SECTION 3

CELL BIOLOGY

LIFE IN THE FUNDAMENTAL UNIT

CELL STRUCTURE AND FUNCTION

INTRODUCTION

Welcome learners! In this section we will explore cell biology as a branch of biology that studies the structure and function of cells. Cells are the basic building and functional blocks of all living things and were discovered by a British scientist, Robert Hooke in 1665 (*that was a very long time ago*). A few years after the discovery of a cell, under a microscope, a living cell was seen to be externally covered by a thin transparent, elastic, regenerative and selectively permeable membrane called plasma membrane. Later the term cell membrane was given by C. Nageli and C. Cramer (1855). The knowledge you will acquire in this section will help you explain the transport of minerals, water and other nutrients we get from our diet is absorbed by our cells which in turn provides us with energy.

After this section, you should be able to:

- Discuss the factors that affect the movement of substances across the cell membrane
- Discuss the effect of the movement of substances across cell membrane

Key ideas

- The cell is the basic structural and functional unit of living things
- The cell membrane (plasma membrane/plasmalemma) is a biological membrane in all cells that separates and protects the interior of the cell from the outside environment
- The cell membrane allows movement of certain substances (like **water, respiratory gases** (O_2 and CO_2), **nutrients, essential mineral ions, excretory products**, **hormones** and **enzymes**, **etc.)** in and out of the cell through diffusion, osmosis, plasmolysis, active transport, endocytosis and exocytosis

- Factors that affect the movement of substances across cell membrane include: concentration gradient, temperature, energy (ATP), size of the molecules, surface area of membrane, distance travel by substance, stirring.

CELL MEMBRANE

In a typical cell, we have inner contents of a cell is surrounded by a membrane referred to as the **cell membrane** also known as the **plasma membrane**. Many organelles such as the mitochondria, endoplasmic reticulum and the nucleus within a cell are also bound by membrane(s). The membranes of cells are thin and made almost entirely of **phospholipids** and **proteins**. The lipids form two layers referred to as **phospholipid bilayer** which is mobile. One end of the bilayer molecule is hydrophobic tail (repelled by water) and the other is hydrophilic head (attracted to water).

The molecular structure of the cell surface membrane is described as **fluid mosaic** because the components (lipids and proteins) move around within their layer. The movements of the lipid molecules are rapid, whereas mobile proteins move about more slowly. The word mosaic described the scattered pattern of the proteins, when viewed from above.

Significance of the fluid mosaic structure of cell membrane

1. Lipids also allow small molecules such as water molecules to pass through unaided.
2. The surface area of cells or organelles can be increased by the folding of membranes.
3. As a consequence of their fluidity, they can often recover from minor physical damage.
4. Because they are composed of proteins and lipids, membranes are easily damaged by heat, acids and by fat solvents such as alcohol.

The diagram below shows a section of the cell membrane showing the phospholipid bilayer and some proteins.

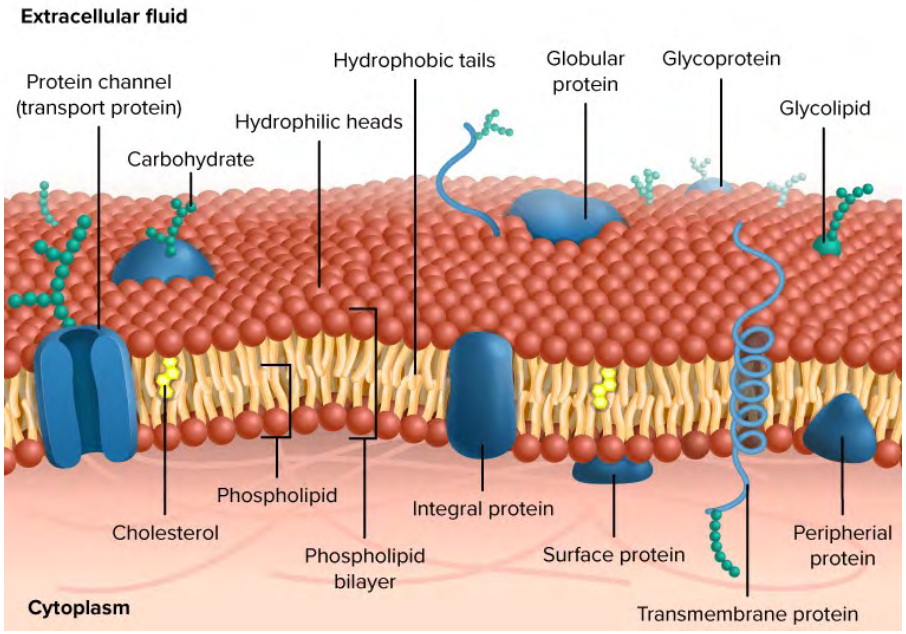


Fig 3.1: A diagram of a section of cell membrane. *Scale: The membrane is around 5 to 10 nanometres thick, and a nanometre is one billionth of a metre. [10^{-9} m]*

Functions of the cell membrane

The cell membrane has the following functions discussed below.

1. The cell/plasma membrane functions as a physical barrier between the external environment and the cytoplasm of a cell and the organelles within the cell.
2. The cell membrane is selectively permeable and therefore only allows the movement of selected molecules in and out of the cell.
3. It functions by facilitating communication and signalling between the cells.
4. The plasma membrane plays a vital role in anchoring the cytoskeleton to provide shape and structure to the cell.

Some functions of membrane proteins

The membrane proteins within the cell membrane also have roles they play.

1. There are enzymes present in membranes for many chemical reactions which take place on the surface of the membranes. E.g. stages in protein synthesis, respiration and photosynthesis.
2. There are receptor sites for hormones which then influence the activity of the cell.

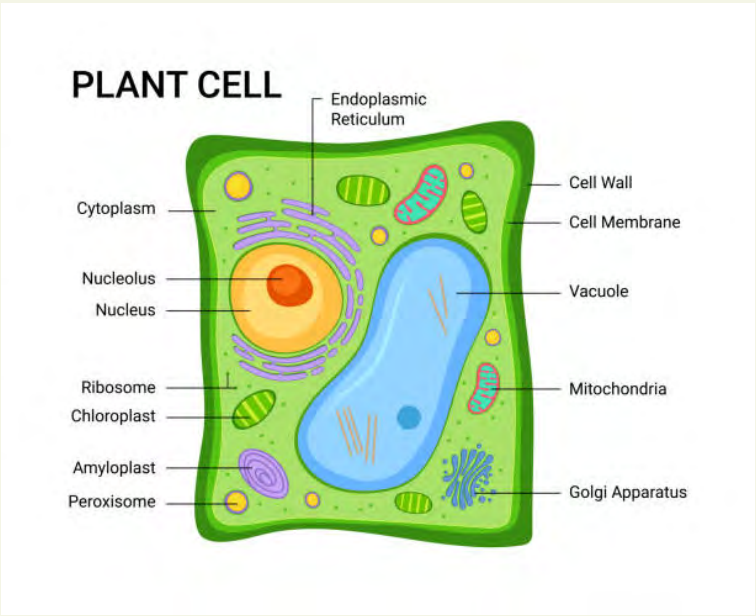
3. There are proteins which act as a skeleton for the membrane to give it shape and to allow it to move. For example, the membrane moves during phagocytosis and when cilia waft to and fro.
4. There are proteins which actively transport materials across the membrane using chemical energy obtained from the cell in the form of Adenosine Triphosphate (ATP).
5. There are proteins which form pores in the membrane through which substances can pass.

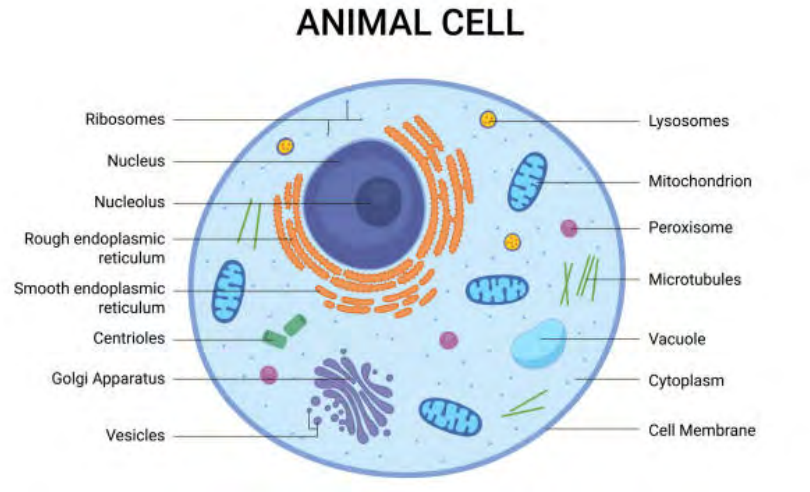
Hello learner, by now, you will realise some of these terms are familiar. And you are right! In your science lessons from Junior High School (JHS) you learnt something on the basic structure of both plant and animal cell. You surely talked about some organelles within the cell as well. If you do not remember any of this don't worry, follow the activities below to revise.

So let us do some activities!

Activity 3.1: Cells 101

1. Study carefully the diagrams below and use it to answer the questions.





a) What is the main difference between the outermost layer of the plant and animal cells.

b) Identify any six structures/organelles in the

i. Animal cell

ii. Plant cell

c) Which three organelles in the animal cell is bound by a double membrane?

d) Describe (by writing) the shapes, structures and functions of any four (4) structures of the cell.

2. What is the composition of the cell membrane?

a) This exercise can be done at home. Let the diagram below guide you through the steps for the experiment.

A

B

C

Step A: Get a coloured vegetable like beetroot

Step B: Wash and neatly cut beetroot into slices. Note the colour of beetroot before moving onto step C.

Step C: Bring a pot of water to a boil and place beetroot in boiling water for about 15 minutes.

b) What was the colour of beetroot and the boiling water after 15 minutes.

c) What is the reason for the change of colour of the boiling water after 15 minutes.

When you are done with all the activities, compare/discuss your answers with your two friends and show it to your teacher.

MOVEMENT OF SUBSTANCES IN AND OUT OF THE CELL THROUGH THE CELL MEMBRANE.

Water, respiratory gases (oxygen and carbon dioxide), nutrients, essential mineral ions and excretory products move into and out of the cell through cell membrane. Substances move in and out of the cell through osmosis, diffusion , plasmolysis, exocytosis and endocytosis which are discussed below.

Diffusion

Atoms and molecules of gases and liquids have the ability to move about at random. As a result, they tend to spread themselves from areas of high concentration to areas of low concentration. This process is called **diffusion.** Therefore, diffusion can be defined as *the net movement of molecules from a region higher concentration to a region of lower concentration (until the molecules become evenly distributed).* Real-life examples of the process of diffusion are;

a) Lipton dissolving in hot water,

b) dye (blue) dissolving in water,

c) the spread of insecticide spray or perfume in a room, after spraying in one corner of the room.

Factors Which Affect the Rate of Diffusion

a) **Concentration gradient:** this is the difference in the concentration between two regions (that is, the source and where molecules are moving to). The steeper or higher the concentration gradient, the higher or faster the rate of diffusion.

b) **Temperature:** the higher the temperature, the faster the rate of diffusion. When there is heat, the medium gains heat thus increasing the kinetic energy and increases the rate of diffusion.

c) **Particle size:** the smaller the particles, the faster the movement and rate of diffusion.

d) **Surface membrane** the thicker the surface membrane, the slower the rate of diffusion.

e) **Stirring:** stirring increases the collision of the molecules hence causing the rate of diffusion to be fast.

f) **Surface area:** the longer/larger the surface area, the faster the rate of diffusion.

g) **Distance travelled by molecules**: the shorter the distance, the faster the rate of diffusion

Examples of Diffusion in Animals

a) Gaseous exchange in the lungs: Movement of oxygen from the lungs into the blood and movement of carbon dioxide from the blood into the lungs.

b) Absorption of food nutrients in the villi/small intestine into the blood stream

c) Gaseous exchange the gills: Movement of dissolve oxygen from the water into the gill filaments of fishes and movement of carbon dioxide from the gill filaments into the water.

d) Movement of oxygen from the leaves of plants into the atmosphere during respiration and movement of carbon dioxide from the atmosphere into the leaves during photosynthesis.

e) Absorption of some mineral salts from the soil into the hair of roots of plants.

f) Movement of hormones out of the endocrine glands into the blood.

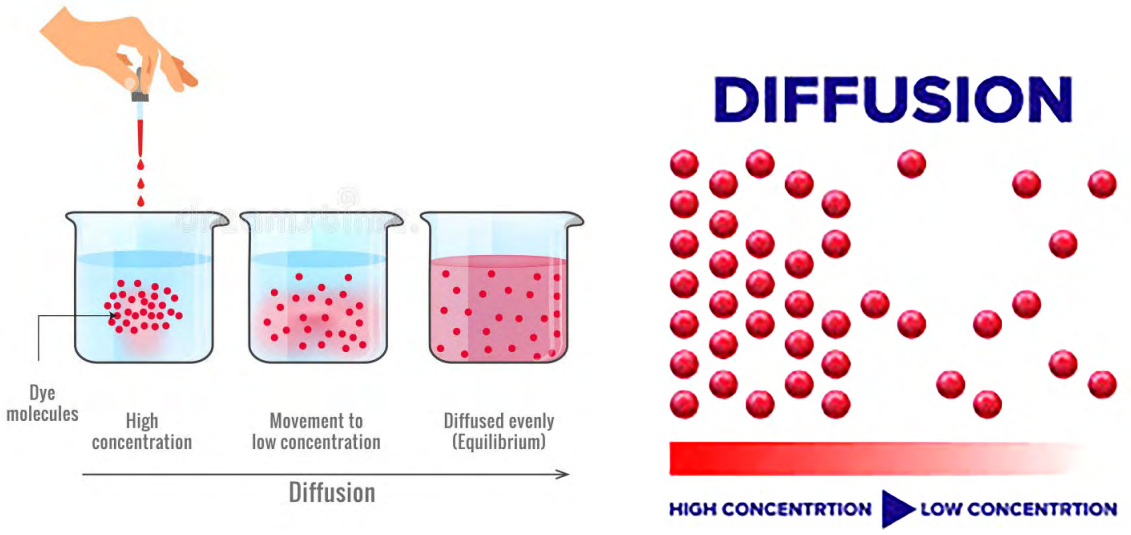


Fig 3.2: Illustration of the process of diffusion

Osmosis

This describes the movement/passage of water molecules across a membrane from a weak solution (higher water concentration) to a strong solution (lower water concentration) through a semi-permeable membrane.

NOTE: A weak solution has a high proportion of water molecules making and is said to be **hypotonic** to other solutions. A strong solution has a low proportion of water molecules making it concentrated and is known to be **hypertonic** to a weaker solution. Solutions of the same strength are said to be **isotonic**.

Factors that affect the rate of osmosis includes

a) **Increase in the temperature**: the higher the temperature, the faster the rate of osmosis because increase in temperature, increases the kinetic energy of the water molecule therefore increases the rate of osmosis

b) **Concentration gradient:** the steeper/higher the concentration gradient, the higher/faster the rate of osmosis

c) **Permeability and surface area of the membrane:** the larger and more permeable the membrane the more the water moves

Applications of osmosis in everyday life or in living things

a) Absorption of water from the soil by root hairs.
b) Movement of water across cell membrane in the leaf.
c) Movement of water from roots hairs into the cortex of plant.
d) Entry of water into body of Amoeba.
e) Absorption of water in the colon of mammals
f) Reabsorption of water in the nephron of the kidney

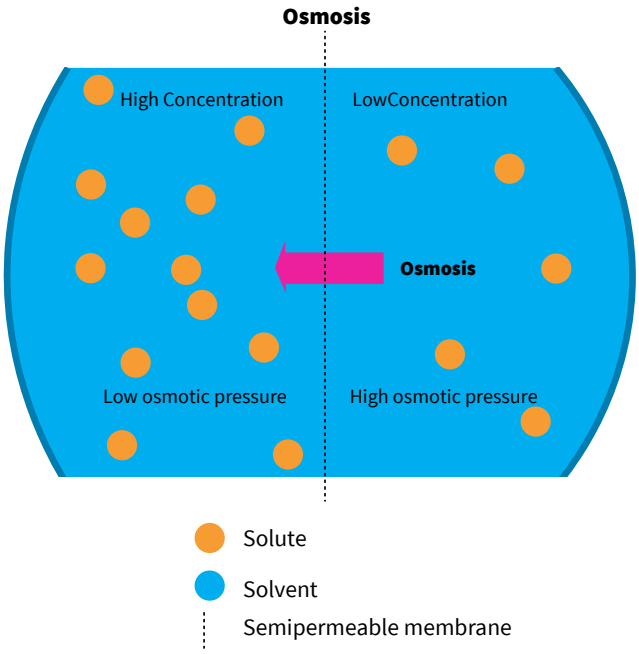


Fig 3.2: Illustration on the process of osmosis

Because all cells are surrounded by a membrane, water can move into and out of cells with ease. Animal cells and plant cells behave differently however, because animal cells do not have a strong supportive porous cell wall surrounding them. **Table 3.1** and **Fig 3.3** & **3.4** shows what can happen to animal and plant cells when placed in water solutions of different strengths.

Table 3.1: Plant and animal cells in different solutions

	Hypotonic Solution (very little or no salt)	Hypertonic Solution (salty)
Animal Cells	Bursts (haemolysis)	Shrinks (crenation)
Plant Cells	Become turgid/firm	Become flaccid

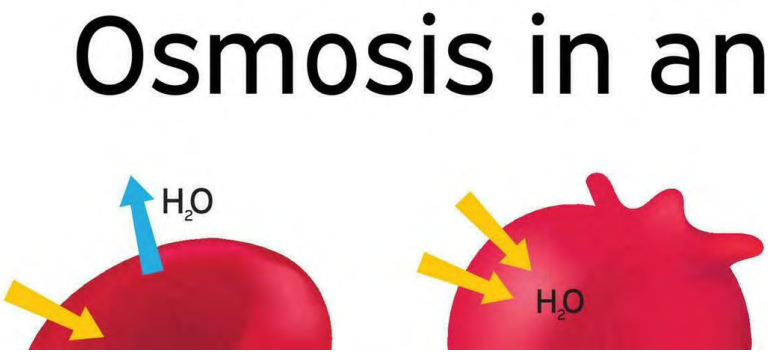


Fig 3.3: Osmosis in an animal cell

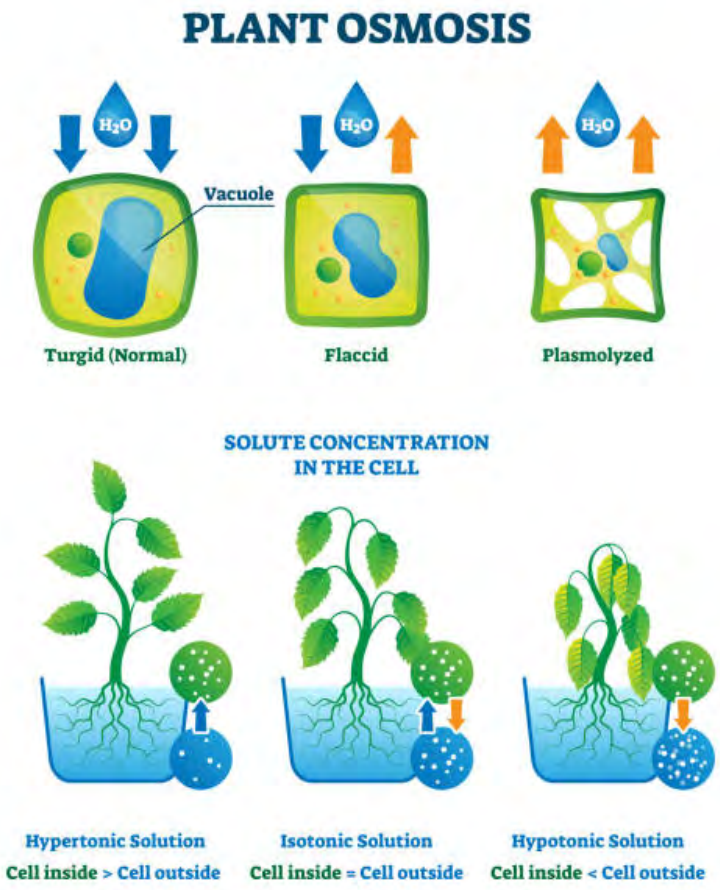


Fig 3.4: Osmosis in a plant cell

Plasmolysis

Plant cells have strong walls made of cellulose fibres that let substances pass through their gaps. These walls give plants their structure, which animal cells do not have.

If plant cells are put in very salty water, they lose a lot of water. The inside of the cell (cytoplasm and vacuole) shrinks so much that the cell membrane pulls away from the wall. This is called **plasmolysis**, and the cell is then said to be plasmolysed (see fig 3.4 above). You can see this happen with potato or onion slices in different salt solutions and fresh water (see Activity 3.2). All cells use the process of diffusion to absorb and release/secrete substances. But diffusion alone isn't enough for all substances. Cells have other ways to move things across their membranes.

Sometimes, cells need to move substances against their natural flow. This takes energy from the cell that is, against the concentration gradient. This requires energy which is supplied by the cell. The process is called active transport.

Active transport

In active transport, special proteins in cell membranes act like carriers, moving molecules from one side of the membrane to the other using the chemical energy of a compound called Adenosine Tri-phosphate (ATP). It involves the movement of ions such as $^{Na+, Cl-, K+}$.

Active transport is affected by the presence of oxygen and temperature.

Examples of active transport

a) Absorption of sugar and amino acids into the blood system from the small intestine.

b) Absorption of mineral salts from the soil by root hairs in plants.

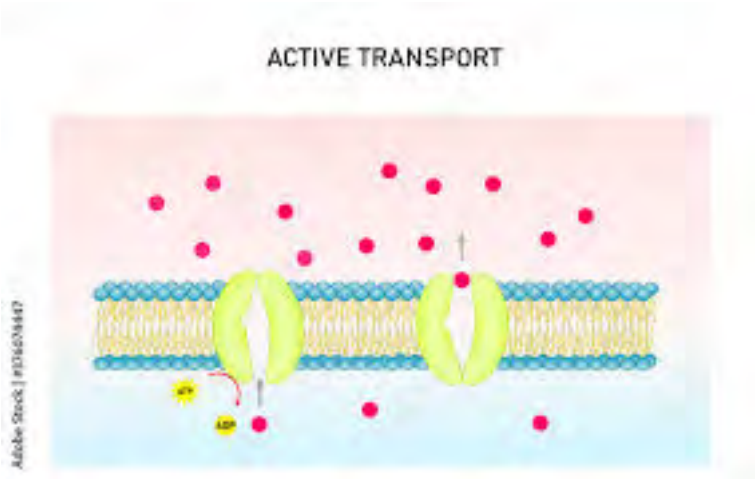


Fig 3.5: Active transport across a membrane

Endocytosis

Another way substances move across a membrane is endocytosis. This is the process of transporting large molecules into cells by forming vesicle. When the vesicles are formed in the cell and its content released in the interior of the cell gives the term endocytosis. There are two types which are;

a) **Phagocytosis** (cell eating); This is when the cell takes in large solid materials by engulfing it. e.g. Amoeba feeding, white blood cells taking up bacteria.

b) **Pinocytosis** (cell drinking); This is when the cell takes in liquid form of substance by forming vesicle.

Exocytosis

This process just like endocytosis involves the transport of large molecules by forming vesicle. Exocytosis differs from endocytosis due to the fact that the vesicle is formed inside the cell and the content of the vesicle is released to the exterior. Examples include;

a) Removal of materials from the cytoplasm to build cell wall.

b) Secretion of enzymes

Activity 3.2: Illustrating Diffusion in Liquids

Materials/equipment/chemicals: Beaker/ jar/bottled Water, Potassium permanganate crystals/ blue/ dye

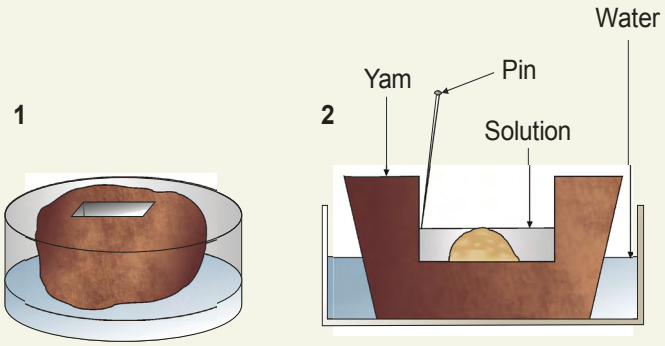
1. Half-fill the beaker/jar with water.
2. Put the straw in the water so that its bottom rests in a corner of the beaker.
3. Gently drop a crystal of potassium permanganate/ blue / dye down the straw into the water in the beaker.
4. Leave the beaker undisturbed on a flat table for about 30 minutes.
5. Observe the water in the beaker at intervals of 5 minutes.
6. Describe and explain any changes you have observed with your friend.

Activity 3.4: Illustrating osmosis using a living membrane (Raw Yam).

(Can be done at home or in the lab)

Equipment / materials/ chemical; Yam tuber, 3 dishes (e.g. petri dishes/ bowls), Pins, Saturated sugar/salt solution

Caution. Handle scalpel/knife with caution



1. Peel a yam tuber and cut it into three cubes of about 5cm x 5cm x 5cm.
2. With a knife or scalpel, make a cup shaped cavity about 2cm deep and 3cm in diameter in each cube (see Fig. 1).
3. Put one of the yam cubes in boiling water for about two minutes.
4. Half fill one of the raw yam cubes and the boiled yam cube with a saturated sugar solution. Half fill the second raw yam cube with water.
5. Mark the level of liquid on each yam cube with pins as indicated above.
6. Place each yam cube in a petri dish of water and label the dishes A, B and C.
7. Note and record the liquid levels after two hours.
   a) What is the reason for boiling one of the yam cubes?
   b) Explain your observations.
   c) What is the meaning of the term 'isotonic'?

REVIEW QUESTIONS

1. State three ways by which substances can move in and out of cells
2. Describe four functions of membrane proteins
3. Explain why plant cells and animal cells behave differently when placed in fresh water.
4. A farmer applies too much fertilizer to his/her maize plant. When it hasn't rained, the plant withered and died after one week. Explain this.

ANSWERS TO REVIEW QUESTIONS

1. Substances move in and out of the cell through osmosis, diffusion, active transport, plasmolysis, exocytosis and endocytosis
   - There are enzymes present in membranes for many chemical reactions which take place on the surface of the membranes. E.g. stages in protein synthesis, respiration and photosynthesis.
   - There are receptor sites for hormones which then influence the activity of the cell.
   - There are proteins which act as a skeleton for the membrane to give it shape and to allow it to move. For example, the membrane moves during phagocytosis and when cilia waft to and fro.
   - There are proteins which actively transport materials across the membrane using chemical energy obtained from the cell in the form of Adenosine Triphosphate (ATP).
   - There are proteins which form pores in the membrane through which substances can pass.
2. Both cells absorb water by osmosis and increase in size. Plant cell has cell wall which prevents it from osmotic bursting, making it turgid but animal cell lacks cell wall, hence it will burst.
3. The fertilizer absorbs water from the plant by osmosis, and the plant cells plasmolysed due to chemical in the fertilizer moves into the plant by diffusion.

EXTENDED READING

Click on the link below to watch a video on the cell membrane

The Cell Membrane (youtube.com)

Click on the links below to watch videos on the transport/movement of substances in and out of a cell

Diffusion | Membranes and transport | Biology | Khan Academy (youtube.com)

detailed animation on tonicity - YouTube

Cell Transport (youtube.com)

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