CELL PHYSIOLOGY

Introduction:

Materials move in and out of cells by the following processes: Osmosis, diffusion, active transport, phagocytosis and pinocytosis. Some of these processes require energy while others do not. The materials include water, gases, enzymes, hormones, antibodies, among other solvents and solutes.

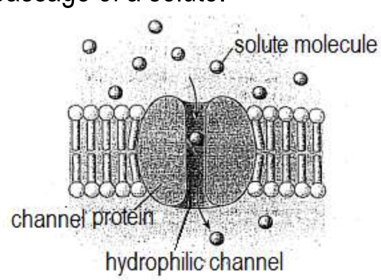
Cell membranes are a barrier to most of these substances which results in the property that cell membranes are selectively permeable. This ensures that materials are concentrated inside the cell excluded from the cell or simply separated from the extra cellular environment. This property is a result of the **lipid bi-layer** and the **specific transport proteins.**

The lipid bi-layer allows non polar molecules or ions such as hydrocarbons, carbon dioxide and oxygen across it. However, the hydrophilic molecules and ions do not pass through the bi-layer or if they do, their movement is very slow.

The transport proteins (integral proteins) allow polar molecules such as glucose, water or ions to pass across the membrane. This is accomplished by integral proteins which span across the membrane. There are 2 types of transport proteins, i.e. channel proteins and carrier proteins.

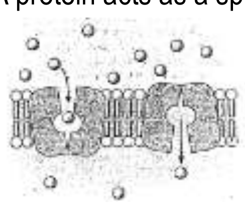
i) Channel proteins:

These have a channel through which substances move. They normally allow tiny molecules or ions to pass through. They have a corridor that allows a specific molecule or ion cross the membrane. These channels provide the quickest pathways for hydrophilic molecules including water and small ions. A protein provides a functional pore in the membrane for the passage of a solute.



ii) Carrier proteins:

These have no channels but allow molecules or ions to get hold of it and it changes shape in a way that pushes the substance across the membrane. They bind larger polar molecules such as amino acids, sugars, fatty acids, ions and glycerol to them and undergo rapid changes in shape. These pick molecules from outside of cell and deposit them inside. A protein acts as a specific carrier molecule in the membrane.



Adaptations of the plasma membrane to movement of materials across it

- Possession of channels filled with a fluid in which substances dissolve to get carried across.
- Possession of carrier proteins with specific sites on to which the substance bind and get carried across.
- Phospholipids are not tightly fixed into each other hence can open and close during exocytosis and endocytosis.
- Phospholipids being fluid and mobile enables the carrier protein to float across with the substances attached.
- Possession of hydrophilic and hydrophobic layers that restrict entry and exit of substances thus making the membrane semi permeable.
- Possession of trans-membrane proteins with pores that allow entry and exit of materials across the membrane.

MOVEMENT IN AND OUT OF CELLS

The movement of materials across the membrane takes place in the combination of the following ways;

- Diffusion
- Osmosis
- Active transport
- Bulk transport (using vesicles)

Note: diffusion and osmosis are passive means of transport because they do not require energy but instead molecules move along their concentration gradient.

Active transport and bulk transport are said to be active means of transport because the cell membrane uses energy to move the molecules or ions in and out of the cell.

Reasons why materials need to move across membranes

Materials must move across the membranes because cells need to:

- Obtain nutrients from the surrounding.
- To excrete waste substances.
- To secrete useful substances.
- To generate ionic gradients essential for neuron/muscular activity/chemiosmosis and stomatal movements.
- To obtain suitable PH/acid base balance.
- To maintain osmo-neutrality/ionic balance.
- To maintain electroneutrality.
- To obtain raw materials for metabolic reactions like respiration and photosynthesis.

DIFFUSION

This is the movement of ions or molecules from a region of high concentration along a concentration gradient.

Concentration gradient refers to the difference in concentration between two points of a diffusing particle.

Diffusion occurs because the molecules are in a random motion e.g. if molecules are closed in a vessel occupying one side and are in random motion, they collide with each other and the sides of the vessel.

Diffusion of molecules occurs until the concentration is uniform in the two regions.

The **materials transported** by diffusion are small molecules such as carbon dioxide, oxygen, water, etc. and ions such as sodium, potassium, chloride ions, etc.

Factors affecting the rate of diffusion

1) **Temperature:**
   Increase in temperature increases the rate of diffusion since temperature increases the kinetic energy of the molecules hence more collisions.
2) **Size of diffusing molecules:**
   Small molecules may diffuse faster than larger molecules.
3) **Surface area over which diffusion occurs:**
   The larger the surface area the faster the rate of diffusion. The surface area of membranes is always increased by extensively being folded or possession of structures such as villi or microvilli.
4) **Concentration gradient:**
   The greater the concentration gradient, the higher the rate of diffusion and vice versa.
5) **Chemical nature of diffusing molecules:**
   Fat soluble diffuse more rapidly through cell membranes than non-fat soluble molecules.
6) **Density of the diffusing particles/molecules:**
   The denser the diffusing particles, the lower the rate of diffusion and vice versa.
7) **Distance over which diffusion occurs:**
   The shorter the distance between two regions of different concentrations, the faster the rate of diffusion. Therefore any structure of an organism where diffusion takes place must be thin. Reducing diffusion distance in organisms so that none of the cells are far from the surface is achieved by:
   - The body may be flattened, thus reducing the distance between the two surfaces e.g. flatworms and the leaves of plants.
   - The body may be constructed in such a way that the tissues are thin e.g. Hydra and sea anemones.

- There may be a system whereby the external medium is brought into the body so that it comes into intimate association with all the tissues e.g. the tracheal system of insects.

The rate of diffusion in a given direction across the exchange surface:
- Is directly proportional to the area of the surface.
- Is directly proportional to the concentration gradient.
- Is inversely proportional to the distance (the length of the diffusion pathway).

This is known as **Fick's law** and can be summarized as:

Rate of diffusion is proportional to $\frac{surface\ area\ x\ difference\ in\ concentration}{length\ of\ diffusion\ path}$

Increasing factors on the top line of the equation will make diffusion faster, while increasing that on the bottom will slow it down. Fick's law applies to situations where there is no barrier to the movement of substances. Like the diffusion of a dye in a container of water, the diffusion of substance into or out of a cell is a form of passive transport. It does not require the expenditure of energy.

Adaptation for diffusion

As would be expected from Fick's law, cellular diffusion is a very slow process unless there is a large concentration gradient over a short distance. Tissues such as those in the lungs and small intestine are especially adapted to maximize the rate of diffusion by:
- Maintaining a steep concentration gradient.
- Having a high surface area to volume ratio.
- Being thin, minimizing the distance over which the diffusion takes place.
- Individual cells increase the surface area for diffusion by having microvilli.

Types of diffusion

1. **Simple diffusion:**
   This is a type of diffusion where molecules and ions cross directly through the lipid bi-layer of the membrane. These are the fat soluble molecules (non-polar) such as steroids, carbon dioxide and oxygen. There is no need of carrier molecules to be carried across the membrane.

2. **Facilitated diffusion:**
   This is the diffusion where by polar molecules (lipid insoluble molecules) cross the membrane by the help of integral proteins. It is carried out by both channel and carrier proteins.

Differences between simple and facilitated diffusion

Simple diffusion	Facilitated diffusion
Occurs in any medium	Occurs only across plasma membrane.
Doesn't require carrier proteins.	Require carrier proteins.
Occurs in both living and dead tissues.	Occurs only in living tissues.
Non-specific.	Very specific.

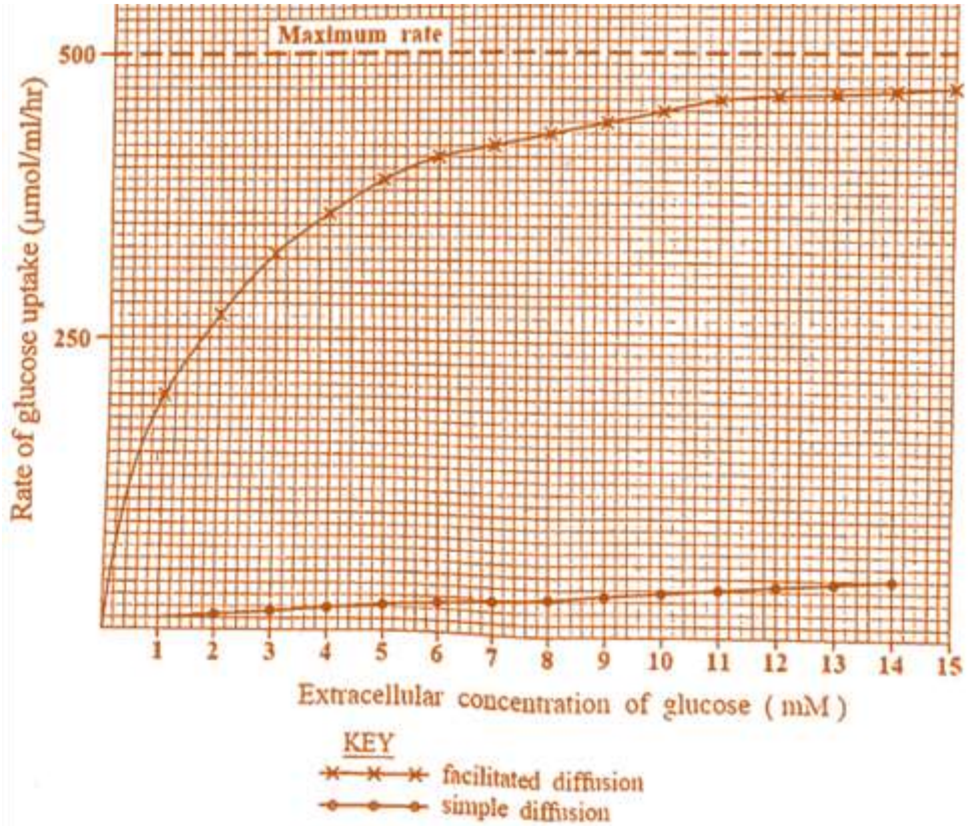
Similarities:
- Both involve movement of substances along concentration gradient.
- In both there is no use of energy.

Significance of diffusion to organisms

- Digested food substances such as glucose enter the blood stream from the gut by diffusion.
- Gas exchange at the respiratory surfaces is by diffusion.
- Waste products leave cells to blood by diffusion.
- Glucose and oxygen leave blood to body cells by diffusion.

Worked out examination question

In an experiment, the rate of uptake of glucose by the blood using simple and facilitated diffusion at varying extracellular concentration of glucose was measured. The results are shown in the graph below. Study the information and answer the questions that follow.



a) Describe the rate of glucose uptake with increasing extracellular concentration when diffusion is facilitated.
   - *At 1mM, glucose uptake is low.*
   - *From 1mM to 5mM extracellular concentration of glucose, the rate of glucose uptake increases rapidly.*
   - *The rate of glucose uptake then increases gradually from 5mM to 11mM.*
   - *From 11mM up to 15mM, the rate of glucose uptake is very slow/almost constant.*

b) Compare the rate of glucose uptake when diffusion is facilitated and when it is not.
   - *In both, increase in concentration in extracellular glucose results in increase in glucose uptake. However, facilitated diffusion causes a much higher levels of glucose uptake than simple diffusion.*
   - *Also the rate of increase in glucose uptake for simple diffusion is constant/low with increase in concentration while that for facilitated diffusion is high at low concentration but slows down as the concentration of glucose increases.*
   - *Both did not reach maximum rate.*
   - *Rate of facilitated diffusion is not directly proportional to increase in extracellular concentration of glucose while simple diffusion is directly proportional.*
   - *Facilitated diffusion increases rapidly while simple diffusion increases gradually.*
   - *Uptake of glucose in facilitated diffusion shows a curve while uptake of glucose by simple diffusion is linear.*

c) Explain the effect of increasing extracellular concentration of glucose on the uptake of glucose, when diffusion is facilitated.

Results in more rapid uptake of glucose because protein molecules offer glucose transport channels/carriers all not saturated steep concentration gradient rapid diffusion. Above 4-6mM, low rate of glucose uptake because most protein channels are saturated.

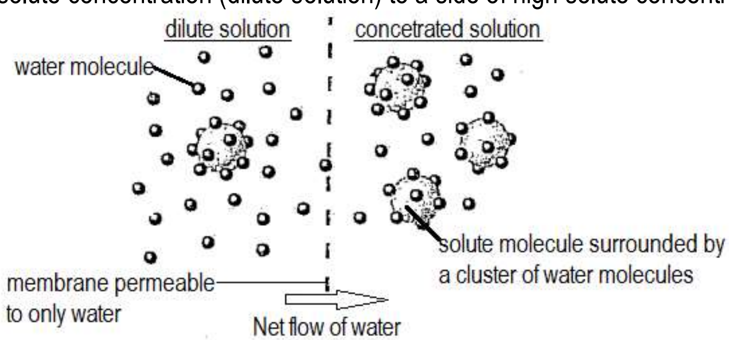
d) Suggest what would happen to the rate of glucose if a respiratory poison was introduced into the cell membrane. Give an explanation for your answer.
No effect/uptake of glucose continues because facilitated diffusion does not require energy/passive process does not require enzymes and uptake continues whenever concentration gradient exists.

e) Explain why
i) Facilitated diffusion occurs.
- *When molecules are large e.g. amino acids.*
- *When molecules are polar e.g. amino acids.*
- *When particles are charged e.g. ions.*

ii) The cell membrane is able to carry out facilitated diffusion.
Cell membrane have special protein molecules which are large and traverse the lipid bilayer, these proteins are of two types.
Channels proteins have fixed shape but with hydrophilic pores and for selective transport of ions.
Carrier proteins rapidly change shape to bind specifically to the molecules they assist to carry over.

OSMOSIS

Pure water contain the greatest concentration of water molecules. However, addition of solutes to pure water lowers its concentration. This is because solute molecules or ions associate with water molecules and hence an increase in solute concentration reduces the amount of free water molecules. In case where two solutions with different concentrations of solutes are separated by a selectively permeable membrane, water molecules will diffuse to both sides. However, net movement will occur along the concentration gradient of water i.e. from a side of lower solute concentration (dilute solution) to a side of high solute concentration (concentrated solution).



The net diffusion of water continues from A to B until the water concentration of both sides of the membrane are equal.
Note: the diffusion of water molecules across a selectively permeable membrane is called **osmosis**.
Osmosis is the movement of water molecules from a region of their high concentration to a region of their low concentration across a semi-permeable membrane. OR
Osmosis is the movement of water molecules from a dilute solution to a concentrated solution across a semi-permeable membrane.

Factors that affect osmosis

1) **Amount of solute molecules dissolved in water:** the higher the amount of solute molecules, the higher the rate of osmosis. This is because water molecules will be attracted to move towards the solute molecules.
2) **Temperature:** the higher the temperature, the more the kinetic energy in the water molecules which brings about faster collision in molecules hence the faster the rate of osmosis. The lower the temperature the lower the rate of osmosis.
3) **Pressure:** the greater the pressure the faster the rate of osmosis and the lower the pressure the slower the rate of osmosis.

Water balance in cells without cell wall

Depending on the solute concentration of the cell, a cell may lose or gain water from the extra cellular environment. This is described by the term **tonicity**. Tonicity is the relative concentration of solutes dissolved in solution which determine the direction and extent of diffusion **or** simply the ability of a solution to cause a cell to lose or gain water.

Types of solutions

1) **Isotonic solution:**
This is a solution which has the same concentration of the solutes as that in the cell. When the cell is surrounded by an isotonic solution there is no net gain or loss of water in the cell, hence the cell shape and size remains unchanged.

2) **Hypotonic solution:**
This is a solution which has a lower solute concentration than that of the cell. When a cell is surrounded by a hypotonic solution, net entry of water into the cell from the solution occurs. The cell swells and eventually bursts.
Note: the plasmodia parasites which causes malaria lives in the red blood cells. In order to observe the parasites under a microscope, red blood cells are exposed to a saline solution which causes them to burst hence releasing the plasmodia parasites. The bursting of the red blood cells is known as **haemolysis**.

3) **Hypertonic solution:**
This is a solution which has a higher solute concentration than inside the cell. When a cell is surrounded by a hypertonic solution, net movement of water molecules from the cell into the solution occurs. The plasma membrane collapses and the cell may die. The cell in this condition is said to be crenated.

A cell with no rigid walls therefore cannot tolerate excessive uptake nor excessive loss of water. This problem of water balance however is automatically solved if such a cell lives in an isotonic surrounding.

Animals and unicellular organisms living in hypertonic or hypotonic environments have special adaptations for control of water balance, a life process called **osmoregulation.**

Protoctists that live in fresh water (hypotonic to the cell) like paramecium have contractile vacuoles which eliminates excess water and gets rid of it by letting it out thus maintaining or balancing the amount of water in its body.

If a solution is separated by a semipermeable membrane from pure water, the hydrostatic pressure required to resist the osmotic flow of water into the solution is called the ***osmotic pressure*** of that solution.

Water balance in cells with cell wall

The cells of plants, prokaryotes, fungi and some Protoctists have cell walls. The movement of water in or out of such cells is determined by two factors, i.e.

- Solute concentration.
- Physical pressure by the rigid cell wall.

Consider a plant cell, to survive, plants must balance water absorption and loss occurring by osmosis. This depends however on 3 factors which occur within the cell.

- Water potential (Ψ)
- Solute potential (Ψ_s)
- Pressure potential (Ψ_p)

1) **Water potential (Ψ):**

Water potential is the ability of water molecules to move out of a cell by osmosis. If two systems containing water are in contact, the random movements of water molecules will result into the net movement of water molecules from the system of the higher water potential to one with the lower water potential until the concentration of water molecules in both systems is equal. This is in effect diffusion involving water molecules.

Water potential is usually expressed in pressure units by biologists (such as Pa; 1Pa = $1Nm^{-2}$).

Pure water has the maximum water potential which is zero (0). Water always moves from a region of high water potential to one of lower water potential.

All solutions have lower water potential than that of pure water and therefore has ***a negative value of psi (-Ψ).***

The water potential of a solution falls when solutes are added because water molecules cluster around the solute molecules. As the concentration of solutes increases, clustering also increases, further lowering the water potential.

Factors that affect water potential (Ψ)

- **Amount of solute dissolved:** addition of solute molecules to pure water reduces the concentration of water molecules and hence lowers the water potential of the solution formed.
- **External pressure:** when external pressure is applied to a solution, its water potential decreases. This is because the pressure tends to force the water out of the solution.

2) **Solute potential (Ψ_s):**

This is the measure of the reduction of the water potential in the cell due to presence of solute molecules. It is also defined as the degree of lowering or measure of change in water potential of the system due to the presence of solute molecules. It is also called the **osmotic potential.** *It always has a negative value*. The more solute molecules present, the lower (more negative) is the solute potential. For a solution, $\Psi = \Psi_s$

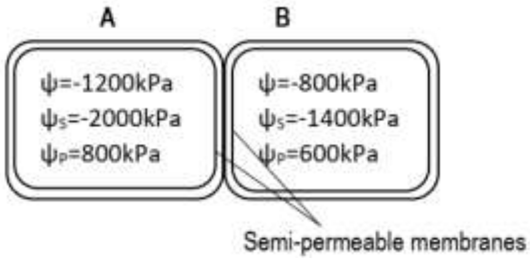
3) **Pressure potential (Ψ_p):**
This is the physical pressure exerted to a solution. In relation to the plant cell, pressure potential refers to the pressure exerted by the cell wall against the ***protoplasm***. This pressure is called turgor pressure. Pressure potential is usually ***positive.***

Water potential is affected by both solute potential and pressure potential, and the following equation summarizes the relationship between the two terms;

Water potential = solute potential + pressure potential

$\Psi_{cell} = \Psi_s + \Psi_P$

Consider the figure below in which two plant cells possessing different water potential are in contact.



Since cell B has the highest water potential of -800kPa, water will flow from ***B*** to cell ***A*** by osmosis.

At equilibrium, the two cells will have the same water potential which will be the average of the two i.e. -1000kPa. Assuming Ψ_s does not change significantly, the Ψ_P at equilibrium in cell ***A*** and cell ***B*** would be calculated as follows:

Cell *A:*

$\Psi = \Psi_s + \Psi_P$

$\Psi_P = \Psi - \Psi_S$

$\Psi_P = -1000 + 2000$

$\Psi_P = 1000kPa$

Cell B:

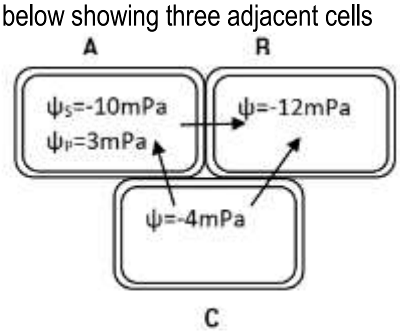
$\Psi = \Psi_s + \Psi_P$

$\Psi_P = \Psi - \Psi_S$

$\Psi_P = -1000 + 1400$

$\Psi_P = 400kPa$

For example, consider the diagram below showing three adjacent cells



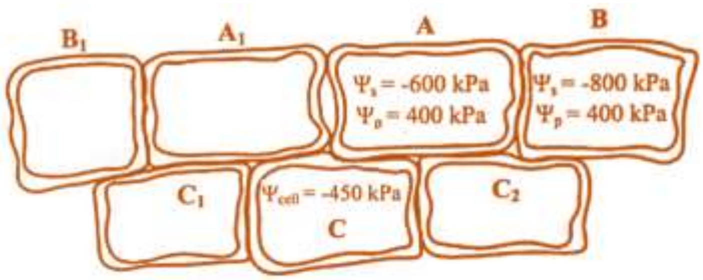
a) Calculate the water potential of cell A.
$\Psi = \Psi_s + \Psi_P$
$\Psi = -10 + 3$
$\Psi = -7mPa$

b) By means of arrows, show the direction of water movement between the cells.
Water moves by osmosis from a region/cell of high water potential (less negative) to a region/cell of low water potential (more negative).

c) Explain why water potential of sucrose solution has a negative value.
This is because water has a water potential of zero therefore sucrose having a negative value (lower water potential) enables water molecules to move into sucrose solution by osmosis and cannot move out of the solution.

Worked out examination questions:

1. The figure below shows two guard cells A and A_1 with adjacent cells B, B_1, C, C_1 and C_2. The values of the solute potential and pressure potential shown in cells A and B are exactly the same as those for cell A_1 and B_1 respectively. Similarly, the water potential indicated in cell C is the same as that in cells C_1 and C_2. Use the figure to answer the questions that follow.



a) Calculate the water potential of cells A and B.

Cell A:

$\Psi = \Psi_S + \Psi_P$

$= -600 + 400$

$= -200kPa$

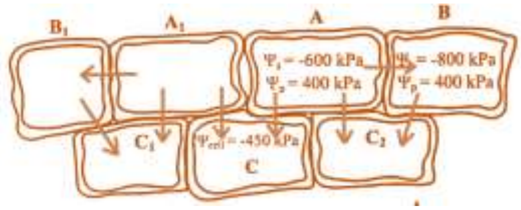
Cell B:

$\Psi = \Psi_S + \Psi_P$

$= -800 + 400$

$= -400kPa$

b) Show by means of arrows the net movement of water in the seven cells.



c) Explain why the net movement of water in the cells is as you have indicated in (b).

Water moves from a region of high water potential to a region of low water potential. Water moves from cell A and A_1 with highest water potential to the rest of the other cells and moves from cells B and B_1 of higher water potential to cells C_1 and C_2.

d) What would be the effect of the net movement of water indicated in (b) to guard cells A and A_1?

The guard cells would lose their turgidity and the stoma would close.

2. a) Explain how changes in the solute potential of a cell affects turgidity.

Decrease in solute potential (more negative) of the cell causes water to enter it by osmosis and the cell become turgid.

Increase in solute potential (less negative) causes the cell to lose water by osmosis thereby becoming plasmolysed/flaccid.

b) A plant cell with a solute potential of -1240kPa and a pressure potential of 350 kPa was immersed in a sucrose solution whose water potential was -530kPa.

i) Calculate the water potential gradient between the cell and the sucrose solution.

$\Psi = \Psi_S + \Psi_P$

$= -1240 + 350$

$= {}^{--}890kpa$

Water potential gradient $= -890 - {}^{--}530$

$= {}^{--}360kpa$

ii) State the direction in which the water will flow.

Sucrose solution to cell

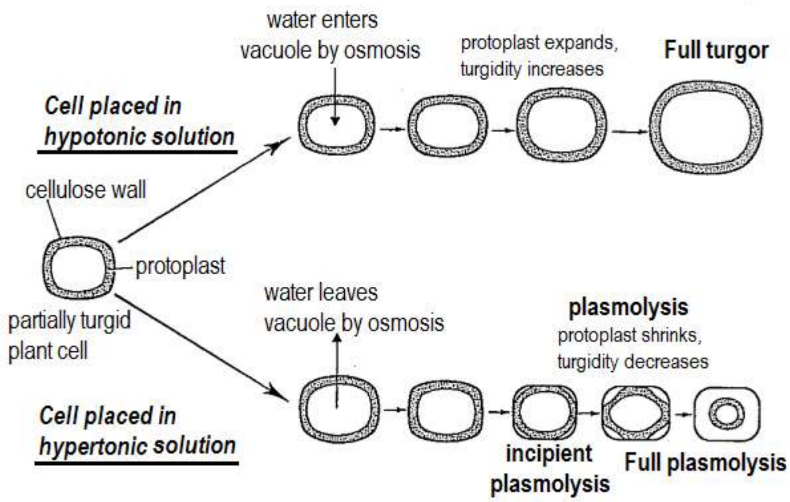
Effect of hypotonic and hypertonic solutions in plant cell

Depending on the concentration of fluid outside the plant cells, they show turgidity or plasmolysis.

Turgidity: when the plant cells are placed in a hypotonic solution, water flows into the cell by endosmosis. The cells' protoplasts are not disrupted due to the presence of cell wall and thus become ***turgid***.

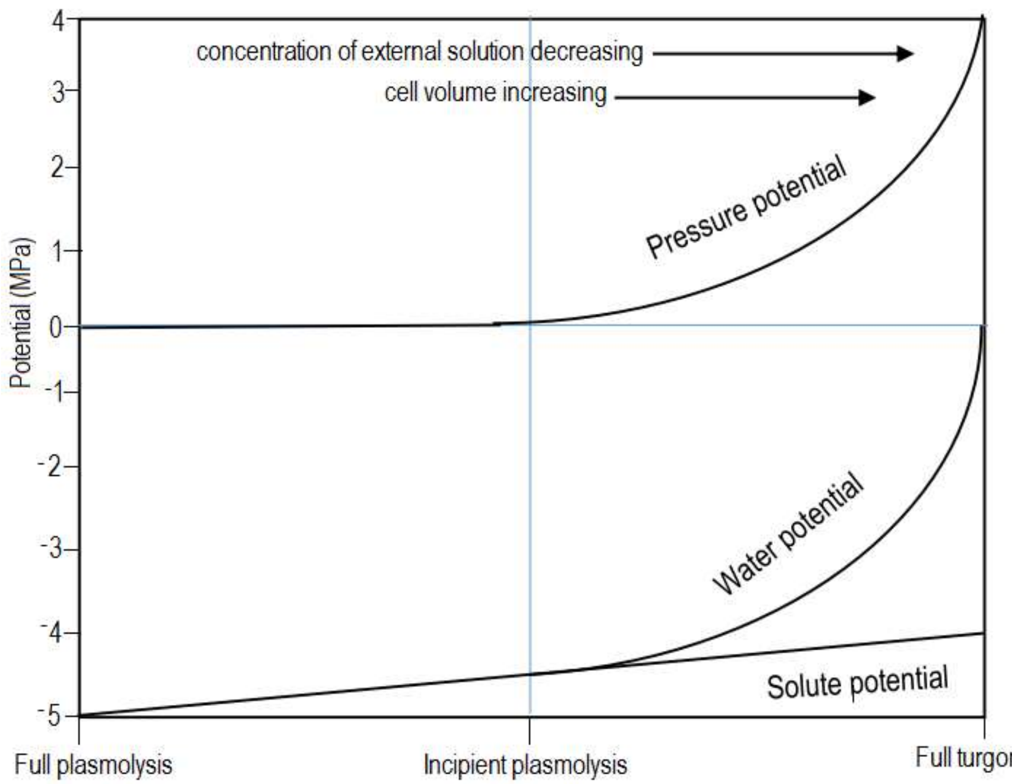
Plasmolysis: when the plant cells are placed in a hypertonic solution, water flows out by exosmosis. The protoplasm (cytoplasm along with the plasma membrane) withdraws from the cell wall. The ***vacuole shrinks*** and this process is called ***plasmolysis.***

When a plant cell ***starts*** losing water by exosmosis, the plasma membrane slightly pulls away from the wall, a phenomenon called ***incipient plasmolysis***. Incipient plasmolysis is a state where by a plant cell has lost water by osmosis, the protoplasm and cell membrane have *just* started to pull away from the cell wall making the cell flaccid. Eventually, the plasma membrane fully pulls away from the wall, and in this state, it is said to be ***fully plasmolysed.*** Full plasmolysis is when the cell protoplasm is completely detached from the cell wall.



Changes of potentials of a plant cell placed in a hypotonic solution

The graph below shows the variation of water potential, solute potential and pressure potential of a cell with the concentration of the external environment.



Explanation of the changes in potentials

1) Pressure potential:

At full plasmolysis, the pressure potential is zero since the protoplast is completely pulled away from the cell wall and the wall exerts no pressure at the cell contents.

From full plasmolysis to incipient plasmolysis, the pressure potential remains zero since the protoplast remains pulled away from the cell wall and so the wall still does not exert any pressure against the protoplasm.

Between incipient plasmolysis and full turgor, the pressure potential increases very rapidly because the volume of the vacuole increases as more water is taken in by endosmosis. The vacuole pushes the protoplast and exerts pressure on the cell wall and the rigidity of the cell wall causes a rapid rise in pressure potential.

2) Solute potential:

This is component of water potential due to presence of solutes.

From full plasmolysis to full turgor, the solute potential increases gradually (becomes less negative) because entry of water into the cell gradually reduces the concentration of solute molecules in the cell. At full turgor, $\Psi_P = \Psi_S$ but opposite i.e. Ψ_P is positive and Ψ_S is negative.

3) Water potential:

At full plasmolysis, the water potential of the cells is very low (very negative) due to high concentration of solute molecules in the cell.

From full plasmolysis to incipient plasmolysis, as water enters the cell by endosmosis, both the solute potential and water potential increase at the same gradual rate, i.e. $\Psi = \Psi_S$.

Between incipient plasmolysis and full turgor, as the cell continues to expand, the pressure potential gets steadily greater and the water potential increases rapidly i.e. gets less and less negative due to rapid absorption of water by endosmosis.

At full turgor, the cell can no longer expand, the water potential of the cell reaches zero and the osmotic potential of the sap is exactly counterbalanced by the pressure potential.

Comparison of dilute and concentrated solutions

Dilute solution	Concentrated solution
Low concentration of solute molecules.	High concentration of solute molecules.
High concentration of water molecules.	Low concentration of water molecules.
Low osmotic pressure.	High osmotic pressure.
High osmotic potential.	Low osmotic potential (i.e. more negative).
High water potential (less negative).	Low water potential (i.e. more negative).
High solute potential.	Low solute potential.

Wilting

When the cells in the stem and leaves of a plant lose more water by evaporation than they can absorb, turgor is reduced and the plant visibly droops. This phenomenon is called **wilting.** It can often be observed on hot, dry days. The plants usually recover at night when evaporation is reduced by closure of the stomata, but if the water supply to the roots is inadequate permanent wilting occurs and the plants die.

A plant is said to suffer from **water stress** if it loses more water through transpiration than it can absorb into its roots by osmosis.

Effects of water stress in plants

- Excessive water loss leads to drooping of the shoot and leaves, a condition known as wilting.
- The stomata rapidly close due to the secretion of Abscisic acid by the cells in the wilted leaves.
- The closing of the stomata to reduce on the rate of water loss reduces the rate of photosynthesis due to lack of carbon dioxide.
- Reduced photosynthesis causes a reduced growth rate hence stunting.
- Loss of water can lead to desiccation and often death of plant.

Differences between wilting and plasmolysis

Plasmolysis	Wilting
Occurs due to presence of osmotic gradient.	Occurs due to high temperature.
Only the protoplast shrinks leaving the cell wall behind.	The whole cell including cell wall shrinks and no gap develops between the plasma membrane and cell wall.
Does not result into drooping of the shoot and leaves of the plant.	Results into drooping of shoot and leaves of plants.

The importance of turgidity in plants

- Increased turgidity/full turgor of plant cells offer support and maintain shape and form a non-woody/herbaceous plants, keeping them in an erect position.
- Full turgor/increased turgidity keep the leaves in a flat and horizontal position to expose a large surface area for trapping sunlight.

- Increased turgidity of guard cells enables opening of stomata for exchange of gases or promotes transpiration. Loss in turgidity causes stomata to close so as to reduce transpiration.
- Increased turgor pressure enhances cell enlargement and stretches the stems leading to growth.
- Increased turgidity enables the insect traps of insectivorous plant leaves to open so as to attract insects. Loss in turgidity causes the leaves to close so as to trap the prey.

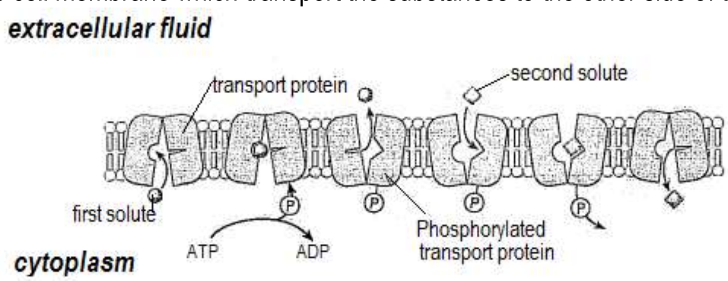
Differences between diffusion and osmosis

Diffusion	Osmosis
It is the random and spontaneous movement of solute or gas molecules.	It is the passage of solvent molecules.
It is the movement of ions or molecules from a region of high concentration to a region of their low concentration.	It is the movement of solvent (water) molecules from their high concentration to low concentration.
Occurs when there are no barriers to movement such as through a freely permeable.	Occurs through a partially permeable membrane.

ACTIVE TRANSPORT

This is the movement of solute particles from a region of low concentration to a region of high concentration against a concentration gradient using energy.

Active transport only takes place in a living system that is actively producing energy by respiration. Active transport takes place by means of carrier molecules in the cell membrane which transport the substances to the other side of the membrane.



One of the most important is the sodium-potassium pump which pumps sodium ions out of the cell and potassium ions in. The cells have higher Na^+ concentration outside than inside the cell. This is important in generating impulses in nerve cells.

Cells and tissues carrying out active transport are characterized by:

- The presence of numerous mitochondria.
- A high concentration of ATP.
- A high respiratory rate.

The sodium potassium pump

This is a carrier protein which spans the membranes from one side to the other. This protein actively pumps sodium ions out of the cell while at the same time accumulating potassium ions into the cell from the environment.

The mechanism of the sodium potassium pump

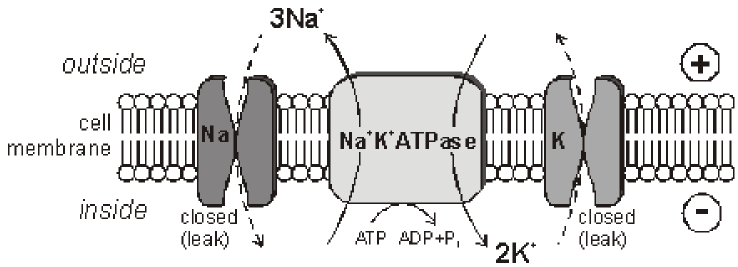
The pump binds three sodium ions and ATP inside the cell. ATP is then hydrolysed to ADP and a phosphate group releasing a lot of energy. The hydrolysis of ATP to ADP is catalyzed by the enzyme ATPase.

The phosphate group phosphorylates the pump leading to the formational change of the pump. This exposes ions to the outside from where they are subsequently released.

The pump then binds to potassium ions from outside the cell. This causes the release of the phosphate group from the pump which results into its dephosphorylation.

The dephosphorylated pump reverts or changes back to its original shape thereby transporting potassium ions into the cell.

Na-K pump removes 3 Na^+ for every 2 K^+ brought in. It therefore moves 3 Na^+ out of the cell and 2 K^+ into the cell.



Importance of the pump

- It is important in maintaining osmoregulation.
- Maintaining electrical activity (nerve impulse in nerve cell).

Factors that affect active transport

- Oxygen concentration.
- Temperature.
- Presence of respiratory inhibitors e.g. potassium cyanide (KCN).

Examples of active transport

- Loading of sugar into the phloem/un loading for transport.
- Absorption of some mineral salts by plant roots.
- Active pumping of K^+ into the guard cells.
- Secretion of salts in halophytes.
- Secretion of nectar from nectaries.
- Secretion of water by hydathodes.
- Secretion of salts into the xylem by the endodermis.
- Active pumping of H^+ into the thylakoid space/intermembrane space of mitochondrion.

Importance of active transport

- Absorption of mineral salts by plant roots.
- Absorption of nutrients in the gut (digestive system).
- Re-absorption of glucose, amino acids and salts in the nephron.
- Transmission of nerve impulses.
- Active loading of sugars into the phloem tissue for translocation.

Differences between active transport and diffusion

Active transport	Diffusion
• Movement is in one direction • Requires energy • Movement against a conc. gradient • Selective • Involves protein carriers • Affected by metabolic poison • Occurs only in living cells. • Equilibrium is not established • It is a rapid process.	• Movement is in both directions. • No energy required. • Movement is along a concentration gradient. • Non-selective. • May or may not involve carriers. • Not affected by metabolic poison. • Can occur in both living and nonliving cells. • Equilibrium may not be established. • It is a slow process.

BULK TRANSPORT

This involves two processes i.e. **endocytosis** and **exocytosis**. They are the processes through which the cell transport large quantities of materials (solid or liquid) into and out of the cell.

1) Endocytosis

This is the process of active intake of large quantities of materials by the membranes. These materials cannot pass through the plasma membrane and occurs by an infolding or extension of the plasma membrane to form a vesicle or vacuole. It is of two types i.e. phagocytosis (solid materials) or pinocytosis (liquid materials).

i) Phagocytosis:

It is also known as cell eating. The material is taken up in a solid form. The cells specialized in the process are called phagocytes. E.g. macrophages and white blood cells.

The sequence of events during phagocytosis is given below:

- Binding of the solid (germs, bacteria, damaged cells) with the membrane receptor of the phagocyte.
- Invagination of the membrane and pseudopodia-like formation.
- Fusion of pseudopodial membranes and formation of vesicle phagosome.
- Fusion of phagosome with lysosome.
- Hydrolysis of contents by enzymes.

ii) Pinocytosis:

It is also called cell drinking. The material is taken up in the liquid form (solution, colloid, suspension). The events during pinocytosis are given below:

- Extracellular solute binds with the specific membrane receptor of the membrane.
- Invagination of the membrane.
- Formation of vesicle containing colloid/solute with water droplet.
- Pinching off of membrane bound vesicle containing colloid/solute.
- Digestion of the contents.

2) Exocytosis

It is also known as reverse endocytosis. By this process the materials (solid secretions or undigested remains) are removed from the cells. The material is stored in the membrane bound vesicle which moves to the plasma membrane and fuse with it. As it fuses, the contents are released through the channel formed. Excretion in amoeba and secretion of hormones is done by this process only.

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"If you want to change the fruits, you will first have to change the roots. If you want to change the visible, you must first change the invisible."