

CHAPTER – 16



Transportation of substances inside the body

If we put a few drops of blue ink into water in a glass tumbler and leave it undisturbed, we will see that all the water in the glass has become blue after a few minutes. Also if we put a spoonful of common salt in a glass of water and leave it undisturbed, we will notice that the salts crystals have dissolved and the water in the whole glass has become salty. Further, we will notice that when a tea bag is placed in a cup of hot water, the reddish-brown tea in solution will automatically pass out through the material of the tea bag, and we will get a cup of tea after a few minutes even without touching the bag. Another interesting day to day observation is that the smell of a tasty curry being prepared in the neighbour's kitchen reaches us.

16.1 What is diffusion?

All the above observations are possible only because the particles, or molecules, of the different substances have a tendency to distribute themselves throughout the medium or available space. This tendency of molecules of solids, liquids and gases to get distributed throughout the available space is known as **diffusion**. It is due to the fact that the molecules are in a state of perpetual motion due to the kinetic energy present in them. This perpetual motion, also known as **Brownian movement**, results in the net movement of the substances from a place of their higher concentration to the place where they are in a lower concentration. The movement of particles continues even at the point of equilibrium, when they have occupied all available space in the medium. So, the particles still have the tendency to occupy more available space. Therefore, diffusion or observable movement of particles from one place to another can take place only when there is a difference in the concentration of a substance in the different parts of the system.

The term diffusion is derived from the Latin verb *diffundere* which means "to spread apart" but can also mean "to pour away" or "give vent to". According to **Fick's laws of diffusion**, derived by Adolf Fick in the year 1855, there are two usages of the term diffusion. Fick's first law deals with the passage of a gas through a membrane or porous material, while Fick's second law is concerned with the dispersion of particles that occur when there are different concentrations within a container.

Activity 16.1 Experiment to demonstrate diffusion

Take a wide glass tube, two corks, some cotton wool soaked in ammonia solution and some red litmus paper. Close one end of the wide glass tube with a cork. The litmus paper can be hung with a thread within the tube. Plug the other end of the tube using the wet cotton wool and the other cork. Note down what you observe.

It will be observed that the red litmus papers turn blue.

This is because the ammonia molecules travel by diffusion from the higher concentration in the cotton wool to the lower concentration in the rest of the glass tube. As the ammonia, which is alkaline, reaches the other end of the tube by diffusion, the red litmus papers turn blue.

By changing the concentration of ammonia, the rate of colour change of the litmus papers can also be changed.

16.2 Diffusion across Membranes

In the **living systems**, diffusion is a main form of transport within cells and across cell membranes. Metabolism and respiration rely in part upon diffusion in addition to bulk or active processes. For example, in the alveoli of mammalian lungs, due to differences in partial pressures across the alveolar-capillary membrane, oxygen diffuses into the blood and carbon dioxide diffuses out. Lungs contain a large surface area to facilitate this gas exchange process.

Diffusion in the living system occurs in the following ways, viz. i) Simple diffusion, ii) Osmosis, and iii) Active transport.

16.2.1 Simple diffusion

The term simple diffusion refers to a process whereby a substance passes through a membrane without the aid of an intermediary such as an integral membrane protein. The force that drives the substance from one side of the membrane to the other is the force of diffusion. In order for substances to pass through a cell membrane by simple diffusion it must penetrate the hydrophobic core of the phospholipid bilayer. The types of molecules that can do this are themselves substantially hydrophobic in nature such as carbon dioxide, oxygen or ethanol. Simple diffusion of molecules does not require expenditure of energy. Hence, it is also known as **passive transport**.

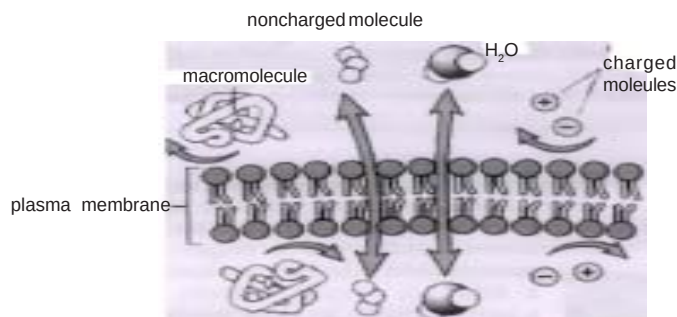


Fig. 16.1: Simple diffusion through the cell membrane

Water, oxygen, carbon dioxide, ethanol and urea are example of molecules that readily cross cell membranes by simple diffusion. They pass either directly through the lipid bilayer or through pores created by certain integral membrane proteins. The relative rate of diffusion is roughly proportional to the concentration gradient across the membrane. For example, oxygen concentrations are always higher outside than inside the cell and oxygen therefore diffuses down its concentration gradient into the cell; the opposite is true for carbon dioxide.

Rate of transport for a particular molecule by simple diffusion across a cell

membrane is also proportional to the lipid solubility or hydrophobicity of that molecule. Oxygen, carbon dioxide and ethanol are highly lipid soluble and therefore diffuse across the bilayer almost as if it were not there.

So what about water? We know that water crosses cell membranes very readily – the amount of water that diffuses back and forth across the membrane of the red blood cell every second is roughly equivalent to 100 times the volume of the whole cell. Water, however, is not at all lipid soluble. However, it seems that the water molecule is small enough and has sufficient kinetic energy that it can diffuse through the lipid bilayer with minimal interference. Certain other small, uncharged, hydrophilic molecules, urea, for example, diffuse across lipid bilayers with relative ease.

Ions and charged molecules diffuse cross the lipid bilayer of cell membranes very, very poorly. Their charge, either positive or negative, causes them to be repelled from like charges in the cell membrane. Additionally, their charge causes them to electrically bond water molecules, causing them to be hydrated and effectively quite large.

To summarize, many small and uncharged molecules diffuse across the plasma membrane by virtue of their kinetic energy of motion. In most cases, such molecules are hydrophobic, nonpolar and can dissolve in and out of membrane lipid. Charged molecules are not easily transported across the plasma membranes by simple diffusion. There are other means to facilitate their transport.

Polar and nonpolar solvents: Solvents that can dissolve and split solute molecules into charged ions are polar solvents, e.g. water, liquid ammonia. Solvents that can dissolve only nonpolar covalent compounds are called non-polar solvents, e.g. Benzene.

16.2.2 Osmosis

A partition or a membrane which allows passage of certain small molecules while preventing passage of other larger molecules across it is called a **semi-permeable membrane**. **Osmosis** is the spontaneous movement of water molecules across a semi-permeable membrane from a region of low solute concentration to a solution with a high solute concentration, down a solvent concentration gradient. It is a physical process in which a solvent moves, without input of energy, across a semi permeable membrane (permeable to the solvent, but not the solute) separating two solutions of different concentrations. Osmosis releases energy, and can be made to do work, as when a growing tree-root splits a stone.

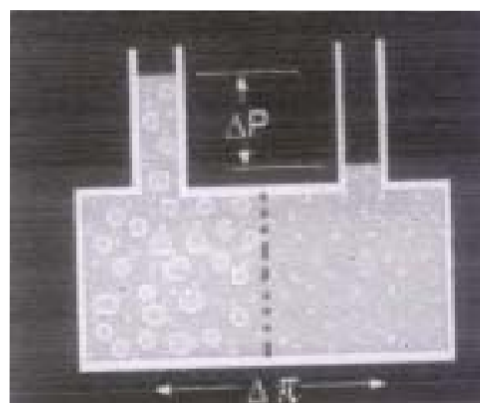


Fig.16.2: Osmosis

Net movement of solvent is from the less-concentrated (hypotonic) to the more-concentrated (hypertonic) solution, which tends to reduce the difference in concentrations. This effect can be countered by increasing the pressure of the hypertonic solution, with respect to the hypotonic. The osmotic pressure is defined to be the pressure required to maintain equilibrium, with no net movement of solvent. Osmotic pressure depends on the molar concentration of the solute but not on its identity. Osmosis is thus the result of diffusion across a semi-permeable membrane(Fig.16.3).



Fig.16.3: Semi-permeable membrane

Now let us try the following activities

Activity 16.2

Osmosis with an egg

Let us take an egg and remove the egg shell by placing it in dilute hydrochloric acid (HCl). The egg shell is made up mainly of calcium carbonate. A thin outer skin now encloses the egg. Put the egg in pure water and observe after 5 minutes. You will observe that the egg shrinks because water passes out of the egg solution in the salt solution because the salt solution is more concentrated.

Activity 16.3

Osmosis with Raisins and Apricots

Put dried raisins or apricots in pure water and leave them for some time. Then place them into a concentrated solution of sugar or salt. Each gains water and swells when placed in pure water. but, when they are placed in the concentrated solution it loses water, and consequently shrinks.

Osmosis is important in biological systems as many biological membranes are semipermeable. In general, these membranes are impermeable to organic solutes with large molecules, such as polysaccharides, while permeable to water and small, uncharged solutes. Permeability may depend on solubility properties, charge, solute size, etc. Water molecules travel through the plasma cell membrane tonoplast (vacuole) or protoplast in two ways, either by diffusing across the phospholipid bilayer directly, or via aquaporins (small transmembrane proteins). Osmosis provides the primary means by which water is transported into and out of cells. The turgor pressure

of a cell is largely maintained by osmosis, across the cell membrane, between the cell interior and its relatively hypotonic environment.

16.2.3 Active Transport

When molecules move across a membrane regardless of the concentration gradient, it is known as active transport. During active transport, the molecules move against the concentration gradient, i.e. they move from the region of their higher concentration to the region of their lower concentration. Such movement requires energy (hence the term "active"), which is provided by ATP Adenosine triphosphate molecules. A good example of active transport mechanism is the sodium-potassium pump, which pumps potassium ions into the cell while pumping sodium ions out.

16.3 Facilitated Diffusion: Carrier Proteins and Ion Channels

Glucose, sodium ions and chloride ions are just a few examples of molecules and ions that must efficiently get across the plasma membrane but to which the lipid bilayer of the membrane is virtually impermeable. Their transport must therefore be "facilitated" by proteins that span the membrane and provide an alternative route or bypass. Facilitated diffusion is the name given to this process. It is similar to simple diffusion in the sense that it does not require expenditure of metabolic energy and transport is again down an electrochemical gradient.

16.4 Role of diffusion in metabolism

Diffusion plays the main role in nutrition, particularly in transport of water and food materials into every cell in the body. The exchange of gases during respiration and excretion in living organisms also occur by diffusion.

16.4.1 Diffusion in nutrition

Nutrition is the way our body takes in and uses food. Digestion is the process during which complex food particles are broken down into smallest possible units so that they can be absorbed or taken inside the cell. Digestion in animals occurs inside the alimentary canal or gut, which includes the mouth, pharynx, esophagus, stomach, small intestine, large intestine, rectum and anus. Along with the associated digestive glands, viz. liver, pancreas, etc. they constitute the digestive system.

In vertebrate animals, the process of digestion of food may begin in the mouth, and is normally completed within the small intestine. Absorption of the digested food is the most important step in nutrition. It mainly occurs by diffusion through the wall of the small intestine, though certain items such as pepper, mustard, condiments and alcoholic drinks may be absorbed in the stomach.

The digested material from the intestine is absorbed by diffusion either into the blood capillaries or into the lymphatics, both of which occur in the intestinal **villi**. The absorbed material is then carried to the liver through the mesenteric veins and portal veins. From the liver they are sent to the general circulation.

Carbohydrates are absorbed through the intestinal villi in the form of monosaccharides, for the most part, by active transport. Proteins enter blood only in the form of amino acids. Their transport system across the cell membrane requires the presence of high concentration of Na^+ in the lumen of the intestine. It occurs not by simple diffusion, but by a rapid and active process.

Fats are absorbed in the form of small molecules and free fatty acids along with glycerol. They are said to be taken onto the cell by **pinocytosis**. However, short chain fatty acids are directly absorbed by simple diffusion. Nucleic acids diffuse into the capillaries in the form of small nucleoside molecules. Most of the water-soluble vitamins are absorbed by simple diffusion along with water. They are believed to enter the cells by pinocytosis. Ca^+ is absorbed by active transport against the concentration gradient.

16.4.2 Diffusion in excretion

Excretion involves both passive diffusion and active transport of molecules across the cell membrane. In the Bowman's capsule of kidneys, a watery filtrate containing molecules that can pass through the semi-permeable membrane is formed. This filtrate, however, contains some useful materials like glucose, amino acids, fatty acids, salts, etc. Water, sodium chloride, glucose and amino acids first enter the cells of the nephron by passive diffusion. Sodium, glucose and amino acids are then actively transported into the intercellular space, while chloride moves out by passive diffusion. These materials are again reabsorbed by the blood capillaries by the same process. Reabsorption of water from the filtrate occurs mostly through osmosis.

16.5 Diffusion in gaseous exchange

Gaseous exchange between the organism and its environment occurs during respiration. During the process, oxygen is absorbed from the surrounding medium by osmosis. This osmosis occurs when the oxygen-containing medium (water or atmosphere) comes in contact with the semi-permeable cell membrane of the respiratory surface (plasma membrane, gills, lungs, skin, etc). As the medium contains a higher concentration of oxygen compared to that inside the cells, the gas diffuses by osmosis through the plasma membrane into the cytoplasm or circulatory fluid (blood, haemolymph, etc). At the same time, carbon dioxide diffuses out due to differences in osmotic concentration (higher concentration inside and lower outside). When the circulatory fluid reaches the tissues, oxygen is offloaded and carbon dioxide is picked up, again due to differences in their osmotic concentrations.

POINTS TO REMEMBER

- * The tendency of molecules of solids, liquids and gases to get evenly distributed through the available space is known as diffusion.
- * The perpetual motion of molecules due to the kinetic energy present in them is known as Brownian movement.
- * Diffusion is the main form of transport within cells and across cell membranes.

- * Diffusion occurs in three ways, viz.
 - (i) Simple diffusion,
 - (ii) Osmosis and
 - (iii) Active transport.
- * Simple diffusion occurs without expenditure of energy.
- * Simple diffusion is also known as passive transport.
- * Water, oxygen, carbon dioxide, ethanol and urea molecules are transported by simple diffusion.
- * A semi permeable membrane allows movement of certain small molecules and prevents movement of larger molecules across it.
- * During osmosis, water moves from a region with low solute concentration to a region with higher solute concentration across a semi permeable membrane.

EXERCISES

1. *Define diffusion. Explain it citing some common examples.*
2. *What is the importance of diffusion in the living system ?*
3. *What are the different ways in which diffusion occurs in the living system ?*
4. *Explain how diffusion occurs in the following ways :*
 - (i) *Simple diffusion*
 - (ii) *Osmosis*
5. *What are polar and non-polar solvents? Give example.*
6. *What is a semi-permeable membrane ? Explain the process of osmosis across a semi-permeable membrane.*
7. *Write on the importance of osmosis in the living systems.*
8. *Write on the role of diffusion in nutrition.*
9. *Write on the role of diffusion in excretion.*
10. *Write on the role of diffusion in respiratory gaseous exchange.*