as polyunsaturated fatty acids
- **Plants**, such as *Arabidopsis thaliana*, have shown fatty acid unsaturation pathways that appear to have key roles in the acclimatisation of membranes to high temperature

Cholesterol

- Cholesterol is an important membrane **lipid**
- Just like phospholipid molecules, cholesterol molecules have **hydrophobic** and **hydrophilic regions**
  - Their chemical structure allows them to exist within the bilayer of the membrane
- Cholesterol **affects the fluidity and permeability** of cell membranes
  - It **maintains membrane fluidity** at low and high temperatures
    - It disrupts the close-packing of phospholipids, **increasing the flexibility** of the membrane at **low temperatures**
    - It holds the fatty acid tails together, providing **increased membrane stability** at **high temperatures**
  - It acts as a **barrier**, fitting in the spaces between phospholipids
    - This prevents water-soluble substances from diffusing across the membrane

Cholesterol structure diagram



The structure of a cholesterol molecule gives it a hydrophobic region and a hydrophilic region

Active Transport & Bulk Transport (HL)

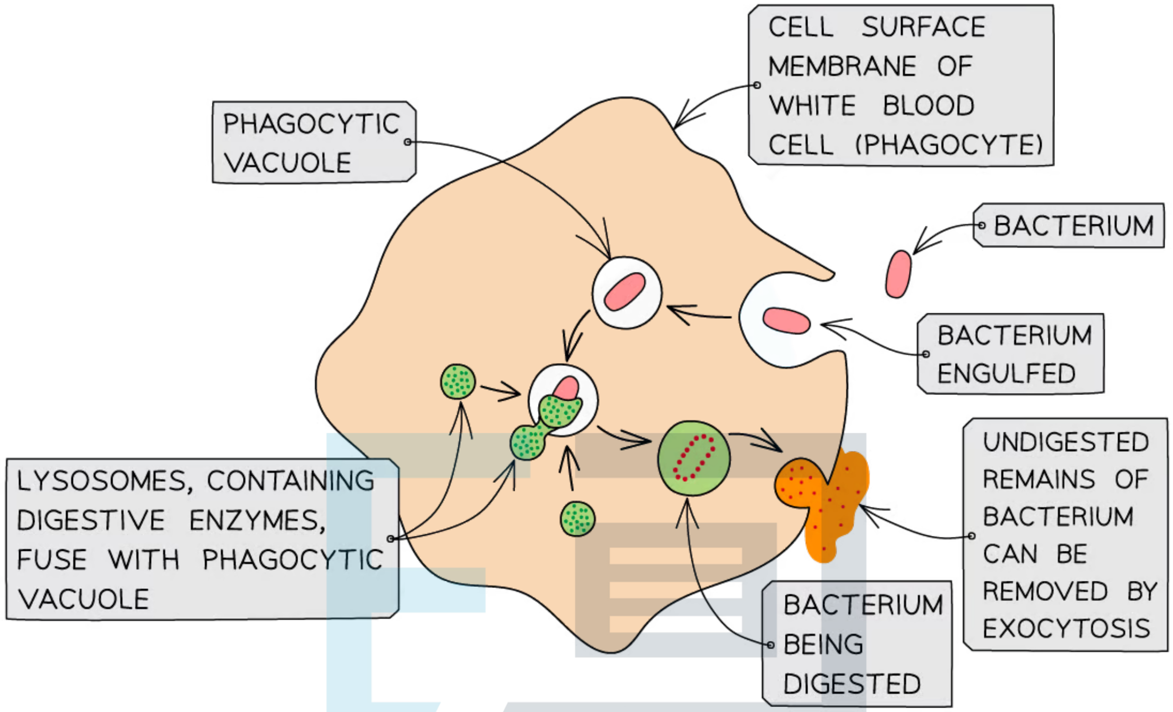
Bulk Transport

- The processes of diffusion, osmosis and active transport are responsible for the transport of **individual molecules or ions** across cell membranes
- However, the **bulk transport of larger quantities of materials** into or out of cells is also possible
- Examples of these larger quantities of materials that might need to cross the membrane include:
  - Bulk transport **into** cells = **endocytosis**
  - Bulk transport **out** of cells = **exocytosis**
- Bulk transport processes **require energy** and are therefore forms of **active transport**
- They also require the formation of **vesicles**, which is dependent on the fluidity of membranes
  - **Vesicles** are **small spherical sacs** of plasma membrane that containing substances for transport, e.g. enzymes
  - The formation of vesicles is an **active** process and involves a small region of the plasma membrane being **pinched off**
  - Vesicles can also **fuse with** cell membranes, at which point they are re-incorporated into a larger membrane
  - In order to form from or fuse with membranes, vesicles need membranes to flex and bed, so **fluidity is essential**

Endocytosis

- Endocytosis transports material **into** cells
- During endocytosis the plasma membrane **engulfs material**, forming a small sac around it
- There are two forms of endocytosis:
  - **Phagocytosis**:
    - This is the bulk intake of solid material by a cell
    - Cells that specialise in this process are called **phagocytes**
    - The vacuoles formed are called phagocytic **vacuoles**
    - An example is the engulfing of bacteria by phagocytic white blood cells
  - **Pinocytosis**:
    - This is the bulk intake of liquids

Endocytosis diagram

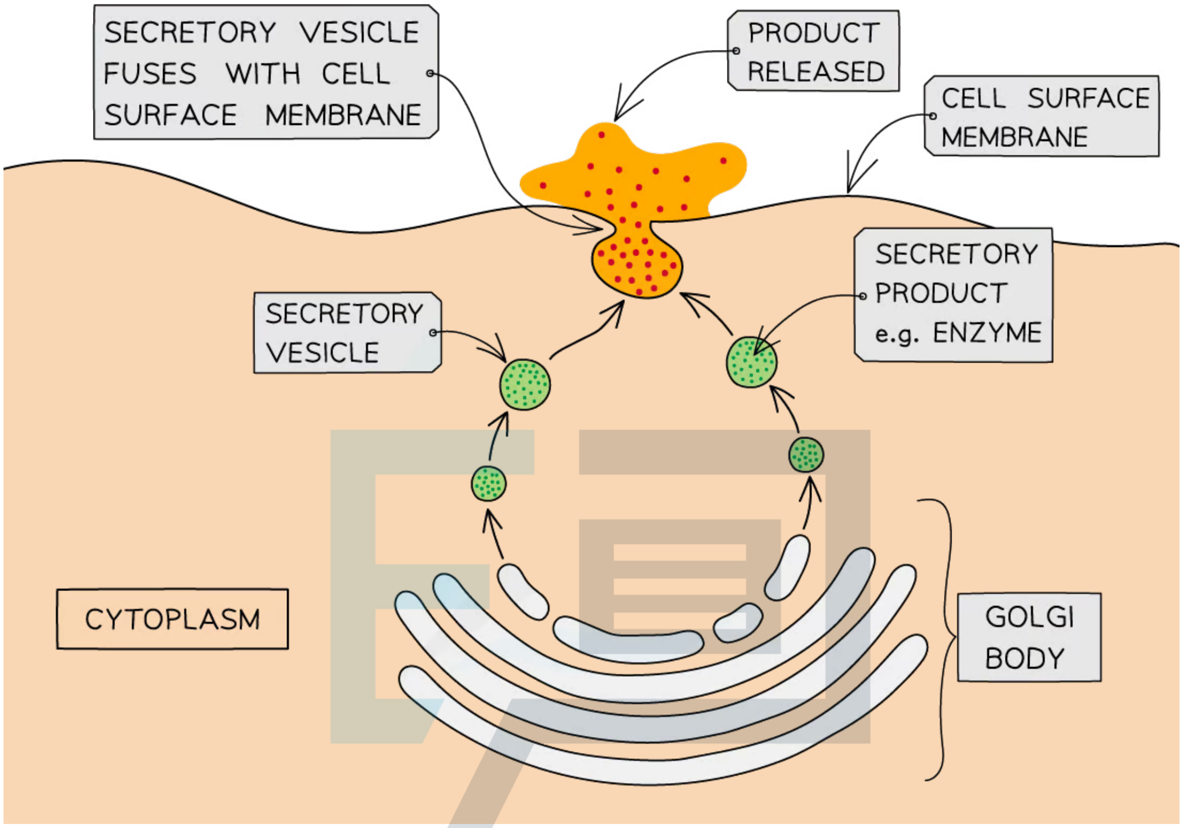


Phagocytosis is an example of endocytosis

Exocytosis

- Exocytosis is the process by which materials are removed from, or transported **out of**, cells
  - It is the **reverse of endocytosis**
- The substances to be released are packaged into **secretory vesicles**
- These vesicles then travel to the cell surface membrane
- Here they **fuse** with the cell membrane and **release their contents** outside the cell
- An example is the secretion of digestive enzymes from pancreatic cells

Exocytosis diagram



Exocytosis involves the fusion of a vesicle with the cell surface membrane

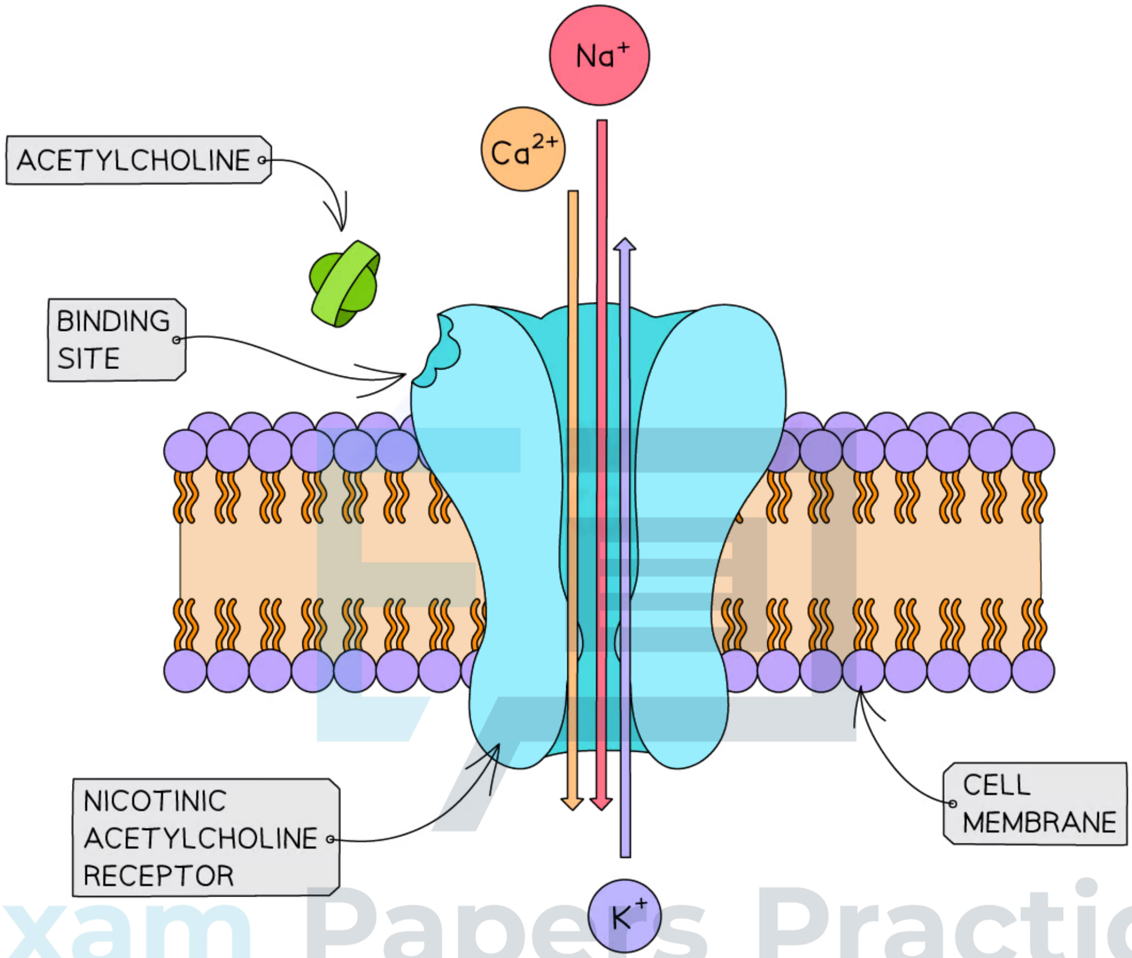
Gated Ion Channels

- Specialised ion channels, called **gated ion channels**, are present in some cell membranes
  - These channels operate in response to **chemical** or **electrical stimuli**

Nicotinic acetylcholine receptors

- Nicotinic acetylcholine receptors are an example of a gated ion channel, more specifically a **neurotransmitter-gated** ion channel
- The neurotransmitter acetylcholine can bind to nicotinic acetylcholine receptors which triggers the **ion channel to open** allowing certain ions, such as calcium (Ca^{2+}) or sodium (Na^{+}), to pass through
- The influx of ions causes the membrane potential to change; this can generate an action potential in neurones
- Nicotinic acetylcholine receptors are found specifically at the **neuromuscular junction**; the point at which nerve cells connect to muscles

Nicotinic acetylcholine receptor diagram

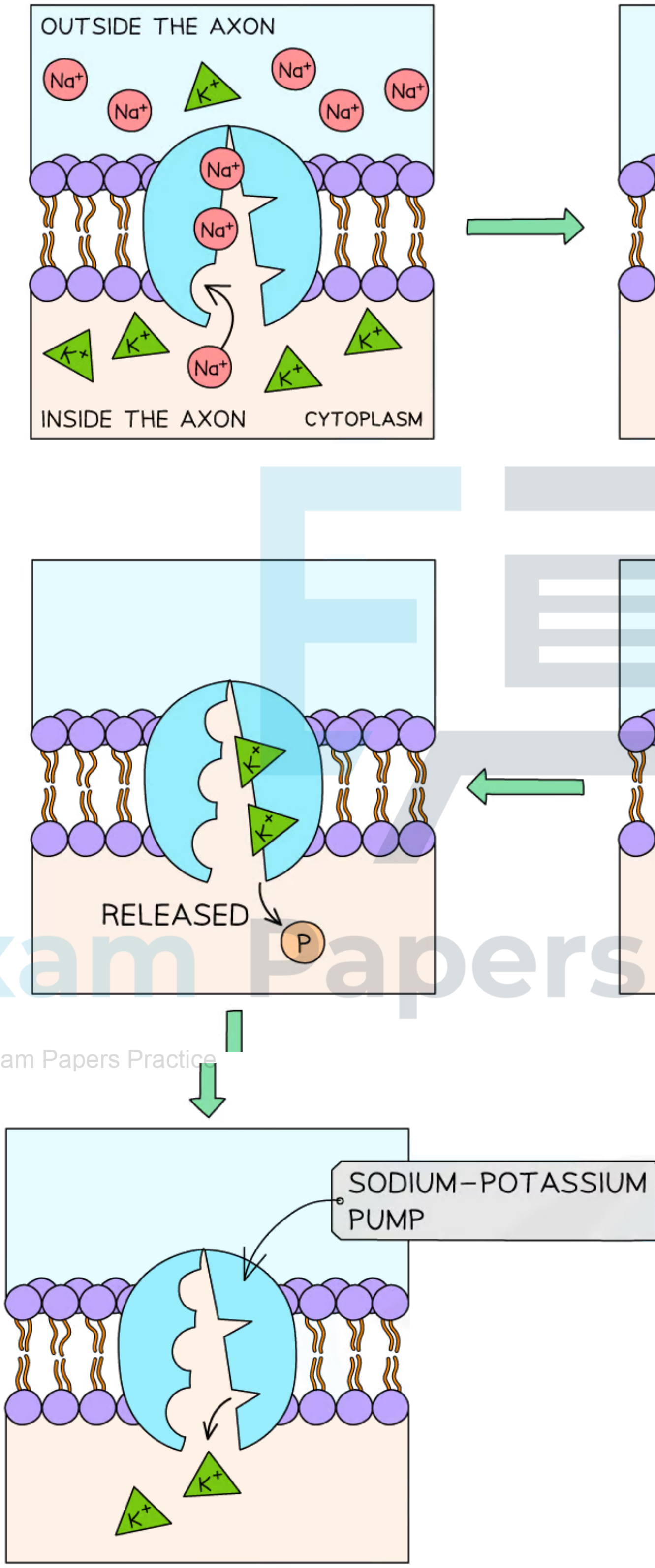


Nicotinic acetylcholine receptors are an example of a gated ion channel

Sodium-Potassium Pumps

- **Sodium-potassium pump** proteins are **integral proteins** that generate an electrochemical gradient between the inside and outside of a nerve cell
- Sodium-potassium pumps are an example of an **exchange transporter**
  - The **sodium-potassium pumps** move **three sodium ions out** of the cell and **two potassium ions into** the cell using **one ATP molecule**
  - The pumps are always moving the ions **against their concentration gradient** via **active transport**
- The steps that occur during the pumping process are:
  1. **Three sodium ions** from the **inside** of the axon **bind** to the **pump**
  2. **ATP attaches** to the **pump** and **transfers** a **phosphate** to the pump (phosphorylation), causing it to change shape and resulting in the pump opening to the outside of the axon
  3. The three **sodium ions** are **released** out of the axon
  4. **Two potassium ions** from **outside** the **axon** enter and **bind** to their sites
  5. The **attached phosphate** is **released** altering the shape of the pump again
  6. The change in shape causes the **potassium ions** to be **released inside** the axon
- This process is essential to the function of nerve cells
  - The sodium-potassium pumps transport more positively charged sodium ions to the outside of the cell than positively charged potassium ions to the inside; the inside of the cell is **therefore negatively charged** in comparison to the outside
  - When nerve cells are stimulated, sodium ion channels open and sodium ions rush in down the electrochemical gradient, **reversing the charge** across the membrane
  - This can lead to the generation of a **nerve impulse**

Sodium-potassium pump diagram



Sodium-potassium pumps use ATP to transport sodium and potassium ions across cell membranes

Glucose Cotransporters

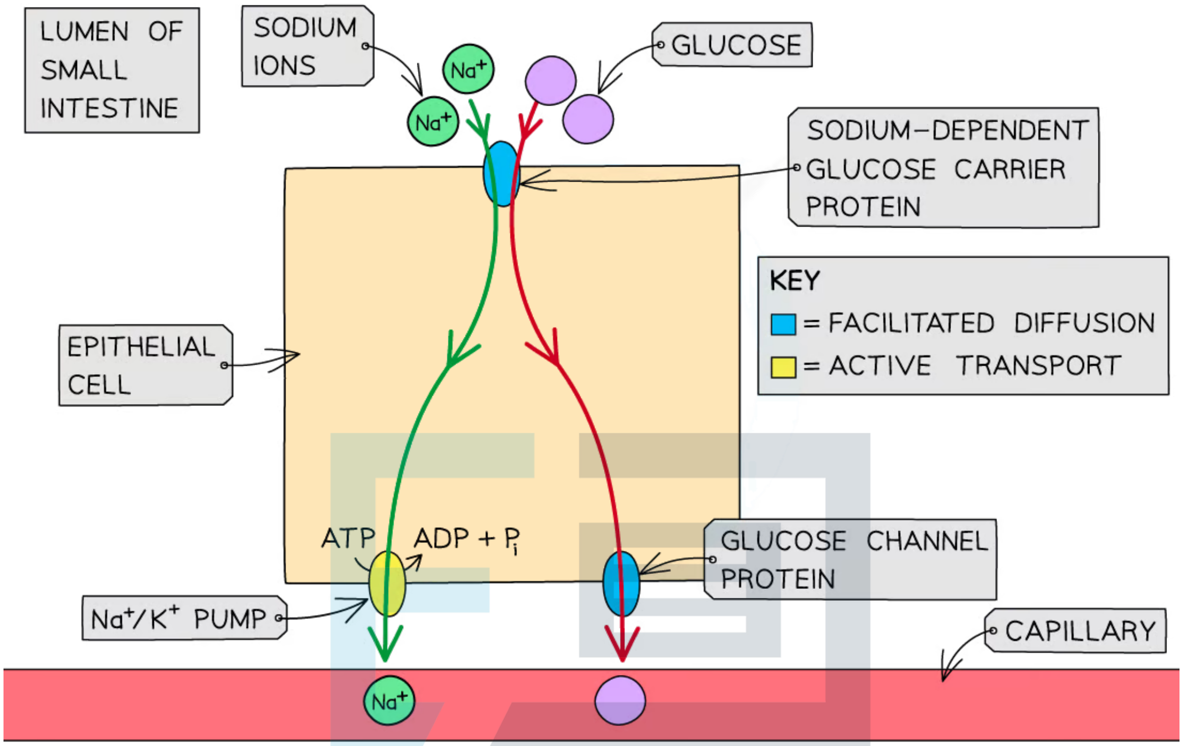
Cotransport & indirect active transport

- Co-transport is the **coupled movement** of substances across a cell membrane via a carrier protein
  - Coupled processes occur at **the same time** and do not occur independently of each other
- Cotransport involves a combination of **facilitated diffusion** and **indirect active transport**
  - Indirect active transport uses the energy released by the movement of one molecule **down** its concentration gradient to move another **against** its concentration gradient
  - ATP is used to set up the initial gradient

Sodium-dependent glucose co-transport

- A well-known example of a co-transporter protein can be found on the cell surface membrane of the epithelial cells lining the mammalian ileum
- This specific **sodium-dependent glucose co-transporter protein** is involved in the absorption of **glucose** into the blood
  1. Sodium-potassium pumps actively transport sodium ions into the blood, **reducing the concentration of sodium ions** in the cell
  2. Sodium ions move **down their concentration gradient** into the cell via a **cotransporter protein**
  3. Glucose is **drawn into the cell along with sodium ions** via the same cotransporter protein
     - Glucose moves against its concentration gradient
  4. Glucose then moves down its concentration gradient into the blood
- The active part of the process is the generation of the initial sodium ion gradient; the transport of glucose itself does not require energy; this is why the process is described as indirect active transport

Co-transport in the small intestine diagram



Both facilitated diffusion and active transport occur during co-transport. Glucose molecules can only enter the epithelial cell when sodium ions are present.

- This process also takes place in the kidney
  - **Reabsorption of glucose** back into the blood is under the control of **sodium-dependent glucose cotransporter proteins**
  - Glucose is **co-transported** with sodium ions in the way described above

Exam Tip

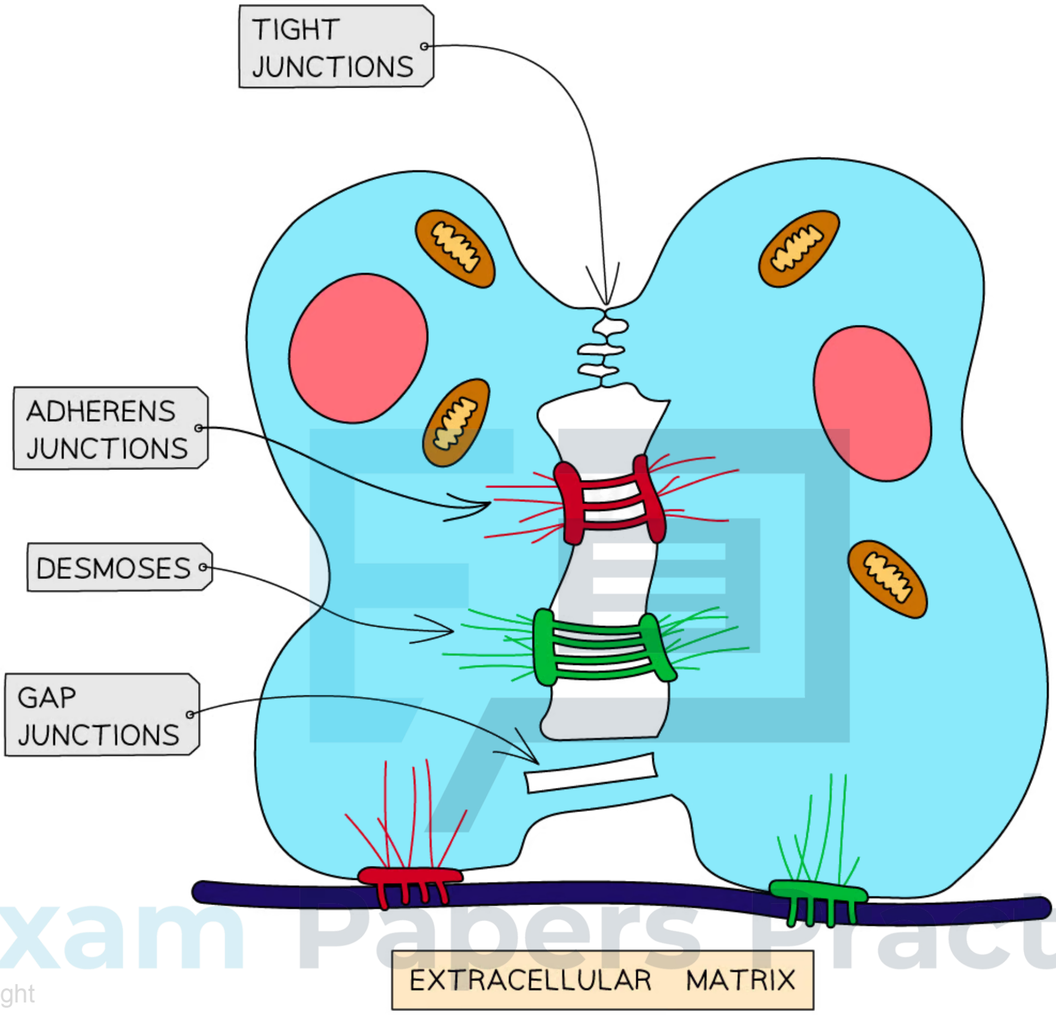
It is worth being aware that the sequence of events in cotransport are sometimes given in a different order; the order above may seem a bit backwards, but it can be helpful to begin with the generation of the sodium gradient, as all the other steps then flow logically

Cell Adhesion (HL)

Cell Adhesion

- In order for an organism to be multicellular, its cells need to **adhere**, or stick, to one another to form **tissues**
- The **plasma membrane** is responsible for cell adhesion and this can be permanent or temporary
- **Cell adhesion molecules (CAMs)** are required to carry out cell adhesion
  - CAMs are a type of **cell surface protein**
  - They work by **binding cells** with **other cells** or with the **extracellular matrix**
    - The extracellular matrix contains supporting structures, such as collagen proteins, and provides support for the cells
  - **Different CAMs** are present in different types of cell-cell junction
- Examples of different cell-cell junctions include:
  - Tight junctions
  - Adherens junctions
  - Desmosomes
  - Gap junctions

Cell adhesion diagram



Cell adhesion involves the binding of CAMs to other cells or to the extra-cellular matrix

Different types of cell-cell junction contain different CAMs