Chapter 14

TRANSPORT

Every living cell, whether it exists alone as a single celled organism or is a component of a multicellular one, must perform its own metabolic activities. It must synthesize its own ATP by cellular respiration. It follows, then, that every cell must obtain the necessary raw materials to support its metabolism. Obviously, some mechanism is needed for transporting substances between the specialized systems of procurement, synthesis or elimination and the individual living cells throughout the body.

14.1 INTRODUCTION: Need for transportation of materials

All living organisms must perform metabolic activities in their cells. Each living cell must synthesize its own ATP by cellular respiration/ photosynthesis and carry out for itself those activities necessary for its growth and maintenance. It follows, then, that every cell must obtain the necessary raw materials to support its metabolism. It must obtain nutrients, and. if it uses aerobic respiration, it must obtain oxygen. At the same time, it must get rid of metabolic wastes such as carbon dioxide and in animals nitrogenous compounds. In short, every cell must be exposed to a medium from which it can extract raw materials and into which it can dump wastes.

In unicellular organisms and some of the structurally simpler multicellular ones, each cell is either in direct contact with the environment or only a short distance from it. But in the large and structurally more complex multicellular organisms, the more internal cells are far from the body surface and from the general environmental medium. In these organisms nutrient procurement gas exchange and waste expulsion take place in certain restricted regions of the body specialized for those functions. Obviously, some mechanism is needed for transporting substances between the specialized system of procurement, synthesis, or elimination and the individual living cells throughout the body.

14.2 TRANSPORT IN PLANTS

Materials to be transported in plants:

Plants are in contact with both soil and atmosphere. Various materials from atmosphere and soil are transported in and out of plant body. At the same time certain materials are transported through out the plant.

Transport in plants occurs on three levels; i) Water, gases and solutes move in and out across cell membrane, ii) loading of food from photosynthetic cells into sieve tubes (short distance transport); iii) conduction of water with dissolved minerals and food along the whole plant through xylem and phloem, respectively (long distance transport).

14.3 UPTAKE AND TRANSPORT OF WATER AND MINERALS

Soil is the source of water and minerals for plants. They are taken up by roots. Various processes are involved in uptake of these minerals. These are diffusion, facilitated diffusion, osmosis, imbibition and active transport.

14.3.1 Processes involved in the uptake:

i) Diffusion:

If a few crystals of a coloured soluble salt like ($KMnO_4$) are dropped in a beaker containing water, the crystals dissolve and permagnate ions move in alldirections. As a result, the colour of water changes from colourless to purple. Initially, the concentration of ions is greater in the proximity of crystals, so the ions move away from higher concentration to lower concentration. This movement of ions or molecules from the region of higher concentration to the region of lower concentration is known as **diffusion**. One of the most common example of diffusion is, if a bottle of perfume is opened in a comer of a room, it can be smelt in the entire room after some time.

The rate of diffusion depends upon size and nature of molecule, small molecules move faster than large ones and vice versa. The rate of diffusion is high at high temperature. The other factor which affects rate of diffusion is concentration gradient. It is the difference in concentration of ions or molecules between two regions. Greater the difference in concentration and shorter the distance between two regions greater will be the rate of diffusion. When ions or molecules are evenly distributed through out the system, an equilibrium is established. Even after equilibrium there is movement but then equal number of ions or molecules move from, one point to other.

In principle, all solutes diffuse in solvent, but through a cell membrane which is living and differentially permeable, certain molecules move freely while the passage of others is resisted. Small, non-polar molecules such as gases like CO_2 and O_2 and fats soluble molecules move freely across the cell membrane. Their movement will continue till the concentration on either sides equalizes.

ii) Facilitated diffusion:

Charged particles and large molecules such as glucose do not pass through cell membrane. Certain intrinsic proteins that reach from one side of membrane to other help them to cross the barrier. These proteins are membrane transport proteins such as channel proteins and carrier proteins. The shape of channel protein molecule is such that it forms a water filled pore in the membrane. Theseproteins facilitate passage of water soluble substances. Carrier proteins being highly selective like enzymes, combine with certain molecules or ions and transport them across the membrane. This movement of ions or molecules in and out of cell is called **facilitated diffusion.** Diffusion, whether simple or facilitated is called **passive transport** because it does not require input of cell's metabolic energy (ATP) and takes place down the concentration gradient and kinetic energy accounts for molecular movement.

iii) Osmosis:

Osmosis is diffusion of water molecules across the plasma membrane from a region of its higher concentration to a region of its lower concentration. This can be proved by an experiment.

Consider a U shaped tube with side A filled with pure water and side B with same quantity of sucrose solution (sugar dissolved in water) separated by a membrane permeable to water and impermeable to sugar. Since membrane is permeable to water molecules, it can move from side "A" to "B" and from "B" to "A". At side "A"there are only water molecules whereas at side "B"the presence of sucrose molecules means concentration of water molecules is less than at side "A". Thus in unit time more water molecules will diffuse from side "A" to "B" than from "B"to "A". In other words there is net movement of water molecules from "A"to "B". As a result, level of sugar solution will begin to rise and that of water will begin tofall. This movement of water molecules from region of higher concentration to the region of lower concentration through a semipermeable membrane is known as **osmosis.**

Biological membranes in strict sense are not semipermeable because they are not completely impermeable to solutes. They allow passage of solutes as well as solvent though not at the same rate. All that is necessary for osmosis to occur is that the solvent molecules diffuse rapidly than the solute molecules.

iv) Active transport:

Certain molecules or ions move across the cell membrane against the concentration gradient i.e. from lower concentration to higher concentration with the help of specific transport proteins embedded in cell membrane. The transport takes place at the expense of cell's metabolic energy-ATP and is called **active transport.** The cells or tissues carrying out active transport are characterized by presence of numerous mitochondria, high rate of respiration and high concentration of ATP.

In plants, phloem loading is an active translocation process. In source cell of leaves the sucrose concentration of the sieve elements and companions cells is much greater than that of mesophyll cells. It means that the sucrose is transported against its chemical potential gradient which requires metabolic energy.

Active transport is of utmost importance because it enables the cell to take up nutrients from outside and wastes to be expelled against the concentration gradient as shown in figure 14.1.

v) Imbibition:

Adsorption of water and swelling up ofhydrophilic (water loving) substances is known as **imbibition**. Substances such as starch, gum, protoplasm, cellulose and proteins have great affinity for water and are called **hydrophilic**. Living and dead plant cells are hydrophilic colloids as they possess large amount of carbohydrates and as such they have very strong affinity for water. Seeds which have very low water potential swell up when placed in water. Wrapping up of wooden framework during rainy season is another example of imbibition.

14.3.2 Water status in plants:

Water is important in the life of plants because it makes up the matrix and medium in which biochemical processes essential for life occur. In most land plants, water is continually lost to the atmosphere and is taken from the soil. The movement of water may occur by diffusion, osmosis, bulk flow or some combination of these fundamental transport mechanisms. Diffusion moves water from region of high water concentration (low solute concentration) to region of low water concentration (high solute concentration). It occurs because molecules are in constant thermal agitation. Bulk flow occurs in response to a pressure difference, whenever, there is a suitable pathway for bulk movement of water. Osmosis is the process by which water moves across differentially permeable membrane. It depends upon the chemical potential of water or water potential, osmotic potential of two separating solution and pressure potential across the membrane and wall of the cells. Therefore, it is necessary to understand these terms to explain the process of water movement across the membrane.

i) Water potential:

The chemical potential of water is a quantitative expression of the free energy associated with the water. Thermodynamically, free energy represents a potential for performing work. All living things including plants, require a continuous input of free energy. In the case of water movements this free energy is involved in water flow. The unit of chemical potential is energy per mole of a substance (joules per mole).

For practical reason, it turns out that the unit of chemical potential is inconvenient for most work in plant physiology. Therefore, plant physiologist have defined another parameter called **water potential** as the difference between the free energy ofwater molecules in pure water and energy ofwater in any other system (e.g. water in solution or in cell sap of plant). Now, the free energy of water is expressed in pressure unit such as megapascals and symbolised by Greek letter Ψ psi [MPa; IMPa=9.87 atmosphere].

Pure water has been assigned the value ofwater potential 0 MPa. Addition of solute particles lowers the mole fraction (number of mole of substance divided by total number, of all substances in the system/solution) of water. Hence, there is a decrease in water potential. Therefore, values ofwater potential remains less than zero or in negative value.

ii) Osmotic Pressure:

The pressure exerted upon a solution to keep it in equilibrium with pure water when the two are separated by a semipermeable membrane is known as **osmotic pressure.** Therefore, the osmotic pressure of a solution is a measure of the tendency of water to move by osmosis into it. In other words we can say that the osmotic pressure is the pressure that must be exerted on a solution to prevent the passage of solvent molecule into when the solvent and solution are separated by a differentially permeable membrane. Thus, it prevents the process of osmosis proceeding.

iii) Osmotic Potential or Solute Potential:

Osmotic potential is the tendency of a solution to attract water molecules when the solutions of two different concentrations are separated by a differentially permeable membrane. Pure water is assigned the osmotic potential zero as the highest value. Since the osmotic potential decreases as the osmotic concentration (theno: of osmotically active particles per unit volume) increases, all solutions have value of less than zero. Under constant temperature and pressure, water moves from the solution of lower osmotic potential to the solution of higher osmotic potential when the two solution are separated by a differentially permeable membrane. It is represented by $\Psi_s$or solute potential.
Another term used in relation to water potential is pressure potential, which is defined as the hydrostatic pressure in excess of atmosphere pressure.

14.3.3 Water relations of Plant Cell:

For practical purposes a plant cell can be divided into three parts: (i) Cell Wall: This is non-living, permeable, outer most boundary of cell made up of cellulose, (ii) Cytoplasm alongwith nucleus forms protoplasm—the living material bounded by cell membrane, (iii) In the centre, there is a vacuole enclosed by tonoplast, central vacuole is filled with cell sap—an aqeous solution of salts, organic acids and sugar.

> Tonoplast, the membrane of the central vacuole is the another important site of regulation in plant cell after plasma-membrane. Transport proteins embedded in the tonoplast control the movement of solutes between the cytosol and the vacuole e.g. it has proton pumps that expel H^+ from the cytoplasm into vacuole.

The presence of solute particles lowers the water potential Ψ of cell sap. Greater the number of solute particles, the more negative will be the water potential of cell sap. The concentration of solute particles in a solution is known as **solute potential** Ψ_s. (This has been previously referred as osmotic potential). The value of solute potential is always negative.
When a cell is placed in pure water or in an aqueous solution with higher water potential (less negative) than the cell sap, water flows into the vacuole by osmosis through plasma membrane and tonoplast. As more water flows into the vacuole, the tension developed by cell wall causes an internal hydrostatic pressure to develop. This is called **pressure potential** Ψ_p and it opposes the continued uptake of water into the cell by osmosis. When the cell wall is fully stretched and pressure potential reaches at its maximum, the cell cannot take any more water, and is said to be fully **turgid**. The relationship between water potential Ψ, solute potential Ψ_s and pressure potential Ψ_p is represented by following equation.
$\Psi = \Psi_s + \Psi_p$
In a turgid cell $\Psi_p$is equal and opposite to Ψ_s, so Ψ = o.

14.3.4 Plasmolysis and deplasmolysis:

If a turgid cell is placed in a hypertonic solution which has more negative solute potential and water potential than the cell sap, it will lose water by exosmosis. At first there will be slight decrease in the volume of cell content. Eventually, the cytoplasm begins to separate from cell wall leaving a noticeable gap between cell wall and cell membrane. This withdrawal of protoplasm from cell wall is known as **plasmolysis**. The point when cytoplasm just starts to separate from cell wall is called **incipient plasmolysis**. When protoplasm completely separates from cell wall, full plasmolysis is achieved. In a plasmolysed cell Ψ_p is zero and $\Psi_w = \Psi_s$

When a plasmolysed cell is placed in pure water, or hypotonic solution, water begins to flow into the vacuole by endosmosis. Protoplasm expands gradually and presses the cell wall. Pressure potential begins to develop. With rise in pressure potential water potential also increases becoming less negative. Eventually, the cell become, turgid. This recovery of cell from plasmolysis is known as **deplasmolysis.**

14.4 WATER AND MINERALS UPTAKE BY ROOT

Absorption of water and mineral salts takes place through root system. Roots are provided by enormous number of tiny root hairs which are outgrowths of epidermal cells and found at the root tips. The root hairs greatly increase the surface area of root. Because of large root surface area plants absorb enough quantities of water and inorganic ions for their survival and growth.

Root hairs possess sticky walls and adhere tightly to soil particles which are usually coated with water and dissolved minerals salts. Most of the absorption takes place near the root tip where epidermis is permeable to water and root hairs. From root hairs and epidermal cells water flows through cortex endodermis, pericycle and enters xylem. Since transport of water takes place in radial direction it is also termed as **lateral transport.**

Three pathways are available for water to enter xylem. The first route is from **cell to cell**. Water enters the root hair or epidermal cell down a gradient of water potential. It flows out of one cell across the cell wall, cell membrane vacuole and enters the adjacent cell which may again pass the substance along the next cell in the pathway. This is known as **cellular path way.**

The second pathway is **symplast.** Through the pores in the cell walls, cytoplasm of cortical cells remain connected with cytoplasm of adjoining cortical cells. These cytoplasmic connections through pores are known as **plasmodesmata** (sing: Plasmodesma). These cytoplasmic connections provide another pathway for transport of water and solutes known as **symplastic pathway**. This requires only one crossing of plasma membrane at root hair.

The third pathway is **apoplast.** The cell walls of epidermal cells and that of cortical cells form a continuous matrix. These walls are hydrophilic. Soil solution flows freely through hydrophilic walls of epidermal and cortical cells. This movement of soil solution through extracellular pathway provided by continuous matrix of cell walls is known as **apoplastic pathway**. As solutes move along extracellular pathway some of the water and solutes are taken up by the cells of cortex thus changing the route from apoplast to symplast.

The inner limiting layer of cortex is endodermis which serves as a barrier or checkpoint because of **casparian strip** a waxy belt that extends through the walls of endodermal cells. Thus, water and minerals cannot cross the endodermis and enter xylem via apoplast (extracellular pathway). Symplast is the only way to cross the barrier. Endodermal cells actively transport salts to pericycle resulting in high concentration of salts. This causes a low water potential and water moves into them by osmosis. From pericycle water flows into xylem both via symplast and apoplast

14.5 ASCENT OF SAP

Water is absorbed by roots and transpired through leaves. Before transpiration-water is conducted upto leaves. This upward movement ofwater from absorptive surfaces (roots) upto transpiring surfaces (leaves) against the downward pull of gravity is known as **ascent of sap**. The distance travelled by water in upward direction is the shortest in plants like herbs and longest in case of tall trees. In tall trees like eucalyptus and red wood the distance is more than 90 meters.
Two aspects of the problem need to be explained.

(i) Path of ascending stream of water.

(ii) The mechanism of ascent of sap.

14.5.1 Path of movement of water and minerals:

Experimentally it has been proved that the path of ascending stream ofwater is xylem. Xylem is a complex tissue consisting of two types of water conducting cells. These are open ended cells called vessels and porous cells called tracheids.

(i) Vessels: These are thick walled tube like structures which extend through several feet of xylem tissue. They range in diameter from 20 µm to as much as 70 µm (0.7 mm). Their walls are lignified and perforated by pits. At the pit lignin is not deposited and cell wall is thin made up of cellulose. The pits match up with pits of adjacent cells so that cell cavities are connected to adjacent cells cavities. Xylem vessels arise from cylindrical cells which are placed end to end. At maturity, the end walls of these cells dissolve and cytoplasmic contents die. Thus a continuous duct is formed which offers a better route for long distance transport of water from roots upto leaves. The rate of flow of water is 10 times faster than tracheids. Vessels are mostly found in angiospermic plants.

(ii) Tracheids: These are individual cells about 30µm in diameter and several mm in length. They can be distinguished from vessels by their angular walls and smaller size. They taper at each end and tapered ends of one cell overlap tapered ends of other cells, like xylem vessels they are dead with thick lignified walls. Their walls are perforated by small holes called pits which are of two types; simple and bordered. The pits in the cross walls connect upper tracheid with lower one. Through these pits water and minerals flow freely from one tracheid to another. In ferns and conifers, tracheids are the only water conducting ducts.

14.5.2 Mechanism of ascent of sap:

Water and dissolved mineral salts present in xylem (sap), flow to upward direction at the rate of 15 meters per hour. Xylem sap ascends against the downward pull of gravity without the help of any mechanical pump. The rise of sap in xylem is either due to push from below or a pull from above. Several theories have been advanced to explain to ascent of sap in tall trees against the force of gravity but no single theory seems to offer a complete explanation due to objections. Among these are two theories seem to explain the mechanism of ascent of sap better. Let us examine the contribution of the two possible mechanisms.

(i) Root pressure theory.

(ii) Adehesion - cohesion theory.

i) Push from below— Root pressure theory:

If the stem of well watered potted plant is cut a little above the soil, the cut end exudes water for some time suggesting that there is a force pushing water upto the stem from roots. This force is known as **root pressure.** It was discovered by Stephen Hales in 1727. According to Hales, this force could be responsible for raising water to a height of 6.4 meters. He also observed that the pressure develops at certain times of a year.

Root pressure, which is active primarily at night, is caused by the continued active accumulation of ions by the roots of a plant at times when transpiration from leaves is very low or absent.

Root pressure also causes **guttation**. The exudation of water droplets can be seen on the tips of grass blades and leaf margins of small herbaceous dicot plants. During night when rate of transpiration is very low, the root pressure pushes xylem sap into shoot system. More water enters leaves than is transpired. The excess of water is forced out in the form of liquid (droplets) through openings, called **hydathodes**.

While root pressure is a demonstrated fact, it seems unlikely that it can account completely for upward conduction of water in xylem because it raises water upto few meters only. Moreover, many tall trees do not generate root pressure. Thus it is not a potent factor and we must look for an alternative mechanism.

ii) Transpiration pull (Adhesion—Cohesion—Tension theory):

Ascent of sap mainly depends upon two factors. These are (i) transpiration which generates pulling force and (ii) physical properties of water i.e. adhesion and cohesion. Adhesion is the sticking together of molecules of different kinds. Water molecules tend to adhere to cellulose molecules of the walls of xylem vessels. Cohesion is the clinging together of molecules of same kind. Extensive hydrogen bonding in water gives rise to property of cohesion. It also gives water a high tensile strength defined as the ability to resist the pulling force. The cohering water molecules in xylem vessels form a continuous column.

Californian red wood trees are over 100 meter tall. Transpiration from their leaves pulls water up the trunk. On the other side a village pump working based on atmospheric air to raise water. The maximum column of water that can be raised is about 10 m only.

Transpiration pull results from chain of events that starts when leaves begin to absorb solar radiation in the morning. Sunlight raises temperature of leaves so the water begins to evaporate from moist walls of mesophyll cells. The evaporated water is immediately replaced from water inside the cell which is replaced with water from neighbouring cell deeper in the leaf. Ultimately, water is pulled from xylem to meet the loss ofwater. Thus water in xylem is placed under tension which is transmitted to root through vessels. This downward transmission of tension is because of cohesive property of water columns in vessels and tracheids. Water column moves upward by mass flow due to transpiration pull. Adhesion ofwater molecules to hydrophilic walls of xylem cells, small diameter of vessels and tracheids are important factors in overcoming the force of gravity.

To transport water over a long distance, plants do not use their metabolic energy. Forces like adhesion, cohesion and evaporating effect of sunlight are mainly responsible for upward conduction ofwater. Thus ascent of sap is solar powered.

14.6 TRANSPIRATION

Plants absorb large quantities of water from soil. Only 1 -2% of the absorbed water is used in photosynthesis, in other metabolic activities and in the maintenance of turgor of the cells. The remainder is lost from leaves and other aerial parts in the form of vapours. This loss of water in vapour form through aerial parts of plant body is known as **transpiration.**

Transpiration takes place at three sites. These are stomata, cuticle and lenticels. Accordingly, there are three types of transpiration: i) stomatal transpiration ii) cuticular transpiration and iii) lenticular transpiration.

i) Stomatal transpiration:
In lamina of leaf there are microscopic pores known as stomata (sing: stoma). Through these pores water in vapour form escapes into outer atmosphere. This loss of water in vapour form through stomata is known as stomatal transpiration. Since greater loss of water takes place through stomata, therefore, leaves are regarded as chief transpiring organs.

ii) Cuticular transpiration:
Cuticle is a layer of waxy substance cutin found outside the epidermis of leaves and stems. Loss of water in vapour form from epidermal cells through cuticle is known as cuticular transpiration.

iii) Lenticular transpiration:
Lenticels are also pores found in old dicot stems which are formed as a result of secondary growth. Smaller quantities of water are also given out through lenticels. This is known as lenticular transpiration.

14.6.1 Mechanism of transpiration (Stomatal):
Since greater loss of water in vapour form takes place through stomata, therefore, we shall discuss here only the mechanism of stomatal transpiration. Two processes are involved in this type of transpiration. These are: i) evaporation ii) diffusion. Water absorbed by roots is conducted to aerial parts (leaves) through xylem, Mesophyll cells, of leaves are supplied with water through xylem (veins). These mesophyll cells are water filled (turgid). Their walls remain saturated with water are in contact with intercellular spaces, which are connected with outer atmosphere through stomata. In the first step water evaporates from wet surfaces of turgid mesophyll cells. The vapours are collected in the intercellular spaces. In the next step, water vapours diffuse out from intercellular spaces (where they are in higher concentration) to outer atmosphere (where vapour, are in lower concentration) through stomata.

14.6.2 Structure of stomata:
Stomata are microscopic pores present in the epidermis of leaves and herbaceous stems. Each stoma is bordered by two modified epidermal cells called **guard cells**. These guard cells unlike epidermal cells are provided with chloroplasts and shaped like kidneys. In general, the stomata remain open during day time and close at night. Thus light appears to be the prime factor which initiates opening of stomata.

14.6.3 Mechanism of opening and closing of stomata:
The opening and closing of stomata and even widening and narrowing of the gap between two guard cells depend upon the turgidity of guard cells, which is due to increase or decrease in the osmotic potential of the guard cells. The changes in water potential that result from the osmotic changes cause water to move in or out of the guard cells. If water move in, the cells expand (become turgid); if water moves out they go flaccid. When guard cells are turgid, the stomata are open, when the guard cells are flaccid, the stomata are closed. To affect this movement ofwater, an exchange must take place between the guard cells and the surrounding mesophyll and epidermal cell.
There are two main factors which greatly influence the opening and closing of stomata. These are light and concentration of K^+ ions.

Light: Generally, the stomata of a leaf are open when exposed to light and remain opened under continuous light. When darkness returns, the stomata are closed. In the presence of light, chlorophyll containing guard cells synthesize sugars which in turn increase the osmotic potential of guard cell. The increase results in endosmosis and ultimately to turgidity. While in dark these guards cells consume carbohydrate or these carbohydrate translated to neighbouring cell which decrease the osmotic potential in guard cells. This decrease result in exosmosis which ultimately leads to flaccid state.

Concentrating of K^+ion: Evidences indicate that the turgidity of guard cells of many species of plants is regulated by K^+ion concentration.
During day time guard cells actively transport K^+ ion from neighbouring cells, Accumulation of K^+ions lowers the water potential of guard cells. This causes in flow of water by osmosis from epidermal cells. When they lose K^+ions water potential increases. Water flows out of guard cell causing them to become flaccid which result in closure of pore.

14.6.4 Factors affecting transpiration:

i) Light: Plants transpire more rapidly when exposed to light than in dark. This is because light stimulates the opening of stomata. In bright sunshine stomata are wide open causing rapid diffusion of water vapours from air space of spongy layer to outside. Light also speeds up transpiration by warming the leaf.

ii) Temperature: Plants transpire more rapidly at higher temperature than at low. Rise in temperature, on one hand increases kinetic energy of water molecules which results in rapid evaporation of water and decreases relative humidity of air on other hand. Both these conditions greatly enhance the rate of transpiration.

iii) Wind: Wind has a profound effect on humidity. During high velocity of winds transpiration becomes more active because water vapours are readily removed and area around transpiring plants is replaced by fresh, drier air.

iv) Humidity: The rate of transpiration is also affected by relative humidity of air. Therate of diffusion of any substance is decreased as the difference in concentration of substance in two regions decreases. The reverse is also true. The diffusion of water from air spaces of leaf to outside goes on rather slowly when the surrounding air is humid. When the surrounding air is dry, diffusion proceeds more rapidly.

> At night, when the relative humidity may approach 100%, there maybe no transpiration, however, under these circumstances, the negative pressure component of water potential caused by evaporation, become very small or non-existent.

v) Soil Water: Aplant cannot continue to transpire rapidly if its moisture loss is not made up by absorption of fresh supplies of water from the soil. When absorption of water by roots fails to keep up with rate of transpiration, loss of turgor occurs and wilting of leaf takes place.

14.6.5 Transpiration as necessary evil:

Transpiration has its advantages and thus it is necessary. On the other hand it has grave disadvantages and thus it is an evil.

Advantages of transpiration:
In normal circumstances, the fate of transpiration is directly proportional to the rate of absorption. It means rapid transpiration increases the rate of absorption. Transpiration helps the intake of raw food material from the soil.
It is universally accepted that transpiration plays an important role in the ascent of sap. Transpiration helps in keeping plants cool and saving them from overheating which might be injurious to protoplasm. It helps in evaporating excess amount of water.

Disadvantages of transpiration:
Sometimes excessive transpiration may cause death of a plant. Some plants shed their food organs (leaves) particularly in autumn in order to reduce the rate of transpiration during unfavourable season. In certain plants, leaves are modified into scales or spines in order to minimize the rate of transpiration.

14.7 TRANSLOCATION OF ORGANIC SOLUTES (Phloem translocation)
The products of photosynthesis move from mature leaves to the growing and storage organs of plants. The direction of transport is determined by the relative locations of the sources and sinks of photosynthates. This movement of photoassimilates and other organic materials takes place via the phloem, and is therefore called **phloem translocation**. Transport occurs in specialized tissues called sieve elements.

14.7.1Source-sink Movement:
The translocation of photosynthates always takes place from source to sink tissues, therefore, this phloem transport is also referred as **source-to-sinkmovement**. This pathway follows developmental changes as some sink and source tissues are interconvertible during the development of the plant e.g. developing and germinating seeds, developing and mature leaves.
A number of steps are involved in the movement of photosynthates from mesophyll chloroplasts to the sieve elements in the phloem of mature leaves. Sucrose is synthesized in the cytosol of mesophyll cells. This sucrose is translocated from the mesophyll cells to the vicinity of the sieve elements in the smallest veins of the leaf. This is generally termed as the short distance transport pathway because the solutes cover only a distance of two or three cell diameters. The sucrose is then actively transported into sieve elements in a step commonly called**phloem loading.**
The pathway of phloem loading may be either symplastic or apoplastic depending upon the species.
The sucrose in sieve elements is exported away from source tissues. The photoassimilates can be moved a long distance hence this is termed as longdistance transport. Finally, the photoassimilate or sucrose is unloaded at the sink in a process referred to as **phloem unloading.**
The driving force for this translocation of photosynthates is believed to be generated by the processes of phloem loading and unloading. Therefore, this source to sink movement has great agricultural importance, because the productivity of a crop could potentially be increased by increasing the accumulation of photosynthates in edible sink tissues like cereal grains.

14.7.2The mechanism of Phloem Translocation:

Pressure flow Hypothesis:
Phloem translocation is mainly explained by a theory called the pressure flow hypothesis proposed by **Ernst MUnch** in 1930, which states that the flow of solution in the sieve elements is driven by a pressure gradient produced due to differences in osmotic pressure between sources and sinks as expained in the model given in figure 14.6b. This pressure gradient is produced due to phloem

loading and unloading at the source and sink, respectively. A high osmotic pressure generated due to active phloem loading in the sieve elements of the source tissue, causes a decline in the water potential. In response to this decline in water potential, water enters into the sieve elements and produces a high turgor pressure. In the sink tissues, present at the other terminal of the translocation pathway, phloem unloading occurs, which produces a low osmotic pressure in the sieve elements of the sink tissues. As a result of this low osmotic pressure, the water potential of the phloem rises above that of the xylem and water tends to leave the phloem in response to the water potential gradient, which causes a decrease in the turgor pressure of the phloem sieve elements of the sink (Fig. 14.6 a).

An equilibrium between the two ends (source and sink pressure) would be reached very soon if the entire translocation pathway were a single membrane bound compartment. The sieve plates which are present in the sieve elements increase the resistance along the pathway and maintain the pressure gradient in the sieve elements between source and sink. The sieve elements contents are physically pushed along the translocation pathway by bulk flow, much like water flowing through a garden hose.

Water movement in the translocation pathway is therefore driven by the pressure gradient rather than the water potential gradient. The passive, pressure driven long distance translocation in the sieve tube ultimately depends on the active short-distance transport mechanism involved in phloem loading and unloading. These active mechanisms are responsible for setting up the pressure gradient in the first place.

14.8 TRANSPORT IN ANIMALS

Like plants, animals also have efficient means of transportation which are according to their complexity. In unicellular organisms, such as Amoeba and Paramecium, food is taken in by direct and simple mechanism. Oxygen diffuses in through the body surface. The digested nutrients and the diffused oxygen are transported within the body by diffusion and cyclosis. The CO_2 and other metabolic wastes are also removed by simple diffusion through body surface. This is possible because, the distances between the external and internal environment and within the internal environment are much smaller and are easily covered by diffusion. However, in multicellular large sized animals due to increase in size and complexity, some other means are adopted for transportation, involving some kind of mass flow.

14.8.1 Transport without special Circulatory system in Hydra and Planaria:

1. HYDRA:

Hydra is the simplest multicellular animals. Its body is composed of two layers, ectoderm and endoderm, with a non-cellular mesogloea in between. The gastrovascular cavity (coelenteron) serves for the dual functions of digestion and distribution of substances through out the body. The fluid inside the cavity is continuous with the water outside through the mouth. Thus both inner and outer layers are bathed by the water. Moreover it possesses a large surface area to volume ratio. So the diffusion is sufficient for the transportation of digested food, oxygen, carbon dioxide and other metabolic waste.

2. PLANARIA:

Plan aria is a triploblastic, much larger and complex animal with a dorsoventrally compressed body. Due to which the cells are close to the external environment. The gaseous exchange takes place by direct diffusion across the general body surface. However, the transport of digested food to the body cells takes place by combining diffusion process with special organization of the intestine.

Planaria possesses an extensively branched intestine. These branches reach very close to the cells of the body. The digested food is pumped into the branches by muscular action of the digestive tube. So that the nutrients reach directly to the cells and diffuse into them.
Planaria has no circulatory system for the transportation of digestedfood and gaseous exchange. However, one special transport system is present to dispose off the excess amount of water along with nitrogenous waste (Protonephridia).

14.8.2 Transport by Special Circulatory System:

Due to the development of a body cavity (coelom), the distances are increased between the external and internal environments. The coelom separates the body wall from the internal organs and confers the advantage of independence of movement of the gut. Materials need to be moved efficiently over long distances within the body by some means. So that metabolic processes may be maintained and toxic materials may be removed from the body. This generally takes the form of a mass flow system or circulatory system.

14.9 CIRCULATORY SYSTEM

The purpose of a circulatory system is to provide rapid mass flow of materials from one place of the body to the other place, covering sufficient distances which cannot be easily covered by diffusion. On reaching their destination the materials must be able to pass through the walls of the circulatory system into the organs and tissues. Like wise materials produced must be able to enter the circulatory system, for disposal.

General characteristics of a circulatory system:

The characteristics of circulatory system are as follows:

(i) It has a circulatory fluid, the blood.
(ii) The blood is pumped by a contractile device around the body which may be a modified blood vessel or a heart.
(iii) The blood circulates through the tubes which are known as blood vessels.
(iv) It has one way valves to keep the medium flowing in one direction.

14.9.1 Types of circulatory system:

The blood circulatory system is basically of two types: (i) open type and (ii) closed type. They both allow the transported materials to be exchanged between the blood and the cells, but there is a different relationship between the blood and the surrounding tissue in each case.

i) Open type circulatory system:

The open type circulatory system is found in Arthropods, Molluscs and Tunicates. The blood circulates within the open body sinuses and bathes the surrounding tissue. These blood sinuses are collectively known as **haemocoel**. Since there is no distinction between blood and interstitial fluid, so the general body fluid is more correctly known as **haemolymph.** The blood is pumped by a heart which propels it into the arteries. The arteries open into the body sinuses, from where it is driven back into the heart. Distribution of blood to the tissues is poorly controlled. Since the blood flows within the sinuses and comes in direct contact with the body tissues, the system is known as open type circulatory system. Because the blood is in large spaces and the heart is weakly muscular, the blood pressure can never be very high. This limits the efficiency of the open system, that is why it is not found in large animals. In insects, gaseous exchange takes place through the tracheal system, so that the circulatory system is not concerned with transportion of gases and lacks any respiratory pigment. How ever, it does play an important role in distributing food substances and eliminating nitrogenous waste.

A comparative chart showing open and closed circulatory system with reference to the transport systems in cockroach and earthworm.

Main features	Cockroach	Earthworm
1. Type	Open type	Closed type.
2. Circulation	The blood flows through blood filled sinuses (Haemocoel).	The blood flows through closed blood vessels.
3. Contact of blood	The blood comes in contact with the surrounding tissues.	The blood does not come in contact with the tissues.
4. Body cavity	The coelom is greatly reduced.	The coelom is large.
5. Interstitial fluid	There is no difference between the interstitial fluid and the blood.	The interstitial fluid is separated from the blood.
6. Distribution of blood	It is poorly controlled.	Fairly controlled and is adjustable.
7. Vessels	A single dorsal vessel runs mid dorsally from head to the posterior end.	One dorsal vessel runs above the alimentary canal and one ventral vessel below the alimentary canal from anterior to the posterior end.
8. Flow of blood	Forward in dorsal vessel.	Forward in dorsal vessel and backward in ventral vessel.
9. Hearts	Modified posterior part of dorsal aorta having thirteen chambers.	Modified circular vessels connecting the dorsal and ventral vessel in 7^{th}, 9^{th}, 12^{th}, 13^{th} segment.
10. Veins and capillaries	Absent.	Present.
11. Blood	Colourless, having no haemoglobin.	Red, haemoglobin is dissolved in plasma.
12. Transport	It transports, digested food and excretory products but no gases.	It transports digested food, excretory products as well as gases.

ii) Closed type circulatory system:
The closed type circulatory system is more commonly found in annelids, echinoderms, cephalopods and vertebrates. The blood circulates through closed blood vessels and is distinct from the interstitial fluid. It does not come out at any place in direct contact with the surrounding tissues. The blood is pumped by the

heart rapidly around the body under sustained high pressure and back to the heart. The distribution ofblood is controlled fairly and is adjustable. Exchange of materials occurs across the walls ofblood capillaries, which ramify through the organs and come into close association with the body cells.
Animals with closed circulatory system are generally larger and often more active than those with open systems. A disadvantage of a closed circulatory system is that the blood is in vessels and their walls form a barrier between the blood and the surrounding tissue cells. The transporting materials have to cross this barrier into the surrounding tissue fluid and hence into the cells. At the same time, waste products diffuse from the cells into the tissue fluid and then into the capillaries.
The open type circulatory system and the closed type circulatory system can be understood well by explaining the transport system in cockroach and earthworm, through a comparative chart.

14.9.2Single circuit plan as in Fish:

The heart offish is two chambered, consisting of an atrium and a ventricle. Blood from the body circulation enters the atrium through a thin walled sinus venosus which opens into a muscular ventricle. When the ventricle contracts the blood is pumped into the ventral aorta via conus arteriosus. All these chambers have valves which prevent backward flow of blood. From the aorta, the venous blood passes into the afferent branchial arteries (4-5 pairs) into the gills for oxygenation. Since the blood flows through the heart only once during each circuit of the body, the fishes are said to possess a single circuit plan.

In fishes the blood flows in one direction and the heart never receives oxygenated blood for pumping.

14.9.3Double circuit plan:

From amphibians onward upto the mammals, the circulatory system has double circuit plan with separate pulmonary and systemic circulation. In amphibians and reptiles, the heart consists of three chambers, two atria and one ventricle. The oxygenated blood from the lungs is returned to the left atrium through the pulmonary veins, whereas the deoxygenated blood from the body is passed to the right atrium via sinus venosus by the anterior and posterior vena cava. These two types of blood remain separated due to atrial septum in between the right and left atria, but get mixed to some extent within the ventricle. Since the oxygenated and deoxygenated blood are mixed, the circulation is known as **incomplete double circulation.**

In crocodile (Reptilian) the ventricle is completely divided and the heart is four chambered.

14.9.4Pulmonary and Systemic circulation in Birds and Mammals:

In birds and mammals the heart is four chambered with two atria and two ventricles. The right atrium and right ventricle are completely separated from the left atrium and left ventricle by inter atrial and inter ventricular septum. The right side receives deoxygenated blood and the left side oxygenated blood. The blood circulates through the heart twice. Once as deoxygenated blood on the right side, from where it is pumped to the lungs for oxygenation (pulmonary circulation). Next time as oxygenated blood on the left side to be distributed to all the parts of the body except lungs (systemic circulation). Thus it is known as **complete double circulation**. Birds and mammals are endotherms, hence, need more oxygen to release more heat energy.

14.9.5Evolution of Heart in Vertebrates:

In the evolution of heart many changes have taken place.

In **fishes**, the heart is S-Shaped having only two chambers. The atrium receives the blood through a thin walled chamber of the veins, the sinus venosus that opens into ventricle which pumps the blood through conus arteriosus a chamber of the aorta into the body.

In **amphibians**, the heart is tri-chambered; two atria and one ventricle. The right atrium receives deoxygenated blood from the body and left atrium receives oxygenated blood from the lungs. But these two types ofblood get mixed in ventricle, to some extent.

In **reptiles,** the same tri-chambered heart is found with a beginning of the partition of the ventricle by inter ventricular septum which is complete in crocodilians.

Birds and **Mammals** have four chambered heart. Two atria and two ventricles. The two types ofblood remain separate. The oxygenated blood circulates through the left side and the deoxygenated through the right side. This brings about a complete double circulation.

14.10 TRANSPORT IN MAN

14.10.1 Blood Circulatory system (Cardio-vascular system):

The fluid circulatory system, with blood as the transporting material has assumed its highest development in man. It consists of a powerful heart, arteries, veins and capillaries.

Blood: Blood is a viscous, red fluid connective tissue, comprising a colourless plasma in which the blood corpuscles float.

Plasma: It constitutes about 55% of the blood. It is a viscous fluid containing a mixture of inorganic salts in true solution form and blood proteins (albumins, globulins and fibrinogen) in colloidal form. In addition, plasma contains glucose, amino acids, triglycerides, urea, hormones, enzymes and auto-toxins. The water is the most abundant component and forms 90% of plasma. The dissolved substances are only 10%.

Blood corpuscles: These are the blood cells which form the remaining 45% of the blood. They are of two types.

Red blood corpuscles (Erythrocytes) are biconcave, non-nucleated circular platelike cells. Their average diameter is 7-8 μm. They contain a respiratory pigment **haemoglobin** which is an iron bound protein and has an affinity for oxygen. The oxygen molecules get attached to the haemoglobin forming **oxyhaemoglobin** which is bright red in colour.
The R.B.Cs are formed in bone marrow of sternum and ribs etc. and are destroyed after 120 days by phagocytosis in spleen or liver. The iron is retained and the rest is passed as bile pigments **bilirubin** and **biliverdin**. R.B.Cs also contain an enzyme **carbonic anhydrase** which plays a role in carbon dioxide transport.
White blood corpuscles (Leucocytes) are irregular, nucleated cells, larger but less numerous than the R.B.Cs. They are formed in bone marrow, spleen, thymus and lymph nodes. They have a short life and are destroyed with in a few (20-30) hours.
The leucocytes maybe **granulocytes** (polymorphonuclear) or **agranulocytes** (mononuclear) on the presence or absence of granules in the cytoplasm. **Neutrophils, Eosinophils** and **Basophils** belong to the first category whereas **monocytes** and **lymphocytes** belong to the second category.

Neutrophils and monocytes are phagocytic whereas lymphocytes, eosinophils and basophils produce antitoxins, histamine and heparin.

Platelets are irregular cell fragments, non-nucleated, produced within the bone marrow. They help in blood clotting.

Mammalian R.B.Cs are non-nucleated and have no other organelles. The lack of nucleus permits more haemoglobin to be packed into the cell.

14.10.2 Functions of Blood:

Blood performs many important functions which are given below. The first five are carried out by plasma.

1) **Transport of Nutrition**: Blood transports digested food, water and other substances, from the alimentary canal to the various parts of the body for storage, oxidation or assimilation.

2) **Transport of Waste Substances:** From the tissues to the excretory organs for their discharge.

3) **Transport of Metabolic By-products:** Prom the area of production to other parts of the body.

4) **Transport of Hormones:** From the endocrine glands to the target organs.

5) **Distribution of Body Heat:** To maintain a uniform body temperature.

6) **Transport of Oxygen and Carbon dioxide:** Oxygen is transported from the lungs to all the parts of the body and carbon dioxide from the cells to the lungs for removal.

7) **Defense against Diseases:** By phagocytosis through neutrophils and monocytes, which engulf and digest the germs that enter the blood stream or by antibodies or antitoxins produced by lymphocytes.

8) **Protection against its Own Loss:** By clotting, making a clot over the injured part.

14.10.3 Leukaemia:

Leukaemia is a malignant disorder of the haemopoietic tissues, associated with increased number of leucocytes in the blood. They obstruct normal blood cell formation in the bone marrow. These are progressive and fatal conditions resulting in death, most often from haemorrhage or infection. The cause of leukaemia is unknown. Several factors however are associated with the development of leukaemia like ionising radiation, cytotoxic drugs, retroviruses, genetic etc.

14.10.4 Thalassaemia:

Thalassaemia is an inherited impairment of haemoglobin production. When the abnormality is heterozygous, the synthesis of haemoglobin is only mildly affected and little disability occur. Synthesis is grossly impaired when the person is homozygous.
Failure to synthesize beta chains (β - thalassaemia) is the most common type. Heterzygotes have thalassaemia minor with mild anaemia. Homozygotes

(thalassaemia major) are either unable to synthesize haemoglobin or produce very little and after 4 months of life, develop a profound hypochromic anaemia. It is more common in children. It results to the enlargement of the kidney. The regular blood transfusion is the only remedy.

14.11 HUMAN HEART

The human heart is the most powerful organ in the circulatory system. It works continuously like a muscular pump and keeps the blood in circulation. The heart lies in the thoracic cavity between the lungs slightly towards left, enclosed with in the rib cage with the sternum in front and vertebral column behind. It is surrounded by a double layered **pericardium**. A **pericardialfluid** is secreted in between the two. It functions as a lubricant and reduces friction between the heart walls and surrounding tissue during the beating of heart.

14.11.1 Structure:

The heart is conical in shape. It is reddish in colour and consists of four chambers. Two upper, thin walled atria and two lower, thick walled ventricles. Two large veins, superior and inferior vena cava enter the right atrium and two pairs of pulmonary veins open into the left atrium. Similarly, two large arteries emerge out, one from the right ventricle pulmonary aorta and the other from the left ventricle, systemic aorta.

Internally, the right and left atria are separated by a vertical membranous **inter-atrial septum**. The right atrium opens into the right ventricle by an aperture guarded by a **tricuspid value**. The left atrium opens into the left ventricle by the aperture guarded by a **bicuspid valve** (Mitral Valve). Semilunar valves guard the emergence of the pulmonary and systemic aorta. These valves prevent backward flowofblood and allow it to move in forward direction.

The right and left ventricles are also separated by a thick muscular **inter-ventricular septum**. The inner walls of the ventricles have **papillary muscles** for the attachment of delicate fibres **chordae tendinae** which are attached to the cusps of the valves. These fibres do not let the valves open back into the atria when the ventricles contract.

The cavity of the left ventricle is narrower than the right ventricle because of more muscular walls. It is due to the fact that the right ventricle has to pump blood into the lungs only (pulmonary circulation) while the left ventricle pumps blood to the entire body (Systemic circulation).

14.11.2 Cardiac Cycle:

Heart muscles contract rhythmically without external stimulation. They are **myogenic.** Their rhythmical contractions arise from within the muscle tissue itself. Following one contraction, the next will not start till the whole has relaxed. There is a short pause between two contractions. This property enables proper timings of the heart beats.

The sequence of events which take place during the completion of one heart beat is called cardiac cycle. The resting period of the heart chambers is known as **diastole** and the period during which they contract is known as **systole**. The right atrium in its diastolic phase, receives deoxygenated blood from the vena cava and the left atrium receives oxygenated blood from the lungs. These chambers become distended and extend a pressure on the atrio-ventricular valves, by which they are pushed open. When the atrial diastole ends, the two atria contract simultaneously. This event is known as **atrial-systole** and the blood contained with in the atria is pumped into the respective ventricles. Immediately, the ventricles contract. This event is termed as **ventricular systole** during which atrio-ventricular valves are closed and the aortic, pulmonary valves are opened. The blood is pumped into the respective aortae. The volume of blood pumped per minute by the left ventricle into the systemic circuit is called **cardiac output.**

14.11.3 Heart Beats:

The contractions of the heart chambers are known as heart beats which are rhythmically and regular. A human normal heart beats 72 times per minute at rest. These beats are audible and are known as heart sounds.

During the ventricular systole blood is forced against the closed **AV-valves.** This produces the first heart sound LUB. Ventricular systole is followed by ventricular diastole. The high pressure developed in the aortae, tends to force some blood back towards the ventricles which closes the aortae valves. This impact of the back flow against the valves causes the second heart sound DUP.

Thus ventricular systole is LUB and the ventricular diastole is DUP. One complete heart beat consists of one systole and one diastole and lasts for about 0.8 second. A defect in one or more of the valves causes a condition known as **heart murmur**, which may be detectable as a **hissing sound**.

Heart starts beating before the birth and never stops till death.

14.11.4 S-ANode:

The stimulus for contraction of the heart originates in a specific region of the right atrium called **sino-atrial node** (S-A Node) close to the point of entry of the superior vena cava. It is a vestige of sinus venosus. It consists of cardiac musclefibres, possessing few myofibrils and a few nerve endings of autonomic nervous system.

14.11.5 Pace Maker:

The S-A node initiates the heart beat. Thus the S-A node is known as pace maker because each wave of excitation for the contraction of atria begins here, and acts as the stimulus for the next wave of excitation.

14.11.6 A-V Node:

The tissues of the A-V node are similar to those of the S-A node. It is located in the right atrium below S-A-Node. They are stimulated by the wave of excitement send by the S-A node. It's excitation travels all parts of the ventricles, through two bundles of specialized muscle fibres of the bundle of His in the ventricular septum and thence into the walls of the ventricle; through a net-work of fibres called **purkinjefibres,** consequently the two ventricles contract. There is a delay of about 0 15 seconds in conduction from the S-A node to A-V node permitting atrial systole to be completed before ventricular systole begins.

14.11.7 Artificial Pace Maker:

It is a device that supplies electrical impulses to the heart to maintain the heartbeat at aregular rate. It consists of a small electronic device and power source connected to heart via an electrical wire. It is implanted beneath the skin in the chest when a person's SAN is not functioning properly or when there is some impairment to the passage of the normal electrical impulses.

Blue Babies:

It is a lay man terminology. In medical science it is known as **cyanosis** (Cyano-blue, Sis-process).

Cyanosis is a blueish discolouration of the skin and mucous membrane due to excessive concentration of reduced haemoglobin in the blood. The most common pause of cyanosis is cyanotic heart disease.

In cyanotic congenital heart disease, there is abnormal connection between right and left side of heart which leads to mixing of oxygenated and deoxygenated blood. This abnormal connection may be due to several reasons, but the commonest causes are the atrial septum defect (ASD), ventricular septum defect (VSD) and persistant ductus arteriosus.

14.12 BLOOD VESSELS

The closed vessels through which transporting medium (blood) circulates within the body are known as blood vessels. They are of two types, arteries and veins. The arteries carry blood away from the heart and the veins towards the heart.

14.12.1 Arteries:

Arteries are thick walled vessels consisting of three layers. The outer **tunica externa** composed of fibrous connective tissue having collagen fibres. The middle layer **tunica media** has smooth muscles and elastic fibres. The inner **tunica interna** (intima) consists of squamous endothelium. The arteries are elastic and dilate during ventricle systole but do not get ruptured. When systole ceases, the arteries contract and promote an even flow of blood along their length. They are pulsatile and maintain the blood pressure. Their lumen is small and does not contain semilunar valves. Blood flows rapidly with jerks in pulsations indicating the ventricular systole. The smaller arteries are known as arterioles. They contain sphincters at their capillary ends which regulate the flow of blood into the capillaries. When the sphincters contract, blood is prevented from flowing through the capillary network, or the contraction of smooth muscle layer in the wall of the arteriole constricts the arteriole decreasing blood flow through it to a capillary bed. The arteries carry oxygenated blood except the pulmonary arteries which carry deoxygenated blood into the lungs for oxygenation. The arteries are deep seated and do not collapse when empty.

14.12.2 Veins:

Veins are thin walled blood vessels. They are also composed of the same three layers as that of arteries, but possess less muscles and less elastic fibres. Their lumen is large. Semilunar valves are present which prevent the back flow of blood. The pressure of blood flowing through them is low and are non-pulsatile. The blood flows slowly and smoothly. The veins carry deoxygenated blood except the pulmonary reins which transport oxygenated blood from the lungs to the heart. The veins are super-ficial and collapse when empty.

14.12.3 Capillaries:

The intimate relationship between the circulatory system and the tissues is achieved by, at the level of capillaries in the form of capillary network. The capillaries are extremely narrow (7-10 μ in diameter), thin walled microscopic vessels. Their walls consist of a single layer of endothelium, which presents very little resistance to the diffusion of dissolved substances in or out. The cells of the tissues are bathed in tissue fluid which provides a medium through which diffusion of materials can take place. The close approximity between the capillaries and the tissue cells facilitates the exchange of materials. It is only here that exchange by **diffusion** or **active transport** can occur. The oxygen carried by the blood is diffused out into the oxygen deficient tissue and the carbon dioxide of the tissue cells is diffused in simultaneously. The nitrogenous waste is**filtered** through the capillaries into the excretory tubules for discharge.

14.12.4 Blood Pressure:

Blood pressure is the hydrostatic force exerted by the blood against unit area of the vessel wall. It is measured in millimetres of mercury (mm Hg). Mercury manometers are being used for measuring the blood pressure which are known as **sphygmomanometer**. Blood pressure is determined partly by cardiac output and partly by the diameter of the arterioles. When wall of the arterioles are constricted (vasoconstriction), the blood pressure rises: when they axe dilated (vasodilation), the blood pressure falls. The constriction and the dilation of

arterioles are due to the constriction and relaxation of the smooth muscles of the arterioles, respectively. These muscles are largely under the control of nerve Impulses, and hormones.
Blood in the arteries of the average adult exerts a pressure equal to a column of mercury about 120 mm high in the glass tube during systole of the ventricles and 80 mm during diastole. This is expressed as a B.P of 120/80. The difference between systolic and diastolic pressure is called **pulse pressure**.

14.12.5 Blood Flow:

Blood flows through the vessels at an uneven speed. It flows much faster in large arteries and much slower in capillaries. Although an individual capillary is much narrower, but the capillary beds have an enormous number ofsuch capillaries, So that the total diameter of these vessels is much greater than the arteries. For this reason the blood flows slowly in the capillaries, permitting the exchange of materials between the blood and interstitial fluid. As blood leaves the capillary bed and passes to the venules and veins, it speeds up again due to the reduction in total cross sectional area.

14.13 LYMPHATIC SYSTEM

A system of blind vessels (lymphatics) that drains lymph from all over the body back into the blood stream is called lymphatic system. In addition to lymphatics and lymph it consists of lymph nodes, spleen, thymus, tonsils and some of the patches of tissues in vermiform appendix and small intestine.

14.13.1 Lymph vessels, Lymph and Lymph nodes:

The lymph vascular system starts at capillary bed, where tissue fluid (interstitial fluid surrounding the cells of the tissues) enters the **lymph capillaries,** which are closed towards the tissue sinuses. These are thin walled anastomosing microscopic vessels, which form a network in every organ except the nervous system. The lymph capillaries merge into **lymph vessels** which have a larger diameter. These vessels contain smooth muscles in their walls as well as internal valves to prevent backward flow of lymph. The lymph circulates through the lymph vessels by the contraction of surrounding skeletal muscles in one direction, towards the heart. These vessels converge into collecting ducts that drain into veins in the lower neck.
All body tissues are bathed in a watery fluid derived from the blood stream. This intercellular or tissue fluid is formed when blood passes through the capillaries. The capillary walls are permeable to all components of blood except the R.B.Cs and blood proteins. The fluid passes from the capillary into the intercellular spaces as the inter-cellular or tissue fluid. About 85% fluid returns into the blood at the venous end of the capillary. The rest 15% of the tissue fluid drains into blindly ending lymphatic capillaries as lymph along with W.B.Cs, cell debris and micro-organisms like bacteria, are transported back to the heart through lymphatic system. Thus **lymph** can be defined as a colourless body fluid, that contains lymphocytes (agranular W.B.Cs). small proteins and fats. Lymph takes fluid substances from cells of tissues and Intercellular spaces, which cannot penetrate the blood capillaries. It is a medium of exchange between blood and body cells.
Through-out the course of lymphatics lie **lymph nodes**, through which lymph flows. Lymph nodes vary considerably in size from microscopic to about one inch in diameter. Each node consists of a thin, fibrous, outer capsule and an inner mass of lymphoid tissue. Penetrating the capsule are several small, lymphatic vessels which carry lymph into the lymph node, while a single large vessel carries it out. The lymphoid tissue contains antibodies, lymphocytes and macrophages. These nodes act as filters that trap microorganisms and other foreign bodies in the lymph. The lymphocytes and macrophages present here, neutralize and engulf the microorganisms, respectively.

14.13.2 Functions of Lymphatic system:

Drainage system: Lymphatic vessels act as drainage channels for water and plasma proteins that have leaked away from blood at capillary bed and that must be delivered back to blood circulation, without which death can occur in 24 hours.

Defense of the body: Microorganisms, foreign cells, cellular debris in the lymph are removed by macrophages residing in the lymph nodes. These are also the site for differentiation of the B cells into antibody secreting cells.

Absorption and delivery of fats: Lymph capillaries called lacteals penetrate the villi of the small intestine where fats are absorbed and delivered to the blood circulatory system.

14.13.3 Edema:

Whenever, the tissue fluid accumulates, rather than being drained into the blood by the lymphatic system, tissues and body cavities become swollen. This condition is known as edema. Any factor that increases the tissue fluid pressure high enough than normal value can cause excess tissue fluid volume causing edema like high blood pressure, kidney failure, heart failure etc.

Causes of Edema:

One of the common cause of edema is severe dietary protein deficiency. When starved for amino acids, the body consumes its own blood proteins. This reduces the osmotic potential of the blood causing tissue fluid to accumulate in body tissues rather than being drawn back into the capillaries, resulting in edema.
Another cause of edema is lymphatic obstruction which results in more and more protein collection in the local tissue fluid, hence, the increased volume. The commonest cause of lymphatic obstruction is **filariasis** (infection by nematodes). Sometimes increased permeability of the capillaries due to burns or allergic reactions causes edema.

14.14 CARDIOVASCULAR DISORDERS (CVD)

Diseases of heart, blood vessels and blood circulation are generally termed as cardiovascular disorders. Some important CVD are discussed as follows:

14.4.1Atherosclerosis:

It is a disease of the arterial wall (intima) which loses its elasticity. Gradually its inner layer thickens causing narrowing of the artery and consequently impairing the blood flow. The narrowing is due to the formation of fatty lesions called **atheromatous plaques** (raised patches) in the inner lining of the arteries. These plaques consist of low density lipoproteins or LDL (cholesterol and proteins), decaying muscle cells, fibrous tissue, clumps of blood platelets and some times calcium.
The arteries become extremely hard and the disease is called arteriosclerosis or simply hardening of the arteries.

Causes: The possible causes of atherosclerosis are smoking, hypertension, male gender, obesity, physical inactivity, a high serum cholesterol level, severe diabetes, family history of arterial disease and possibly an anxious or aggressive personality. The risk of atherosclerosis increases with age.

Effects: Unfortunately atherosclerosis produces no symptoms until the damage to the arteries is severe enough to restrict blood flow. Restriction of the blood flow to the heart muscles due to atherosclerosis can cause angina pectoris (pain in the chest and arms or jaws usually during exercise or stress).

14.14.2 Hypertension:

When the mean arterial pressure is greater than the upper range, accepted normality, the person is said to be hypertensive having hypertension. Usually a mean arterial pressure of greater than 110 mm Hg under resting conditions is considered to be hypertensive. This level normally occurs when the diastolic blood pressure is greater than 90 mm Hg and the systolic pressure greater than 135—140 mm Hg.

Hypertension is called as "Silent Killer", because the affected individuals may show no outward symptoms until a stroke or heart attack occurs. It promotes atherosclerosis. As a prolonged consequence the heart may enlarge and fail to pump the blood effectively. Several factors such as heredity, higher intake of salts in diet, smoking, obesity and disorders of kidney or adrenal gland are responsible for hypertension.

14.14.3 Thrombus formation:

The formation of blood clot (thrombus) within an intact blood vessel is initiated by atherosclerotic plaques. The plaques when destroy the endothelium of the blood vessel, platelets gather at the damaged site to initiate the process of clot. As the growth of the plaque and clot progresses, the lumen of the artery narrows or completely blocks. Ultimately, the blood supply to the concerned organ is either reduced or prevented. Thus due to the lack of oxygen and nutrient, the function of the target organ is impaired. Thrombus of the coronary artery or carotid artery may cause the death of the victim due to heart attack (myocardial infarction) and stroke.

If a clot dislodges and travels in the blood stream, it is termed as embolus. It can obstruct any small artery such as coronary artery, the out come may ranges from angina to heart attack.

14.14.4 Coronary Thrombosis:

Narrowing or blockage of one of the coronary arteries (which supply blood to the heart muscle) by a thrombus is called coronary thrombosis. This causes a section of the heart muscles to die because it has been deprived of oxygen. It is one of the main processes involved in coronary heart disease. Sudden blockage of a coronary artery can cause acute myocardial infarction.

14.14.5 Myocardial infarction—Heart attack:

It refers to the death of the part of heart muscles characterized in most cases by severe continuous chest pain. This is commonly, known as heart attack. Due to the blockage of any of the coronary artery either by thrombus or embolus, the blood supply to some cardiac muscles stops. The area of heart muscle which has zero or little flow of blood that it cannot sustain cardiac muscle function is said to be infarcted and the process is called myocardial infarction. As a consequence the affected cardiac muscles die due to lack of nutrients and oxygen. If the damaged area is small, the victim may recover from the heart attack but death of the large area of cardiac muscles is fatal.

14.14.6 Stroke and Prevention:

Stroke implies to damage to part of the brain caused by interruption to its blood supply (either by a thrombus or embolus) or leakage of blood outside of vessel walls. It is characterized by the impairment of the sensation, movement, or function controlled by damaged part of the brain. Damage to any one cerebral hemisphere can cause weakness or paralysis of one side of the body called **hemiplegia**. Hypertension and atherosclerosis are among the most common causes.

The stroke can be prevented by keeping the blood pressure at normal range, through a proper diet. Salts should be used in less quantities as they increase blood pressure. Fats should also be reduced especially those which are rich in cholesterol. They cause thrombus formation resulting in atherosclerosis of the arteries particularly the coronary arteries. Exercise should be made a regular habit of life. At least 30 minutes brisk walk per day. Smoking should be avoided. Tension is the major cause of hypertension. The life should be made easy and free of extra worries.

Haemorrhage: The haemorrhage is defined as the escape of blood from the vessels. Small haemorrhages are classified according to their size. The massive accumulation of blood within a tissue is called **haematoma.**

The haemorrhage may occur any where in the body. But the most dangerous is the brain haemorrhage causing stroke.

14.15 THE IMMUNE SYSTEM

Immunity:
Animal body is always exposed to the invasion of countless infectious microorganisms such as virus, bacteria, etc. However, due to the defense mechanisms evolved by the animals, such invasions in number of cases, are overcome. The ability of the body to resist microorganisms, their toxins if any, foreign cells, and abnormal cells of the body is termed as **immunity.**

Immune System:
Immunity is conferred, to animals through the activities of the **immune system** which combats infectious agents. The study of the functioning and disorders of the immune system is termed as **immunology.**
Immune system is a collection of cells and proteins that work to protect the body from potentially harmful, infectious microorganisms. It also plays role in the control of cancer, allergy, hypersensitivity, and rejection problems when organs or tissues are transplanted.
The immune system can be divided into two functional divisions:

(1) Innate immune system, and (2) Adaptive immune system.

14.15.1 Innate Immune System:
It is responsible for innate or natural immunity which is **non-specific** in nature since it combats all microorganisms. It consists of physical (e.g. skin, mucous membranes) and chemical (e.g. lysozyme, gastric juice, etc.) barriers against infectious micro-organisms.
Skin and mucous membrane with their secretions act as **first line of defense**. The intact skin provides an impenetrable barrier to the vast majority of infectious agents, most of which can enter only through the mucus membranes that lines the digestive, respiratory, and urino-genital tracts. However, these areas are protected by the movement of mucus and secretions (e.g. lysozyme in tears) to destroy many microbes. Most of the micro-organisms present in food or trapped in swallowed mucus from the upper respiratory tract arc destroyed by the highly acidic gastric juice of the stomach.
If some how micro-organisms are able to penetrate the outer layer of the skin, or mucous membrane, they encounter a **second line of defense** offered by the innate immune system. It is also non-specific in nature and comprises of phagocytes, antimicrobial proteins, and inflammatory response.
Phagocytes are certain type of W.B.C. which can ingest, internalize and destroy the particles including infectious agents. The short-lived phagocytic cells called **neutrophils** (polymorphonuclear neutrophils) ingest bacteria very actively. The

other phagocytic cell, the **monocyte** can develop into large, long-lived **macrophage** (big-eaters) when they reside in various tissues of the body. Macrophages not only, destroy individual microorganisms but also play a crucial role in the further immune response by "presenting" parts of the that micro-organisms to other cells of the immune system. For this reason they are termed as **antigen presenting cells.**

Another group of W.B.C, the **natural killer cells (NK cells)** destroy virally infected own cells of the body. They also attack abnormal cells (cancerous cells). NK cells do not phagocytize the target cells. Instead, they bind to their target cell, release some pore forming proteins into the target cell which eventually cause lysis of the target cell. This kind of destroying the target cells is called **cytotoxicity.**

Among **antimicrobial proteins**, important are lysozyme, compliment proteins and interferons. Lysozyme is an enzyme present in tears, saliva and mucus secretion. It causes the lysis of bacteria. **Complement proteins** work in innate as well as adaptive immune systems. They directly cause lysis of bacteria, serve as chemoattrants for macrophages, and promote phagocytosis ofbacteria. **Interferons** are secreted by virally infected cells or some lymphocytes to induce a state of antiviral resistance in uninfected tissues of the body.

Inflammation (to set on fire) is the body's reaction to an injury or by the entry of microorganisms. Acascade of chemical reactions takes place during inflammatory response. It is characterized by redness, heat, swelling and pain in the injured tissue. When injured, basophils and mast cells release a substance called histamine which causes increase in the permeability of the adjacent capillaries, local vasodilation, and also make capillaries leakier. Due to chemotaxis, phagocytes and macrophages are attracted at the injured site. Thus phagocytes literally eat up microorganisms, dirt, cell debris, etc. forming pus.

In case of warmblooded animals, a number of micro-organism which escape away from the inflammatory response to infect some large part of the body, trigger **fever.** It is usually caused by certain W.B.Cs. that release substance called pyrogen. It sets the temperature of the body higher than the normal. Very high fever is dangerous but moderate fever contributes to the defense of the body. It inhibits the growth of some micro-organism, facilitates phagocytosis, increases the production of interferon, and may speed up repair of the damaged tissue.

14.15.2 Adaptive Immune System:

The adaptive immune system is extremely complex. It produces **specific immune response** against a range of different invading organisms, toxins, transplanted tissues and tumor cells. This is the **third line of defense** which comes into play simultaneously with the second line of non-specific defense.

The responses of the adaptive immune system are provided chiefly by two types of lymphocytes called **B cells** and **T cells**. Depending upon their migration and maturity during the early development in either bone marrow or thymus, they are designated as B and T cells, respectively. Although, B cells and T cells play quite different roles in the immune system, yet they share the basic key features of the immune response.

In order to develop a specific immune response, the immune system must recognize the invading organisms and/or foreign proteins from its self tissues and proteins. A foreign substance that elicits immune response is called **antigen**. The immune system responds to an antigen by activating lymphocytes and producing specific, soluble proteins called **antibodies**. The antibody combines with the antigen and helps to eliminate it from the body. The immune system of a vertebrate has virtually unlimited capacity to generate different antibodies which recognize and bind millions of potential antigens or foreign molecules.

The immune system has also the ability to memorize antigens it has encountered. Thus upon subsequent exposure to the same pathogen, it responds very quickly and effectively.

The adaptive immune system mounts two types of attacks, termed as humoral immunity and cell-mediated immunity (CMI), on invading micro-organism.

i) Humoral Immunity:

Immunity provided by the antibodies secreted in the circulatory system by B cells is termed as humoral immunity. This is particularly helpful in bacterial invasion. It has been determined experimentally that each B cell has specific type of antibodies on its cell surface. This antibody serves as **antigenic receptor**. When an infection occurs, the antibodies borne by a few B cells will bind to antigens on the surface of the micro-organism. Antigen-antibody complex binding causes such B cells to divide rapidly to give rise enlarged, effector cells called **plasma cells** whichsecrete antibodies into the circulation that help eliminate that particular antigen. Some of the effector cells do not secrete antibody, they become **memory cells**. The memory cells play important role in future immunity to this specific organism in case of re-infection. When circulating antibodies bind to antigens, the micro-organism bearing such antigens are easily phagocytized, or lysed by the complement proteins (just like the NK cells do). Moreover, antibodies neutralize the toxins released by bacteria, and also cause agglutination of the microorganisms.

ii) Cell Mediated Immunity (CMI):

Cell mediated immunity is contributed by the second family of lymphocytes called T cells, which do not secrete antibodies. They mediate immunity by killing infected cells, and aiding in inflammation. This is particularly important in the defense against virus as well as some parasites that hide within the host cells, tumor cells and fungi. Several types of T cells contribute to cell mediated immunity: Helper T cells (T_H), Cytotoxic T cells (T_C), and Suppressor T cells (T_S).
LikeBcells, helperTcells and cytotoxic T cells have antigenic receptors, called **T cell receptors (TCRs)** on their plasma membrane. HelperTcells receptors actually recognize a combination of antigen fragment and one of the body's own self marker called **"Major Histo-compatibility Complex (MHC) Class II"** molecules on the surface of macrophage or B cells.
On the other hand, the receptors on the surface of cytotoxic T cells recognize a combination of antigenic fragment and self surface maker molecules called **MHC Class I,** which are found on every nucleated cells of its own body.
After the infection is conquered, another group of T cells called **suppressor T cells** seems to shut off the immune response in both B cells and cytotoxic T cells.
During CMI response, some T cells turn into **memory T cells** to protect the body in case of re-infection in future.

14.15.3 Cytokines (lymphokines):

Cytokines, or the hormones of the immune system are protein molecules secreted by the cells of the immune system to regulate the immune responses. Various cytokines including a range of interleukins (IL), interferons, etc. have been recognized and their roles have been studied.
Interferons belonging to the group of cytokines are a group of proteins produced naturally by body cells in response to viral infections and other stimuli. They inhibit viral multiplication and increase the activity of the natural killer cells.

14.15.4 Primary and Secondary immune responses:

The first exposure of an antigen to the immune system elicits formation of clones effector cells to develop specific immunity. This response of the immune system is termed as primary response. Beginning from the infection to the development of maximum effector cells takes about 5 to 10 days.
Indeed, there is always risk of re-infection with the same pathogen. In such case, the immune response is always quicker than the first one. This is known as secondary immune response. It develops to its maximum within 3 to 5 days. This

quicker response is made possible due to the ability, called **immunological memory**, of the immune system. It is based upon the long lasting memory cells produced with the short lived effector cells of the primary immune response. The development of memory cells may provide life long protection against some diseases like chicken pox.

15.15.5 Active and Passive Tin inanity

i) Active Immunity:
Immunity acquired by own immune response is called active immunity. If it is a consequence of natural infection, it is said to be **Natural Active Immunity**. Active immunity can be acquired artificially by vaccination. In this case it is said to be **Artificial Active Immunity**. The concept of vaccination is already familiar to you as it was introduced in Bacteria (chapter 6). Active immunity, due to the development of immunological memory provides long term protection, even in some case (e.g. in chicken pox) life long protection is provided.

ii) Passive Immunity:
It depends upon the antibodies transported from another person or even an animal. It could be **Natural Passive Immunity,** if antibodies transferred to one person were derived from another of the same species. For example, a pregnant woman passes some of her antibodies to her fetus through placenta. Also, the first breast feeding, the colostrums, of mother pass certain antibodies to her newly born infant. Such immunity is short lived and provides temporary protection.
Passive immunity can also be transferred artificially by introducing antibodies derived from animals or human being who are already immune to that disease. This is termed as **Artificial Passive Immunity**. For example, rabies is treated in man by injecting antibodies derived from persons who have been already vaccinated against rabies. This confers rapid immunity to combat the rapidly progressing rabies in the new victim. Although acquired passive immunity is short lived, it boosts the immune response of the victim several folds.

Immunization:
Immunization is the process of inducing immunity as a preventive measure against certain infectious diseases. The incidence of a number of diseases (e.g. diphtheria, measels, etc.) has declined dramatically since the introduction of effective immunization programmes. Once thought to be the dreadful diseases like tuberculosis, etc. is now under control through immunization and treatment.

KEY POINTS

- Each living organism obtains necessary raw materials, to synthesize molecules for metabolism. These materials are transported within the living organism or from environment to living organism.
- Soil is the source of water and minerals for plants, various processes likes diffusion, facilitated diffusion, osmosis, imbibition and active transport help in the absorption of H_2O and minerals from soil.
- Water is important in the life of plants because it makes up the matrix and medium in which biochemical processes essential for life occur.
- Water potential is a quantitative expression of the freeenergy associated with the water.

- Osmotic pressure is the pressure that must be exerted on a solution to prevent the passage of solvent molecules into when the solvent and solution are separated by differentially permeable membrane.
- Plasmolysis is the withdrawn of protoplasm from cell-wall due to exosmosis and the finish of plasmolysed condition due to endosmosis is called deplasmolysis.
- Symplastic pathway is the transport of water and solutes through plasmodesmata.
- Apoplastic pathway is the transport of water and solutes through extra-cellular pathway.
- Upward movement of water from root to leaves against the downward pull of gravity is known as ascent of sap. The movement takes place through xylem.
- Root pressure was thought to be responsible for ascent of sap as well as guttation.
- Transpiration pull and-cohesion forces are responsible for ascent of sap.
- Loss of water in the form of vapours through aerial parts of plant is known as transpiration, it takes place through stomata, cuticle or lenticle.
- Light, temperature, wind, humidity and soil water are some factor which affect the rate of transpiration.
- Photosynthate move from source to sink, this movement of organic solutes called translocation, takes place through phloem, therefore, also called phloem translocation.
- In small animals the transport of materials can take place by **diffusion.** However larger animals generally require special transport system.
- The circulatory system is of two types; **open circulatory system** and **closed circulatory system.**
- Arthropods, molluscs and tunicates have open circulatory system in which the blood flows within the body cavities and bathes the tissue.
- Annelids, echinoderms, cephalopods and vertebrates have closed type circulatory system in which the blood circulates within the closed blood vessels and the exchange of materials takes place through capillaries.
- A circulatory system in which the blood flows only once through the heart for every complete circuit of the body is called a **single circuit plan** or **simple single circulation.**
- A **double circulation** is one in which the blood flows through the heart twice for every complete circuit of the body.
- **Leukaemia** and **thalassaemia** are two disorders of blood.
- **Cyanosis** (blue babies) is caused by cyanotic heart disease.
- **Edema** is the swelling of the body by the accumulation of lymph.
- **Immunity** is conferred to animals through the activities of the **immune system.**
- **Primary immune response** is against the first exposure of an antigen to the immune system, forming clones of effector cells.
- **Secondary immune response** is against the second infection by the same pathogen which is much quicker than the first one.
- Immunization is the process of inducing immunity as a preventing measure against certain infectious diseases.

EXERCISE

1. Encircle the correct choice:

(i) Which of the following is NOT involved in the cohesion tension theory ofwater movement in plants.
(a) Presence of hydrogen bonds holding water molecules together.
(b) Attraction of H_2O molecule to the walls of xylem.
(c) Diffusion of H_2O from ceils in the root to the cells in the shoot.
(d) Transpiration.

(ii) In the morning when the sunrises, plants open their stomata by:
(a) Pumping H_2O out of the guard cells.
(b) Pumping H_2O into the guard cell.
(c) Pump K^+ ion into the guard cells.
(d) Pump K^+ out of the guard cells.

(iii) Excess water is forced out in the form of droplets through:
(a) Stomata (b) Cuticle
(c) Hydathodes (d) Lenticles

(iv) The point when cytoplasm just starts diffusion to biperant from cell wall is:
(a) Plasmolysis (b) Incipient plasmolysis
(c) Deplasmolysis(d) All of them

(v) Active transport of sucrose into sieve element is a step commonly called:
(a) Phloem loading (b) Unloading
(c) Diffusion (d) Osmosis

(vi) In closed circulatory system blood is completely enclosed within:
(a) Skeleton (b) Sinuses
(c) Vessels (d) Hearts

(vii) The blood corpuscles in earthworm are:
(a) Colourless (b) Yellow
(c) Red (d) Orange

(viii) The body cavity in grasshopper is known as:
(a) Schizocoele (b) Pseudocoele
(c) Haemocoele (d) None of the three

(ix) Blood vessels carrying oxygenated blood from lungs to heart is:
(a) Pulmonary vein (b) Pulmonary arteries
(c) Coronary artery (d) Coronary vein.

(x) Which of the following has no muscular walls?
(a) Artery (b) Vein
(c) Capillary (d) Vena cava

(xi) Living part of blood is:
(a) Plasma (b) Lymph
(c) Serum (d) Corpuscles

2. Write detailed answers of the following questions:

(i) How does the pressure flow theory explain the movement of sugar through the plant?

(ii) Describe the cohesion - tension theory of water movement through xylem? What supplies the cohesion and what is the source of tension? How do these two interact to move water through a plant?
(iii) Describe the structure of human heart and explain the cardiac cycle.
(iv) What is lymphatic system? What functions it performs?
(v) What are cardio-vascular disorders? Give a brief description of each.
(vi) What is immune system? Describe the innate immune system and adaptive immune system.
(vii) What is immunity? What are active and passive immunity? Describe humoral and cell mediated immunity.
(viii) Describe the structure of blood and its function

3. Write short answers of the following questions:

(i) Why the circulatory system of grasshopper is called open type?
(ii) Why we say that, amphibians and reptiles have incomplete double circulation?
(iii) Why white blood corpuscles are known as soldiers of the body?
(iv) Why the capillaries have a single layer of endothelium?
(v) What are LUB and DUP?