TRANSPORT OF MATERIALS IN ORGANISMS

- Transport is the movement of materials from one part of the organism to another.
- Materials transported include oxygen, carbon dioxide, soluble food substances, hormones, waste products such as urea, etc.
- Transport in organisms involves processes like diffusion, osmosis, and active transport.
- In unicellular and simple multicellular organisms the above processes are enough to meet the transport requirements since materials are only transported over very short distances. Larger and more complex organisms require transport systems (circulatory and vascular systems) for effective transport over long distances.

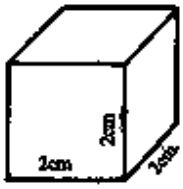
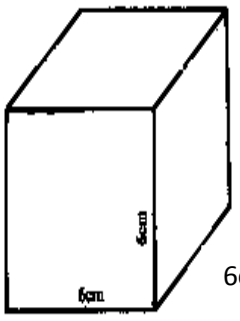
THE NEED FOR A TRANSPORT SYSTEM

- Large organisms require a lot of materials and produce large amounts metabolic wastes. A transport system is therefore important in these organisms for bulk transport of the materials.
- The larger the organism, the longer the distance from the outer body surface/surfaces to the center/middle of the body. Thus materials have to be moved over long distances between the inner cells and the body surfaces for exchange with environment. However simple processes surfaces such as diffusion are not effective over long distances. Thus a transport system is required for the transport of materials.
- The larger an organism becomes, the smaller the surface area to volume ratio which reduces the rate of diffusion of materials from the body surface to the cells in the middle of the organism. Thus a transport system is required for faster transfer of materials from the body surface to the cells in the middle of the organism.

N.B: Small and some flattened organisms lack the transport system e.g. protozoans and Platyhelminthes. This is because, being small in size and being flattened in shape gives these animals a large surface area to volume ratio, this enables rapid diffusion of materials from one part of the body to another.

Meaning of surface area to volume ratio

- The surface area-to-volume ratio is the amount of surface area per unit volume of an object or collection of objects. It shows the comparison between the size of the outside of an object and the amount inside.
- To obtain surface area to volume ratio, the total surface area of the object is calculated and compared with or divided by its volume.
- When an object/organism/cell is very small, it has a large surface area to volume ratio, while a large object/organism/cell has a small surface area to volume ratio.
- For example, consider cubes of different sizes. As the cube size increases, the surface area to volume ratio decreases as shown in the table below.

Cubes represent living organisms of different sizes	**a. Area (A)** = L **x** W **b. Surface area=6(A)6(LxW) or 6(SxS)** **c. Volume (V)** = L **x** W **x** H **d. SA:V ratio =** $\frac{SA}{V}$
 Assume all sides are of length **1cm**	a. A= 1 X 1 = $1cm^2$ b. SA= 6 x 1 = $6cm^2$ c. V = 1 x 1 x 1 = $1cm^3$ d. SA:V $\frac{6}{1}:\frac{1}{1}$ = **6:1**
 Assume all sides are of length **2cm**	a.A= 2 X 2 = $4cm^2$ b. SA = 6 x 4 = $24cm^2$ c. V= 2 x 2 x 2 = $8cm^3$ d.SA:V = $\frac{24}{8}:\frac{8}{8}$ = **3:1**
 6cm	a. A= 6 x 6 = $36cm^2$ b.SA =36 x 6 = $216cm^2$ c. V= 6 x 6x 6 = $216cm^3$ d.SA: V = $\frac{216}{216}:\frac{216}{216}$ = **1:1**

Therefore, large multi-cellular organisms have a very small surface area to volume ratio and so need a well-developed transport system that carries useful substances such as oxygen and glucose to the cells and carries away the waste products of metabolism such as carbon dioxide and urea.

Requirements/components of a transport system in organisms

1. **The materials to be transported;** These include respiratory gases like oxygen and carbon dioxide, nitrogenous waste products e.g. uric acid, nutrients e.g. glucose, amino acid, etc. In plants, they include water, mineral salts, amino acids, hormones, sucrose.
2. **The medium of transport;** for example blood in vertebrates and in a few invertebrates like arthropods, annelids (earth worm). In plants, water provides the general medium in which materials are translocated.
3. **The channels of transport;** Most animals use blood vessels, others like insects use the body cavity (coelom). In higher plants, there is a vascular system or system of xylem and phloem.

MOVEMENT OF MATERIALS IN AND OUT OF THE CELL

Substances like nutrients and excretions are moved in and out of the cell by processes like:

1. Diffusion
2. Osmosis
3. Active transport
4. Phagocytosis

Movement of substances depends on the permeability of the cell membrane or cell wall.

DIFFUSION

- This is the movement of molecules from a region of high concentration to a region of low concentration.
- Diffusion occurs because small molecules are in constant random motion.
- Diffusion only takes place where there is a difference in concentration i.e. where there is a concentration gradient and continues until there is even distribution of molecules. Therefore diffusion involves movement of materials along/across a concentration gradient.

FACTORS AFFECTING THE RATE OF DIFFUSION

1) Concentration gradient:

Concentration gradient is the difference in concentration between the 2 regions where diffusion takes place. The higher the concentration gradient between the two regions, the faster is the rate of diffusion.

2) Temperature:

The higher the temperature, the faster is the rate diffusion, because increasing temperature increases the kinetic energy of molecules causing them to move faster.

3) Size and Density of molecules:

The smaller the molecules the faster the rate of diffusion. The denser the particle, the lower the rate of diffusion.

4) Distance over which diffusion occurs:

The shorter the distance between the two regions of different concentration, the greater is the rate of diffusion. Due to this, exchange surfaces like the alveoli of lungs or the epithelial linings of the ileum are thin to provide a short distance for diffusion thus increasing the rate of diffusion.

5) Surface area over which diffusion occurs:

The larger the surface over which diffusion occurs, the faster is the rate of diffusion e.g. diffusion surfaces like the ileum have numerous villi to increase the rate of diffusion.

Significance/ importance of diffusion to organisms

i) It moves some substances in and out of cells.
ii) Plant root hairs absorb some salts by diffusion.
iii) Unicellular microorganisms like amoeba, take in oxygen and pass out carbon dioxide through their cell membrane by diffusion.
iv) Digested food e.g. simple sugars, amino acids, enter the blood from the gut by diffusion.
v) Food substances diffuse out of the blood into the cells by diffusion.

vi) Oxygen diffuses into blood and CO_2 out of blood in the lungs of mammals and gills of fish by diffusion.

vii) Waste products of metabolism e.g. urea, move out of the animal cells into blood by diffusion.

OSMOSIS

This is the ***movement of solvent/water molecules from a region of their high concentration to a region of their low concentration across a semi permeable membrane.***

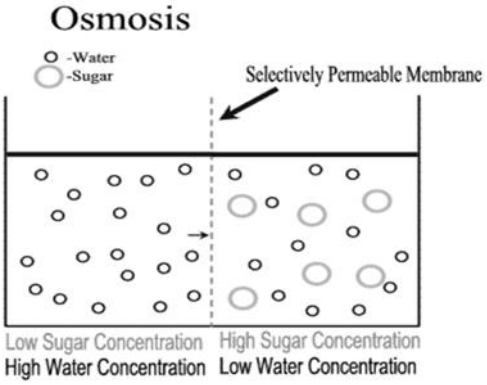
Or

It is the ***movement water molecules from a solution of low concentration to a solution of high concentration across a semi permeable membrane.***

Note; osmosis deals with the movement of water (solvent) molecules only.

A semi/partially/selectively permeable membrane is one which can allow the passage of some materials to occur and prevent other materials from passing across it. Such membranes have very tiny pores which only permit very small molecules to pass through. Permeability may also be determined by the chemical composition of the membrane and the nature of the substances moving.

When two solutions are separated by a semi permeable membrane having small pores, water molecules continue to move from a dilute solution to a concentrated solution through it.



Terms used in osmosis

- **Hypotonic solution:** This is a solution containing less solute and more water molecules compared to another. A hypotonic solution is less concentrated.
- **Isotonic solution:** This is a solution with the same concentration of solutes and water compared to another.
- **Hypertonic solution:** This is a solution with more solutes and less water molecules than the other. A hypertonic solution is more concentrated.
- **Osmotic pressure:** This is the pressure needed to stop osmotic in-flow. The stronger the solution the higher the osmotic pressure. A hypotonic solution is less concentrated and thus has a lower osmotic pressure. A hypertonic solution is more concentrated and has a higher osmotic pressure. While hypotonic solutions have the same osmotic pressure.

OSMOSIS AND CELLS

(a) Animal cells

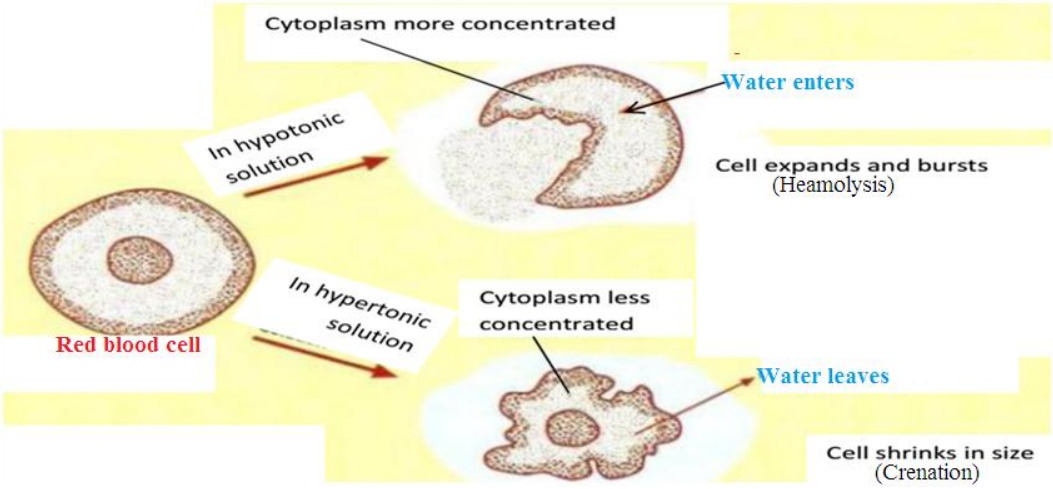
Unlike plant cells, animal cells lack a cell wall and only have a cell membrane which is weak and non-resistant to high internal pressure.

Osmosis and red blood cells

When a red blood cell is placed in a dilute solution (hypotonic solution) or distilled water, water molecules move from the surrounding dilute solution (or distilled water) through the semi permeable cell membrane into the cell by osmosis. This develops a high pressure in the cell causing it to expand/increase in size and eventually burst (**haemolyse**). The cell bursts because it is only surrounded by a cell membrane which is weak and cannot resist the high internal pressure.

When the red blood cell is placed in a more concentrated solution (hypertonic solution) e.g. a strong sugar solution, water moves out of the cell to the surrounding solution by osmosis. As a result, the cells shrink. The process is called **crenation.**

However, when red blood cells are placed in isotonic solution they neither gain nor lose water.



Qn. Explain what happens to a red blood cell when placed in a

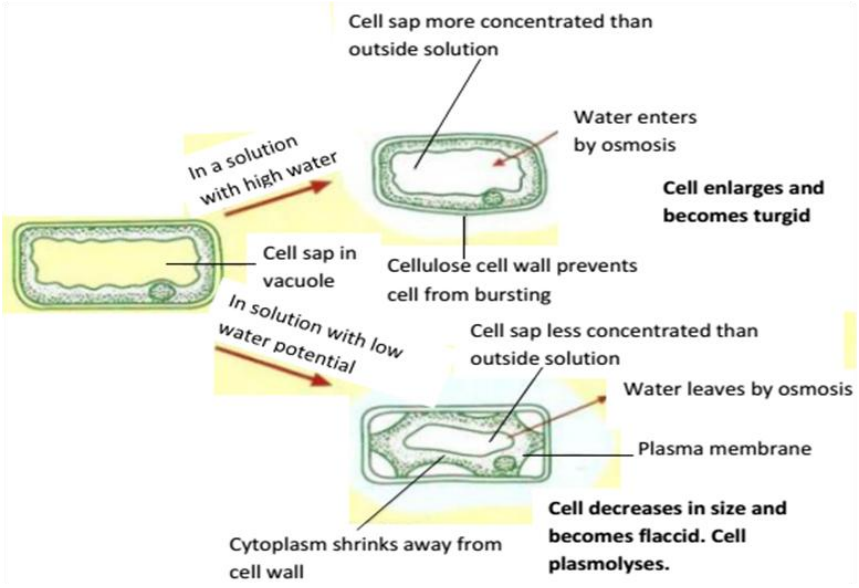
(i) Hypotonic solution.

(ii) Hypertonic solution.

(b) Osmosis and plant cells

When a plant cell is placed in a hypotonic solution/ more dilute solution (or distilled water), water enters by osmosis through the cell wall and semi permeable cell membrane into the cell cytoplasm then into the sap vacuole. The volume of cell sap increases and it makes the sap vacuole expand, pushing the cytoplasm outwards. This causes the cytoplasm and its contents to move towards the cell wall and the cell starts gaining turgidity. A point is reached when all the protoplasm is pressing against the cell wall and no more water can be absorbed. At this state, the cell is said to have gained full turgidity and hence it is said to be **turgid**.

When the plant cell is placed in a more concentrated solution than the cell sap, water moves from the cell sap through the cytoplasm then the cell membrane and cell wall to the surrounding solution. This decreases the volume of cell sap and cytoplasm. As a result the cell vacuole shrinks and the cytoplasm shrinks away from the cell wall, causing the cell membrane to lose contact with the cell wall and the cell is said to be flaccid or **plasmolysed**.



Qn. Explain what happens to a plant cell when placed in a

(i) Hypotonic solution.
(ii) Hypertonic solution.

TERMS USED IN CELL-WATER RELATIONS

- **Heamolysis;** This is the bursting of a red blood cell membrane due to excessive uptake of water by osmosis when placed in a hypotonic solution or distilled water.
- **Crenation;** This is the shrinkage of a red blood cell due to excessive loss of water from its cytoplasm into the surrounding medium when placed in a hypertonic solution or distilled water.
- **Turgor pressure;** This is the internal hydrostatic pressure developed in a plant cell in a hypotonic solution due to uptake of water by osmosis.
- **Turgidity;** This is when a cell has taken upenough water and expanded to maximum size. At this point the cell wall exerts a backward force on the protoplasm preventing further expansion. This is possible because the cell wall is rigid and tough. The cell is said to be turgid.
- **Plasmolysis;** This is the shrinkage of the plant cell vacuole and protoplasm causing the cell membrane to lose contact from the cell wall as a result of loss of water from the cell to the surrounding when placed in a hypertonic solution.
  When the cell is in this condition, it is said to be **flaccid** or **plasmolysed**. Therefore, a flaccid cell is one whose cytoplasm has lost contact with the cell wall due to loss of water from the cell sap of the vacuole.

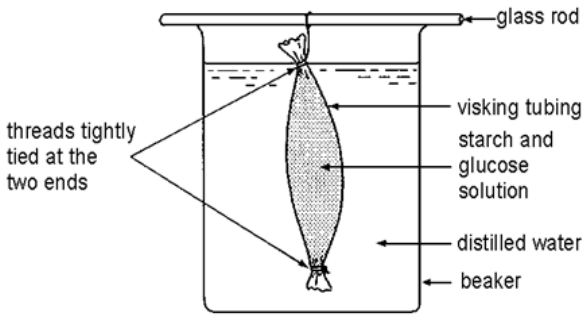
EXPERIMENT TO DEMONSTRATE OSMOSIS AND DIFFUSION IN A NON-LIVING TISSUE USING ARTIFICIAL MATERIAL (VISKING TUBE)

Apparatus and materials

- Thread
- Visking tube which acts as a semi-permeable membrane
- Pure water
- Beaker
- Starch and glucose solution
- Reagents for food tests.

Procedure

i. A Visking tube is tied at the bottom with a thread and filled with the glucose and starch solution.
ii. The Visking tube with the starch and glucose solution is placed into a beaker containing pure water and left to stand for one hour.



Apparatus to show dialysis

iii. After this period test contents of the beaker for starch and reducing sugars.

Observations

- The volume of the starch and glucose solution in the visking tubing increases.
- If tested, the distilled water is found to contain some reducing sugars by the end of the experiment while starch is present.

Explanation for the observation

- The starch and glucose solution increases because water is moving from the beaker (dilute solution) into the Visking bag (concentrated solution) by **osmosis**.
- Reducing sugars are present in the beaker because the glucose molecules move into the distilled water in the beaker by **diffusion** since they are very small in size and so can pass through the tiny pores of the visking tube, while the starch molecules remain in the visking tubing since they are too big to pass through the tiny pores (holes) in the Visking tubing.

Conclusion

- Osmosis occurs in non-living tissue.
- Small sized molecules can diffuse across a selectively permeable membrane.

EXPERIMENT TO INVESTIGATE OSMOSIS IN A LIVING TISSUE

Apparatus and materials

- Sugar
- Water
- 3 petri dishes
- Irish potatoes
- Knife
- Heat source

Procedure

1. Label the petri dishes as A, B, C.
2. Boil one Irish potato in water for ten minutes.

3. After, peel other two fresh and the boiled Irish potatoes using a knife and cut off both ends to obtain cuboids.
4. Make a hole in the potatoes using a knife
5. Pour pure water into petri A and B.
6. Pour a concentrated sugar solution into petri dish labelled C.
7. Insert the boiled potato into petri dish A and the fresh ones into the other petri dishes
8. Place sugar crystals at the base of the cuboids in petri dishes A, and B.
9. Pour pure water into the cuboid in petri dish C.
10. Leave the set up for about two hours and observe

Observations

Cuboid	Observation
A	Sugar crystals remain and the volume of water in petri dish remain the same.
B	Sugar crystals dissolve and volume of solution increases in the cavity of the irish potato cube while the water level in petri dish decreases.
C	Water levels in the cavity of the irish potato cube decreases and the volume of sugar solution in petri dish increases.

Explanation

A	No change in volume because the cell membranes of the potato cells are destroyed by boiling and can no longer acts as a semi permeable membrane for osmosis.
B	The living tissue (potato) acts as a semi-permeable membrane. Water moves from the dilute water through the cell membranes into sugar crystals in cavity which dissolve, more water enters since the sugar solution is concentrated/hypertonic.
C	Water moves from the cavity through the living cell membranes into the sugar solution.

Conclusion

- Osmosis takes place in living cells.

EXPERIMENT TO DEMONSTRATE TURGIDITY AND PLASMOLYSIS

Materials

- ✓ Cock borer
- ✓ Four beakers
- ✓ Water
- ✓ Irish potato
- ✓ Razor blade
- ✓ Sugar crystals

Procedure

- Get four beakers and pour ¾ of water in the first beaker.
- Mix the sugar in the second beaker to make 5% solution.
- Mix sugar in the third beaker to make 50% solution.

- Leave the fourth beaker empty.
- Use a cock borer to obtain 4 potato cylinders and trim them to the same length e.g. 4cm.
- Note this initial length.
- Deep one potato cylinder into each beaker.
- Leave the setup for one hour and observe.
- Remove the cylinder from each beaker and measure each length. Note this final length.
- Also feel the texture.
- Tabulate your results shown in the in the table below (with the provisional results).

Initial length/cm	Final length/cm	Change in length/cm	% change in length	Texture(soft/ tough)
4.0	4.3	+0.3	+7.5	Tough
4.0	4.0	0	0	Tough
4.0	3.8	-0.2	-5	Soft/flabby
4.0	3.9	-0.1	-4	Soft

Observation

- The cylinder in water had increased in length and became tougher.
- The cylinder in 5% sucrose solution didn't have any change in length and the texture remained the same.
- The cylinder in 50% sucrose solution decreased in length and became soft, flabby.
- The potato in the empty beaker decreased in length and became soft.

Explanation

- The cylinder in water increased in length because water molecules moved into it from the surrounding medium (water) by osmosis because the cell sap had a higher concentration than the surrounding medium.
- The cylinder also became tougher because the cells expanded and became turgid due to uptake of water, tightly pushing against each other making the potato tissue tougher.
- There was no change in length for the cylinder in 5% sucrose solution because the solution had the same concentration as the cell sap of a potato cylinder hence no net osmosis.
- There was a decrease in length for the cylinder in 50% sucrose solution because water molecules moved out of the cylinder which had a lower concentration by osmosis into the more concentrated/hypertonic solution in the beaker. As a result the cell contents decreased and cells became plasmolysed.
- There was a decrease in length for the cylinder in the empty beaker because water was lost to the surrounding by evaporation.

Conclusion

- Turgor and plasmolysis occur in plant cells.

Significance of osmosis in plants

i) Absorption of water by root hairs from soil.
ii) It enhances movement of water from root hairs via the cortex to the xylem.
iii) It brings about support in non- woody plants as their cells take up water and become turgid.
iv) It facilitates opening and closing of stomata due to changes in turgidity.
v) In germination, the initial absorption of water is by osmosis.

Significance of osmosis in animals

i) It enables movement of water to capillaries in villi.
ii) Movement of water from tissue fluid into the cell.
iii) It enables reabsorption of water into the blood stream via the kidney tubules.

Note: Many semi- permeable membranes allow the passage of solute and solvents though not to the same extent. All that is required for osmosis to occur is that the solvent molecules move more rapidly than the solute molecules.

ACTIVE TRANSPORT

This is the movement of molecules from the region of low concentration to the region of higher concentration i.e. movement against concentration gradient using energy.

Energy for this process is derived from respiration. Anything that affects the rate of respiration also affects the active transport e.g. cyanides prevent ATP synthesis and therefore stops active transport.

Active transport takes place by means of carrier molecules in the cell membranes which are proteins. The carrier proteins expend the energy (ATP) to deliver the molecules across the cell membrane against a concentration gradient.

Importance of active transport

1) Used by plant roots or root hairs to absorb minerals from the soil.
2) Used in the absorption of food materials from the ileum into the blood stream
3) Used in the reabsorption of minerals in the kidney during urine formation
4) Used in the secretion and active uptake of ions in the fish gills from fresh water

PHAGOCYTOSIS

This is the process by which a cell takes in solid materials by engulfing/invagination to form a vacuole in which the food particle is contained. This breaks off/pinches off the cell surface membrane to form a food vacuole which is moved into the cytoplasm where the food is digested. The soluble products of digestion are absorbed into the cytoplasm while undigested particles are retained in the food vacuole and released out of the cell by exocytosis. It requires energy. Phagocytosis only occurs in animal cells and some protoctists e.g amoeba.

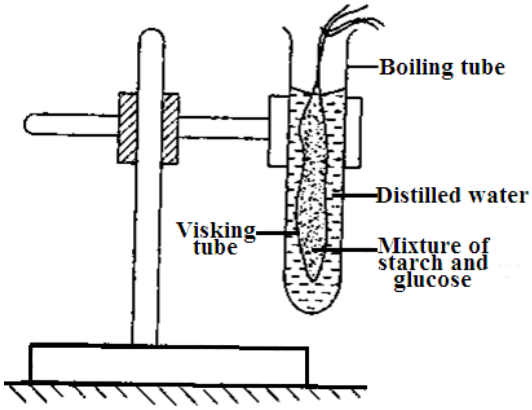
Importance of phagocytosis

1) Used by amoeba during feeding.
2) White blood cells destroy pathogens by phagocytosis.

NOTE: Pinocytosis: This is the process by which animal cells take in liquid materials in bulk. The mechanism is similar to phagocytosis thus, it is said to be cell-drinking, while phagocytosis is said to be cell eating.

REVISION QUESTIONS

1. A solution containing starch and glucose was put in a visking tube in the set up shown in the figure and left to stand for 30 minutes. After 30 minutes, samples were drawn from the contents of the visking tube and boiling tube, then iodine and Benedict's tests carried out on each of them.



(a) Describe what was observed with iodine test on
  (i) visking tube content.
  (ii) boiling tube content.

(b) Explain your observation in (a).

(c)Describe what was observed with Benedict's test on (i) visking tube content.
  (ii) boiling tube content.

(d) Explain your results in (c).

(e) Giving reasons, state the nature of the visking tube.

2. Red blood cells burst or haemolyse when immersed in low salt concentrations. The table below shows effects of salt solution on red blood cells.

% salt concentration	0.30	0.35	0.40	0.45	0.50	0.55
% red blood cells haemolysed	100	95	85	50	20	0

a) Using % salt concentration on the X – axis and red blood cells haemolysed on Y – axis, draw a graph to represent the data in the table above.

b) At what percentage of salt concentration are all red blood cells haemolysed?

c) Briefly explain how haemolysis occurs.

d) i) From your graph, what is the safest percentage of concentration for human blood?
ii) Give a reason for your answer.

e) At what percentage of salt concentration are the numbers of haemolysed cells equal to unhaemolysed cells?

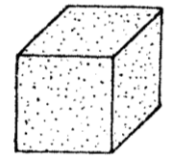
f) What would you expect to happen to red blood cells if they are placed in 0.6% salt solution?

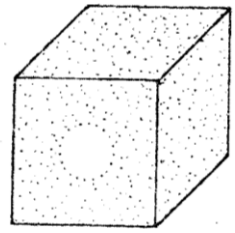
3. Six identical potato cylinders measuring 2.0 cm in length were each placed in a different concentration of sugar solution. After two hours, the potato cylinders were removed from the solutions and measured. The table below shows the results.

Concentration of sugar solutions mol l^{-1}	**Length of potato cylinders after 2 hours (cm)**	**Difference in length of potato cylinders after 2 hours (cm)**
0.1	2.40	
0.2	2.25	
0.3	2.15	
0.4	2.05	
0.5	1.90	
0.6	1.62	

a) Complete the table by filling in the difference in length of each potato cylinder after 2 hours (i.e. length after 2 hours subtract initial length).
b) Plot a graph of the difference in length after 2 hours against concentration of sugar solutions.
c) i) From your graph, determine the concentration of the sugar solution that would give no difference in length of a potato cylinder.
ii) Explain what happens in a potato cylinder when no change in length occurs.
d) Explain the effect of the following concentrations of the sugar solutions on the length of the potato cylinders.
(i) 0.1-0.4 **mol l $^{-1}$**
(ii) 0.5-0.6 **mol l $^{-1}$**
e) Suggest one other observation other than change in size that would be made on the potato cylinders and show how the different sugar concentrations would affect the cylinders.

4. Two different sized cubes of colourless jelly A and B were used to represent models of living organisms. They were submerged in a coloured dye for a period of time and then removed and cut into half. The diagrams below show the penetration of the dye.


Cube A after halving


Cube B after halving

(a) (i) Explain the difference between the penetration of the coloured dye in two cubes.
(ii) Suppose that the dye represents an essential substance being absorbed by a living organism. Explain how the problem in B could be overcome by a living organism without altering its shape.
(b) Explain how the shape of a red blood cell helps it to function efficiently.

5. (a) What do you understand by the term diffusion?
(b) Describe how various factors affect the rate of diffusion.
(c) Explain why certain organisms require a transport system.

6. a) What do you understand by the term osmosis?
b) An onion epidermis was placed in a strong or concentrated sugar solution for 40 minutes. Another epidermis was placed in pure water for 40 minutes. Explain what happened in the epidermal cells.

-END-