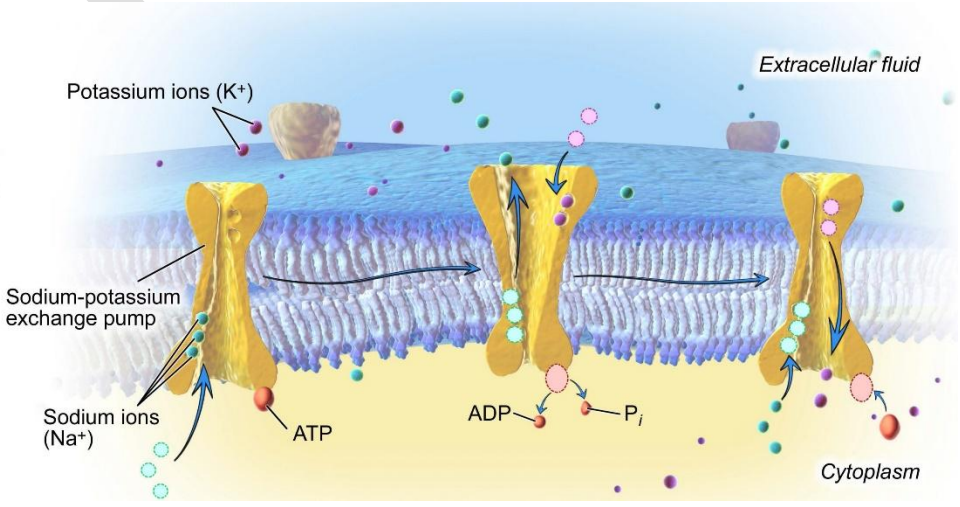
Cambridge AS level Biology

CODE: (9700)

Chapter 04

Cell membranes and transport



Phospholipids

The structure of membranes is based on the structure of phospholipids, which form small bags that allow chemicals to be isolated from the environment. Phospholipid molecules can form polar (hydrophilic) or non-polar (hydrophobic) structures on water surfaces. When shaken with water, they form stable ball-like structures called micelles or bilayers, which are the basic structure of membranes.

Structure of membranes

The phospholipid bilayer, visible under an electron microscope, is composed of hydrophilic heads and a hydrophobic interior. Membranes, about 7nm wide, also contain proteins. In 1972, Singer and Nicolson proposed the **fluid mosaic model,** which describes the movement of both phospholipids and proteins by diffusion. The bilayer has a fluidity like olive oil, with phospholipids moving sideways and some protein molecules remaining fixed to cell structures.

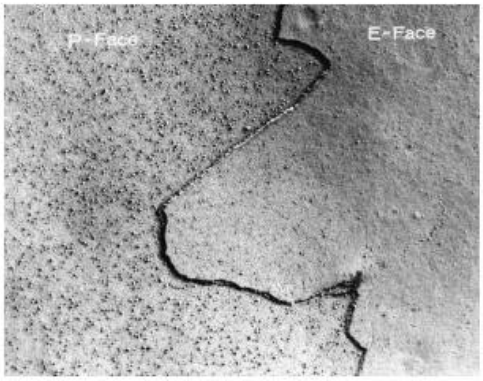


Figure 4.3 Scanning electron micrograph of a cell surface membrane. The membrane has been prepared by freeze-fracturing, which has split open the bilayer. The P-face is the phospholipid layer nearest the inside of the cell and shows the many protein particles embedded in the membrane. The E-face is part of the outer phospholipid layer (×50 000).

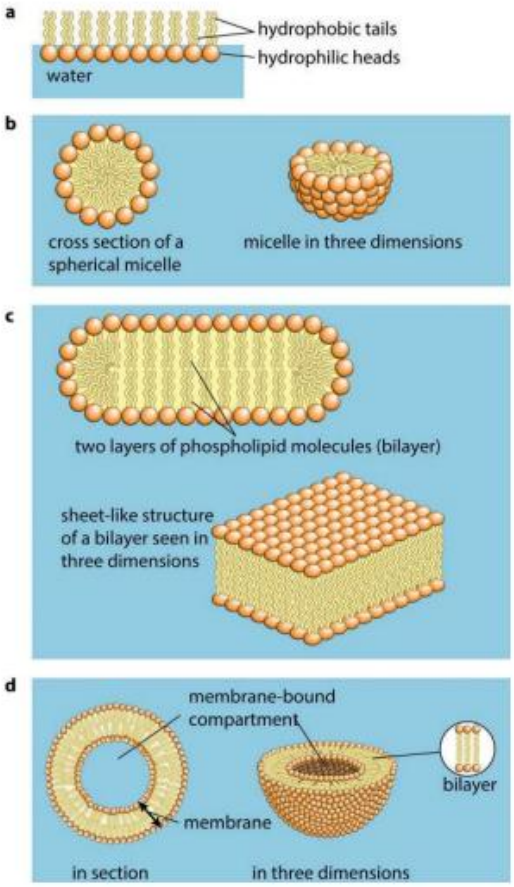


Figure 4.2 Phospholipids in water: **a** spread as a single layer of molecules (a monolayer) on the surface of water **b** forming micelles surrounded by water **c** forming bilayers **d** bilayers forming membrane-bound compartments.

Features of the fluid mosaic model

The membrane is a double layer of phospholipid molecules, with phospholipid tails facing each other, forming a non-polar hydrophobic interior. Some are saturated, while others are unsaturated, making the membrane more fluid due to their loose fit.

The longer the tail, the less fluid the membrane. As temperature decreases, membranes become less fluid, but some organisms which cannot regulate their own temperature.

Two types of protein are recognised, according to their position in the membrane.

Proteins that are found embedded within the membrane, such as those in Figure 4.5, are called **intrinsic proteins (or integral proteins).** Intrinsic proteins may be found in the inner layer, the outer layer or, most commonly, spanning the whole membrane, in which case they are known as **transmembrane proteins.**

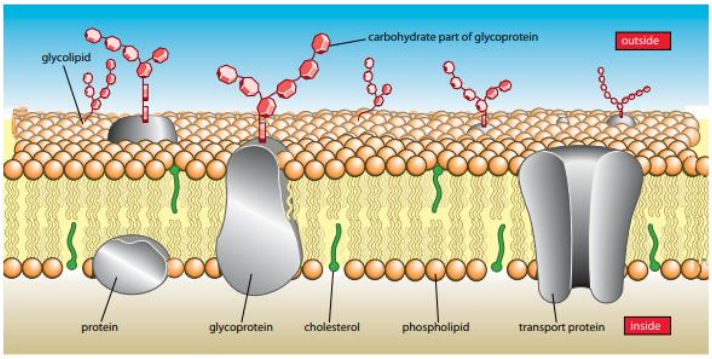


Figure 4.4 An artist's impression of the fluid mosaic model of membrane structure.

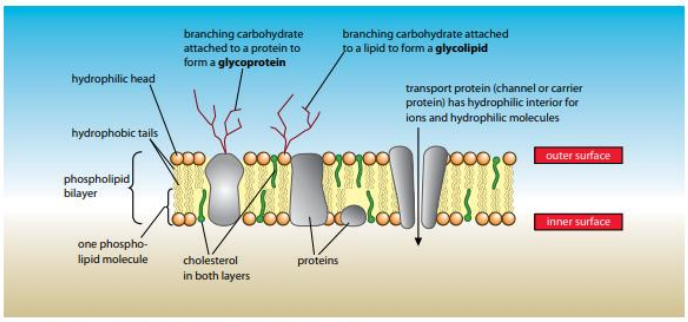


Figure 4.5 Diagram of the fluid mosaic model of membrane structure.

A second type of protein molecule is the **extrinsic protein (or peripheral protein).** These are found on the inner or outer surface of the membrane. Many are bound to intrinsic proteins. Some are held in other ways – for example, by binding to molecules inside or outside the cell, or to the phospholipids.

Roles of the components of cell membranes

Cell membranes consist of various molecule types, including lipids like phospholipids, cholesterol, and glycolipids, proteins, and glycoproteins, each with specific roles in membrane structure and function.

Phospholipids

Phospholipids form the membrane's bilayer, acting as a barrier to water-soluble substances like sugars, amino acids, and proteins. They can be modified chemically to act as signaling molecules, activating enzymes or releasing small, water-soluble molecules that bind to specific receptors. This results in the release of calcium ions from the ER, leading to exocytosis of digestive enzymes.

Cholesterol

Cholesterol is a small molecule with hydrophilic heads and hydrophobic tails, like phospholipids. It is found in animal cell surface membranes and less common in plant cell membranes. Cholesterol increases membrane fluidity at low temperatures, preventing rigidity and stabilizing cells at higher temperatures. It is also crucial for mechanical stability, as without it, membranes can break, and cells burst open. It prevents ions and polar molecules from passing through the membrane.

Glycolipids, glycoproteins and proteins

Cell surface membranes contain lipid and protein molecules with short carbohydrate chains, known as glycolipids and glycoproteins. These chains stabilize membrane structure by forming hydrogen bonds with water molecules and forming a sugary coating, known as **glycocalyx**.

The carbohydrate chains help the glycoproteins and glycolipids to act as **receptor molecules,** which bind with substances at the cell surface.

Some glycolipids and glycoproteins act as cell markers or **antigens**, allowing cell–cell recognition.

Many proteins act as **transport proteins.** These provide hydrophilic channels or passageways for ions and polar molecules to pass through the membrane. There are two types of transport protein: **channel proteins** and **carrier proteins.**

Other membrane proteins may be **enzymes** – for example, the digestive enzymes found in the cell surface membranes of the cells lining the small intestine. These catalyse the hydrolysis of molecules such as disaccharides.

Cell signaling

Cell signaling is a crucial area of modern biology, focusing on the control and coordination of living organisms. It involves receiving a stimulus, transmitting the message, and responding appropriately. This process is essential for cells to respond appropriately to their environments. Signaling pathways, which are complex and shared across all living organisms, involve a range of activities, including transduction, which involves crossing barriers like cell surface membranes. Signaling molecules are typically small for easy transport.

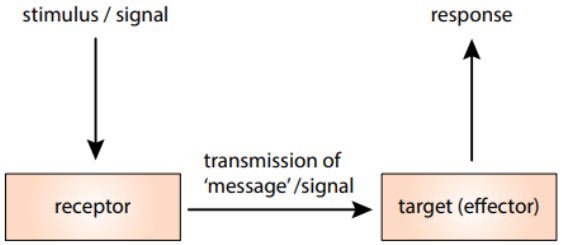


Figure 4.6 Basic components of a signalling pathway.

Besides examples involving second messengers, there are three other basic ways in which a receptor can alter the activity of a cell:
■opening an ion channel, resulting in a change of membrane potential.

■Acting directly as a membrane-bound enzyme (e.g. insulin receptor)

■ Acting as an intracellular receptor when the initial signal passes straight through the cell surface membrane. For example, the oestrogen receptor is in the nucleus and directly controls gene expression when combined with oestrogen.

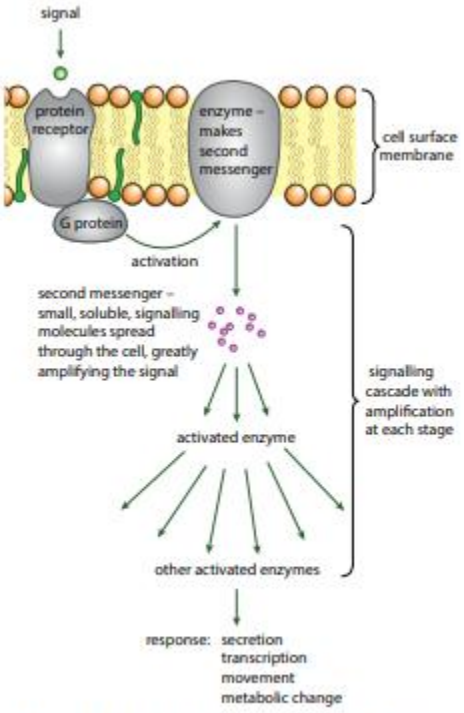


Figure 4.7 A simplified cell signalling pathway involving a second messenger.

Movement of substances into and out of cells

Phospholipid bilayer around cells acts as a barrier against water-soluble molecules and ions, preventing cell aqueous contents from escaping. Exchange between cells and environment is essential.

Diffusion

Diffusion can be defined as the net movement, because of random motion of its molecules or ions, of a substance from a region of its higher concentration to a region of its lower **concentration**. The molecules or ions move down a concentration **gradient**.

The rate at which a substance diffuses across a membrane depends on several factors, including the following

■ The '**steepness'** of the concentration gradient - The 'steepness' of the concentration gradient refers to the difference in the concentration of a substance on two surfaces. A higher concentration gradient results in more molecules moving randomly from one side, accelerating diffusion.

■ Temperature - At high temperatures, molecules and ions have much more kinetic energy than at low temperatures. They move around faster, and thus diffusion takes place faster.

■ The surface area - The surface area of a cell determines the speed of diffusion, with larger surfaces allowing more molecules or ions to cross at once. Cell membranes can be increased through folding, while larger cells have smaller surface areas relative to volume.

■ The nature of the molecules or ions - large molecules diffuse slower due to energy requirements, while non-polar molecules like glycerol, alcohol, and hormones diffuse easily through cell membranes. Respiratory gases like oxygen and carbon dioxide cross membranes through diffusion, while water molecules can diffuse rapidly due to their small size.

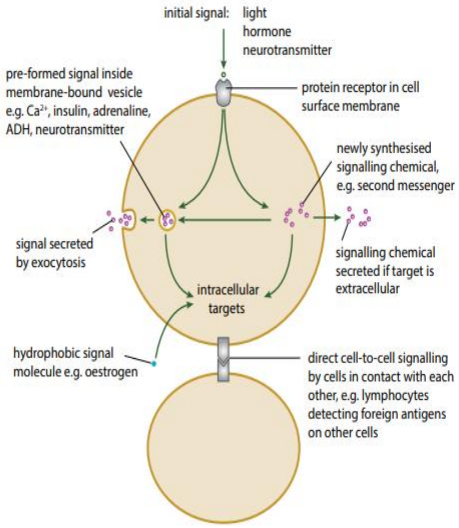


Figure 4.8 A few of the possible signalling pathways commonly found in cells. Note the role of membranes in these pathways.

Facilitated diffusion

Facilitated diffusion occurs when large polar molecules, ions, and certain protein molecules cross the membrane, preventing diffusion of glucose, amino acids, sodium, and chloride.

There are two types of protein involved, namely **channel proteins** and **carrier proteins**. Each is highly specific, allowing only one type of molecule or ion to pass through it.

Osmosis

Osmosis is a special type of diffusion involving water molecules only. In the explanations that follow, remember that:

solute + solvent = solution

In a sugar **solution**, for example, the **solute** is sugar, and the **solvent** is water. In Figure 4.10 there are two solutions separated by a **partially permeable membrane**. This is a membrane that allows only certain molecules through, just like membranes in living cells. In the situation shown in Figure 4.10a, solution B has a higher concentration of Solute molecules than solution **A**. Solution **B** is described as more **concentrated** than solution A, and solution A as more **dilute** than solution **B**.

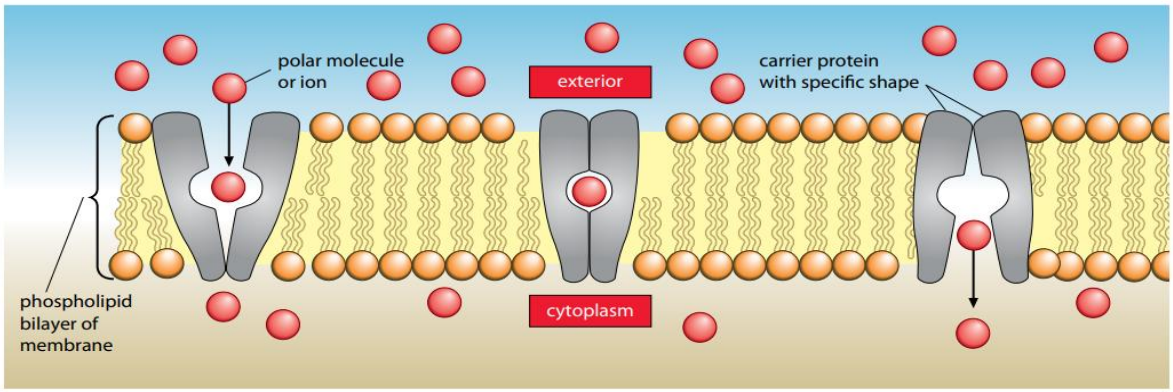


Figure 4.9 Changes in the shape of a carrier protein during facilitated diffusion. Here, there is a net diffusion of molecules or ions **into** the cell down a concentration gradient.

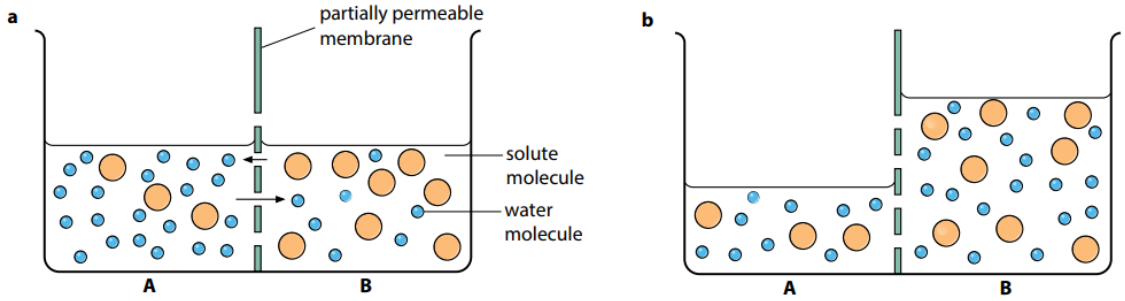


Figure 4.10 Two solutions separated by a partially permeable membrane. **a** Before osmosis. The solute molecules are too large to pass through the pores in the membrane, but the water molecules are small enough. **b** As the arrows show, more water molecules moved from A to B than from B to A, so the net movement has been from A to B, raising the level of solution in B and lowering it in A.

In a solution without a membrane, solute and water molecules would move randomly, spreading evenly. However, when a partially permeable membrane is present, solute molecules cannot pass through, leaving only water molecules. Over time, water molecules spread more evenly between solutions, resulting in concentrated solutions with fewer water molecules in A and more concentrated solutions with more water molecules in B. This process is known as osmosis, where the volume of liquid in B increases due to the increased water molecules.

Water potential

The term water potential is very useful when considering osmosis. The Greek letter psi, ψ, can be used to mean water potential. You can think of water potential as being the tendency of water to move out of a solution. This depends on two factors:

- How much water the solution contains in relation to solutes, and
- How much pressure is being applied to it.

Solute potential and pressure potential

The contribution of the concentration of the solution to water potential is called **solute potential.**

The contribution of pressure to the water potential of a solution is called **pressure potential.**

Osmosis in animal cells

Figure 4.12 illustrates the impact of osmosis on animal cells, particularly red blood cells. The cell's swelling and burst behavior depends on the water potential surrounding it, highlighting the importance of maintaining a constant water potential within animals' bodies.

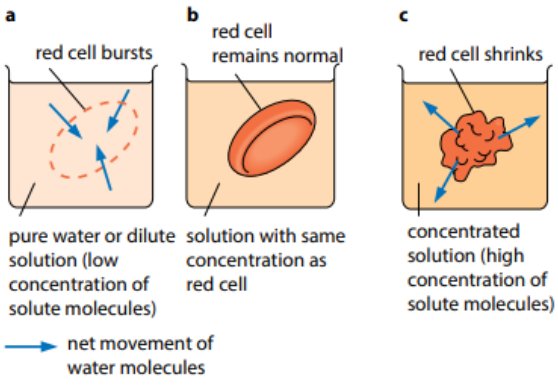


Figure 4.12 Movement of water into or out of red blood cells by osmosis in solutions of different concentration.

Osmosis in plant cells

Plant cells have strong, rigid cell walls, unlike animal cells. When placed in water or a dilute solution, water enters the cell through osmosis, increasing its volume. The cell wall pushes back against the protoplast, increasing pressure potential and water potential. This

inelastic structure prevents cell burst, unlike animal cells. When fully turgid, water potential is a combination of solute and pressure potential.

When a plant cell is fully inflated with water it is described as fully **turgid**. For plant cells, then, water potential is a combination of solute potential and pressure potential. This can be expressed in the following equation:

$$\psi = \psi_s + \psi_p$$

In such a solution, water will **leave** the cell by osmosis

As the protoplast continues to shrink, it begins to pull away from the cell wall (Figure 4.14). This process is called **plasmolysis**, and a cell in which it has happened is said to be **plasmolyzed** (Figures 4.13c and 4.14). The point at which pressure potential has just reached zero and plasmolysis is about to occur is referred to as **incipient plasmolysis**.

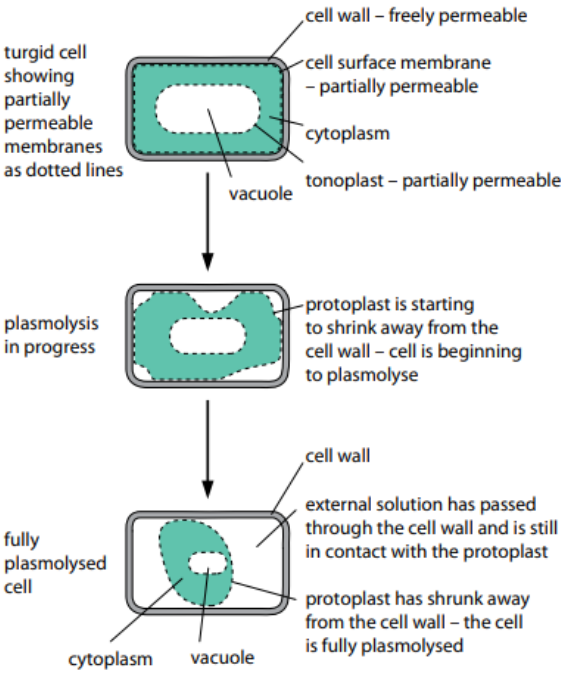


Figure 4.14 How plasmolysis occurs.

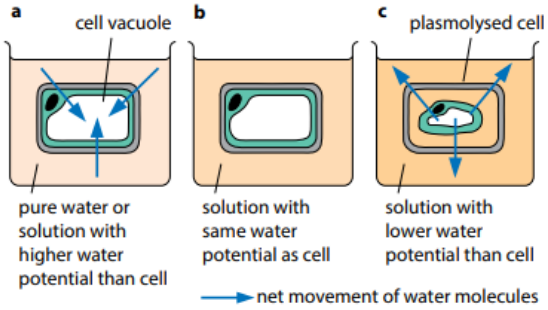


Figure 4.13 Osmotic changes in a plant cell in solutions of different water potential.

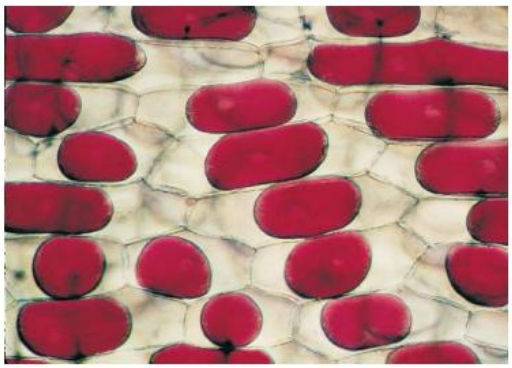


Figure 4.15 Light micrograph of red onion cells that have plasmolysed (×100).

Active transport

Ion concentration in cells is typically 10-20 times higher inside than outside, creating a concentration gradient. This gradient is not due to diffusion, as ions initially come from external solutions. Instead, they accumulate **against** this gradient, indicating that ions must diffuse from high to low concentration.

The process responsible is called **active transport.**

Active transport in cells involves carrier proteins that change shape to transfer molecules or ions across the membrane. Energy is supplied by ATP, produced during respiration, which makes the carrier protein change shape. An example is the sodium-potassium pump, found in all animal cells and using 30% of a cell's energy. The pump pumps three sodium ions out of the cell and allows two potassium ions in, creating a potential difference across the membrane**.**

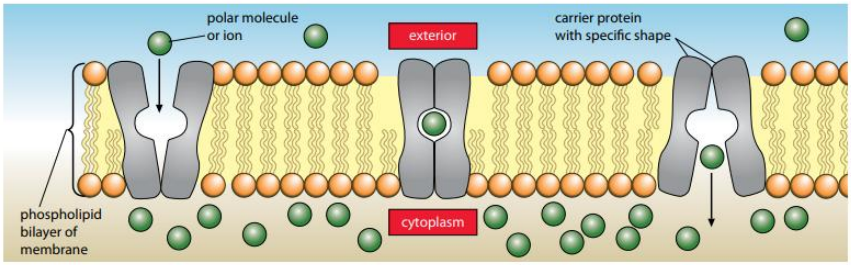


Figure 4.17 Changes in the shape of a carrier protein during active transport. Here, molecules or ions are being pumped into the cell **against** a concentration gradient. (Compare Figure 4.9.)

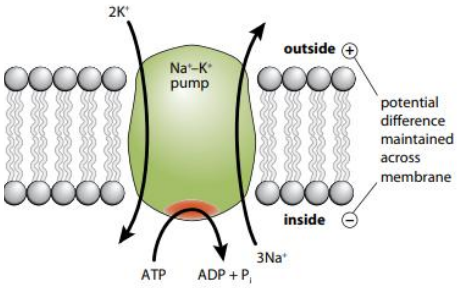


Figure 4.18 The $Na^+ - K^+$ pump.

Bulk transport

So far, we have been looking at ways in which **individual** molecules or ions cross membranes. Mechanisms also exist for the bulk transport of large quantities of materials into cells (**endocytosis**) or out of cells (**exocytosis**).

Endocytosis involves the engulfing of the material by the cell surface membrane to form a small sac, or 'endocytic vacuole'. It takes two forms.

■Phagocytosis or 'cell eating' – this is the bulk uptake of solid material. Cells specializing in this are called phagocytes. Th e process is called phagocytosis and the vacuoles phagocytic vacuoles.

■Pinocytosis or 'cell drinking' – this is the bulk uptake of liquid. Th e vacuoles (vesicles) formed are often extremely small, in which case the process is called micropinocytosis.

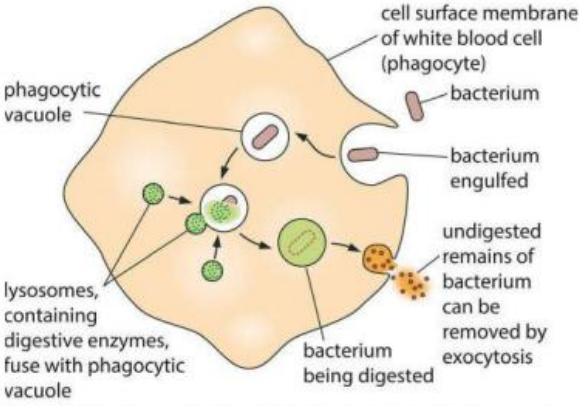


Figure 4.19 Stages in phagocytosis of a bacterium by a white blood cell.

Exocytosis, the reverse of endocytosis, removes materials from cells, such as secreting digestive enzymes from pancreas cells. It involves secretory vesicles from the Golgi body.

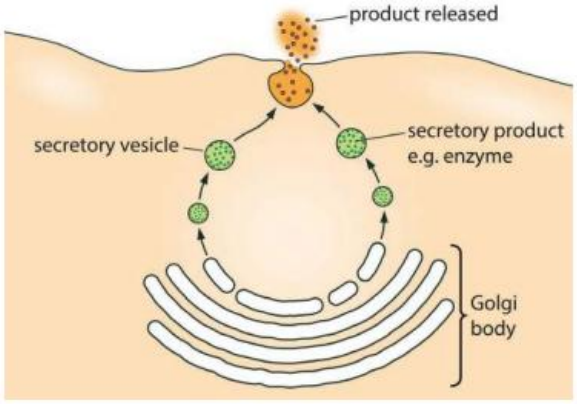


Figure 4.20 Exocytosis in a secretory cell. If the product being secreted is a protein, the Golgi body is often involved in chemically modifying the protein before it is secreted, as in the secretion of digestive enzymes by the pancreas.

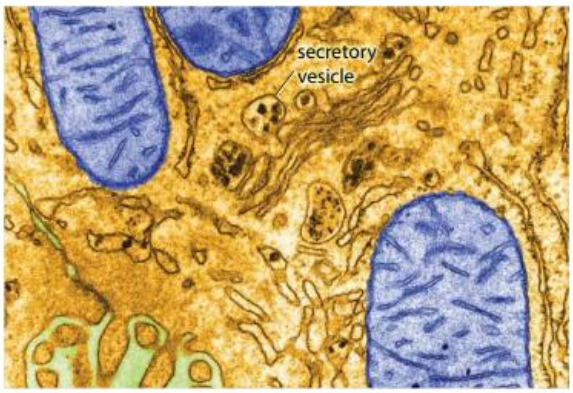


Figure 4.21 Transmission electron micrograph of pancreatic acinar cell secreting protein. The outside of the cell is coloured green. Golgi (secretory) vesicles with darkly stained contents can be seen making their way from the Golgi body to the cell surface membrane.

Revision questions

(1) Fig. 5.1 shows a section of a cell surface membrane.

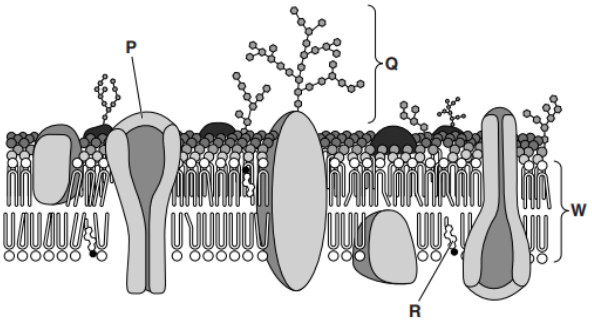


Fig. 5.1

(a) State the functions of structures P, Q and R.

(b) Membranes, such as the cell surface membrane, are described as having a fluid mosaic structure.

Explain what is meant by the term *fluid mosaic.*

(c) Aquaporins are membrane channel proteins in plant and animal cells. They permit the movement of water across membranes. Explain why they are necessary.

(2) Fig. 2.1 is a diagram of the structure of a protein channel for ions in a cell surface membrane.

Fig. 2.1a shows the channel when open and Fig. 2.1b shows the same channel when closed.

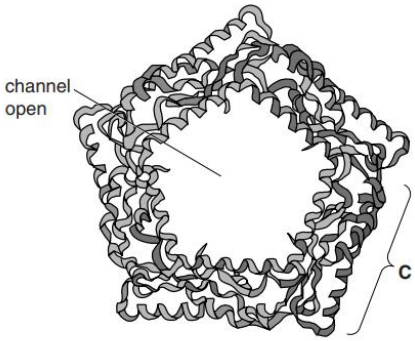


Fig. 2.1a

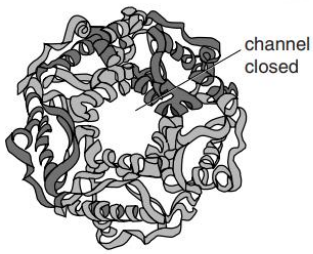


Fig. 2.1 b

(a) (i) Name the process by which ions pass across the membrane using channel proteins.

(ii) Explain why a channel protein is needed for ions to pass across a cell membrane.

(b) The channel protein in Fig. 2.1 is made from five identical polypeptide chains.

(i) Name the level of protein structure which is present when five polypeptide chains form the protein.

(ii) The part labelled C in Fig. 2.1 is another level of protein structure. Name this level.

(c) Channel proteins are examples of transmembrane proteins. The polypeptides are held together and interact with phospholipids in the membrane.

Suggest how the polypeptides are held together and suggest how they interact with phospholipids

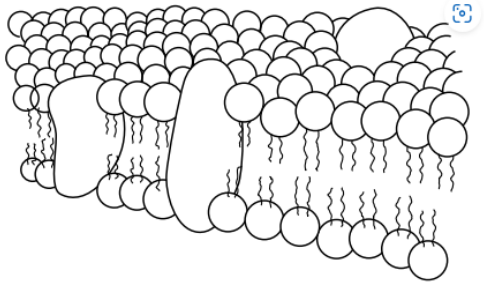


Fig. 6.1

(3) Fig. 6.1 shows an incomplete diagram of the fluid mosaic model of membrane structure. The diagram shows the cell surface membrane of a eukaryotic cell.

a) State what is meant by the term fluid mosaic.

(b) State the thickness of a cell surface membrane.

(c) List four features of cell surface membranes of eukaryotic cells that are not visible in Fig. 6.1.

(4)Human prolactin (hPRL) is a globular protein. It is a single polypeptide composed of 199 amino acids. The protein is transported in the bloodstream and has an effect only on cells that have a cell surface membrane protein known as PRLR.

One effect of hPRL is to stimulate cells in the mammary glands to produce breast milk. Cells that have been stimulated by hPRL need more glucose and therefore the passive uptake of glucose increases.

(a) State one reason why the cells in the mammary glands that have been stimulated by hPRL need more glucose.

(b) An experiment was carried out to investigate the movement of glucose and hPRL across Visking tubing membrane.

A short section of Visking tubing, tied at both ends and containing distilled water, was placed into a beaker containing a solution of glucose and hPRL.

After 20 minutes, separate samples of the solution in the Visking tubing and the solution in the beaker were each tested for the presence of protein and reducing sugar.

A summary of the methods used, the experimental results and the deductions made are shown in Table 5.1

sample	method used	colour obtained after testing	deduction
solution in Visking tubing	biuret solution added to sample		protein absent from solution in Visking tubing
solution in beaker			protein present in solution in beaker
solution in Visking tubing	Benedict's solution added to sample and mixture heated in a water-bath		reducing sugar present in solution in Visking tubing
solution in beaker			reducing sugar present in solution in beaker

(i) Complete the column in Table 5.1 headed colour obtained after testing.

(ii) With reference to the deductions made in Table 5.1, explain the movement of hPRL and reducing sugar across Visking tubing membrane.

(c) Outline how glucose crosses the cell surface membranes of the cells of the mammary glands.

(5) Fig. 1.1 is an electron micrograph of part of a eukaryotic cell.

(a) State how it is possible to deduce that Fig. 1.1 is a transmission electron micrograph and not a scanning electron micrograph.

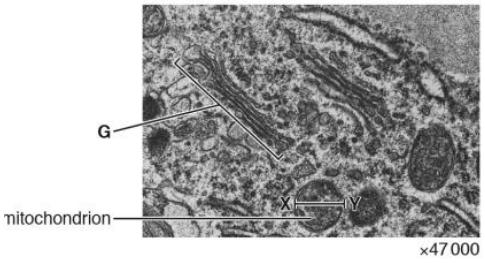


Fig. 1.1

(b) Both the Golgi body and the rough endoplasmic reticulum are part of the internal network of membranes in cells.Outline structural features shown in Fig. 1.1 that identify G as the Golgi body and not the rough endoplasmic reticulum.

(c) Calculate the actual diameter, X-Y, of the mitochondrion labelled in Fig. 1.1.

Write down the formula that you will use to make your calculation. Give your answer to the nearest whole nanometre (nm).

(6) Fig. 6.1 shows an incomplete diagram of the fluid mosaic model of membrane structure. The diagram shows the cell surface membrane of a eukaryotic cell.

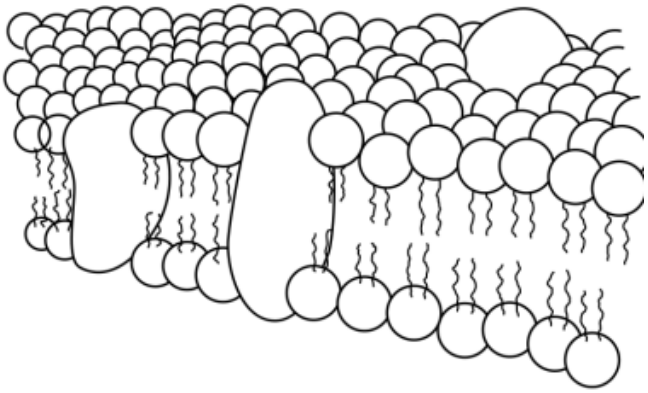


Fig. 6.1

(a) State what is meant by the term fluid mosaic.

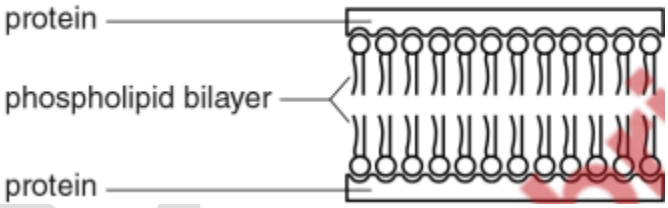
(b) State the thickness of a cell surface membrane.

(c) List four features of cell surface membranes of eukaryotic cells that are not visible in Fig. 6.1.

(7) The cell surface membrane has a fluid mosaic structure.

(a) Describe what is meant by the term fluid mosaic.

(b) In 1934, the biologists Davson and Danielli published their suggestion for the structure of the cell surface membrane, as shown in Fig. 1.1.



They suggested that the membrane was a phospholipid bilayer with a layer of hydrophilic protein on both surfaces.

State one way in which the Davson-Danielli structure is similar to the fluid mosaic structure and one way in which it differs from the fluid mosaic model.

(c) One way in which substances can cross cell membranes is by active transport.

Describe the mechanism of active transport.

(d) High temperature can damage cell membranes. One factor contributing to this damage is the denaturation of membrane proteins.

Describe how proteins become denatured at high temperature and explain how this could lead to damaging cell membranes.