# Cell Membranes and Transport

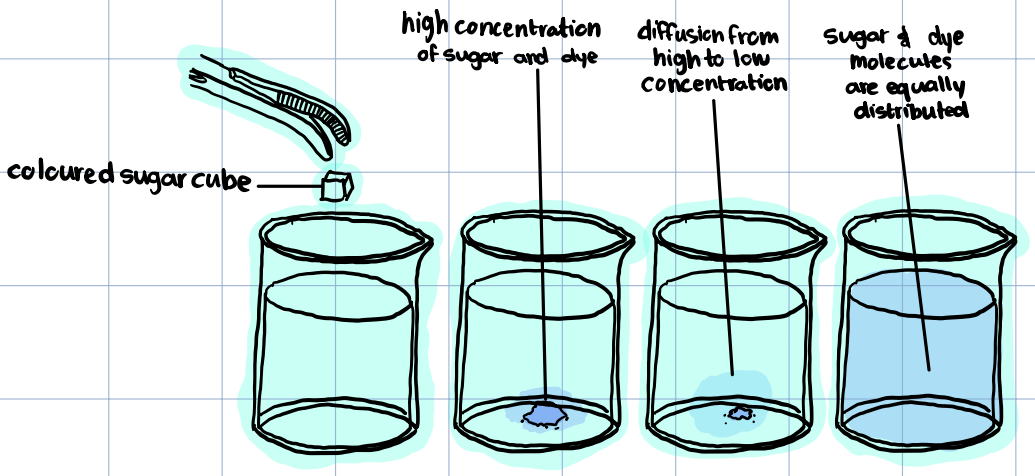
## .MOVEMENT OF SUBSTANCES INTO AND OUT OF CELLS

### Diffusion

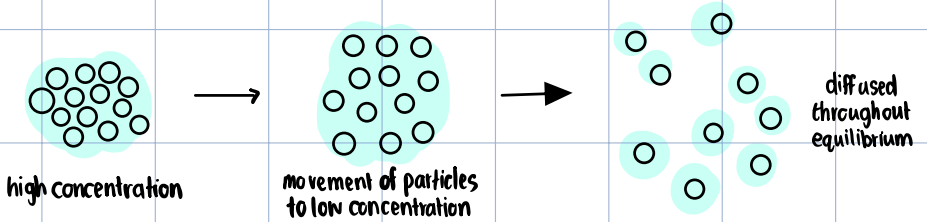
**Diffusion:**
It is the net movement of molecules or ions from a region of higher concentration to a region of lower concentration down a concentration gradient, as a result of the random movements of particles.

**Simple diffusion:**
It is a type of diffusion across membranes in which substances move down their concentration gradient through a phospholipid bilayer.

Diffusion can be defined as the net movement, as a result 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 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.




Some molecules are able to pass through living cell membranes by simple diffusion. It occurs where the lipid bilayer of the membrane is permeable to non-polar substances like steroids, fatty acids and glycerol, and also gases like oxygen and carbon dioxide. All these non-polar substances diffuse via this route (through the phospholipid bilayer) from a high to a low concentration.



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

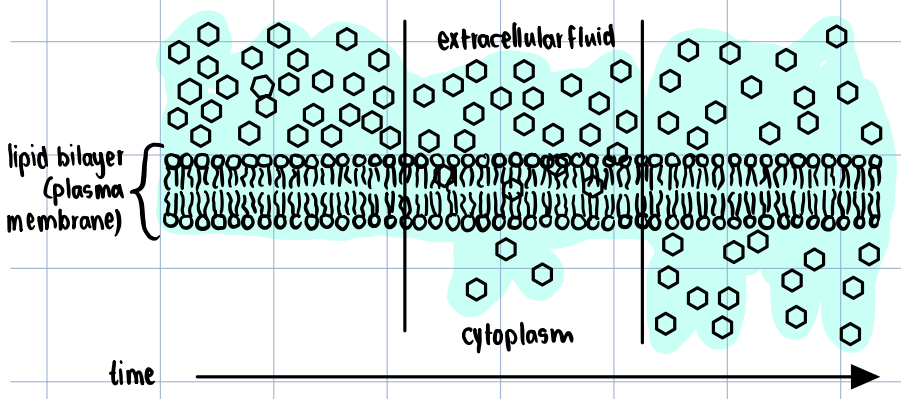
• The 'steepness' of the concentration gradient between two areas – that is, the difference in the concentration of the substance on the two sides of the surface. If there are, for example, many more molecules on one side of a membrane than on the other, then at any one moment more molecules will be moving (entirely randomly) from this side than from the other. The greater the difference in concentration, the greater the difference in the number of molecules passing in the two directions and hence the faster the rate of diffusion.

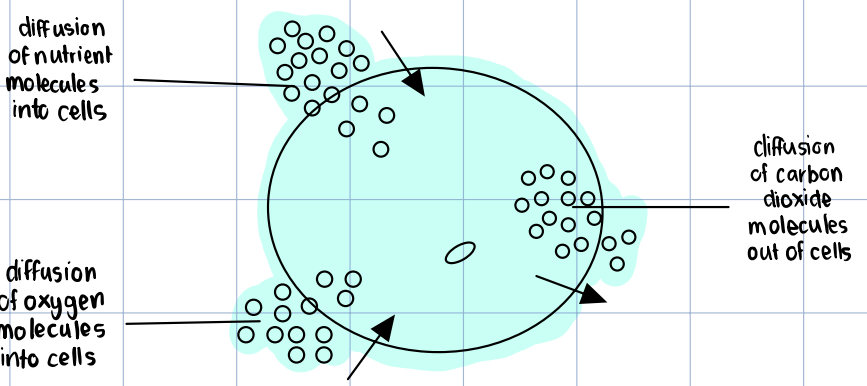
• Temperature. At high temperatures, molecules and ions have much more kinetic energy than at low temperatures. They move around faster and thus diffusion takes place faster.

• The surface area across which diffusion is taking place. The greater the surface area, the more molecules or ions can cross 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 in the cristae inside mitochondria. The larger the cell, the smaller its surface area in relation to its volume.

• The nature of the molecules or ions. Large molecules 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 glycerol, alcohol and steroid hormones, diffuse much more easily through cell membranes than polar ones, because they are soluble in the non-polar phospholipid tails.

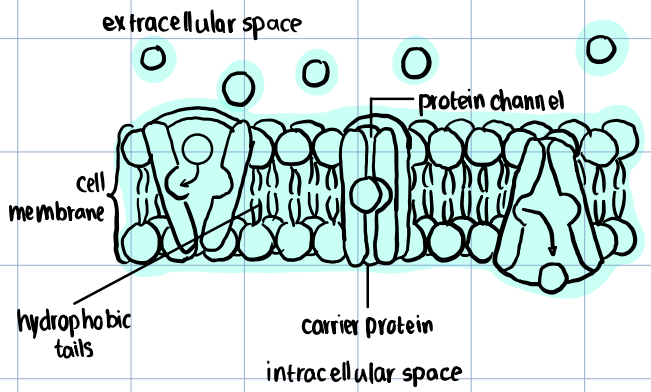
The respiratory gases – oxygen and carbon dioxide – cross membranes by diffusion. They are uncharged and non-polar, and so can cross through the phospholipid bilayer directly between the phospholipid molecules. Water molecules, despite being very polar, can diffuse rapidly across the phospholipid bilayer because they are small enough.



Cells rely on simple 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. In fact, the rate falls in proportion to the square of the distance. Diffusion is therefore only effective over very short distances, such as the 7 nm across a membrane. 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 50 m in diameter.

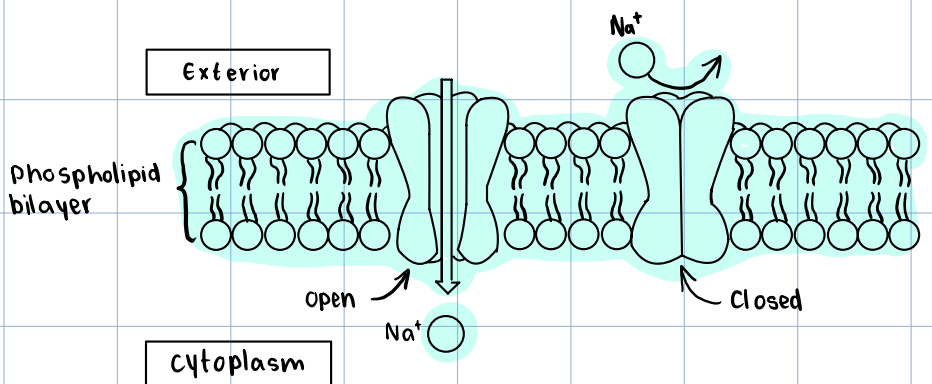
## Facilitated diffusion

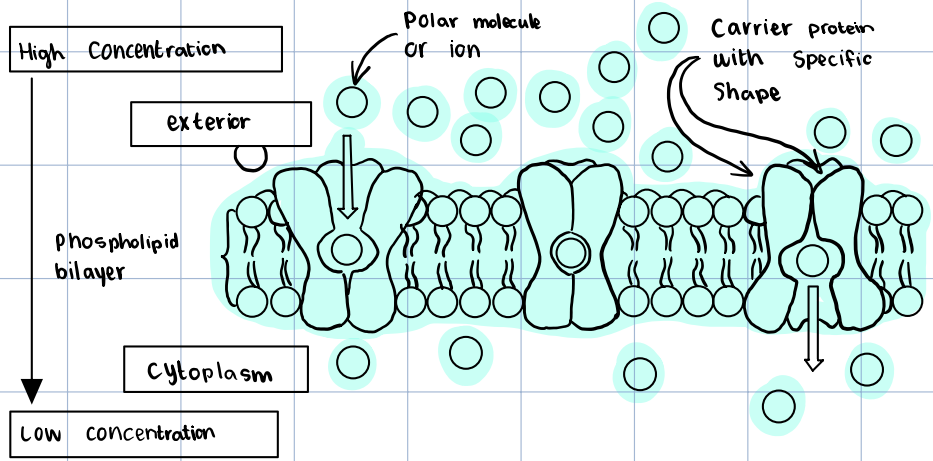



Facilitated diffusion:

It is the diffusion of a substance down their concentration gradient through transport proteins (channel proteins and carrier proteins) in a cell membrane.

Unless they are very small, polar molecules cannot pass through the phospholipid bilayer. Large polar molecules, such as glucose and amino acids, thus cannot diffuse through the phospholipid bilayer, nor can ions such as sodium ($Na^+$) or chloride ($Cl^-$). These, and AD that enters the mitochondria and ATP that exits the mitochondria, can only cross the membrane with the help of certain protein molecules. Diffusion that takes place in this way is called facilitated diffusion. 'Facilitated' means made easy or made possible, and this is what these proteins do.



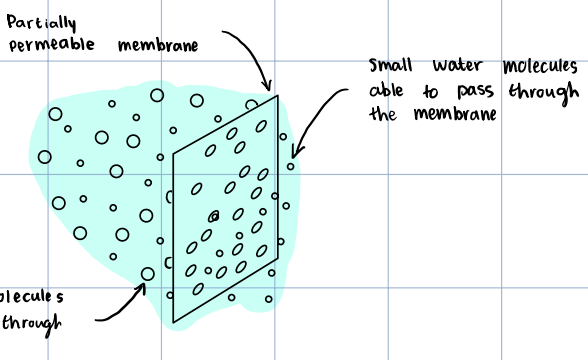



There are two types of transport protein involved, namely channel proteins and carrier proteins.
Each is highly specific, allowing only one type of molecule or ion to pass through it. Channel proteins are water-filled pores. They allow charged substances, usually ions, to diffuse through the membrane. Most channel proteins are 'gated'. This means that part of the protein molecule on the inside surface of the membrane can move to close or open the pore, like a gate. This allows control of ion exchange. Whereas channel proteins have a fixed shape, carrier proteins can flip between two shapes. As a result, the binding site is alternately open to one side of the membrane, then the other. If the molecules are diffusing across the membrane, then the direction of movement will normally depend on their relative concentration on each side of the membrane They will move down a concentration gradient from a higher to a lower concentration. However, the rate at which this diffusion takes place is affected by how many channel or carrier protein molecules there are in the membrane, and, in the case of channel proteins, on whether they are open or not.

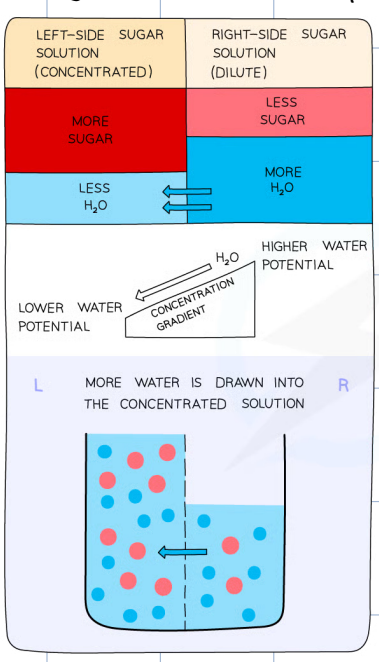
## Osmosis

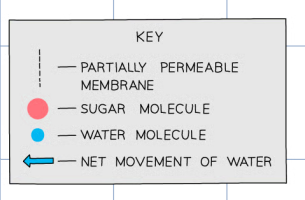
### Osmosis:

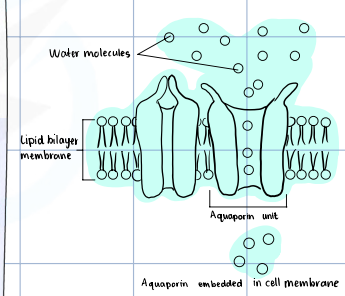
It is the net movement of water molecules from a region of higher water potential to a region of lower water potential, through a partially permeable membrane, as a result of their random motion (diffusion).




Osmosis is a special type of diffusion involving water molecules only. In the explanations that follow, remember that:
solute + solvent = solution (example: sucrose + water = sugar solution)
In a sugar solution, for example, the solute is sugar and the solvent is water.



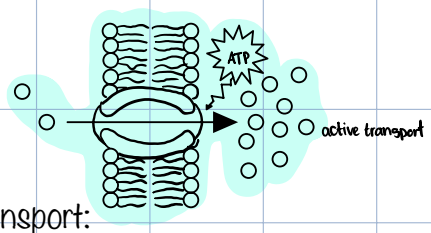



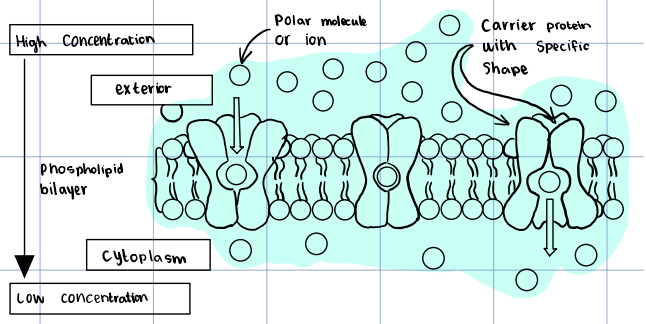

Theoretically, the lipid bilayer of the cell membrane is impermeable to water molecules, because water molecules are polar. Yet, water molecules, despite being very polar, can diffuse across the phospholipid bilayer as well, because they are small enough.
Molecules of the lipid bilayer are always on the move, producing tiny (short-lived) pores that are large enough for water molecules to pass through.

Water molecules are polar. Cells have aquaporins which are channel proteins specialised for the transport of water across membranes.

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# Active transport




Active transport:

It is the movement of molecules or ions by carrier proteins across a cell membrane, against their concentration gradient, using energy supplied by ATP.

If the concentration of particular ions, such as potassium and chloride, inside cells is measured, it is often found that they are 10-20 times more concentrated inside than outside. In other words, a concentration gradient exists, with a lower concentration outside and a higher concentration inside the cell. The ions inside the cell originally came from the external solution, therefore diffusion cannot be responsible for this gradient because, as we have seen, ions diffuse from high concentration to low concentration. The ions must therefore accumulate against a concentration gradient. The process responsible is called active transport.

It is achieved by carrier proteins, each of which is specific for a particular type of molecule or ion.
The carrier protein changes shape (conformational change) to move ions and polar molecules, such as glucose, across the membrane. The substance concerned binds to the carrier protein and this prompts a change in shape, so that the substance is moved through the membrane.
When the ion or polar molecule is deposited on the opposite side, the carrier protein returns to its original shape ready for another ion or molecule to bind. Unlike facilitated diffusion, active transport requires energy, because movement occurs up a concentration gradient. The energy is supplied by the molecule ATP (adenosine triphosphate), which is produced during respiration inside the cell. The energy is used to make the carrier protein change its shape, transferring the molecules or ions across the membrane in the process.

Active transport can therefore be defined as the energy-consuming transport of molecules or ions across a membrane against a concentration gradient (from a lower to a higher concentration).
The energy is provided by ATP from cell respiration. Active transport can occur either into or out of the cell.
Active transport is important in reabsorption in the kidneys, where certain useful molecules and ions have to be reabsorbed into the blood after filtration into the kidney tubules.
It is also involved in the absorption of some products of digestion from the gut. In plants, active transport is used to load sugar from the photosynthesising cells of leaves into the phloem tissue for transport around the plant and to load inorganic ions, e.g. iron ions, from the soil into root hairs.

Active transport through carrier protein which changes shape (conformational change) to move ions and polar molecules across the membrane.

## Bulk transport

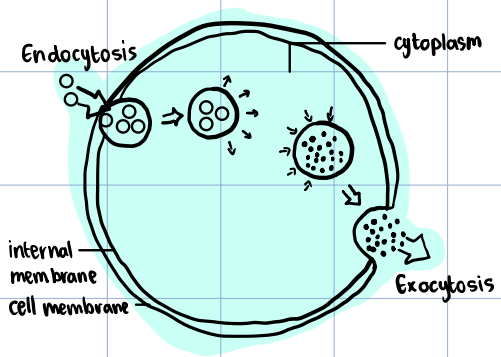
Mechanisms also exist for the bulk transport of large quantities of materials into cells (endocytosis or out of cells (exocytosis. Large molecules such as proteins or polysaccharides, parts of cells or even whole cells may be transported across the membrane. This requires energy, so it is a form of active transport.

### Endocytosis:

It is the bulk movement of liguids (pinocytosis) or solids (phagocytosis into a cell, by the infolding of the cell surface membrane to form vesicles containing the substance; endocytosis is an active process requiring ATP.

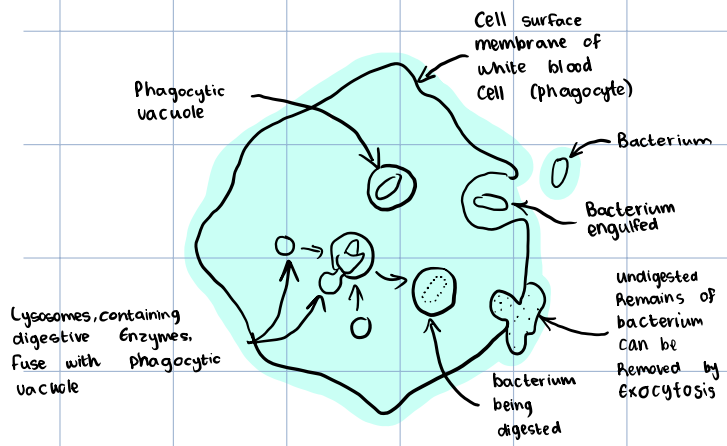
### Exocytosis:

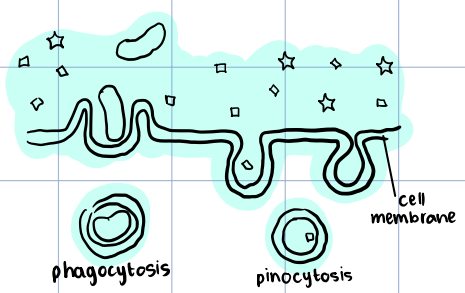
It is the bulk movement of liquids or solids out of a cell, by the fusion of vesicles containing the substance with the cell surface membrane; exocytosis is an active process requiring ATP.




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

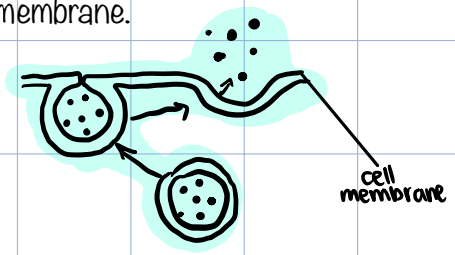
- Phagocytosis or 'cell eating' - this is the bulk uptake of solid material. Cells specialising in this are called phagocytes. The process is called phagocytosis and the vacuoles phagocytic vacuoles. An example is the engulfing of bacteria by certain white blood cells
- Pinocytosis or 'cell drinking' - this is the bulk uptake of liquid. The vacuoles (vesicles) formed are often extremely small, in which case the process is called micropinocytosis.

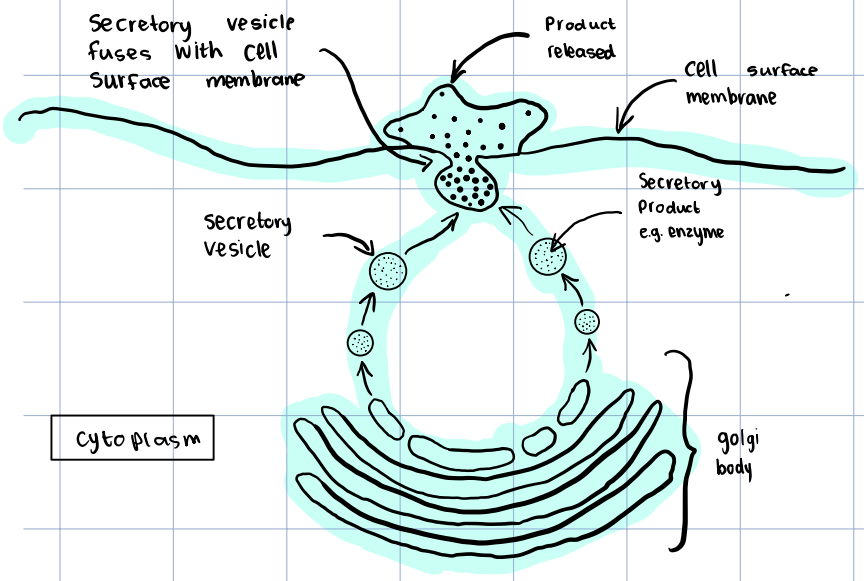



Exocytosis is the reverse of endocytosis and is the process by which materials are removed from cells. It happens, for example, in the secretion of digestive enzymes from cells of the pancreas.

Secretory vesicles from the Golgi body carry the enzymes to the cell surface and release their contents. Plant cells use exocytosis to get their cell wall building materials to the outside of the cell surface membrane.






## 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 how much water the solution contains in relation to solutes.

Water molecules thus move from where there are a lot of free water molecules to where there are less free water molecules.

Water always moves from a region of high water potential to a region of low water potential. We say water always moves down a water potential gradient. This will happen until the water potential is the same throughout the system, at which point we can say that equilibrium has been reached.

For example, a solution containing a lot of free water molecules (a dilute or hypotonic solution) has a higher water potential than a solution containing only a little water (a concentrated or hypertonic solution).

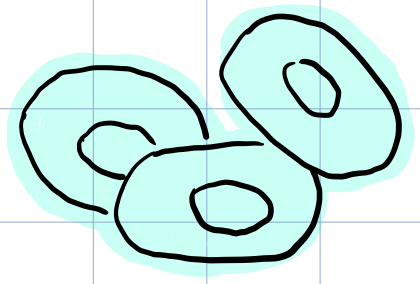
## OSMOSIS IN ANIMAL CELLS

the effect of osmosis on an animal cell. A type of animal cell that is convenient to study in practical work, is the red blood cell. A microscope slide of fresh blood viewed with a microscope will show large numbers of red blood cells. Different samples of blood can be mixed with solutions of different water potential.

A shows red blood cells in the correct concentration, e.g. blood plasma.

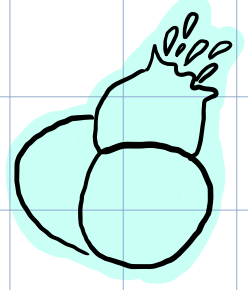
B shows that if the water potential of the solution surrounding the cell is too high, the cell swells and bursts (lyse). If it is too low, the cell shrinks(C). This shows one reason why it is important to maintain a constant water potential inside the bodies of animals.

red blood cells A



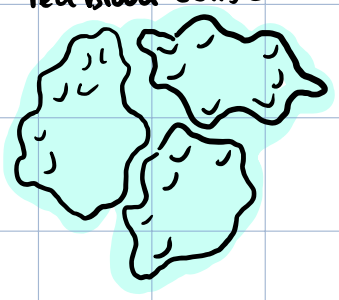
RBCs in a solution with same concentration as red blood cell - isotonic solution same amount moves into and out of the red blood cells and they remain normal

red blood cells B



RBCs in pure water or dilute solution or weak solution or hypotonic solution (low concentration of solute molecules) water moves into red blood cells and their volume increases which causes them to burst (lyse) eventually

red blood cells C



RBCs in concentrated solution or strong solution or hypertonic solution (high concentration of solute molecules) water moves out of red blood cells and their volume decreases which causes them to shrink

## OSMOSIS IN PLANT CELLS

Turgid:

It refers to cells or tissues that are swollen from water uptake.

Many cell types in many different organisms can become turgid due to water uptake. This swells the vacuole, creating pressure on the walls of the cell. This pressure is called turgor pressure.

Flaccid:

It is when a cell is placed into a more concentrated solution (low water potential), the cell contents lose water by osmosis and shrink a bit.

Plasmolysis:

It is the shrinking of the cytoplasm of a plant cell or bacterium due to water loss from osmosis, thereby resulting in the cell membrane tearing away from the cell wall, leaving gaps between the cell wall and cell membrane.

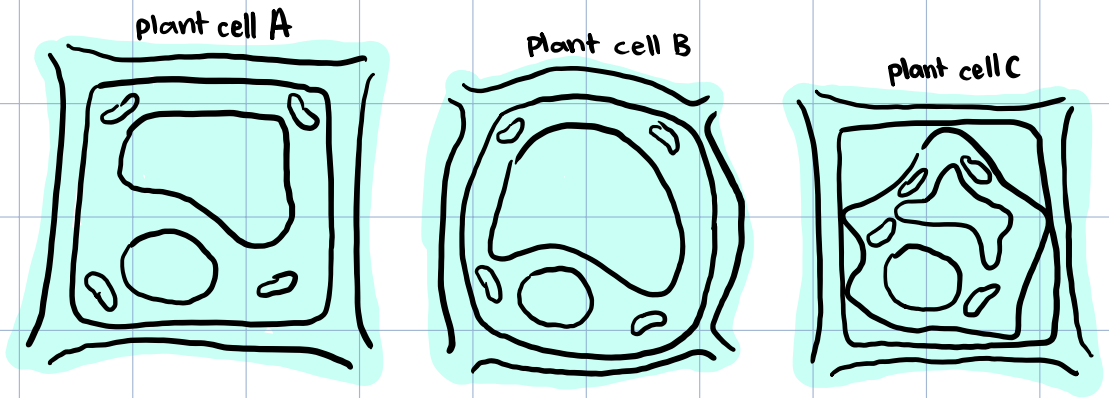
unlike animal cells, plant cells are surrounded by cell walls, which are very strong and rigid.

Imagine a plant cell being placed in pure water or a dilute solution. The water or solution has a higher water potential than the plant cell, and water therefore enters the cell through its partially permeable cell surface membrane by osmosis. Just like in the animal cell, the volume of the cell increases, but in the plant cell the cell wall pushes back against the expanding protoplast (the living part of the cell inside the cell wall) and pressure starts to build up rapidly. This is the pressure potential, and it increases the water potential of the cell until the water potential inside the cell equals the water potential outside the cell and equilibrium is reached. The cell wall is so inelastic that it takes very little water to enter the cell to achieve this.

The cell wall prevents the cell from bursting, unlike the situation when an animal cell is placed in pure water or a dilute solution. When a plant cell is fully inflated with water it is described as fully turgid. Turgidity in plant cells is important. When water moves into a plant cell, the vacuole gets bigger, pushing the cell membrane against the cell wall. The force of this increases the turgor pressure within the cell making it firm or turgid. The pressure created by the cell wall stops too much water entering and prevents cell lysis.

The turgidity of all the cells plays a key part in the support of the plant body of herbaceous plants (non woody plants). If a herbaceous plant experiences a shortage of water for a while, it wilts. The cells promptly recover when water becomes available. A wilted plant will die if it y does not receive water.

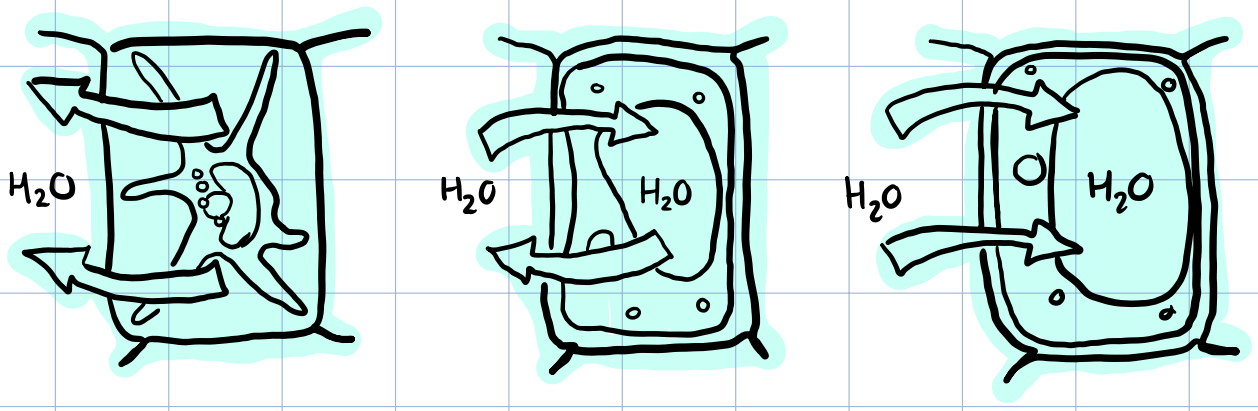
If a plant cell is placed in a concentrated solution, the plant cell is in a solution of lower water potential. An example of the latter would be a concentrated sucrose solution. In such a solution, water will leave the cell by osmosis.
As this happens, the protoplast gradually shrinks until it is exerting no pressure at all on the cell wall. Both the solute molecules and the water molecules of the external solution can pass through the freely permeable cell wall, and so the external solution remains in contact with the shrinking protoplast. As the protoplast continues to shrink, it begins to pull away from the cell wall. This process is called plasmolysis and a cell in which it has happened is said to be plasmolysed. Eventually, as with the animal cell, equilibrium is reached when the water potential of the cell has decreased until it equals that of the external solution. The changes described can easily be observed with a light microscope using strips of epidermis peeled from swollen storage leaves of onion bulbs and placed in a range of sucrose solutions of different concentrations.




plant cell in a solution with same water potential as the cell
- isotonic solution
water moves into and out of the plant cell and it remains normal

plant cell in pure water or solution with higher water potential than cell - hypotonic solution water moves into the plant cell and its volume increases, which causes it to become turgid

plant cell in concentrated solution with a lower water potential than in the cell
- hypertonic solution
water moves out of the plant cell and its volume decreases, which causes it to plasmolyse




Comparison of simple diffusion, facilitated diffusion, osmosis, active transport and bulk transport across cell membranes

| simple diffusion | facilitated diffusion | osmosis | active transport | bulk transport |
|---|---|---|---|---|
| passive process - no energy required | passive process - no energy required | passive process - no energy required | active process - energy from ATP required | active process - energy from ATP required |
| down a concentration gradient | down a concentration gradient | down a concentration gradient | against a concentration gradient | against a concentration gradient |
| cross the membrane at phospholipid bilayer | cross the membrane at channel and carrier proteins | cross the membrane at aquaporins and phospholipid bilayer | cross the membrane at carrier proteins | use a length of the membrane to form vesicles |
| movement of individual molecules | movement of individual molecules | movement of individual molecules | movement of individual molecules | movement of large quantities of molecules, large macro molecules, e.g. proteins, as well as whole cells, e.g. bacteria |

Active transport vs passive transport

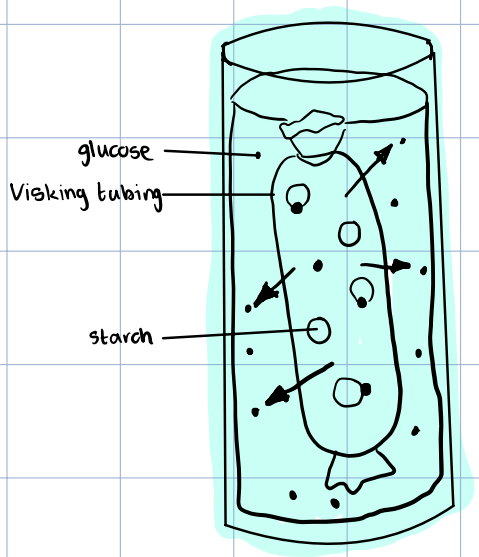
| active transport | passive transport |
|---|---|
| pumps molecules through the cell membrane against a concentration gradient | allows molecules to pass through the cell membrane down a concentration gradient |
| utilises cellular energy in the form of ATP | does not require cellular energy |
| it is a rapid movement | it is a slow movement |
| endocytosis, exocytosis and active transport are types of active transport | simple diffusion, facilitated diffusion and osmosis are types of passive transport |
| comolex sugars, ions, large insoluble proteins and cells get transported through the membrane | water-soluble molecules like small monosaccharides, lipids, carbon dioxide, oxygen and water are transported through the membrane |
| the main function is to transport molecules across the membrane | the main function is to maintain the delicate equilibrium of gases, water, nutrients, etc. |

## DEMONSTRATING DIFFUSION

### Demonstrating diffusion using Viking tubing

Visking tubing (also known as dialysis tubing) is a partially permeable, nor-iving membrane made from cellulose. It possesses molecular-sized pores which are small enough to prevent the passage of large molecules, such as starch and sucrose, but will allow the passage of smaller molecules by diffusion, such as glucose.

- Diffusion can be demonstrated by filling a length of Visking tubing (about 15 cm) with a mixture of starch and glucose solutions.
- If the tubing is suspended in a boiling cylinder of water for a period of time, the presence of starch and glucose outside the tubing can be tested for at intervals to monitor whether diffusion out of the tubing has occurred.



This experiment can be made more quantitative, It would be interesting, for example, to try to estimate the concentration of glucose at each time interval by setting up separate tubes, one for each planned time interval, and using a semi-quantitative Benedict's test each time. A colorimeter would be useful for this. Alternatively, a set of colour standards could be prepared. A graph could be drawn showing how the rate of diffusion changes with the concentration gradient between the inside and outside of the tubing.

Further experiments could be designed if sucrose and an enzyme that breaks down sucrose (sucrase) are added to the Visking tubing. Experiments involving amylase, which breaks down starch, could also be designed.

## Demonstrating diffusion using plant tissue

An experiment showing how the permeability of membranes is affected by environmental factors such as chemicals and temperature can be performed with beetroot. Pieces of beetroot can be placed into water at different temperatures or into different alcohol concentrations. Any damage to the cell membranes results in the red pigment, which is normally contained within the large central vacuole, leaking out of the cells by diffusion. Changes in the colour of the surrounding solution can be monitored qualitatively or quantitatively. You could simply put the tubes in order and make up a colour scale (e.g. from 0 to 10), using water as 0 and the darkest solution as 10. There is an opportunity to design your own experiment.

What is being observed is diffusion of the red dye from a region of high concentration in the vacuoles to a region of low concentration in the solution outside the pieces of beetroot. Diffusion is normally prevented by the partially permeable nature of the cell membranes. After reading how molecules cross membranes, you may like to think about how the dye gets into the vacuoles in the first place.

## Investigating the effect of size on diffusion

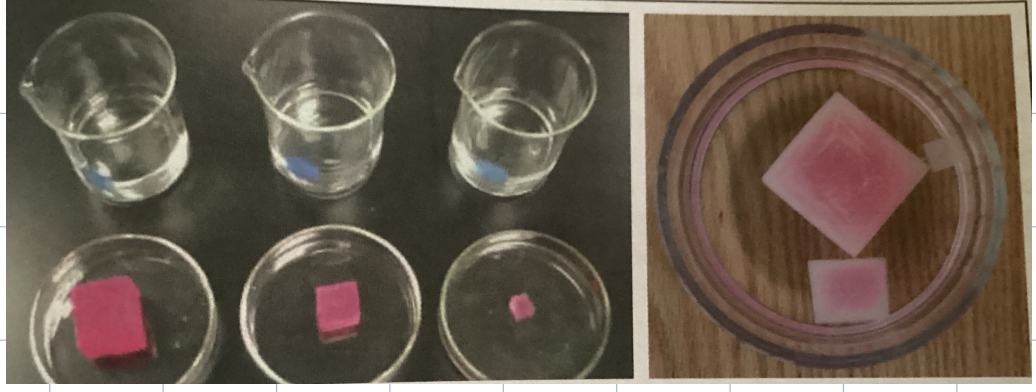
The effect of size on diffusion can be investigated by timing the diffusion of ions through blocks of agar of different sizes. Solid agar is prepared in suitable containers such as ice cube trays.

If the agar is made up with a very dilute sodium hydroxide solution and Universal indicator, it will be coloured purple. Cubes of the required dimensions (for example, sides of 2 cm × 2 cm;

1 cm x 1 cm, 0.5 cm x 0.5 cm) can be cut from the agar, placed in a container and covered with a diffusion solution such as dilute hydrochloric acid. (The acid should have a higher molarity than the sodium hydroxide so that its diffusion can be monitored by a change in colour of the indicator.

Alternatively, the agar can be made up with Universal Indicator only, although its colour will be affected by the pH of the water used). Either the time it takes for the acid to completely change the colour of the indicator in the agar blocks, or the distance travelled into the block by the acid in a given time (e.g. 5 minutes), can be measured. The times can be converted to rates. Finally. the rate of diffusion (rate of colour change) can be plotted against the surface area: volume ratio.

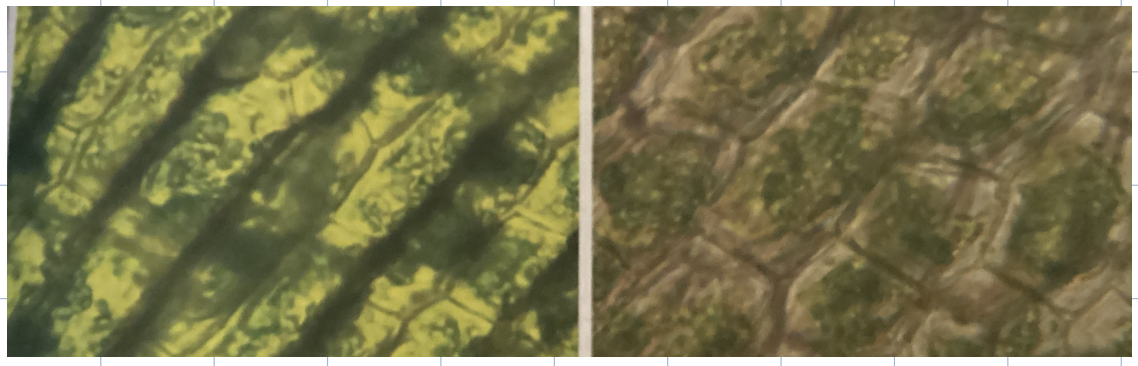
Using the same techniques, you may be able to design further experiments. For example, you could investigate the effect on the rate of diffusion of the steepness of the concentration gradient.



# INVESTIGATING OSMOSIS IN PLANT CELLS

## Observing osmosis in plant cells

Epidermal strips are useful material for observing plasmolysis. Coloured sap makes observatind easier suitable sources are the inner sufaces or the seny storage leaves of red onion bulbs and red cabbage.
The strips of epidermis may be placed in a range of molarities of sucrose solution (up to 1.0 moldm$^{-3}$) or sodium chloride solutions of up to 3%. Small pieces of the strips can then be placed on microscope glass slides, mounted in the relevant solution and observed with a microscope. Plasmolysis may take several minutes, if it occurs.



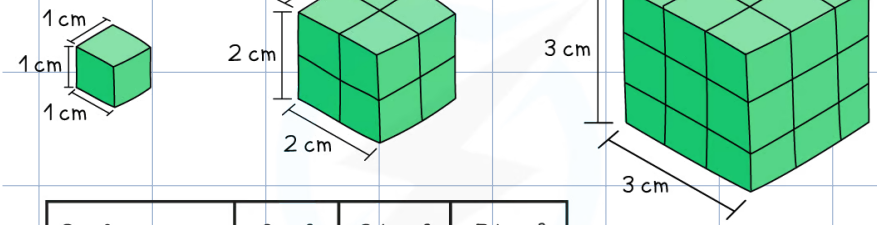
## Determining the water potential of a plant tissue

The principle in this experiment is to find a solution of known water potential which will cause neither a gain nor a loss in water of the plant tissue being examined. Samples of the tissue - for example, potato - are allowed to come into equilibrium with a range of solutions (for example, sucrose solutions) of different water potentials, and changes in either mass or volume are recorded.
Plotting a graph of the results allows the solution that causes no change in mass or volume to be determined. This solution will have the same water potential as the plant tissue.

# THE PRINCIPLE OF SURFACE AREA TO VOLUME RATIOS

Surface area is how much area of the object is exposed to the outside. The volume is how much space is inside the shape. The surface area to volume ratio tells you how much surface area there is per unit of volume. If you are given the numbers, then you simply divide the surface area number by the volume number.

How might surface area to volume ratios help decide the size of cells? Big cells may have a hard time getting rid of wastes or getting enough nutrients to the centre of the cells because they are larger - the increased volume makes it difficult to get things diffused into and out of the centre of the cell.



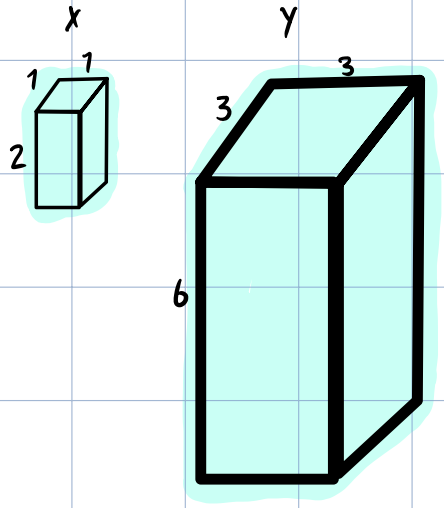

| | | | |
|---|---|---|---|
| Surface area | 6 $cm^2$ | 24 $cm^2$ | 54 $cm^2$ |
| Volume | 1 $cm^3$ | 8 $cm^3$ | 27 $cm^3$ |
| Surface area: volume | 6:1 | 3:1 | 2:1 |

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## Investigating surface area: volume ratio: Example one

A student investigated the effect of changes in the surface area to volume ratio by using diffusion.

- Two different-sized blocks of agar, X and Y, were made.
- The agar contained Universal Indicator solution.
- Universal Indicator solution changes colour when acid is added.
- The blocks were placed in dilute hydrochloric acid at the same temperature.
- The student timed how long it took for each block to change colour completely.




surface area of block X
2 x 1 x 4 = 8 $mm^2$
1 x 1 x 2 = 2 $mm^2$
8 + 2 = 10 $mm^2$

volume of block X:
2 x 1 x 1 = 2 $mm^3$

surface area : volume ratio
= 10 ÷ 2 = 5
= 5:1

Surface area of block Y:
6 x 3 x 4 = 72 $mm^2$
3 x 3 x 2 = 18 $mm^2$
72 + 18 = 90 $mm^2$

volume of block Y:
6 x 3 x 3 = 54 $mm^3$

surface area : volume ratio
= 90 ÷ 54 = 1.67:1