CORE IDEA 1: THE CELL AND BIOMOLECULES OF LIFE
TOPIC 1.4: MEMBRANES & CELLULAR TRANSPORT

Learning Outcomes

You should be able to:

(j) explain the fluid mosaic model and the roles of the constituent biomolecules (including phospholipids, proteins, glycolipids, glycoproteins and cholesterol) in cell membranes

(k) outline the functions of membranes at the surface of cells and membranes within the cell

(l) explain how and why different substances move across membranes through simple diffusion, osmosis, facilitated diffusion, active transport, endocytosis and exocytosis

Textbooks and References

Campbell, Urry, Cain, Wasserman, Minorsky, Reece (2018) **Biology – A Global Approach (11th Edition)(Global Edition) Chapter 8: Cell Membranes pg. 196 – 211** (Pearson Publication) ISBN-10 1-292-17043-3

Note: This textbook is available in our library. You may wish to borrow them to supplement your reading when necessary.

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Introduction

The following question should help you frame your learning:

1. How do cells regulate the movement of substances into and out of themselves, and what are the implications of such movements?

Biomolecules make up cells and cells regulate many cellular processes, including the movement of substances into and out of themselves, through membranes.

Phospholipids, cholesterol, carbohydrates and proteins are important components in biological membranes. Cells need to regulate the movement of substances into and out of themselves. Substances such as water, oxygen, glucose and minerals are important in the synthesis of new molecules and important cellular processes.

According to the fluid mosaic model, cell membranes are partially permeable due to the nature of the phospholipids and proteins from which they are made. The movement of different molecules depends on the nature of the substances through transport processes such as osmosis, diffusion and active transport. Membranes allow cells to create and maintain internal environments that are different from external environments.

Learning Outcome (j):

Explain the fluid mosaic model and the roles of the constituent biomolecules (including phospholipids, proteins, glycolipids, glycoproteins and cholesterol) in cell membranes

1.1 Fluid mosaic model of membrane structure

Practices of Science

- As early as 1915 scientists were aware that the structure of membranes isolated from cells included proteins and lipids.

- Early theories were mostly concerned with phospholipids forming a bilayer with proteins, forming thin layers on the exterior and interior of the bilayer.

- The Davson–Danielli model, proposed by Hugh Davson and James Danielli in 1935, used this lipid bilayer model, suggesting there was a thin layer of globular protein on both sides.

- In 1972, Seymour J. Singer and Garth L. Nicolson proposed that proteins are inserted into the phospholipid bilayer and do not form a layer on the phospholipid bilayer surfaces.

- There were several reasons why Singer and Nicolson proposed a model that was different from the Davson–Danielli model:

    - Not all membranes are identical or symmetrical, as the first model implied.

    - Membranes with different functions also have a different composition and different structure, as can be seen with an electron microscope.

    - A protein layer is not likely because it is largely non-polar and would not interface with water, as shown by cell studies.

- Much of the evidence used to change the Davson–Danielli model was gathered with the use of the electron microscope.

- Since 1972 further evidence has been gathered about membranes, and slight changes to the Singer–Nicolson model have been made.

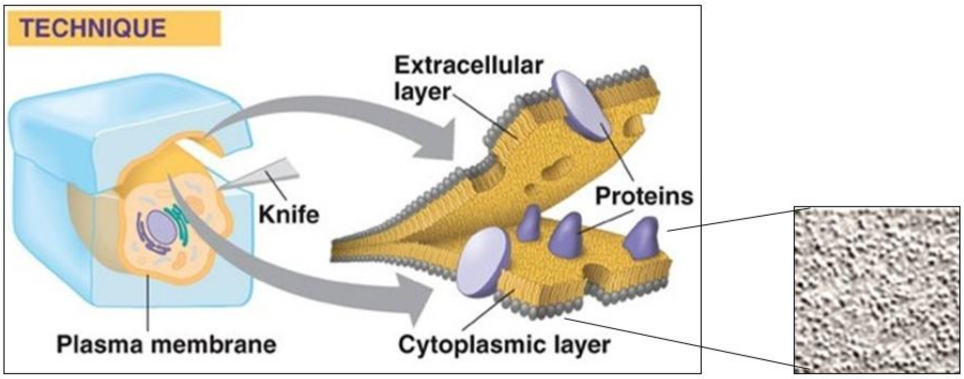


Fig. 1.1.1 Freeze-Fracture of Phospholipid Bilayer

This demonstrates that scientific knowledge is reliable and durable, yet subject to revision in the light of new evidence.

- The current agreed model for the cellular membrane is the **fluid mosaic model**.

- All cellular membranes, whether cell surface membrane or organelle membranes, have the same general structure.

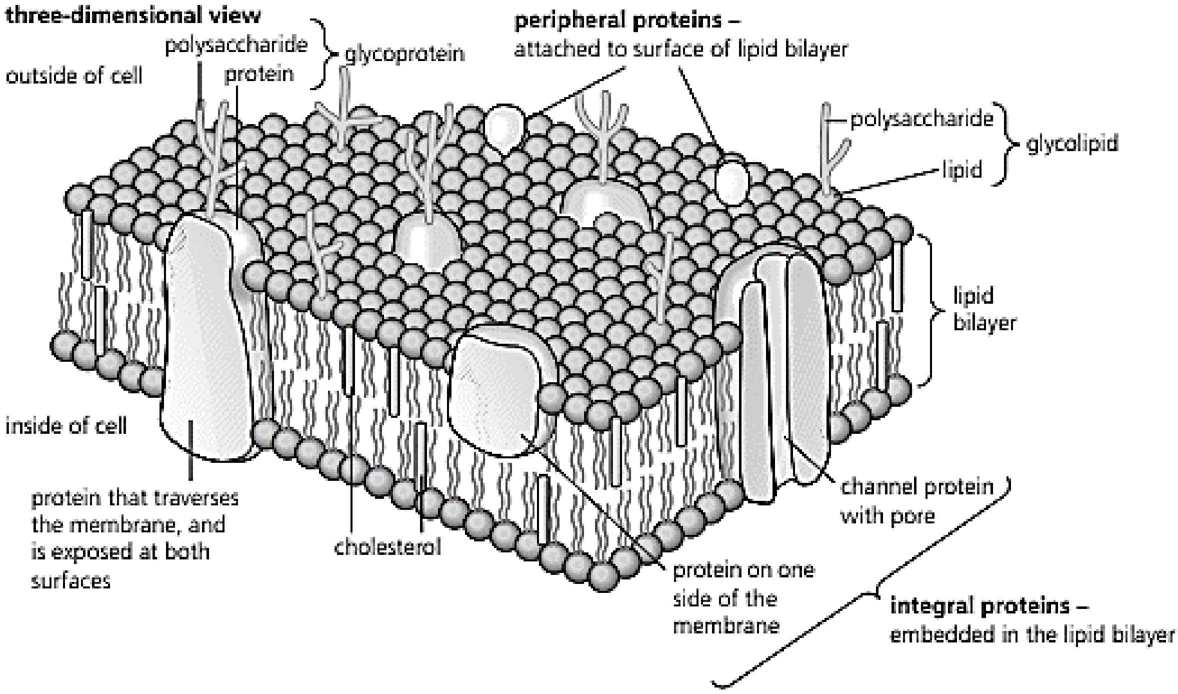


Fig. 1.1.2 The Fluid Mosaic Model of Cell Membrane

- The cell surface membrane is made almost entirely of protein and lipid, together with a small and variable amount of carbohydrate.

- The cell surface membrane is described as **fluid** because:

  - **phospholipid** molecules are capable of **rapid lateral and rotational** ("flip-flop") **movement** within the monolayer, as they are held together only by relatively weak hydrophobic interactions.

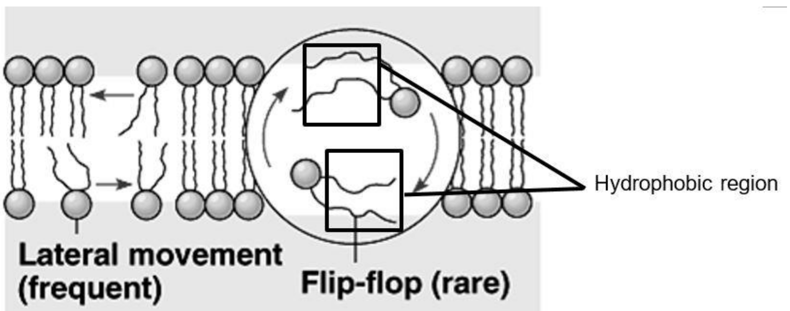


Fig. 1.1.3 Lateral and flip-flop movement of phospholipids in the membrane

  - **membrane proteins** can also **move slowly** although most are immobile due to anchorage to cytoskeleton.

A group of enzymes called flippase, floppase and scramblase catalyses the lateral and rotational movement.

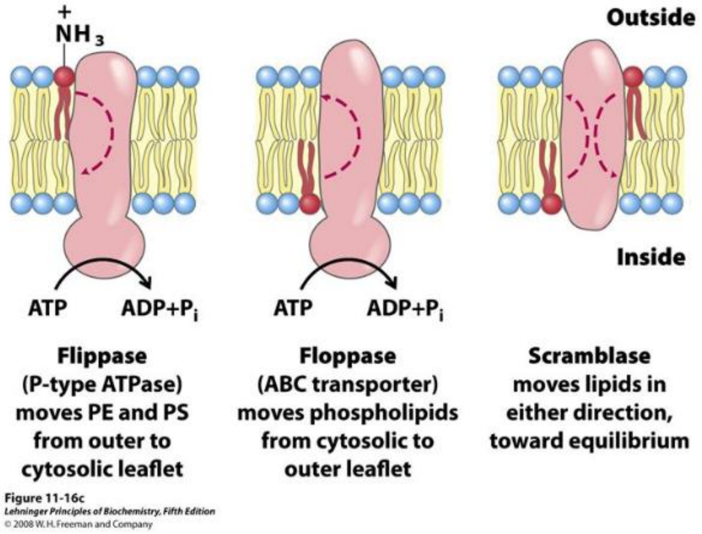


Fig. 1.1.4 Flippase, floppase and scramblase

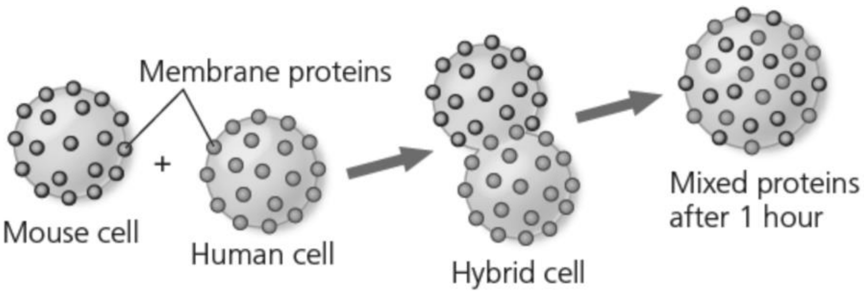
PE: Phosphatidylethanolamines (PE) are a class of phospholipids found in biological membranes. PE are found in the inner (cytoplasmic) leaflet of the lipid bilayer.

PS: Phosphatidylserine (PS) is a phospholipid and is a component of the cell membrane.

ABC transporter: The ATP-binding cassette transporters (ABC transporters) consist of multiple subunits, one or two of which are transmembrane proteins and one or two of which are membrane-associated ATPases. The ATPase subunits utilize the energy of adenosine triphosphate (ATP) binding and hydrolysis to provide the energy needed for the translocation of substrates across membranes, either for uptake or for export of the substrate.

Experiment: Larry Frye and Michael Edidin, at Jonhn Hopkins University, labelled the cell surface membrane proteins of a mouse cell and a human cell with two different green and red fluorescent dyes. The two cell types were fused to form a hybrid cell with a continuous membrane. Using a microscope, they observed the labelled proteins on the hybrid cell and found that the hybrid cell membrane had initially distinct regions of green and red dye.

Results:



In less than an hour, the two colours were intermixed.

Conclusion: The mixing of the mouse and human membrane proteins indicates that at least some membrane proteins move sideways within the plane of the cell surface membrane.

- The cell surface membrane is also described as **mosaic** because:
    - the proteins of various sizes are **randomly embedded in or attached** to the bilayer.
    - the phospholipid composition differs in the 2 monolayers - **asymmetrical distribution**.

1.2 Roles of the constituent biomolecules in membrane

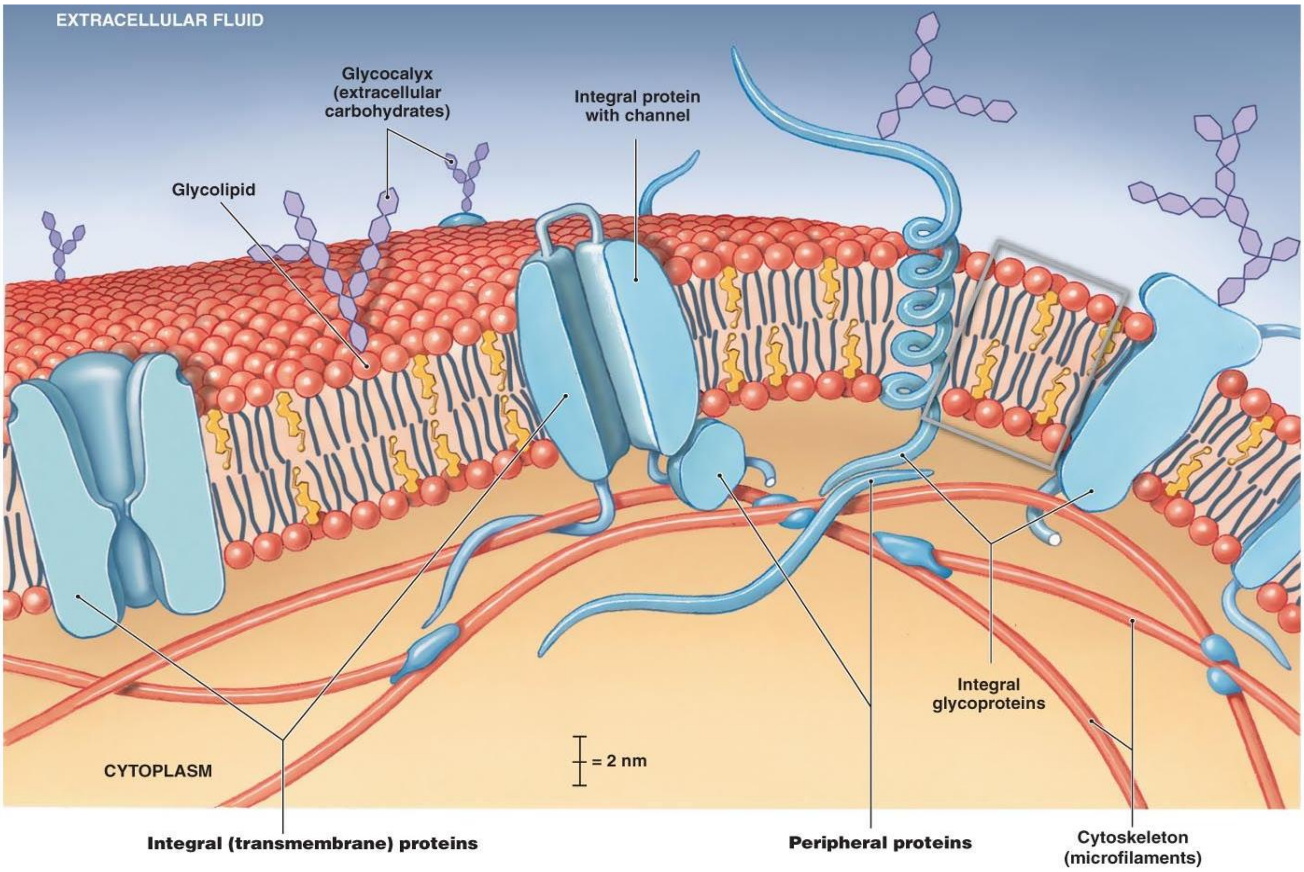


Fig. 1.2.1 Biomolecules in membrane

1.2.1 Phospholipids

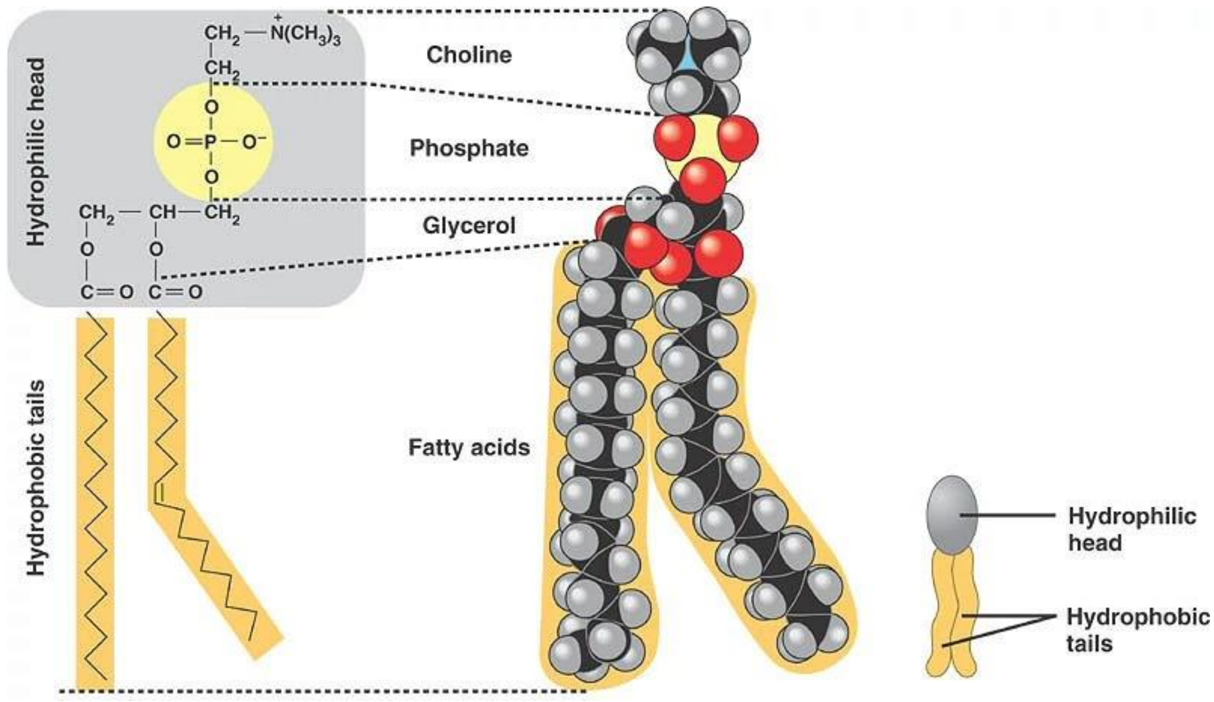


Fig. 1.2.1.1 Structure of phospholipid
FYI: This phospholipid is a phosphatidylcholine.

- The membrane is a bilayer produced from huge numbers of phospholipids.
    - Each phospholipid is composed of a glycerol (three-carbon compound).
    - Two of the glycerol carbons have fatty acids.
        - Fatty acids are non-polar because they are not able to form hydrogen bonds with water molecules.
    - The third carbon is attached to a highly polar organic alcohol that includes a bond to a phosphate group.
        - The organic alcohol with phosphate is highly polar because hydrogen bonds readily form between the phosphate head and water molecules.

- This structure means that membranes have two distinct areas when it comes to polarity and water solubility. This is referred to as ‘amphipathic’.

- Phosphorylated alcohol side is polar and is referred to as hydrophilic (water-loving).

- Hydrocarbon side is non-polar and is referred to as hydrophobic (water-fearing).

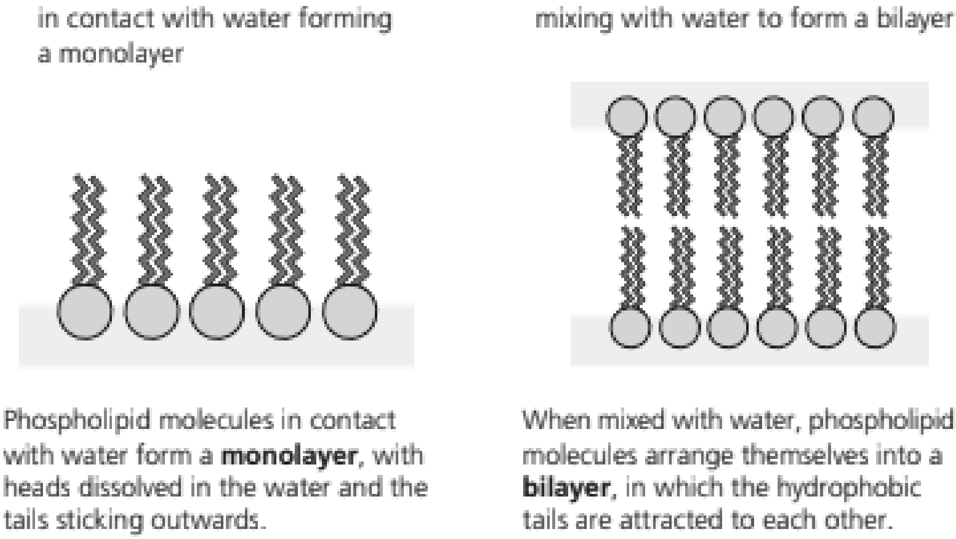


Fig. 1.2.1.2 The phospholipid molecule and its response when added to water.

- The hydrophobic and hydrophilic regions cause phospholipids to align as a bilayer if there is water present and there are many phospholipid molecules.

- Because the fatty acid ‘tails’ do not attract each other strongly, i.e. hydrophobic interactions are weak intermolecular bonds, the membrane tends to be fluid.

    - This allows animal cells to have a variable shape and allows the process of bulk transport (i.e exocytosis and endocytosis) to take place.

- Micelles are lipid molecules that <u>spontaneously</u> arrange themselves in a spherical form in aqueous solutions.
- The formation of a micelle is a response to the amphipathic nature of fatty acids, meaning that they contain both hydrophilic regions (polar head groups) as well as hydrophobic regions (the long hydrophobic chain).
- The polar head groups of micelles form the outside surface of the molecule, facing the aqueous environment, and their hydrophobic chains are clustered in the interior, where water is excluded since they are nonpolar.

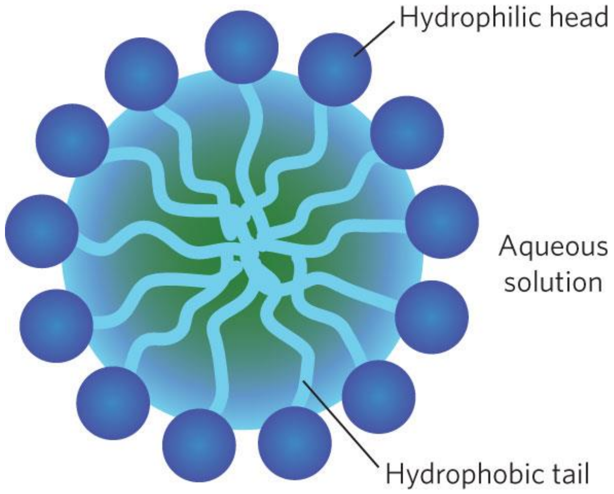


Fig. 1.2.1.3 Structure of micelle

1.2.2 Proteins

- Proteins of various types are embedded in the fluid matrix of the phospholipid bilayer.
    - These proteins create the extreme diversity in membrane function.
- There are usually two major types of proteins.
    - One type is referred to as integral proteins and the other type is referred to as peripheral proteins.

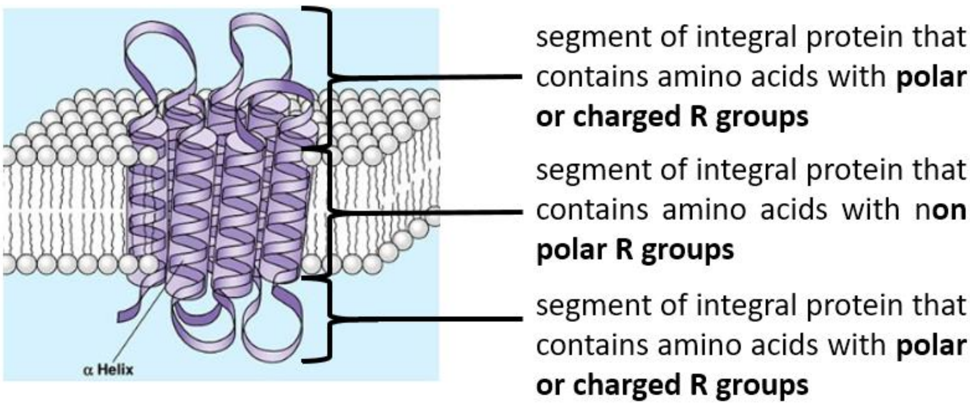


Fig. 1.2.2.1 The G-protein linked receptor (GPLR), an example of an integral protein (GPLR)

- **Integral proteins** show an **amphipathic** character, with both hydrophobic and hydrophilic regions within the same protein. These proteins will have the hydrophobic region to interact with fatty acid tails of phospholipid bilayer via hydrophobic interactions. Their hydrophilic region will be exposed to the aqueous environment on either side of the membrane.

- **Peripheral proteins** remain bound to the surface of the membrane. Often these peripheral proteins are anchored to an integral protein.

● The membrane proteins impart different functions to the different membranes.

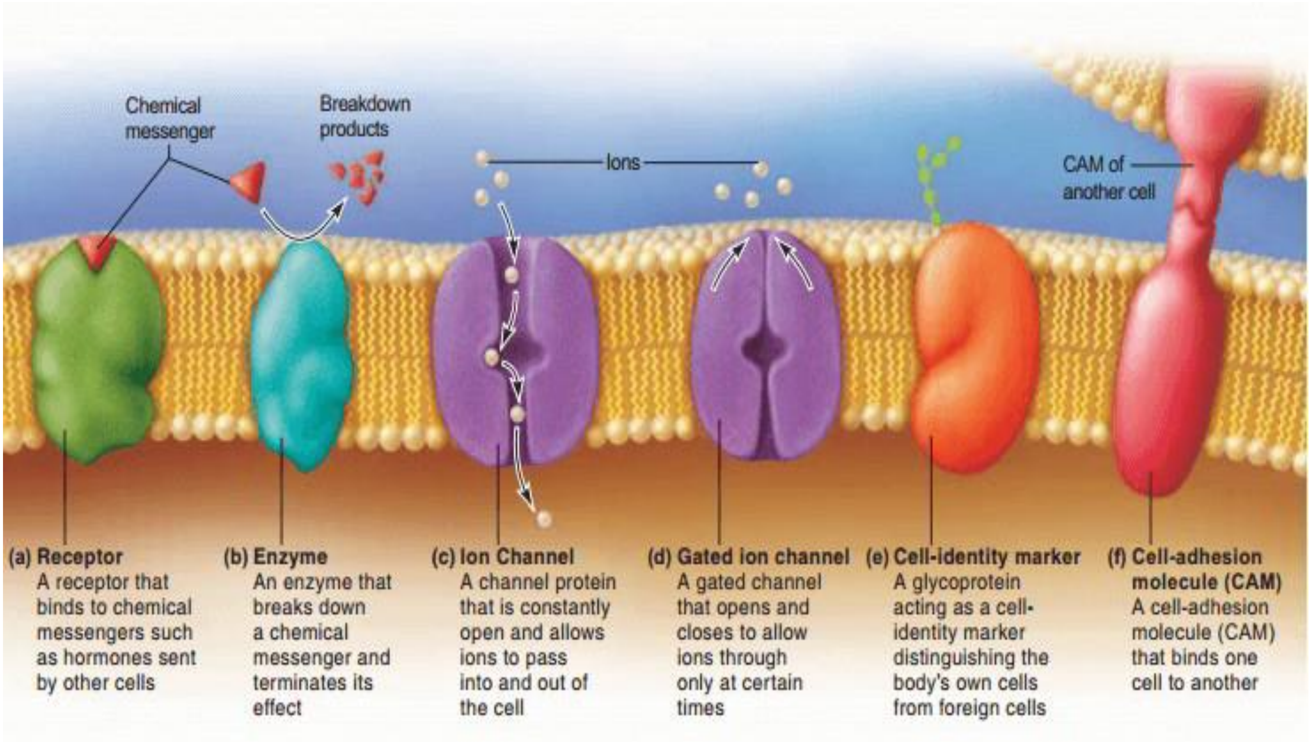


Fig. 1.2.2.2 Functions of membrane proteins

Table 1.2.2.1 Functions of membrane proteins

Function	Elaboration
sites for hormone-binding, i.e. receptor	• Proteins, e.g. GPCR, that serve as hormone-binding sites have specific shapes exposed to the exterior that fit the shape of specific hormones. • The attachment between the protein and the hormone causes a change in the shape of the protein, which results in a message being relayed to the interior of the cell. ***You will learn more this in the JC2 topic: Cell Signalling.***
enzymatic action, i.e. enzyme	• Cells have enzymes attached to membranes that catalyse many chemical reactions. • Often, they are grouped so that a sequence of metabolic reactions, called a metabolic pathway, can occur.

Function	Elaboration

transport proteins	• Some proteins contain channels that span the membrane, providing passageways for substances to be transported through.
	  ○ channels for passive transport, i.e. ion channel, gated ion channel
	    ▪ When this transport is passive, material moves through the channel from an area of high concentration to an area of lower concentration.
	  ○ pumps for active transport, i.e. sodium-potassium pump
	    ▪ In active transport, proteins shuttle a substance from one side of the membrane to another by changing shape.
	    ▪ This process requires the expenditure of energy in the form of ATP.

cell-to-cell communication, i.e. cell-identity marker	• Many of the cell-to-cell communication proteins have oligosaccharides attached. • They provide an identification label that represents the cells of different types. ***Refer to the section on glycoproteins.***
cell adhesion, i.e. cell-adhesion molecule (CAM)	• Cell adhesion is provided by proteins that can hook together in various ways to provide permanent or temporary connections. • These connections, referred to as junctions, can include gap junctions and tight junctions.

1.2.3 Glycolipids & Glycoproteins

- Short carbohydrate chains (known as **oligosaccharides**) may be covalently bonded to membrane lipids or proteins on the extracellular surface forming glycolipids or glycoproteins.

- Oligosaccharides are only found on the outer surface of the cell surface membrane.

- Collectively, the oligosaccharides are known as the **glycocalyx**.

    - Its various functions include cell–cell recognition, acting as receptor sites for chemical signals, and the binding of cells into tissues.

    - This is the basis for sorting an animal embryo's cells into tissues and rejection of foreign cells in the immune systems.

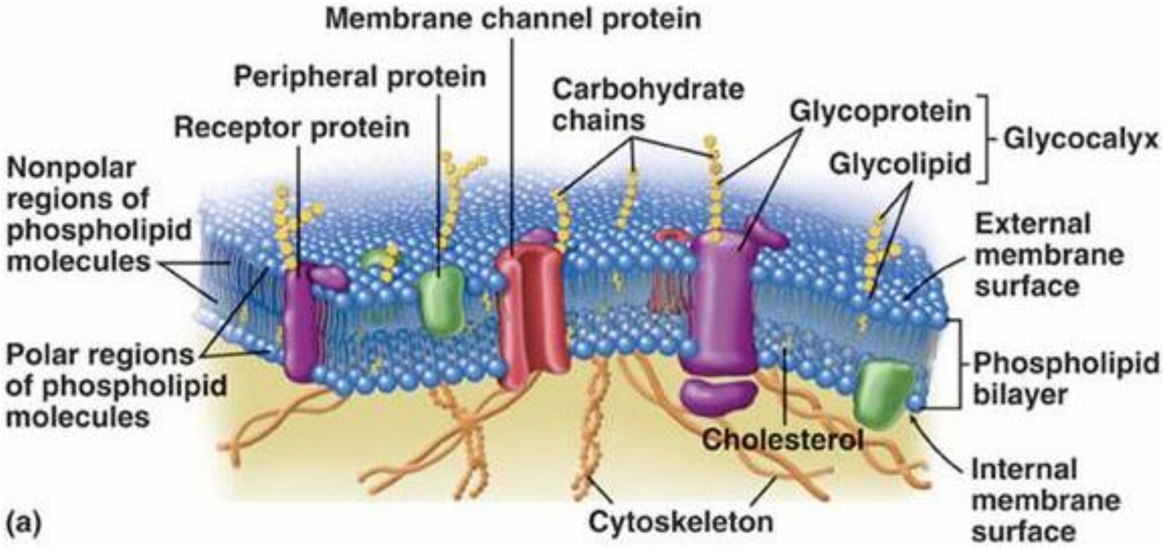


Fig. 1.2.3.1 Structure of cell surface membrane

1.2.4 Cholesterol

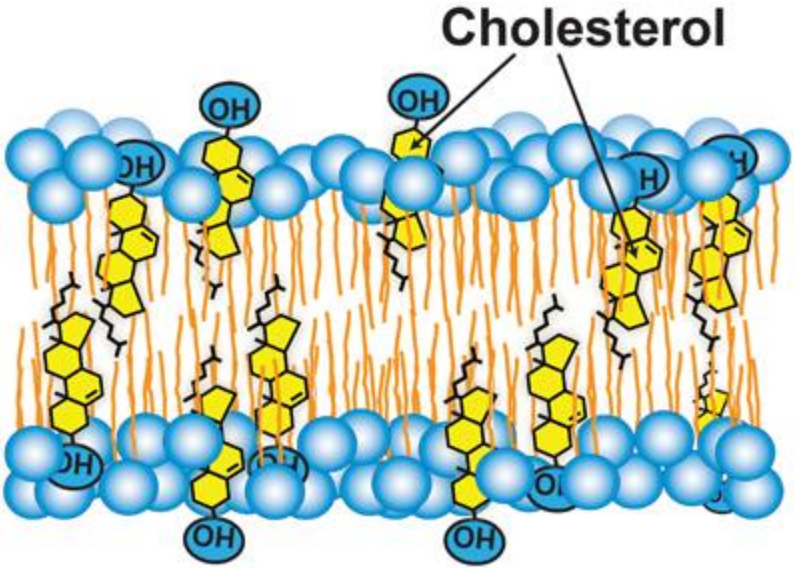


Fig. 1.2.4.1 Structure and function of cholesterol

- At various locations in the hydrophobic region (fatty acid tails) in animal cells are cholesterol molecules.
- These molecules have a role in determining membrane fluidity, which changes with temperature.

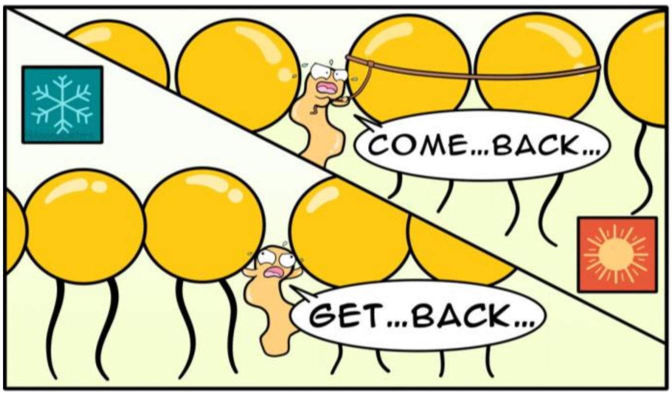


Fig. 1.2.4.2 Role of cholesterol at high and low temperature

Table 1.2.4.1 Role of cholesterol at high and low temperature

At high temperatures	At low temperatures
• Phospholipid molecules have high kinetic energy • Membrane becomes more fluid • Cholesterol binds to the fatty acid tails of phospholipids • This restricts the movement of phospholipids • This prevents phospholipids from moving away from each other • This results in decrease in membrane fluidity	• Phospholipid molecules have low kinetic energy • Membrane becomes less fluid • Cholesterol disrupts the regular order of phospholipid molecules • This prevents the freezing of the membrane • This results in increase in membrane fluidity

FUN FACT

Plant cells do not have cholesterol molecules; they depend on saturated or unsaturated fatty acids to maintain proper membrane fluidity. These evolutionary adaptations help to maintain the appropriate fluidity under specific environmental conditions.

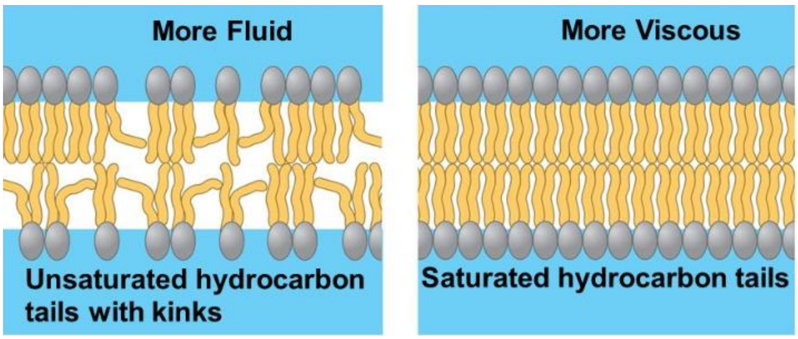


Fig. 1.2.4.3 Saturated phospholipids and unsaturated phospholipids

Learning Outcome (k):

Outline the functions of membranes at the surface of cells and membranes within the cell.

1.3 Functions of membranes

1.3.1 At surface of cells

- Boundary
  - The cell surface membrane forms a boundary that separates the cell contents from the external environment.
  - This allows the internal environment of the cell to be kept relatively constant to function optimally.
- Regulate movement of certain substances in and out of cell ***(Refer to the section on roles of membrane proteins.)***
  - The fatty acid tails of phospholipids repel hydrophilic molecules such as charged ions and polar molecules.
  - Close packing of phospholipids prevents large molecules such as glucose from passing through.
  - Specific protein transporters allow these ions and molecules to be transported across the membrane.
- Cell communication and signalling ***(Refer to the section under roles of membrane proteins and glycoproteins & glycolipids)***
  - The cell membrane contains glycoproteins and glycolipids which allow cell-cell recognition whereby the cells to interact and adhere together.
  - The cell membrane also contains certain glycoproteins and proteins which act as receptor sites for sensing external stimuli and respond to them.

1.3.2 Within the cell

- Compartmentalization *(**Refer to functions of membrane system and organelles in the topic of Organelles and Cellular Structures)***
  - Internal cell membranes enable compartmentalisation of cell contents and prevent indiscriminate mixing.
  - This allows for specialisation of cell function by concentrating specific substances (e.g. enzymes and chemicals) needed for biochemical processes.

- Allows embedment of different enzymes for formation of multi-enzyme complexes
    - Most metabolic reactions in the cell involve a series of coordinated reactions and each step is catalysed by a specific enzyme**.** E.g. in photosynthesis and respiration. Presence of electron carriers on inner membrane of mitochondrion and thylakoid membrane in chloroplast.
    - Each enzyme is interdependent with the ones adjacent to it. The product from the first enzyme becomes the substrate of the adjacent enzyme in the complex and so on until the end product is released.

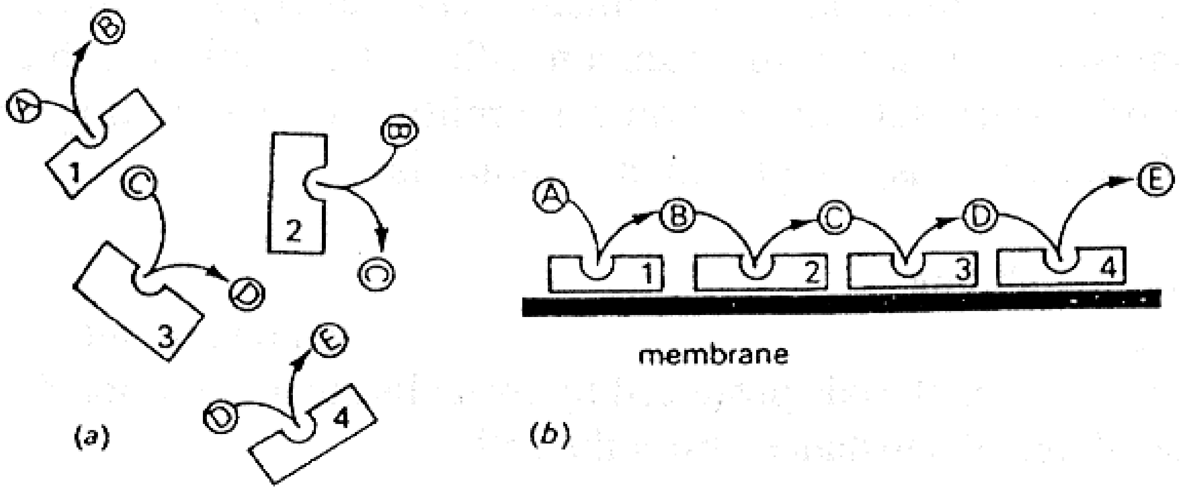


Fig. 1.3.2.1 (a) Free enzymes and (b) Membrane-bound enzymes

- Therefore, the conversion of substance A to B to C will not be efficient if the enzymes involved move randomly in the cytosol, as in (a).
- Instead, the enzymes are attached to a membrane surface in a sequential manner to form a multi-enzyme complex as shown in (b) and the reactions proceed more readily.

Learning Outcome (I):

Explain how and why different substances move across membranes through simple diffusion, osmosis, facilitated diffusion, active transport, endocytosis and exocytosis.

2.0 Transport across membrane

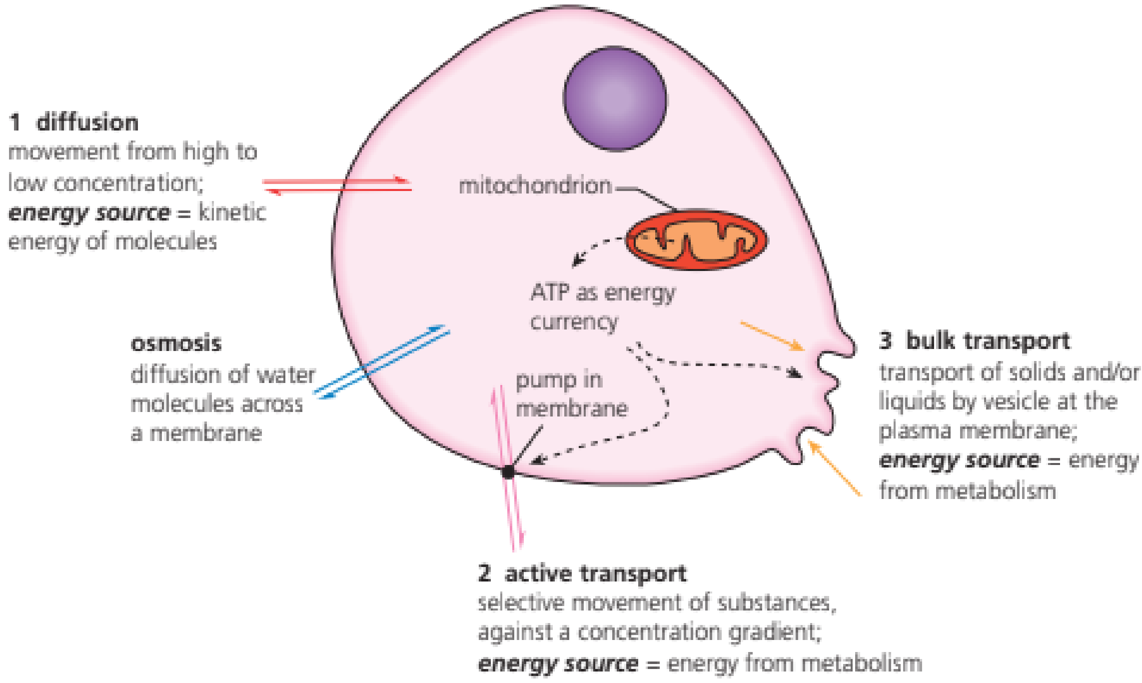


Fig. 2.0.1 Transport mechanisms

- Movement of molecules across the cell surface membrane of living cells is continual. Into and out of cells pass water, respiratory gases (oxygen and carbon dioxide), nutrients such as glucose, essential ions, and excretory products.

- There are two general types of cellular transport - passive transport and active transport.

    - Passive transport does not require ATP, but active transport does.

    - Passive transport occurs in situations where there exists a concentration gradient for a particular substance. Movement of the substance occurs from an area of higher concentration to an area of lower concentration. Movement is said to occur along a concentration gradient.

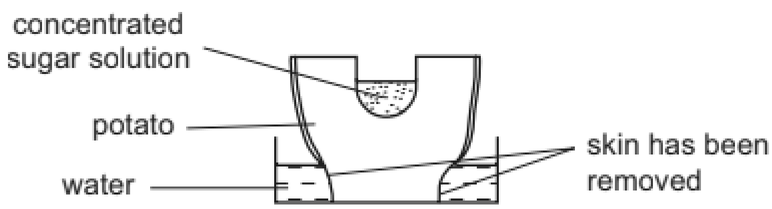
    - When active transport occurs, the substance is moved against a concentration gradient, from an area of lower concentration to an area of higher concentration, so hydrolysis of ATP must occur.

A bridge to O Level Biology
(6093 syllabus and 5078 syllabus)

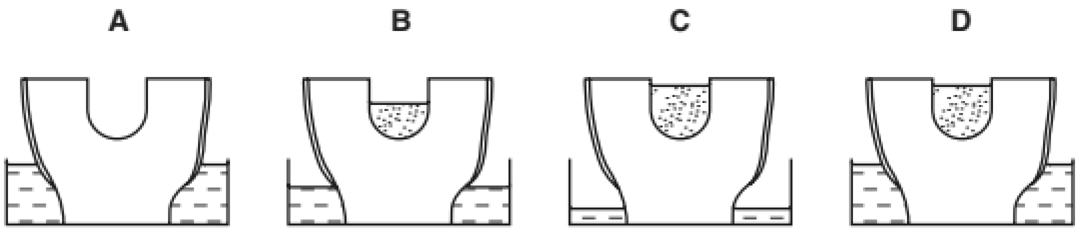
You should be able to:

(a) define diffusion and describe its role in nutrient uptake and gaseous exchange in plants and humans

Check your understanding (1)
The diagram shows an experiment using an uncooked potato. The skin of the potato was removed as shown



Which diagram shows the result of the experiment after 24 hours?



Explain your answer.

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Check your understanding (2)
The table shows the concentration of gases in a blood vessel and in an alveolus.

Which row shows the conditions that cause a gas produced in respiration to diffuse from the blood vessel into the alveolus?

	gas produced	concentration in the blood vessel	concentration in the alveolus
A	carbon dioxide	low	high
B	carbon dioxide	high	low
C	oxygen	low	high
D	oxygen	high	low

Explain your answer.

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2.1 Passive transport

2.1.1 Simple diffusion

- **Diffusion** is the net movement of molecules or ions from a region of higher concentration to a region of lower concentration down a concentration gradient until dynamic equilibrium is reached.

- The random movement is caused by the natural kinetic energy (energy of movement) of the molecules or ions.

- As a result of diffusion, molecules or ions tend to reach an equilibrium situation, where they are evenly spread within a given volume of space.

- The rate at which a substance diffuses across a membrane depends on the following:

    - The nature of the molecules or ions

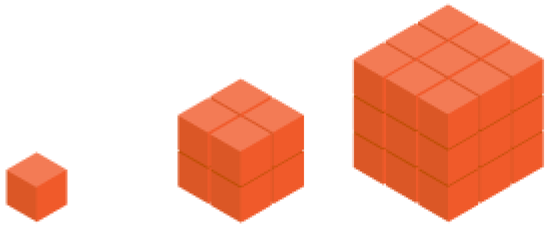
        - Large molecules, such as glucose, require more energy to get them moving than small ones do, so large molecules tend to diffuse more slowly than small molecules.

        - Non-polar molecules, such as steroid hormones, diffuse more easily through cell membranes than polar molecules, because they are soluble in the non-polar phospholipid tails.

        - The respiratory gases – oxygen and carbon dioxide – cross membranes by diffusion.
            - They are small, uncharged, and non-polar, and so can cross through the phospholipid bilayer directly between the phospholipid molecules.
        - Water molecules, despite being polar, can diffuse rapidly across the phospholipid bilayer because they are small enough.
    - ‘Steepness’ of the concentration gradient
        - Difference in the concentration of the substance on the two sides of the membrane
        - Greater the difference in concentration, the faster the rate of diffusion
    - Temperature
        - At high temperatures, molecules and ions have more kinetic energy.
        - They move around faster, and thus diffusion takes place faster.
    - Surface area across which diffusion is taking place
        - Greater the surface area, the more molecules or ions can cross it at any one moment, and therefore, the faster diffusion can occur.
        - The surface area of cell membranes can be increased by folding, as in microvilli in the intestine and kidneys or the cristae inside mitochondria.
        - The larger the cell, the smaller its surface area in relation to its volume.

Practices of Science

The diagram shows three cubes.



1 cm	2 cm	3 cm
SA = 6 cm^2	SA = 24 cm^2	SA = 54 cm^2
Vol = 1 cm^3	Vol = 8 cm^3	Vol = 27 cm^3
SA:Vol = 6:1	SA:Vol = 3:1	SA:Vol = 2:1

- As the dimension of the cube increases from 1 cm to 3 cm, the surface area to volume ratio decreases from 6 to 2.
- Cells rely on diffusion for internal transport of molecules. This results in a limit on the size of cells, because once inside a cell, the time it takes a molecule to reach a certain destination by diffusion increases rapidly with distance travelled.
- The rate falls in proportion to the square of the distance.
- Diffusion is therefore only effective over short distances, such as the 7nm across a membrane.

<u>Example</u>

- An amino acid molecule, for example, can travel a few micrometres in several seconds, but would take several hours to diffuse a centimetre.
- An aerobic cell would quickly run out of oxygen and die if it were too large. Most cells are no larger than about 50μm in diameter.

This demonstrates that appropriate models can be used to explain concepts, solve problems and make predictions

2.1.2 Osmosis

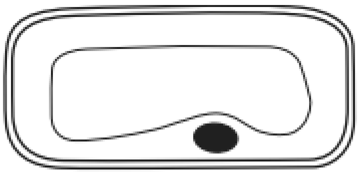
A bridge to O Level Biology
(6093 syllabus and 5078 syllabus)

You should be able to:

(b) define osmosis and describe the effects of osmosis on plant and animal tissues

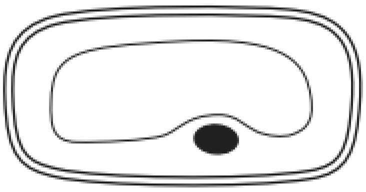
Check your understanding (3)

The diagram shows a plant cell.



What is the appearance of this cell after it has been placed in pure water for 30 minutes?

A



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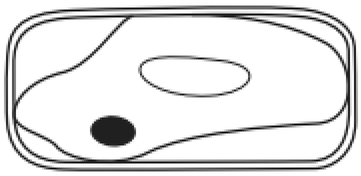

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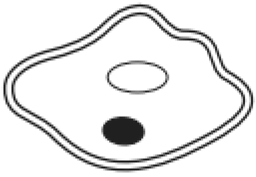

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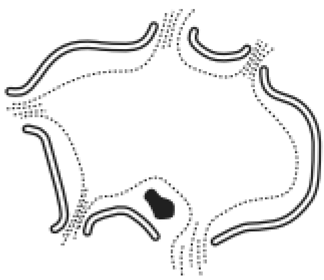

Explain your answer.

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- **Osmosis** is the net movement of **<u>water molecules</u>** from a region of higher water potential to a region of lower water potential, through a selectively permeable membrane.
    - **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
        - how much pressure is being applied to it
- A concentration gradient of water that allows the movement to occur is the result of a difference between solute concentrations on either side of a partially permeable membrane.
    - A lower water potential solution has a higher concentration of total solutes than a higher water potential solution.
    - Water therefore moves from a higher water potential to a lower water potential solution across a partially permeable membrane.
    - If two solutions have equal water solution occur on either side of a partially permeable membrane, no net movement of water is evident.

Osmosis in plant and animal cells

- The effects of osmosis on plant and animal cells can be quite different due to the presence and absence of cellulose cell wall.
- Whether the net direction of water movement is into or out of a plant cell depends on whether the concentration of the cell solution is more or less concentrated than the external solution.

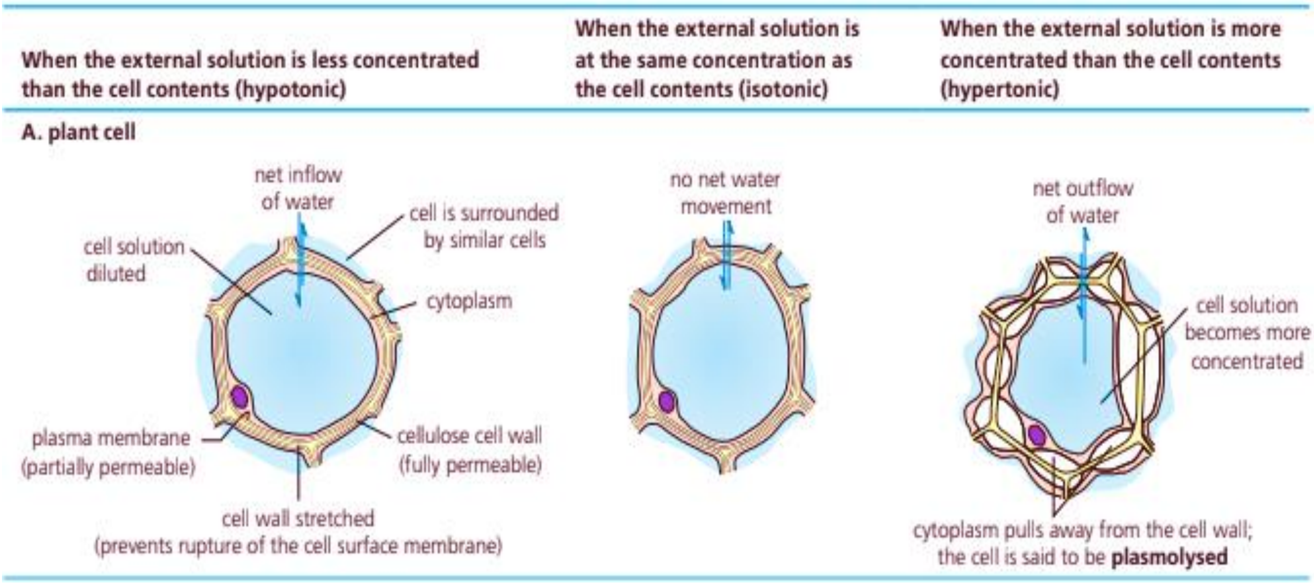


Fig. 2.1.2.1 Osmosis in plant cell

- When the external solution is less concentrated (higher water potential) than the cell solution there is a net inflow of water into the cell by osmosis, and the cell solution becomes diluted.

- Then the cell contents become stretched by water uptake, and they press hard against the cell wall. If this happens, the cell is described as turgid.

- The turgor pressure that develops (due to the stretching of the wall) eventually becomes so great it prevents further uptake of water.

- The cell wall has protected the delicate cell contents from damage due to osmosis, but the tissue may be quite rigid due to the internal pressure.

- When the external solution is more concentrated (lower water potential) than the cell solution there is a net flow of water out of the cell by osmosis, and the cell solution becomes more concentrated.

- As the volume of cell solution decreases, the cytoplasm pulls away from parts of the cell wall (contact with the cell wall is maintained at points where there are cytoplasmic connections between cells).

- The cell becomes flaccid, and it is said to be plasmolysed (from plasmo = cytoplasm, lysis = splitting).

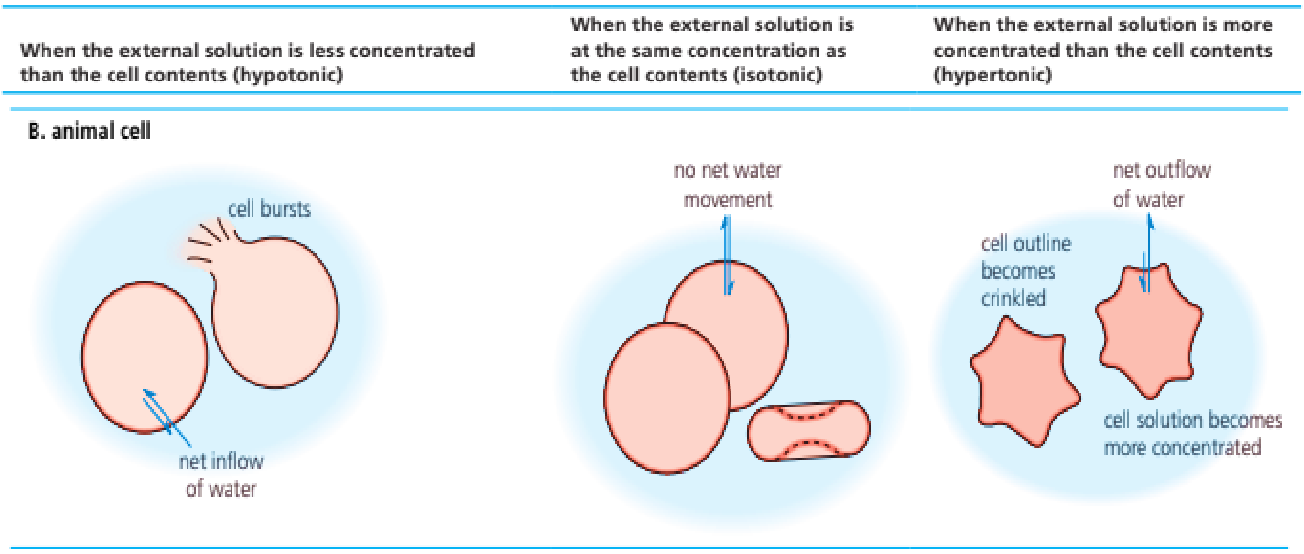


Fig. 2.1.2.2 Osmosis in animal cells

- The absence of a cellulose cell wall in animal cell generates a serious problem in terms of water relations.

- A typical animal cell – a red blood cell – when placed in pure water or a higher water potential solution will quickly lyse (burst) from the pressure generated by the entry of an excessive amount of water by osmosis.

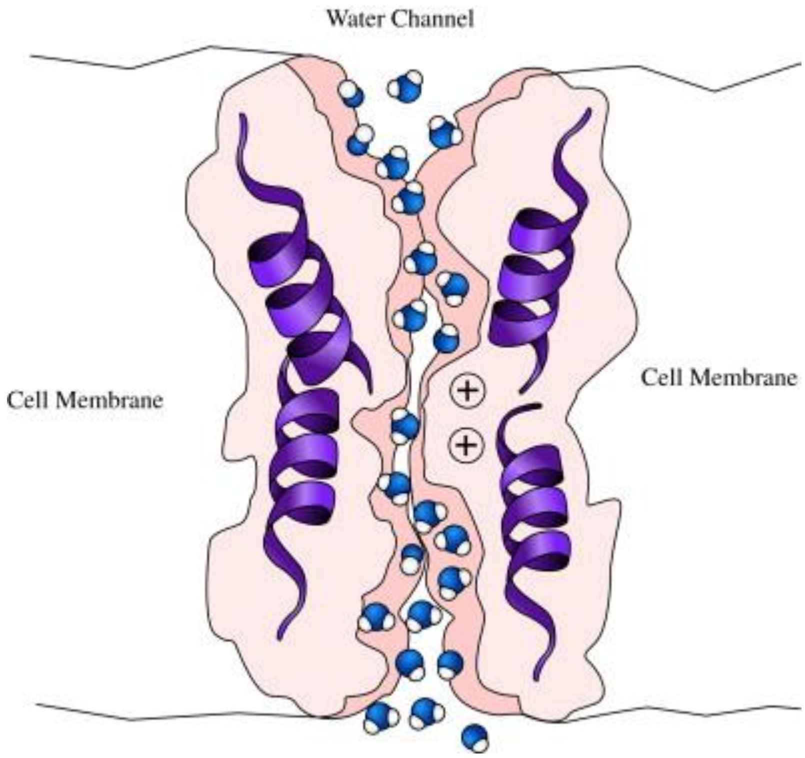
- The same cells, when placed in a lower water potential solution, shrink in size due to net water loss from the cytoplasm.

- In mammals and other animals, the osmotic concentration of body fluids (blood plasma and tissue fluid) is very carefully regulated, maintaining the same osmotic concentration inside and outside body cells (isotonic conditions), which avoids such problems.

FUN FACT	When human organs are donated for transplant surgery, they have to be maintained in a saline solution that is isotonic with the cells of the tissues and organs, in order to prevent damage to cells due to water uptake or loss during transit to the recipient patient.

DID YOU KNOW?

Water can move across the membrane by another mode of transport – facilitated diffusion.



- Aquaporins are integral membrane proteins that facilitate the movement of water across cell membranes.

- They are highly selective for water and can transport water at a much faster rate than osmosis through the lipid bilayer.

  - The selective permeability of aquaporins is due to their unique structure, which allows only water molecules to pass through while excluding other solute.

- They contribute to the maintenance of water homeostasis within cells, ensuring proper cellular function.

  - For instance, in mammalian renal tubules, aquaporins play a vital role in reabsorbing water from the glomerular filtrate, contributing to the concentration of urine and the conservation of water in the body.

  - In plants, aquaporins are involved in various physiological processes such as seed germination, root water uptake, and leaf water transport.

  - In summary, aquaporins are fundamental to the movement of water across cell membranes, playing a critical role in maintaining water balance and supporting numerous biological functions in both plants and animals.

2.1.3 Facilitated diffusion

- **Facilitated diffusion** is the net movement of a substance through transport proteins in a cell membrane from a region of higher concentration to a region of lower concentration down a concentration gradient until dynamic equilibrium is reached.

- The proteins provide hydrophilic areas that allow the molecules or ions to pass through the membrane that would otherwise be less permeable to them.

    - Large polar molecules, such as glucose and amino acids, and ions such as sodium (Na^+) or chloride (Cl^-), cannot diffuse through the phospholipid bilayer.
    - The core membrane is made up of hydrophobic fatty acid tails that prevent diffusion of polar molecules or charged ions.

- There are two types of proteins involved - channel proteins and carrier proteins.

    - Each is highly specific, allowing only one type of molecule or ion to pass through it.

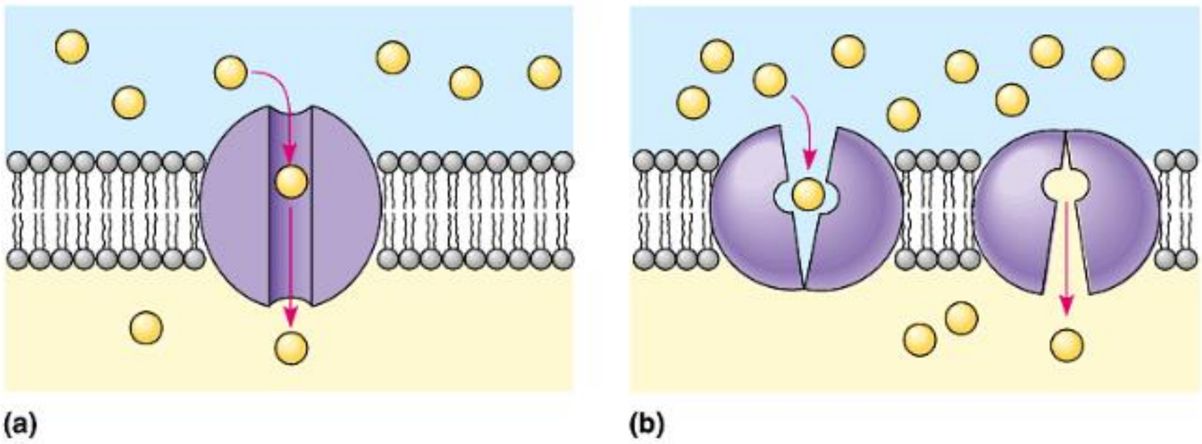


Fig. 2.1.3.1 (a) Channel protein (b) Carrier protein

- **Channel proteins** have amino acids with polar R groups lining the inner part of the channel to allow the polar molecules (such as water and glucose) and/or ions to pass through

    - allow charged ions to diffuse through the membrane,

    - most are ‘gated’

        - part of the protein molecule on the inside surface of the membrane can move to close or open the pore

        - allows control of ion exchange

    - some channels occur in a single protein; others are formed by several proteins combined

    - fixed shape which is complementary to the ions it is transporting

- **Carrier proteins**
  - can flip between two shapes.
  - the binding site is alternately open to one side of the membrane
- The rate at which facilitated diffusion takes place is affected by:
  - how many channel or carrier protein molecules there are in the membrane
  - The rate of facilitated diffusion will level off when total saturation of the available channels and/or carriers occurs.

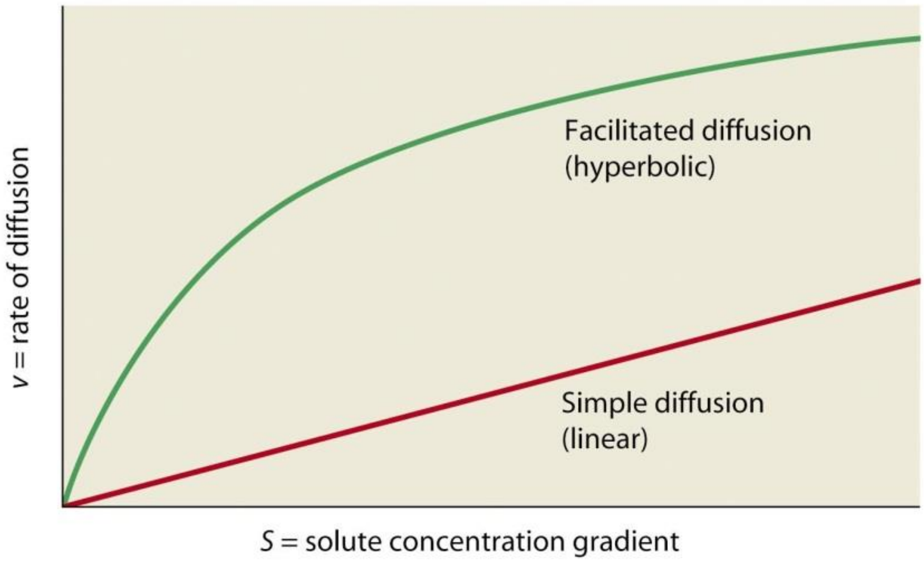


Fig. 2.1.3.2 At low solute, not all carriers are occupied and so an increase in solute increases the rate of diffusion. At high concentrations, the carrier proteins are saturated and the rate reaches a plateau

Did You Know...?

- Cystic fibrosis is caused by a defect in a channel protein (CFTR), that should be present in the cell surface membranes of certain cells, including those lining the lungs.

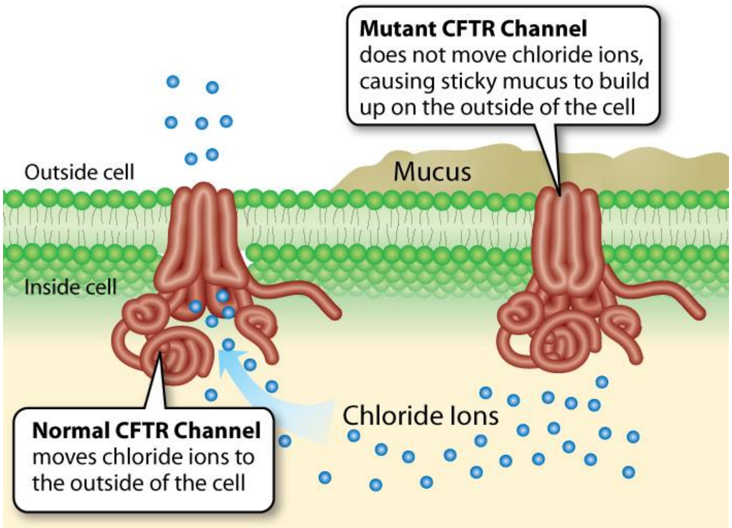


Fig. 2.1.3.3 Action of CFTR

- This protein normally allows chloride ions to move out of the cells.

- If the channel protein is not correctly positioned in the membrane, or if it does not open the chloride channel as and when it should, then the chloride ions cannot move out, leading to accumulation of chloride ions inside the cells.

2.2 Active transport

A bridge to O Level Biology
(6093 syllabus and 5078 syllabus)

You should be able to:

(c) define active transport and discuss its importance as an energy-consuming process by which substances are transported against a concentration gradient, as in ion uptake by root hairs and uptake of glucose by cells in the villi **(6093 syllabus only)**

Check your understanding (4)
A student made the following statements about the movement of ions by active transport.

1. It is the net movement of particles from a low concentration to a high concentration.
2. It is the net movement of particles from a high concentration to a low concentration.
3. It requires the use of energy.
4. It can only take place in living, respiring cells.

Which statements are correct?

A 1, 3 and 4 **B** 1 and 4 only **C** 2 and 4 **D** 2 only

Explain your answer.

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- **Active transport** is the movement of molecules or ions through transport proteins across a membrane, against their concentration gradient, **using energy from the hydrolysis of ATP.**

- Active transport is highly selective and is usually unidirectional.

    - In animal cell where potassium chloride (K^+ and Cl^- ions) is available, K^+ ions are more likely to be absorbed since they are needed by the cell.

    - In plant cell where sodium nitrate (Na^+ and NO_3^- ions) is available to a plant cell, it is likely that more of the NO_3^- ions will be absorbed than the Na^+ since this reflects the needs of plant cells.

Case study: Sodium-potassium (Na^+–K^+) pump

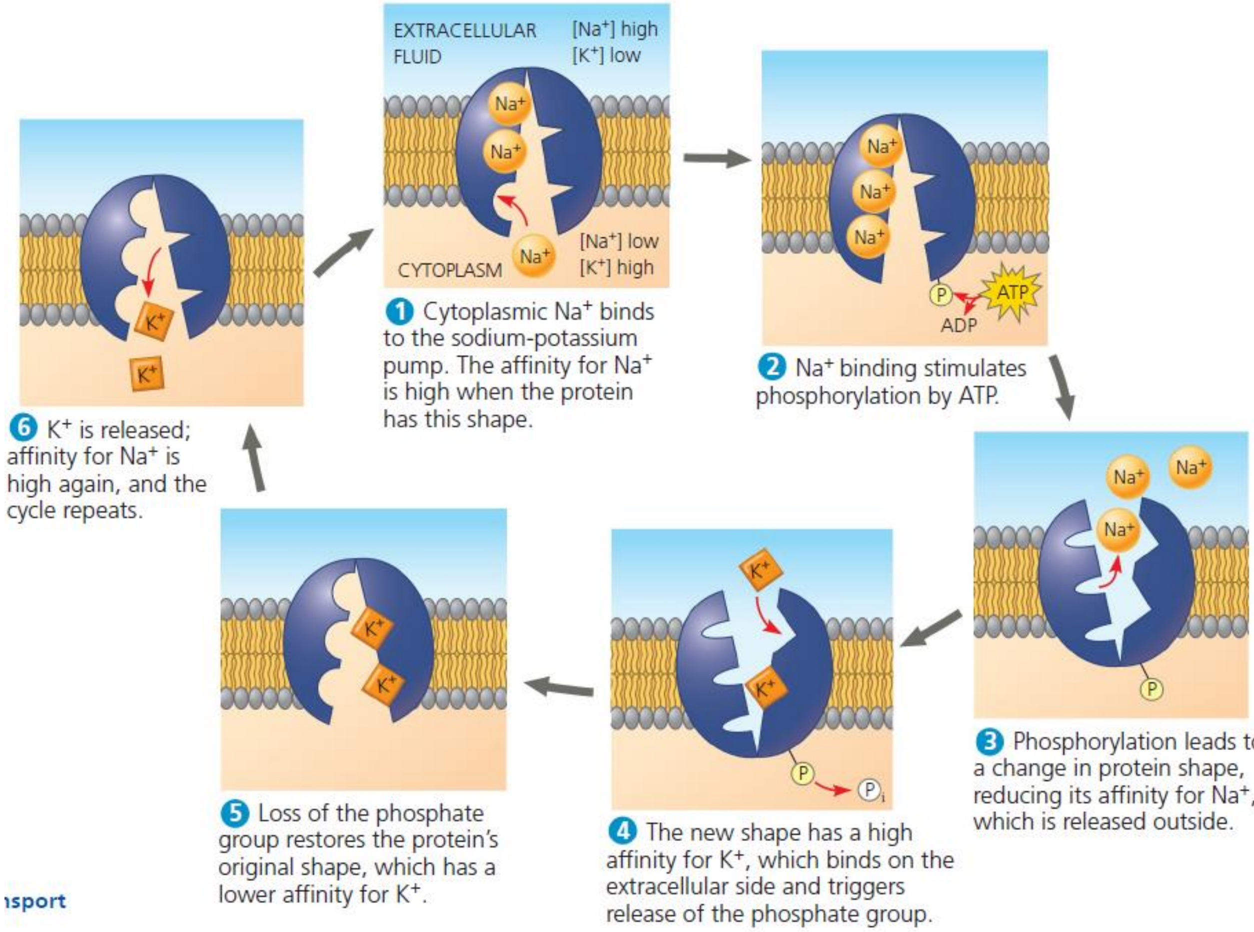


Fig. 2.2.1 Step-by-step guide to Sodium-potassium (Na^+–K^+) pump

- The **sodium–potassium (Na^+–K^+) pump** is a carrier protein used for active transport of three sodium ions out of the cell and two potassium ions into the cell for each ATP molecule hydrolysed.
    - The pump has a binding site for ATP on its inner surface.
    - An ATPase enzyme in the pump catalyses the hydrolysis of ATP to ADP (adenosine diphosphate) and phosphate to release energy.
- These pumps are found in the cell surface membranes of all animal cells.
- Since both the ions are positively charged, the net result is that the inside of the cell becomes more negative than the outside after each transport. This creates a potential difference (p.d.) across the membrane.
- The significance of the potential difference is for nervous transmission.

2.3 Bulk transport

- Endocytosis and exocytosis are bulk transport processes that allow larger molecules to move across the plasma membrane.

    - **Endocytosis** is the bulk movement of large amount of liquids or solids into a cell, by the infolding of the cell surface membrane to form vesicles containing the substance via the hydrolysis of ATP.

    - **Exocytosis** is the bulk movement of large amount of liquids or solids out of a cell, by the fusion of membrane of vesicles / vesicular membrane containing the substance with the cell surface membrane via the hydrolysis of ATP.

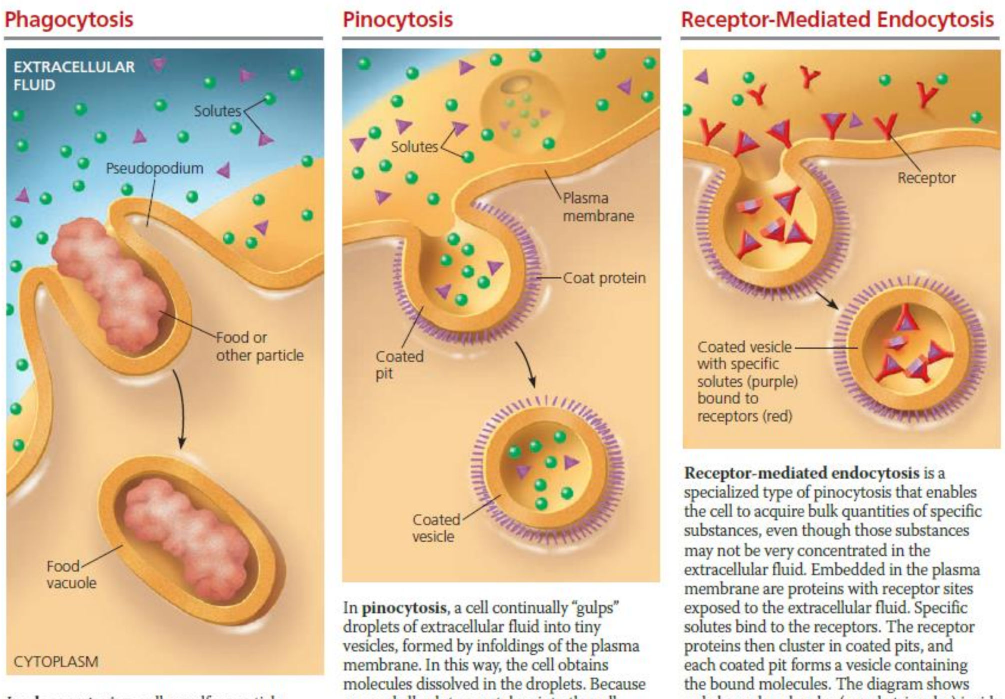
- Both processes depend on the fluidity of the cell surface membrane.

2.3.1 Endocytosis

- Endocytosis occurs when a portion of the cell surface membrane either invaginates inwards as a pocket or extends outwards as pseudopods to enclose the marcomolecules or particulates.

- The ends of the pocket or pseudopods fuse together to encapsulates the macromolecules or particulates into a vesicle.

- The vesicle containing the macromolecules or particulates then enters the cytoplasm of the cell.



In **phagocytosis**, a cell engulfs a particle by extending pseudopodia (singular, *pseudopodium*) around it and packaging it within a membranous sac called a food vacuole. The particle will be digested after the food vacuole fuses with a lysosome containing hydrolytic enzymes (see Figure 6.13).

In **pinocytosis**, a cell continually "gulps" droplets of extracellular fluid into tiny vesicles, formed by infoldings of the plasma membrane. In this way, the cell obtains molecules dissolved in the droplets. Because any and all solutes are taken into the cell, pinocytosis as shown here is nonspecific for the substances it transports. In many cases, as above, the parts of the plasma membrane that form vesicles are lined on their cytoplasmic side by a fuzzy layer of coat protein; the "pits" and resulting vesicles are said to be "coated."

Receptor-mediated endocytosis is a specialized type of pinocytosis that enables the cell to acquire bulk quantities of specific substances, even though those substances may not be very concentrated in the extracellular fluid. Embedded in the plasma membrane are proteins with receptor sites exposed to the extracellular fluid. Specific solutes bind to the receptors. The receptor proteins then cluster in coated pits, and each coated pit forms a vesicle containing the bound molecules. The diagram shows only bound molecules (purple triangles) inside the vesicle, but other molecules from the extracellular fluid are also present. After the ingested material is liberated from the vesicle, the emptied receptors are recycled to the plasma membrane by the same vesicle (not shown).

Fig. 2.3.1.1 Types of endocytosis

Table 2.3.1.1 Types of endocytosis

Phagocytosis	Pinocytosis	Receptor-mediated endocytosis
• **Non-specific** engulfing of **solid material**.	• **Non-specific** engulfing of **liquid material**.	• **Targeted / specific** engulfing of **molecules**.
• Cell surface membrane extends outwards as pseudopods to enclose the solid material. • The ends of the pseudopods fuse together to encapsulate the solid material in a phagocytic vesicle / phagosome which migrates to the interior of the cell. • Membrane of vesicle fuses with membrane of primary lysosome to form a secondary lysosome. • Engulfed material is digested by hydrolytic enzymes. • Products are absorbed or released by the cell.	• Cell surface membrane invaginates inwards as a pocket to enclose the liquid material. • The ends of the pocket fuse together to encapsulate the liquid material in a pinocytic vesicle which migrates to the interior of the cell. • Tiny vesicles containing droplets of extracellular fluid and dissolved solutes are formed.	• Embedded in the membrane are proteins (receptors) with specific receptor sites that are exposed to extracellular fluid. • Only specific molecules bind to these receptor sites to trigger the invagination of the cell surface membrane to form a pocket. • The ends of the pocket fuse together to encapsulate the molecules into a vesicle which migrates to the interior of the cell.
Function • Example: Macrophages of the immune system in mammals engulf pathogens by phagocytosis. ***You will apply this knowledge in the process of antigen presentation in the topic of Infectious Disease.***	Function • Uptake of solutes from the extracellular medium and to retrieve plasma membrane that was inserted into the cell surface membrane.	Function • Allows the cell to take in bulk quantities of specific substances even though they may not be in high concentration in the extracellular fluid. ***You will apply this knowledge in the process of influenza reproductive cycle in the topic of Genetics of Viruses.***

2.3.2 Exocytosis

- Exocytosis is essentially the reverse of endocytosis.

  .
- One example of cell exocytosis involves proteins produced for secretion e.g. hormones.
  - Protein exocytosis usually involves the secretory pathway. **The secretory pathway is covered in Topic 1.1 Organelles and Cellular structures lecture notes.**

- Golgi secretory vesicle bind to a motor molecule (kinesin) to form a transport complex. This transport complex binds to microtubule and hydrolysis of ATP releases energy to enable the motor molecule to transport Golgi secretory vesicle.

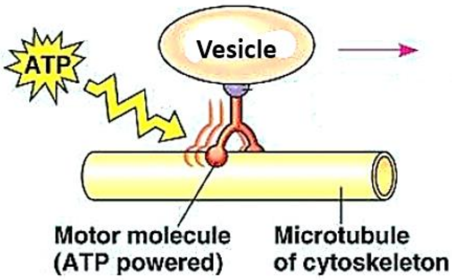


Fig. 2.3.2.1 Vesicle trafficking by microtubule

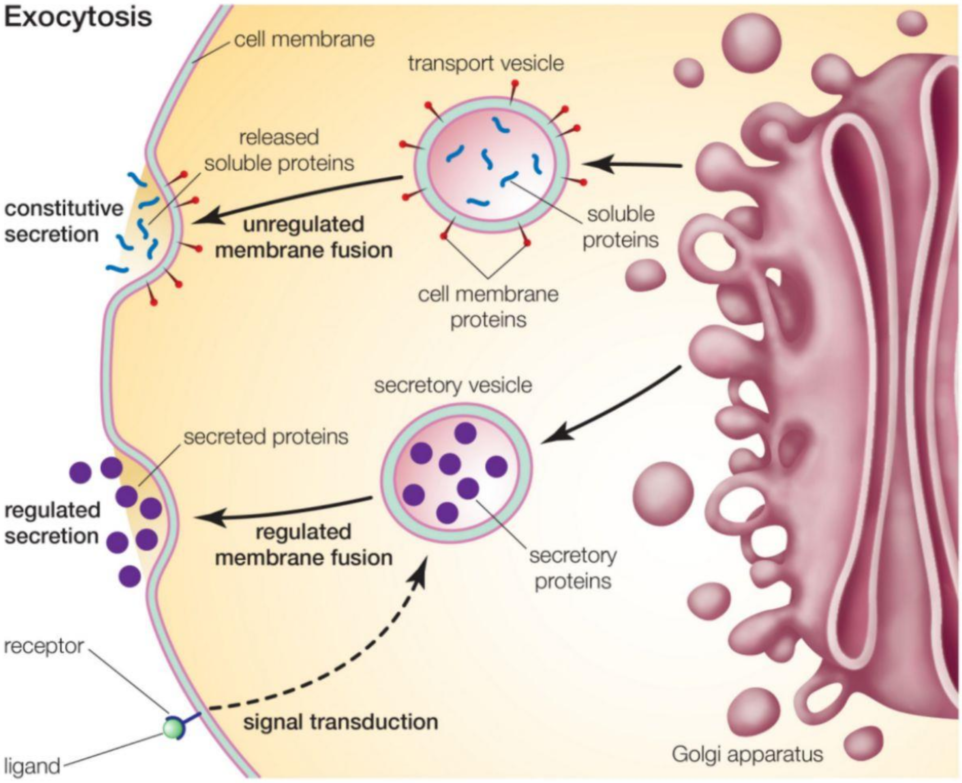


Fig. 2.3.2.2 (top) Constitutive secretion and (bottom) Regulated secretion

- The Golgi secretory vesicle may proceed with either constitutive release pathway or regulated release pathway.
    - Golgi secretory vesicle, containing secretory proteins and/or cell membrane proteins, for constitutive release fuses with the cell surface membrane and release their content.
    - Golgi secretory vesicles in the regulated pathway wait near the membrane for signal via ligand-receptor interaction before fusing with the cell surface membrane to release the content.
- At this point the vesicle membrane is a part of the cell surface membrane. Hence, the vesicle membrane contributes to the renewal of the cell surface membrane.

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Answers (Make sure this is not printed for our students)

Check your understanding (1)

C ;;

Explanation:
- This is because the water potential in the well of the potato is lower than the water potential in the container.
- Therefore, water will move from the container into the well of the potato across the potato down a water potential gradient.
- This will lead to a rise of water level in the well of the potato and a decrease of water level in container.

Check your understanding (2)

B ;;

Explanation:
- Carbon dioxide is produced during respiration.
- Therefore, carbon dioxide will be high in concentration in the blood vessels while low in concentration in the alveolus.
- This promotes the diffusion from carbon dioxide from blood vessels to the alveolus.

Check your understanding (3)

A;;

Explanation:
- A shows turgidity in plant cell as water moves into the plant cell.
- B is wrong because it shows plasmolysis.
- C is wrong because it shows crenation of cell. Plant cell does not crenate because it has a cell wall.
- D is wrong because it shows lysis of cell. Plant cell does not lysis because it has a cell wall.

Check your understanding (4)

A;;

Explanation:
- Statement 2 is the only statement that is not true for active transport because the direction of transport is from low concentration to high concentration.