TRANSPORT

Contents

TRANSPORT IN LIVING ORGANISMS

Syllabus extract

Specific objectives: The learner should be able to:	**Content**
Necessary for transport systems • Explain the limitation of simple diffusion in the transport process.	• Limitations of simple diffusion process: concept of surface area: volume ratio and its effect on diffusion rate.
Water as a medium in plants and animals • Explain the significance of water in transport.	• Significance of water in transport: solvent medium of transport
Circulatory systems in animals • Describe the circulatory systems in insects, annelids and mammals. • Compare the structure and function of veins arteries and capillaries. • Describe types of circulatory system • Explain the advantages and disadvantages of open and closed systems in animals. • Compare the circulatory systems of fish and mammals. • Describe the functioning of the mammalian heart. • Explain the response of the heart to body activities. • Interpret information on the effects of drugs and variation of temperature on the cardiac frequency. • Explain how the heart beat rate is controlled. • Relate the action of adrenalin and acetylcholine to the innervations of the hear • Describe the role of blood components in the transport process. • Explain the diseases related to the circulatory system.	• Circulatory systems in insects, annelids and mammals. • Types of circulatory systems: open and closed, single and double. • Advantages and disadvantages of open and closed systems in animals. • Structure of transport systems in fish and mammals. • Functioning of the mammalian heart: cardiac cycle blood pressure changes, myogenic, myogenic property , control of the heartbeat. • Response of heart to body activities • Effects of drugs and temperature variations on the cardiac frequency. • Action of adrenalin and acetylcholine on the innervation of the heart. • Blood constituents and functions. • Common diseases of the blood and heart, including sickle cell anaemia and coronary artery diseases. • Control of heart beat rate.

Circulatory systems in animals practical • Identify structural features of blood vessels. • Display and draw major structures of the circulatory systems in insects, toads and mammals. • Describe the insects, toad and mammals circulatory system in relation to their functions.	• Structure of blood vessels (veins, arteries capillaries). • Circulatory systems in insects, toads and mammals gross structure and fine structure. • Insect, toads and mammals circulatory systems in relation to functions.
	• Structural adaptation of cardiac muscle and smooth muscle of the circulatory system of mammals .
Defence against diseases • Describe the mechanism of blood clotting. • Describe immune responses in humans. • State the role of the thymus gland in immunity. • Explain the immune responses during blood transfusion. • Describe the effects of the Rhesus factor	• Mechanism of blood clotting • Immune response in humans: definition, primary secondary). • The role of the thymus gland in immunity. • Blood transfusion and blood groups. • Effect of the Rhesus factor during pregnancy.
Vascular system of flowering plants • Describe the structural and functional adoption of the vascular tissues to transport process of materials in monocotyledonous and dicotyledonous plants. • Explain the mechanism of transporting materials in plants. • Describe the evidence for the path of materials in plants. • Describe translocation and uptake of water and mineral salts in plants • Explain the role of transpiration in transport of water and dissolve mineral salts in plants.	• Structure and functional adaptation of vascular tissue in monocotyledonous and dicotyledonous plants. • Mechanism of transporting materials in plants. • Evidence for the path of materials in plants. • Uptake of water and mineral salts in plants. • Role of transpiration in transport of water and dissolved mineral salts in plants.
Vascular system of flowering plants. Practical • Identify types and the pattern of distribution of vascular bundles in the plant organs. • Stain and make temporary mounts of transverse section (T.S) and longitudinal section (L.S) of : stems, roots and T.S of leaves. • Draw and label low power plans to show distribution of issues in T.S and L.S of stems, roots and T.S of leaves. • Make high power labeled drawings of vascular tissues in T.S of leaves.	• Structure and distribution pattern of the vascular tissue in monocotyledon and dicotyledonous plants. • Transverse T.S and longitudinal sections L.S. of stems, roots and T.S of leaves of monocotyledonous and herbaceous dicotyledonous plants. • Labeled diagrams of T.S of stems, root and T.S of leaves.

Need for a transport system

Many materials including oxygen, carbon dioxide, soluble food substances, hormones, urea e.t.c. need to be transported from one point to another using a transport network and medium. The transport system in animals is mainly made up of blood vessels consisting of blood as the medium circulating through them to the various body tissues. The transport system is also made up of the pump i.e. the heart which brings about circulation of blood throughout the body, by pumping it. The transport system is also composed of the lymph vessels containing the lymph fluid.

The larger, compact and more active an organism is, the more the need for a transport system due to a small surface area to volume ratio which reduces the rate of diffusion of materials from the body surface to the cells in the middle of the organism. There are however some organisms which lack the transport system e.g. protozoa and platyhelminthes e.t.c. This is because, being small in size and being flattened in shape gives these animals a large surface area to volume ratio, this enables free and rapid diffusion of materials from one part of the body to another. Consequently large multi-cellular organisms have an elaborate transport system that carries useful substances such as oxygen and glucose to the cells and carries away the waste products of metabolism. An elaborate transport system has two major features;

a. An increased surface area of the sites of exchange of materials. Such sites include the lungs and the gills where oxygen is absorbed and the villi of the ileum where food nutrients are absorbed along the alimentary canal.

b. A system whereby the circulating medium carries the absorbed substances at a faster rate than diffusion. In some organisms with a blood circulating system, blood flow is not confined to blood vessels but instead it flows within a blood filled cavity called *Haemocoel* e.g. in arthropods and molluscs. In other organisms with the blood circulatory system, blood flow is confined to blood vessels only e.g. in vertebrates and some invertebrates such as the earth worm.

Importances of a blood circulatory system (functions of blood)

1. Tissue respiration. It enhances the formation of energy in the tissues by transporting oxygen and soluble food substances to the tissues to be used as raw materials for respiration. Carbon dioxide is also transported away from the tissues mainly in the form of bicarbonate ions (HCO_3^-) as a byproduct of respiration and then taken to the lungs for its removal from the body. Oxygen is transported in the form of oxyhaemoglobin from the respiratory surfaces to the tissues.
2. Hydration. Blood transports water from the gut to all tissues.
3. Nutrition. Blood transports the soluble well digested food materials from the gut to the body tissues.

4. Excretion. Blood transports metabolic waste products from the tissues to the excretory organs for their removal from the body e.g. blood transports urea from the liver to the kidney in order for it to be removed from the body.
5. Temperature regulation. Blood distributes heat from the organs where it is mainly generated e.g. the liver and the muscles, uniformly throughout the body.
6. Maintenance of constant pH. Blood maintains a constant pH through the maintenance of circulation of the plasma proteins manufactured by the liver which act as buffers to maintain the pH of the body fluids constant. This enables enzymes to function efficiently as charges will denature the enzyme.
7. Growth, development and co-ordination. Blood transport different metabolites such as glucose, amino acids and hormones needed for the growth and development of the body.
8. Defence. Blood defends the body against diseases through the following ways;
    - By using some white blood cells (leucocytes) which phagocytotically ingest and destroy pathogens that cause diseases.
    - By formation of a blood clot around the wound so as to prevent entry of microbes or pathogens into the body.
    - By use of the immune response mechanism towards infection e.g. by use of the different types of antibodies to destroy the microbes
    -

BLOOD

This is a highly specialized fluid tissue which consists of different types of cells suspended in a pale yellow fluid known as the blood plasma

Blood plasma

This is a pale yellow fluid component of blood composed of the plasma proteins and blood serum where the blood cells are suspended. Blood plasma carries the biggest percentage of blood and consists of a colourless fluid known as serum and also plasma proteins. It is in the blood serum that all the different soluble materials are dissolved e.g. urea, hormones, soluble food substances, bicarbonate ions e.t.c.

The plasma proteins are manufactured by the liver and include the following;

a. Fibrinogen. This protein is important for normal blood clotting by changing into fibrin in the presence of thrombin enzyme.

$$\text{Fibrinogen (soluble)} \longrightarrow \text{Fibrin (insoluble)}$$

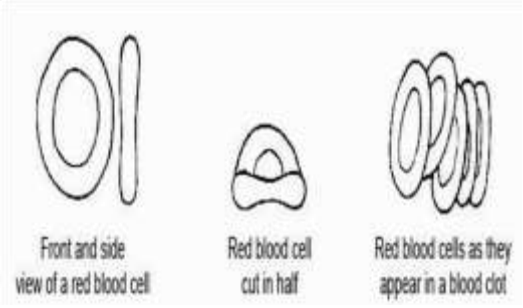
b. Prothrombin. This is the inactive form of the proteoltyic enzyme, thrombin, used in converting fibrinogen to fibrin during the clotting of blood.
c. Globulin. Both Prothrombin and globulin play important roles in the homeostasis. All the plasma proteins maintain pH of the body fluids constant by acting as buffers.
d. Blood cells. There are three main types of blood cells which include;

i. Erythrocytes (Red blood cells)
ii. Leucocytes (White blood cells)
iii. Platelets

ERYTHROCYTES (Red blood cells)

These are small numerous bi-concave disc shaped cells mainly important in transportation of oxygen as oxyhaemoglobin from the respiratory surfaces e.g. lungs and gives it to the tissues as well as transporting carbondioxide from tissues back to lungs. Erythrocytes are manufactured by the bone marrow in adult and by the liver in the foetus.

Diagram showing the shapes of erythrocytes



Note; Erythrocytes have a life span of 120 days.

Adaptations of erythrocytes

1. They have a red pigment called haemoglobin in their cytoplasm which has a high affinity for oxygen and therefore rapidly transports oxygen.
2. They have a thin and permeable membrane which enables faster diffusion of oxygen and carbon dioxide into them
3. They have a pliable membrane (flexible membrane) which can enable them change their original shape and squeeze themselves into the blood capillaries in order to allow the exchange of respiratory gases
4. They have an enzyme known as carbonic anhydrase within their cytoplasm which enables most of the carbon dioxide to be transported in form of bicarbonate ions (HCO_3^-), by catalyzing the reactions between carbon dioxide and water to from carbonic acid.

$$CO_2 + H_2O \xrightarrow{\text{Carbonic anhydrase}} H_2CO_3$$

5. They lack a nucleus so as to provide enough space for haemoglobin in order to carry a lot of oxygen in form of oxyhaemoglobin.
6. They have a bi-concave disc shape which provides a large surface area that enhances maximum diffusion of enough oxygen into them.

LEUCOCYTES (white blood cells)

They are amoeboid cells having a nucleus and a colourless cytoplasm important for defense of the body against infections. They are fewer than erythrocytes i.e. they are about 7000/m^3 of blood. They are mainly manufactured by the bone marrow. They are classified into two main types which include;

Granulocytes (polymorphonuclear leucocytes)

These are leucocytes with granules in there cytoplasm and a lobed nucleus. They originate in bone marrow. There are three types of granular leucocytes which include;

i. Basophils

(0.5%) ii.

Eosinophils (1.5%) iii.

Neutrophils (70%)

Basophils (0.5%) produce *heparin* and *histamine*. Heparin is an anti-coagulant which prevents blood clotting in blood vessels. Histamine is a substance that is released during allergic reactions e.g. hay fever. Histamine brings about allergic reactions by causing dilation (widening) and increased permeability of small blood vessels which results in such symptoms as itching,, localized swellings, sneezing, running nose, red eyes e.t.c.

Eosinophils (1.5%) possess anti-histamine properties and their number increases in people with allergic reactions such as high fever, asthma e.t.c. so as to combat the effects of histamine.

Neutrophils (phagocytes) (70%) engulf pathogens phagocytotically and digest them actively inside to defend the body against diseases.

Agranulocytes (mononuclear leucocytes)

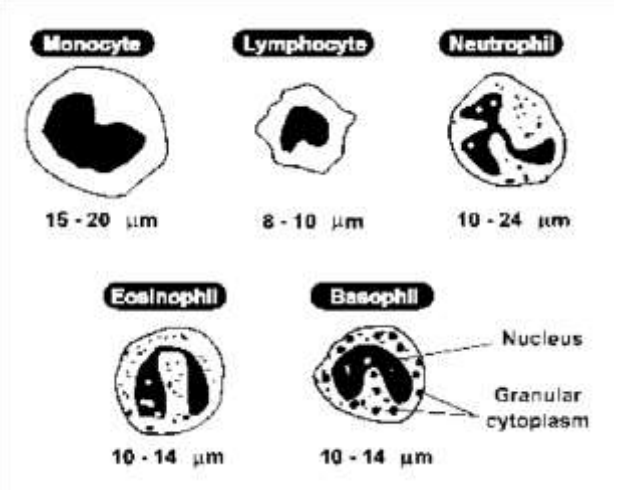
These are leucocytes with no granules in there cytoplasm usually with a spherical or bean shaped nucleus. They originate in bone marrow and lymph nodes. They are divided into two types; i.

Monocytes (4%) ii. Lymphocytes (24%)

Monocytes (4%) are leucocytes which enter the tissues from which they develop into macrophages which carry out Phagocytosis to defend the body against pathogens.

They have a bean shaped nucleus.

Lymphocytes (24%) they are produced in the thymus gland and lymph nodes. The precursor cells of lymphocytes in the bone marrow form a tissue which is called the lymphoid tissue. Lymphocytes are usually round and they possess a small quantity of the cytoplasm. Lymphocytes produce antibodies, agglutins, lysins, opsonins and antitoxins. In adults they are produced and develop in the bone marrow and lymph glands while in embryos they are produced in the thymus gland, liver and spleen.



They have a life span of 21 days

Adaptations of white blood cells to their function

a. They are larger than the pathogens
b. They are numerous
c. Some lymphocytes produce antibodies which attack pathogens
d. They have a sensitive cell surface membrane that detects micro organisms
   i. They have enzymes in their cytoplasm to digest the engulfed micro organisms
   ii. They do not have a fixed shape and hence the amoebic movements used to engulf pathogens.
   iii. They have an irregular shaped nucleus which allows them to squeeze through the narrow capillaries
   iv. They have a large nucleus which contains many genes for the control of antibody production.

BLOOD PLATELETS (thrombocytes)

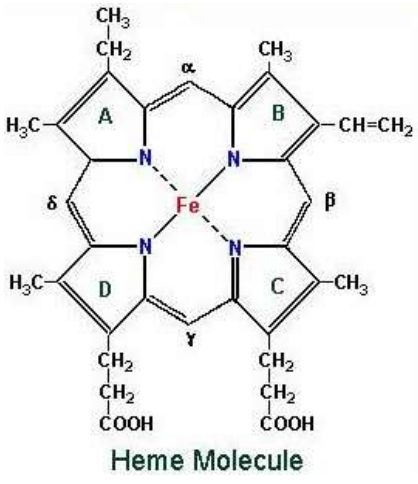
These are irregularly shaped, membrane bound cell fragments lacking the nuclei and are formed from the bone marrow cells. They are responsible for starting up the process of blood clotting. There are abound 250,000 blood platelets per mm^3 of blood.

TRANSPORT OF OXYGEN

The equation below shows how haemoglobin combines with oxygen.

As shown by the equation above, each haem group combines with one oxygen molecule and therefore 1 haemoglobin molecule carries four oxygen molecules.

$$Hb + 4O_2 \leftrightarrow HbO_8$$



Heme Molecule

Haemoglobin

Haemoglobin is a large and complex molecule that is composed of four polypeptide chains (therefore it has a quaternary structure) arranged around four haem groups. Two of the polypeptide chains are coiled to form α-helix, and this in turn is folded on itself into a roughly spherical shape, the other two chains are called β-chains due to unique primary structures in both types of chains. Various kinds of chemical bonds, together with electrostatic attraction, keep the folds of the chain together and maintain the shape of the molecule. Haemoglobin is an example of a conjugated protein: attached to the hydrophobic crevice of the polypeptide chain is a flat group of atoms, the

prosthetic group, consisting of a central iron atom held by rings of nitrogen atoms, which are part of a large structure known as porphyrin rings

The prosthetic group is haem and it is to the iron atom in the middle of it that the oxygen molecule becomes attached. The presence of four haem groups means that a single molecule of haemoglobin can carry four molecules of oxygen. Haem belongs to a class of organic compounds known as the porphyrins.

Other oxygen carrying pigments

There are several other groups of blood pigments and they differ mainly in the nature of prosthetic group. Chlorocruorin and haemoerythrin both contain iron, and haemocyanin contain copper. These three pigments are confined to invertebrate groups, particularly annelids and molluscs.

Pigments differ in their oxygen0-carrying capacities and are located in different areas

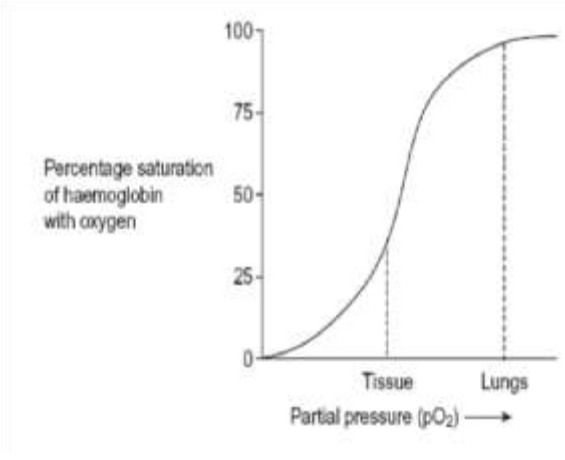
	Haemoglobin	Chlorocruorin (some annelids)	Haemocyanin (snails and crustaceans)	Haemoerythrin (some annelids)
Colour of pigment	Red	Green	Blue	Red
Metal in prosthetic group	Iron	Iron	Copper	Iron
Molecule of oxygen carried per atom metal	1:1	1:1	1:2	1:3
Location in blood	Cells or plasma	Plasma	Plasma	Cells or plasma

Oxygen tension and oxyhaemoglobin formation

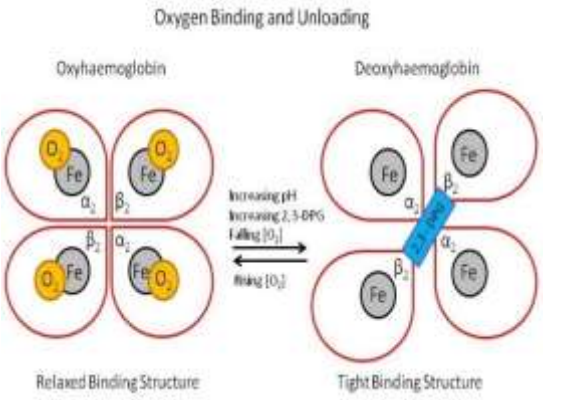
The ability of erythrocytes to carry oxygen to the tissues is due to haemoglobin having a high affinity for oxygen i.e. it can readily combine with oxygen and becomes fully saturated with it at relatively low partial pressures of the gas. Partial pressure of a gas is the measure of the concentration of a gas expressed in Kilo Pascals (Kpa) or milimetres of mercury (mmHg)

The high affinity of haemoglobin for oxygen is measured experimentally by determining the percentage saturation of haemoglobin with oxygen. When the percentage saturation of blood with oxygen is plotted against the partial pressure of oxygen an *S-shaped curve* or *sigmoid curve* is obtained and this curve is called the **oxygen dissociation curve** which is shown on the right The curve indicates that a slight increase in the partial pressure of oxygen leads to a rapid increase in the percentage saturation of haemoglobin with oxygen. This indicates that haemoglobin has a high affinity for oxygen in that it readily combines with it and become saturated with it at low partial pressures of oxygen.

(Toole fig 21.3 pg 414 OR Kent fig 3 pg 129



(Toole fig 21.3 pg 414 OR Kent fig 3 pg 129



The S-shaped curve is due to the way in which haemoglobin binds to oxygen. The first molecule of oxygen combines with a haem group with difficulty and distorts the shape of the haemoglobin molecule during the process. The remaining three haem groups bind with three oxygen molecules more quickly than the first one which increases rapidly the percentage saturation of haemoglobin with oxygen.

When oxyhaemoglobin is exposed to regions where the partial pressure of oxygen is low, e.g. in the respiring tissues, the first oxygen molecule is released easily and faster but the last one is released less readily with a lot of difficulty and least readily.

The steep part of the curve corresponds to the range of oxygen partial pressures found in the tissues. Beyond this part of the curve, any small drop in oxygen partial pressure results into a relatively large decrease in the percentage saturation of blood due to the dissociation of oxyhaemoglobin to release oxygen to the tissues.

Beyond this part of the curve any small drop in the oxygen partial pressure results into a relatively large decrease in the percentage saturation of blood with oxygen, due to the dissociation of oxyhaemoglobin to release oxygen to the tissues.

In conclusion, the curve indicates that haemoglobin has a high affinity for oxygen where the oxygen tension is high e.g. in the alveolar capillary of the lungs. However, the affinity of haemoglobin for oxygen is lower where the oxygen tension is low and instead it dissociates to release oxygen e.g. in the blood capillaries serving blood to respiring tissues.

The oxygen supply can be distributed according to the requirements of different times, with skeletal muscles getting more during exercise or the intestinal tract getting more during digestion. Of particular importance is the constant flow of blood to the brain. For example, falling during fainting actually prevents serious damage to the brain cells as a result of inadequate blood supply. (These responses are often thwarted by well-meaning bystanders anxious to get the affected individual 'back on his feet'. In fact, holding a fainting person upright can lead to severe shock and even death). **Note**: loading tension is the partial pressure of oxygen at which 95% of the pigment is saturated with oxygen, and the unloading tension is the partial pressure at which 50% of the pigment is saturated with oxygen.

Affinity of haemoglobin for oxygen under different conditions

Region of the body	Oxygen tension (concentration)	Carbon dioxide tension (concentration)	Affinity of haemoglobin for oxygen	Result
Gaseous exchange surface	High	Low	High	Oxygen is absorbed
Respiring tissue	Low	High	Low	Oxygen is released

There are many different oxygen dissociation curves because:

- there are a number of different respiratory pigments
- haemoglobin exist in a number of different forms
- the characteristics of each pigment change under different conditions

The many different oxygen dissociation curves are better understood if two facts are always kept in mind:

- the more to the left the curve is, the more readily the pigment associates with oxygen **but** the less easily its dissociates with it
- the more to the right the curve is, the less readily the pigment associates with oxygen **but** the more easily it dissociates from it

Effect of carbon dioxide on the oxygen dissociation curve (Bohr's effect)

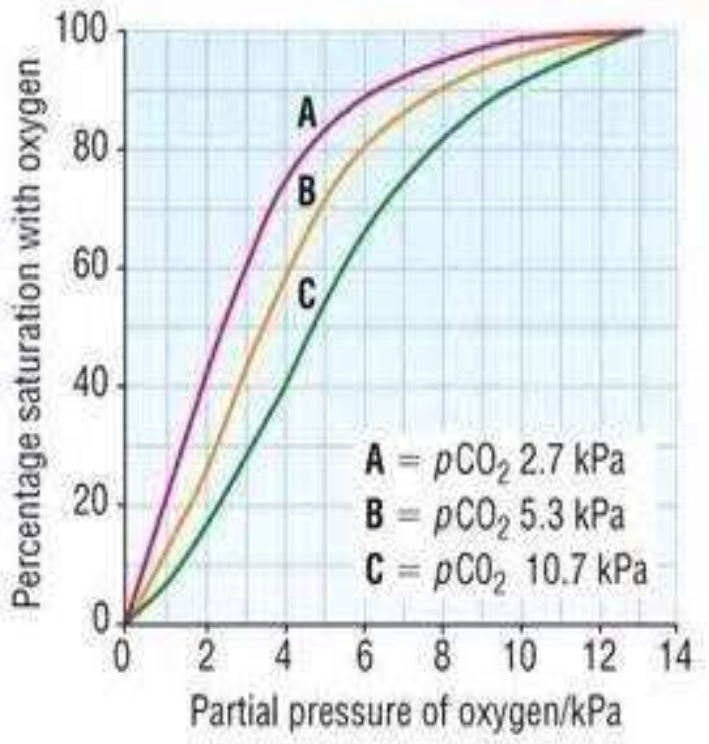
Within tissues there is a high concentration of carbon dioxide produced during aerobic respiration

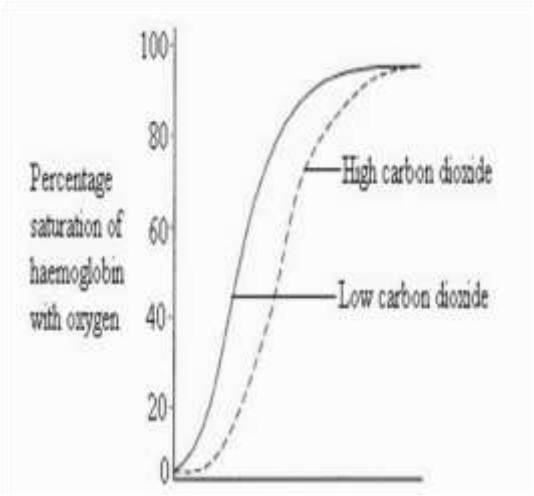
$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

Increase in carbon dioxide concentration decreases the affinity of haemoglobin for oxygen, by making the pH of the surrounding medium more acidic (low), thereby shifting the oxygen dissociation curve to the right. This shifting of the curve to the right is known as Bohr's effect i.e. the shifting of the oxygen dissociation curve to the right due to the increase in partial pressures of carbon dioxide which results into haemoglobin having a low affinity for oxygen and a high affinity for carbon dioxide.

Bohr's effect may be defined as '*the lowering of the affinity of blood's haemoglobin for oxygen due*

to increased acidity caused by increase in carbon dioxide concentration'.

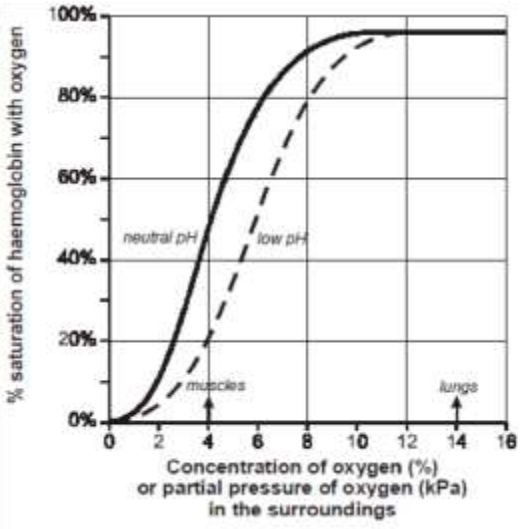




From the dissociation curves above, shifting the oxygen dissociation curve to the left means that haemoglobin has a higher affin ity for oxygen and therefore becomes fully saturated with oxygen it at very low partial pressures of oxygen.

It also means that haemoglobin has a low rate of dissociation to release oxygen to the tissues but a high rate of combining with oxygen.

Shift ing of the oxygen dissociation curve to the right means that haemoglobin has a lower affinity for oxygen and a higher rate of dissociation to release oxygen to the tissues rapidly to support tissue respiration



Effect of carbon monoxide on the affinity of haemoglobin for oxygen

There's a loose and reversible reaction between oxygen molecules and iron (II) atoms of haem groups of haemoglobin to from oxyhaemoglobin. This means that iron (II) is not oxidized to iron (III) as haemoglobin combines with oxygen.

In the presence of carbon monoxide and oxygen, haemoglobin combines readily with carbon monoxide to form a permanent compound known as carboxyhaemoglobinrather than combining with oxygen.

A permanent carboxyhaemoglobin compound is formed because carbon monoxide oxidizes iron (II) to iron (III). This reduces the free haemoglobin molecules available to transport oxygen molecules to the tissues, which makes the tissues develop symptoms of anoxia (total lack of oxygen in the tissues).

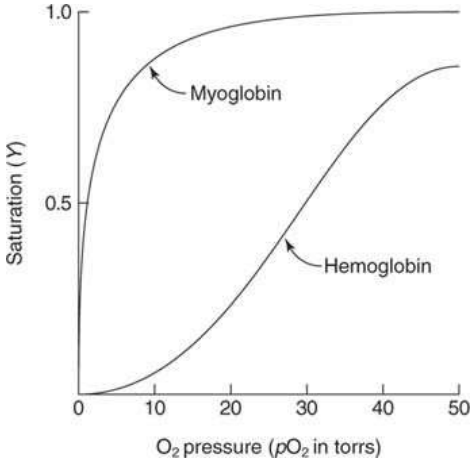
Therefore, carbon monoxide is referred to as a respiratory poison because it can readily combine with haemoglobin much more than oxygen and the product formed i.e. carboxyhaemoglobin does not dissociate.

Note; smokers have 10% of their total haemoglobin in form of carboxyhaemoglobin.

Myoglobin and other pigments

The oxygen dissociation curves for myoglobin lies to the left of that of haemoglobin as shown in the graph (Kent fig 3 pg 131 OR Clegg fig iron 17.31 pg 360) where it remains fully

Myoglobin is a respiratory pigment which also contains containing haem groups mostly found in the muscles saturated at partial pressures below that required for haemoglobin to give up its oxygen. Myoglobin has a higher affinity for oxygen than haemoglobin in a way that it combines readily with haemoglobin and it becomes fully saturated with oxygen at a lower partial pressure of oxygen.



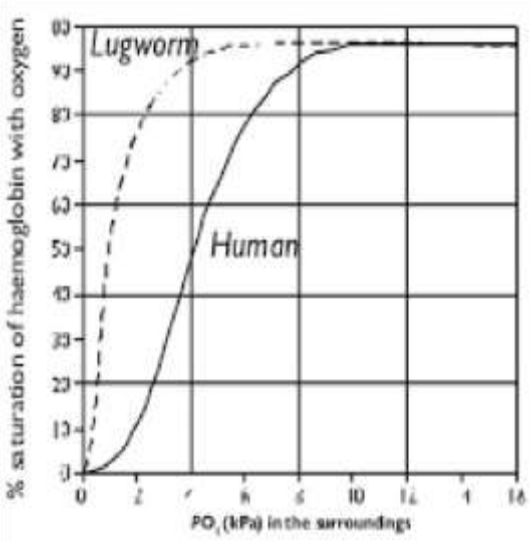
Myoglobin acts as a store of oxygen in resting muscles in form of oxymyoglobin and only releases the oxygen it stores only when oxyhaemoglobin has been exhausted i.e. many vigorous activities because myoglobin has a higher affinity for oxygen than haemoglobin.

Note;

1. High affinity refers to low rate of dissociation of oxyhaemoglobin to release oxygen and a higher rate of association of haemoglobin with oxygen.
2. Low affinity refers to higher rate of dissociation of oxyhaemoglobin to release oxygen and a lower rate of association of haemoglobin with oxygen.

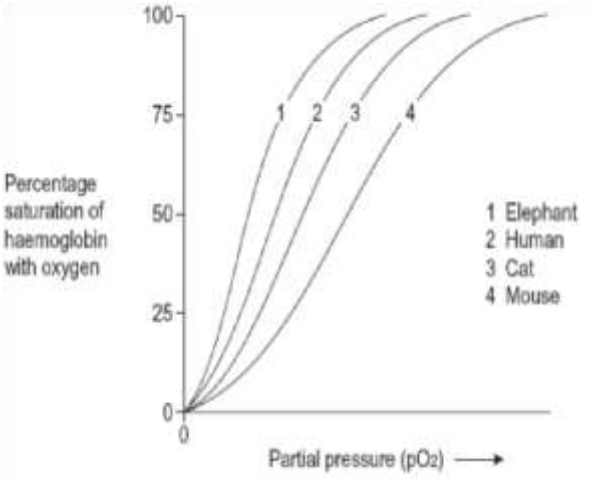
Comparison between the oxygen dissociation curve for Lugworms' (*Arenicola*) haemoglobin and that of Man

The oxygen dissociation curve of the lugworm's haemoglobin lies on the left of that of man's haemoglobin as shown in the graph below This indicates that the haemoglobin of the lugworm has a higher affinity for oxygen than that of man. This is because the lugworm lives in oxygen deficient mud and so in order to extract enough oxygen from that environment of low oxygen tension, the haemoglobin of the lugworm must have a higher affinity for oxygen than that of man thriving in a well-supplied environment with oxygen.

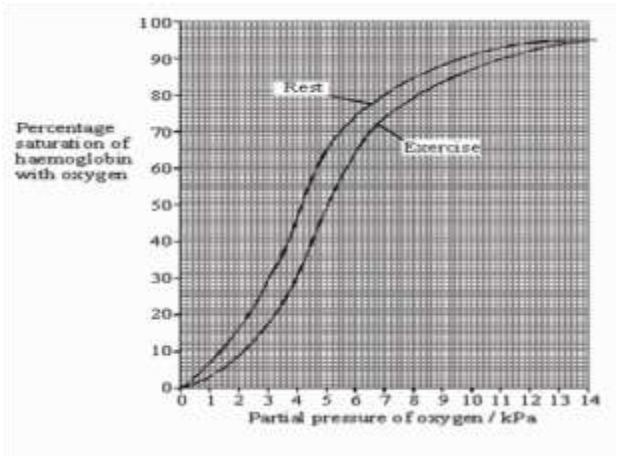


This implies that the lugworm's haemoglobin dissociates to release oxygen to its tissues compared to that of man which makes the lugworm less active than man, who releases much oxygen rapidly to the tissues. (Clegg fig 17.32 pg 360 OR Toole fig 21.5 pg 416)

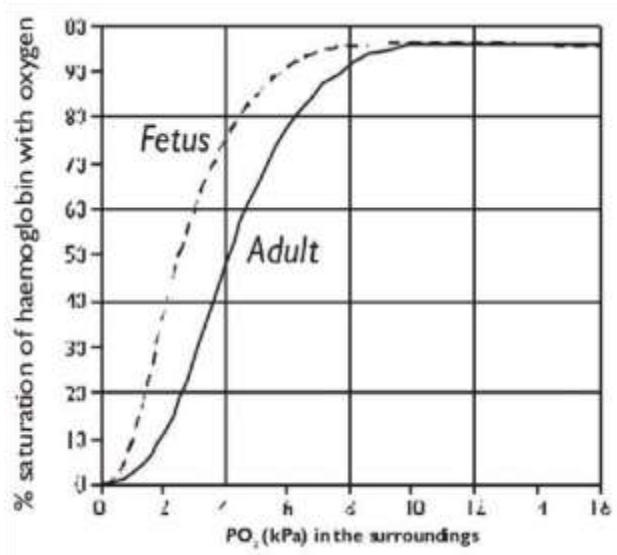
Comparison between the oxygen dissociation curves of different sized mammals The smaller animal size, the higher the surface area to volume ration. Small animals therefore lose a lot of heat from their surfaces and in order to maintain a constant internal body temperature, they have to produce a lot of heat to compensate for the lost heat. Such animals therefore higher metabolic rates and so need more oxygen per gram of tissue than larger animals. Therefore they have blood that gives up oxygen more readily i.e. their dissociation curves are on the right of the larger animals



Comparison between the oxygen dissociation curves at rest and during exercise During exercise, the oxyhaemoglobin releases oxygen more readily hence the oxygen dissociation curve during exercise is to the right of the curve when at rest.



Comparison between the oxygen dissociation curve of maternal haemoglobin and that of the foetal haemoglobin The oxygen dissociation curve of foetal haemoglobin lies to the left of maternal haemoglobin as shown in the diagram besides; (Clegg fig 17.36 pg 363 OR Toole fig 21.7 pg 416 OR Soper fig 14.32 pg 481) This indicates that the foetal hemoglobin has a higher affinity for oxygen than that of the mother. This enables the foetal haemoglobin to pick sufficient oxygen from the mother via the placenta and also increases on the oxygen carrying capacity to the tissues, especially when the foetus needs a lot of energy. It also increases on the oxygen carrying capacity to the tissues of the foetus in the situation whereby deoxygenated and oxygenated blood are mixed due to the bypasses of ductus arteriosus and foramen ovale in the foetus.

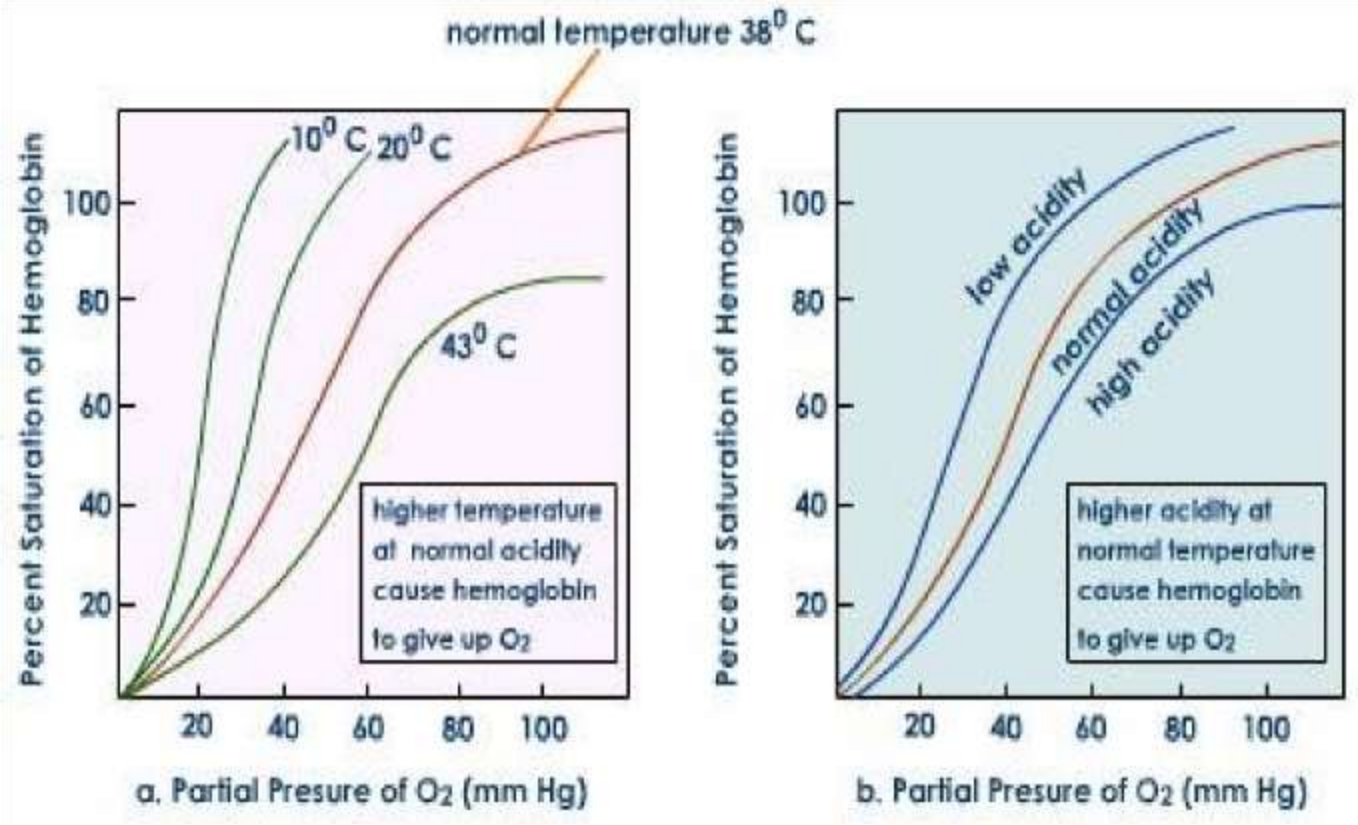


Effect of temperature on haemoglobin oxygen dissociation curve

A rise in temperature lowers the affinity of haemoglobin for oxygen thus causing unloading from the pigment i.e. a rise in temperature increases the rate of dissociation of oxyhaemoglobin to release oxygen to the tissues.

Increased tissue respiration which occurs in the skeletal muscles during exercise generates heat. The subsequent rise in temperature causes the release of extra oxygen from the blood to the tissues. This is so because increase in temperature makes the bonds which combine haemoglobin with oxygen to break, resulting into the dissociation of oxyhaemoglobin.

Oxygen dissociation curve for haemoglobin at different temperatures



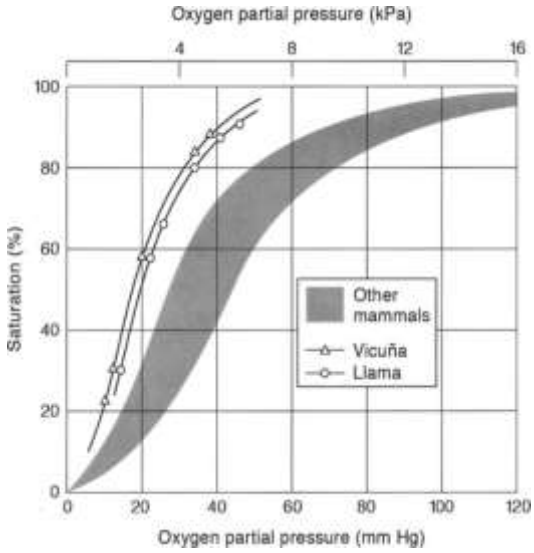
Effect of changing altitude on oxygen carriage

There is a decrease in the partial pressure of oxygen in the atmosphere with increase in altitude from sea level. Therefore the volume of oxygen is less at high altitudes than at sea level. When an organism moves from the sea level to high altitudes, very fast, such an organism tends to develop symptoms of anoxia (lack of oxygen) which include headache, fatigue, nausea, and becoming unconscious. However, when an organism moves slowly from sea level to high altitudes like the mountain climbers, such an organism can at first develop symptoms of anoxia but later on such symptoms disappear due to adjustments in the respiratory and circulatory systems in response to insufficient oxygen reaching the tissues from the surrounding.

The amount of haemoglobin and the red blood cell count increases together with the rate of breathing and the heartbeat. More red blood cell formation occurs in the bone marrow under the control of the hormone called *erythropoietin* secreted by the kidney. Secretion of erythropoietin is stimulated by lower oxygen tension in the tissues. Increase in the amount of haemoglobin and red blood cells together with increase in the breathing rate and heart beat increases the oxygen carrying capacity of the blood to the tissues which leads to the disappearance of the symptoms of anoxia and which also makes the individual organism to be acclimatized.

Acclimatization is therefore a condition whereby an organism carries out a series of physiological adjustments in moving from a low altitude area to a high one to avoid symptoms of anoxia so that such an organism can survive in an environment of low oxygen content.

The graphs below show the oxygen dissociation curves of people living at sea level and at high altitude (Clegg fig 17.37 pg 363 OR Toole fig 21.4 pg 415 OR Soper fig 14.31 pg 481 OR Simpkins fig 8.19 pg 145) The mammals that live in regions of the world beyond the sea level e.g. mountains solve the problem of lack of enough oxygen in the atmosphere by possessing haemoglobin with a higher affinity for oxygen than that of mammals at sea level. This enables the high altitude mammals to obtain enough oxygen through the oxygen deficient environment e.g. the llama. This explain why the oxygen dissociation curve of the haemoglobin of the llama lies to the left of that of other mammals at sea level. The vicuna long necked member of the camel family that stays in the high alpine areas of the Andes



Mammals living at high altitudes

1. These possess an improved capillary network in the lungs which coupled with their deeper breathing (hyperventilation) insures increased oxygen uptake.
2. They have an increased red blood cell which increases the amount of oxygen transported by blood.
3. Increased haemoglobin concentration in the red blood cells which improves the amount of oxygen transported by the blood.
4. Changes in haemoglobin affinity for oxygen. Here the oxygen dissociation curve is shifted to the right to facilitate release of oxygen to the tissues. This particularly occurs at relatively lower altitudes.
5. Mammals living at altitudes about 3500m have their oxygen dissociation curves shifted to the left this favours their survival by promoting an increased affinity for oxygen by haemoglobin.
6. Increased myoglobin levels in muscles myoglobin has a higher affinity for oxygen than haemoglobin. This facilitates the exchange of oxygen from the blood to the tissues making oxygen available to the tissues.

Diving mammals e.g. seals, dolphins and whales.

1. They have a large spleen which can store large volumes of blood e.g. the seals spleen stores 24l of blood after the dive has begun, the spleen contracts and supplies the blood in circulation with additional erythrocytes that are highly leached with oxygen.
2. Have high concentration of myoglobin in their muscles. Myoglobin is an oxygen storing protein.
3. Mammals during the diving reflex slow down the pulse as the heart beat is also slowed down in order to effect an overall reduction on oxygen consumption since there is reduced cardiac output to the tissues.

4. Store oxygen in their blood as oxyhaemoglobin and this they achieve by having concentration of haemoglobin.
5. Blood supply to muscles is restricted and completely cut off during the longest dives hence encouraging anaerobic instead of aerobic respiration.
6. In this way, the muscles use sparingly oxygen stored in their myoglobin.

TRANSPORT OF CARBON DIOXIDE

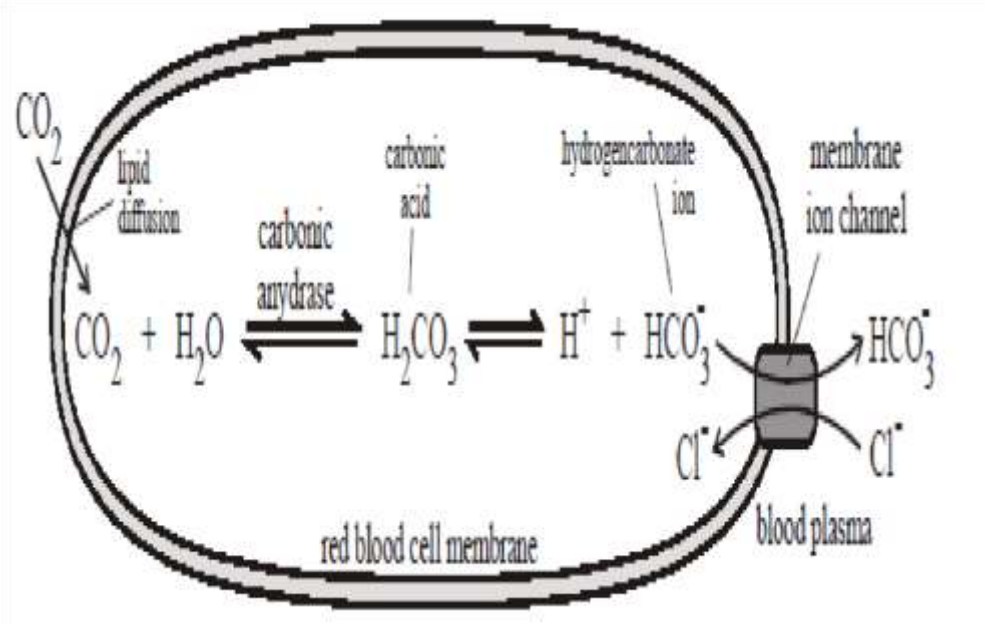
Carbon dioxide is transported from the body tissues mainly inform of bi-carbonate ions in blood plasma to the lungs for removal.

Although carbon dioxide is mainly transported inform of bi-carbonate ions i.e. 85%, carbon dioxide can also be transported in the following ways;

a. About 5% of carbon dioxide is transported in solution form. Most of the carbon dioxide carried in this way is transported in physical solution. A very small amount is carried as carbonic acid. In the absence of haemoglobin, the plasma proteins buffer the hydrogen ions to form weak proteionic acids.
b. About 10% of carbon dioxide combines with the amino group of haemoglobin to form a neutral compound known as **carbamino haemoglobin ($HbCO_2$).**If less oxygen is being carried by haemoglobin molecule, then more carbon dioxide is carried in this way as $HbCO_2$.

Transportation of carbon dioxide inform of hydrogen carbonate ion

When carbon dioxide is formed during respiration, it diffuses from the tissues into the erythrocytes, via their thin and permeable membrane. Inside the erythrocytes, carbon dioxide reacts with water in the presence of carbonic anhydrase enzyme to form carbonic acid as shown below;



$$H_2O_{(l)} + CO_{2(g)} \xrightarrow{\text{Carbonic anhydrase}} H_2CO_{3(aq)}$$

The formed carbonic acid then dissociates into hydrogen ions and bicarbonate ions as shown below

$$H_2CO_{3(aq)} \longrightarrow H^+ + HCO^-_{3(aq)}$$

The formed hydrogen ions decrease the pH in erythrocytes which results into the dissociation of oxyhaemoglobin being carried from the lungs to the tissues into the free haemoglobin molecules as free oxygen molecules.

The free oxygen molecules diffuse into the tissues to be used in respiration. The free haemoglobin molecules buffer the hydrogen ions (H^+) inside the red blood cells into a weak acid known as **haemoglobinic acid**

$$H^+ + Hb \longrightarrow HHb$$

In case of excess H^+ plasma proteins are used to buffer them into another weak acid called **proteinic acid.**

The formed hydrogen carbonate ions within the erythrocytes diffuse out into the plasma along the concentration gradient and combine with sodium to form sodium hydrogen carbonate which is then taken to the lungs.

$$HbO_8 \longrightarrow Hb + 4O_{2\,(g)}$$

The outward movement of bicarbonate ions from the erythrocytes into the plasma results into an imbalance of positively charged and negatively charged ions within the cytoplasm. In order to maintain electrochemical neutrality, to remove this imbalance in the red blood cells, chloride ions diffuse from the plasma into the red blood cells, a phenomenon known as the **chloride shift**
When the bicarbonate ions reach the lungs, they react with H^+ to form carbonic acid which eventually dissociates into carbon dioxide and water.

$$H^+ + HCO_3^- \longrightarrow H_2CO_3$$

$$H_2CO_3 \longrightarrow H_2O + CO_2$$

The carbon dioxide and water formed from the dissociation of carbonic acid in the lung capillaries are then expelled out by the lungs during exhalation so as to maintain the blood pH constant

VASCULAR SYSTEMS IN ANIMALS

In animals, every vascular system has at least three distinct characteristics. a.
It has a circulating fluid e.g. blood

b. It has a pumping device inform of a modified blood vessel or a heart.

c. It has tubes through which the fluid can circulate e.g. blood vessels

Note; animals require a transport system because of;

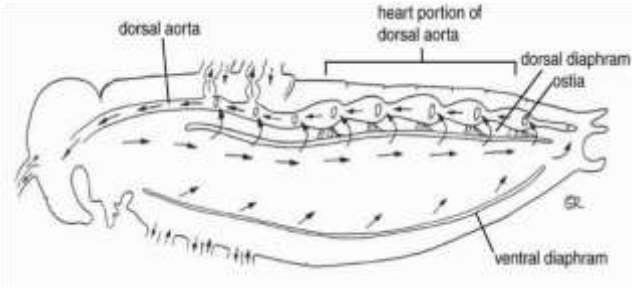
1. Surface area of the organism
2. Surface area: volume ratio of the organism
3. Activity of the organism
4. The diffusion distance for the transported substances between the tissues to and from their sources.
5. There are two types of vascular systems, the open vascular system and the closed vascular system.

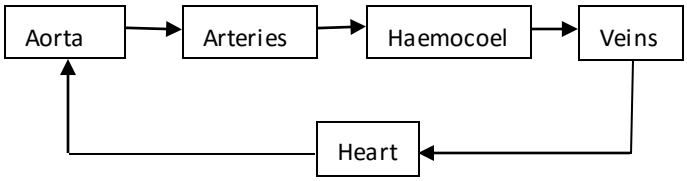
Open vascular systemnot on syllabus

Open circulation is the flow of blood through the body cavities called **Haemocoel** instead of flowing in blood vessels. This exists in most arthropods, molluscs and tunicates.

In this system, blood is pumped by an aorta which branches into a number of arteries which open into the haemocoel. From the haemocoel, blood under low pressure moves slowly to the tissues where there's exchange of materials e.g. gases, nutrients e.t.c. from the haemocoel blood percolates back into the heart via the open ended veins.

In insects the haemocoel is divided into two parts by a transverse pericardial membrane forming a pericardial cavity dorsally and the ventral perivisceral cavity.





In the body of the insects there are no blood vessels except the tubular heart which is suspended in the pericardial cavity by slender ligaments and extends through the thorax and abdomen. The heart is expanded in each segment to form a total of 13 small chambers which are pierced by a pair of tiny tubes called **ostia**. The ostia allow blood to flow from one segment of the chamber to another. Alary muscles are located at each chamber of the heart.

Closed vascular system

In a closed vascular system, blood flows in blood vessels or sinuses. It oc curs in all vertebrates, annelids such as earthworms, cephalopods and echinoderms. The distribution of blood in this system is therefore adjustable e.g. blood from the heart is at high pressure and that to the heart is at low pressure. Closed vascular systems are further divided into single and double circulation.

Single and double circulation

Single circulation is the flow of blood through the heart once for every complete circulation around the body. Single circulation occurs in fish and the deoxygenated blood from the body tissues is pumped by the heart to the gills from where it flows back to the body tissues and eventually returns to the heart.

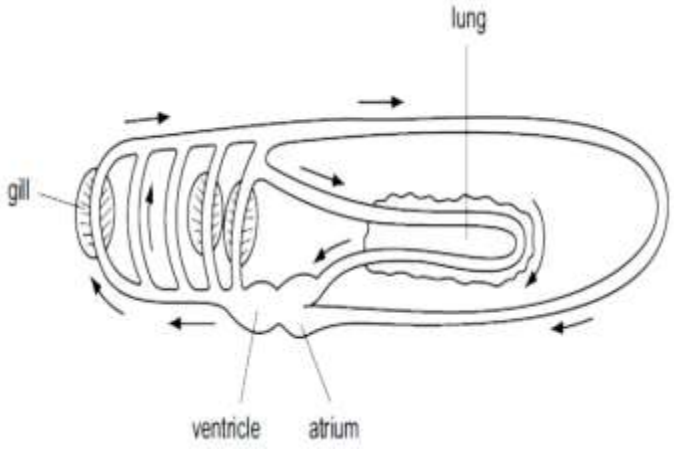
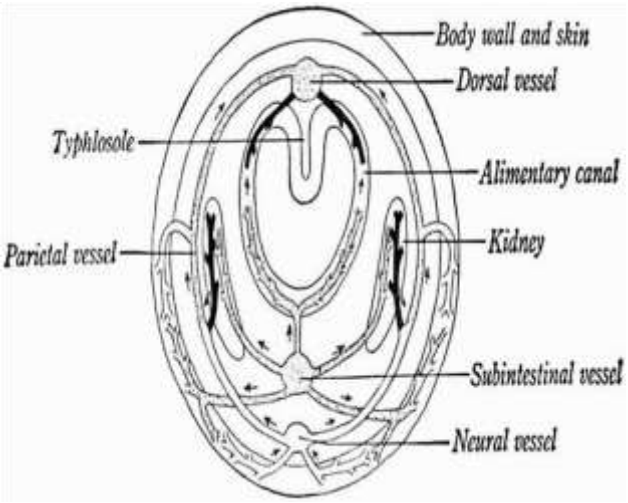


Diagram showing single circulation in fish

The problem of single circulation is that blood tends to move very slowly at the venous side due to the significant drop in pressure before completing the circulation. The drop in pressure is as a result of capillaries having a considerable resistance to blood flow i.e. capillaries in the gills and body tissues. The sluggishness of blood flow at the venous side is solved by replacing the veins with large sinuses

Vascular system of the earthworm (annelid)

The earthworm belongs to phylum annelida. Annelids are coelomate animals i.e. they have a body cavity that separates the muscular wall of the animal from the internal organs

The largest vessel is the longitudinal muscular-walled dorso vessel and it is above the alimentary canal (gut). The peristaltic contraction from the posterior end of the vessel drives blood forward to the anterior end of the animal. The backflow of blood is prevented by valves. Each valve originates from a fold of an internal membrane or tissue of any blood vessel that is called an endothelium. The dorso vessel collects and receives blood from the body wall, the gut, the nerve cord and the nephridia via capillaries.	**Transverse section of the annelid vascular system** Clegg fig 17.6 pg 344 

The dorso vessel connects with the smaller more contractile ventral vessel via five pairs of contractile pseudo hearts.

Each pseudo heart has four valves which permit the blood to flow towards only the ventral vessel and back to the posterior end of the animal.

Between the ventral vessel and the organs in the coelom e.g. nephridia and gut, there are a series of segmented blood vessels which run between them and they end up forming capillaries where there is exchange of materials between the organs and the blood in the capillaries. From the capillaries, blood

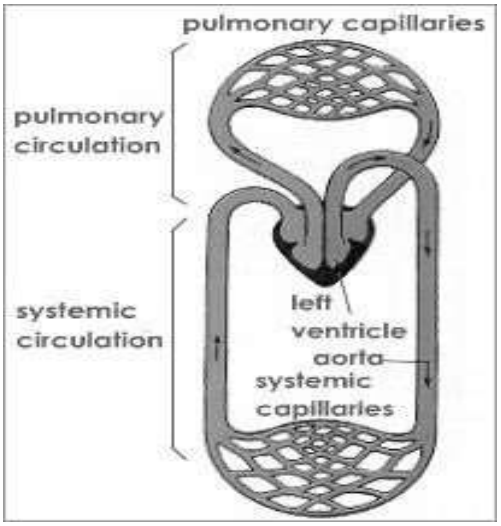
fills its way back to the dorso vessel for its flow to the anterior side due to the peristaltic movement of the dorso vessel. The blood is red in colour with haemoglobin.

Double circulation

Double circulation is the flow of blood through the heart twice for every complete circulation around the body.

In double circulation deoxygenated blood from body tissues is pumped from the heart to the lungs from where it returns to the heart after being oxygenated and it is then re-pumped to the body tissues so as to supply oxygen to the body tissues. A double circulation serves as one of the solutions towards the sluggish flow of blood at the venous side in single circulation In double circulation, the heart must be divided into the left and right chambers to prevent oxygenated blood from mixing with deoxygenated blood e.g. in reptiles, birds and mammals have a four chambered heart made up of the right atrium and ventricle and the left and atrium and ventricle.

Diagram showing double circulation in a frog and a mammal

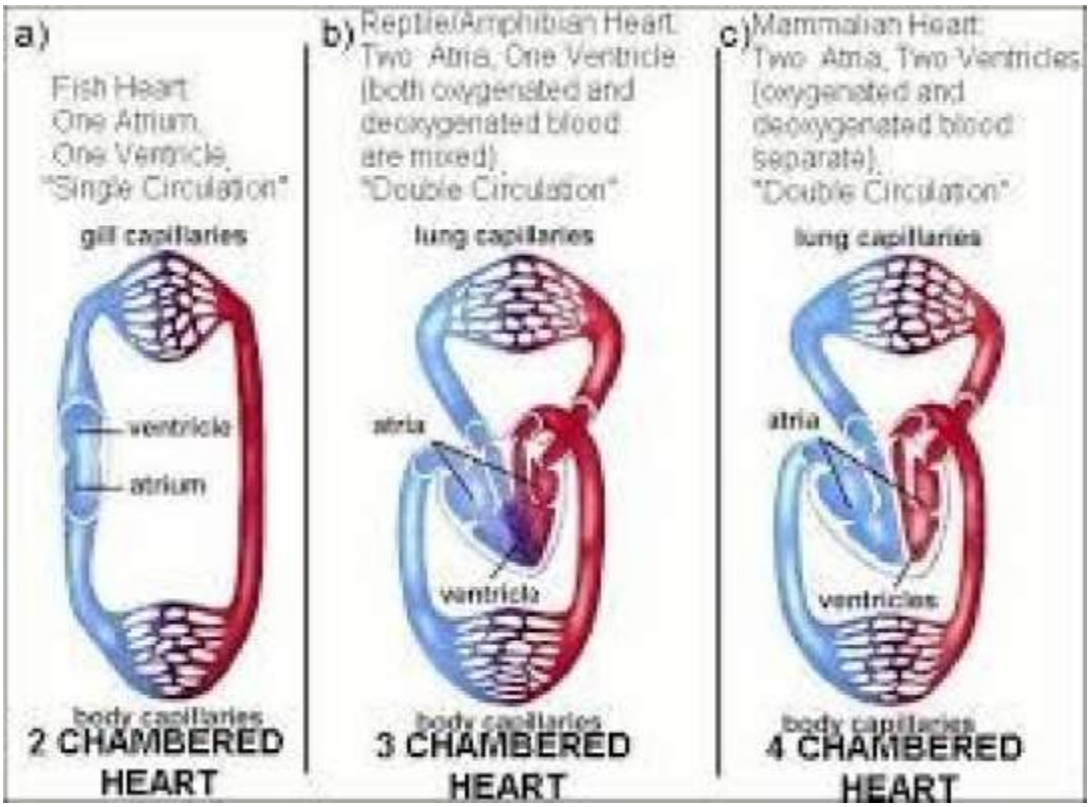


The frog experiences double circulation although its heart has three chambers namely; one ventricle and the two atria i.e. the left and right atria.

Both deoxygenated and oxygenated blood in the frog flow through the same ventricle and conus arteriosus at the same time without mixing. This is achieved due to the folding in the walls of the ventricle which enhances the separation of deoxygenated blood from oxygenated blood and this separation is also facilitated by the spinal valves in the conus arteriosus.

Some organisms e.g. the octopus and squids solve the problem of sluggish flow of blood of the venous side by possessing brachial hearts which pump deoxygenated blood from the body tissues of the gills and eventually back to the main heart. The main heart pumps, oxygenated blood to body tissues from the gills.

(Roberts fig 11.16 pg 175)



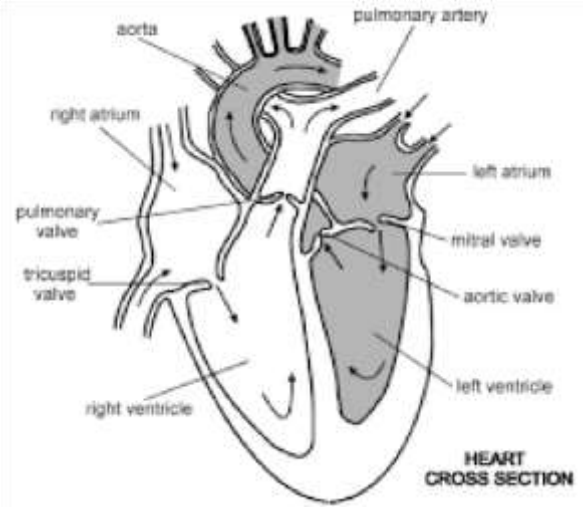
MAMMALIAN BLOOD CIRCULATION

The mammalian blood circulation is a double blood circulation which is mainly based on the heart and blood vessels,

THE MAMMALIAN HEART

Structure of the mammalian heart

The heart is the muscular organ pumping blood to all body organs using its chambers. It is made up of four chambers which include the right and left atria (auricles) and the right and left ventricles.
The four chambers enhance the blood flow through the heart at the same time without mixing it i.e. the deoxygenated blood is separated from oxygenated blood oxygenated blood flows through the left atrium and ventricle while the deoxygenated blood flows through the right atrium and ventricle.



The heart is composed of the **cardiac muscles** within its walls which are **myogenic** in nature, in a

way that, the initiation of their contraction is not under the control of the central nervous system but is within the muscles themselves.

This enables them to contract continuously and rhythmically without fatigue and therefore enables the heart to beat and pump without stopping. The heart consists of atrioventricular valves/ pocket valves and semi lunar valves. The atrioventricular valves include the following;

The three (3) flapped tricuspid valves found between the right atrium and the right ventricle
The two (2) flapped bicuspid valves which prevent back flow of blood from the left ventricle to the left auricle

The semi lunar valves are prevented from turning inside out by connective tissues called **tendinous cords**

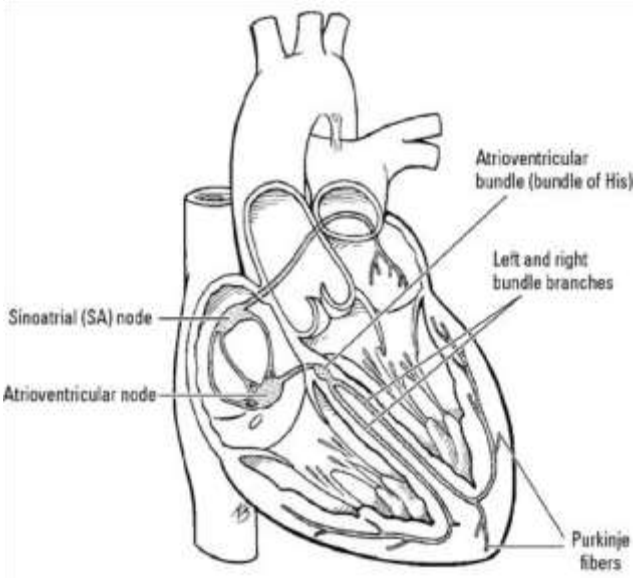
The heart is linked with four blood vessels **(1) The venacava** which transports deoxygenated blood from body tissues through the right atrium of the heart. **(2) The pulmonary artery** which transports deoxygenated blood from the right ventricle of the heart to the lungs. **(3) The pulmonary vein** which transports oxygenated blood from the lungs into the left atrium of the heart. **(4) The aorta** which is the biggest vessel and it transports oxygenated blood from the left ventricle of the heart to the body tissues.

The left ventricle is more muscular (thicker) than the right ventricle because the left ventricle has to contract more powerfully than the right ventricle in order to enable oxygenated blood with high pressure to move for a long distance to the body tissues unlike the right ventricle which pumps deoxygenated blood with low pressure for a short distance to the lungs.

Initiation of the heart beat

The cardiac muscle within the walls of the heart is myogenic in nature in a way that the initiation of its contraction is within the muscle itself, but not under the control of the central nervous system (brain and spinal cord). This enables the muscles to contract continuously and rhythmically without fatigue to enable the heart to beat continuously and rhythmically without stopping. The intrinsic initiation of the heart beat enables the heart to remain beating even it is surgically removed from the body, provided it is under ideal conditions.

The rhythmic contraction of the cardiac muscles Clegg fig 17.8 pg 347 is initiated by specialized network of fine cardiac muscles network found inside the wall of the right atrium close to the entrance of blood from venacava into the right atrium.



This network of fine cardiac muscle fibre is known as **Sino Atrial Node (SAN)** and it serves as a pace maker by giving off a wave of electrical excitations similar to impulses, which spread out very rapidly over both atria causing them to contract and force blood into the ventricles via the open atrial ventricular valves. When the electrical excitations reach the

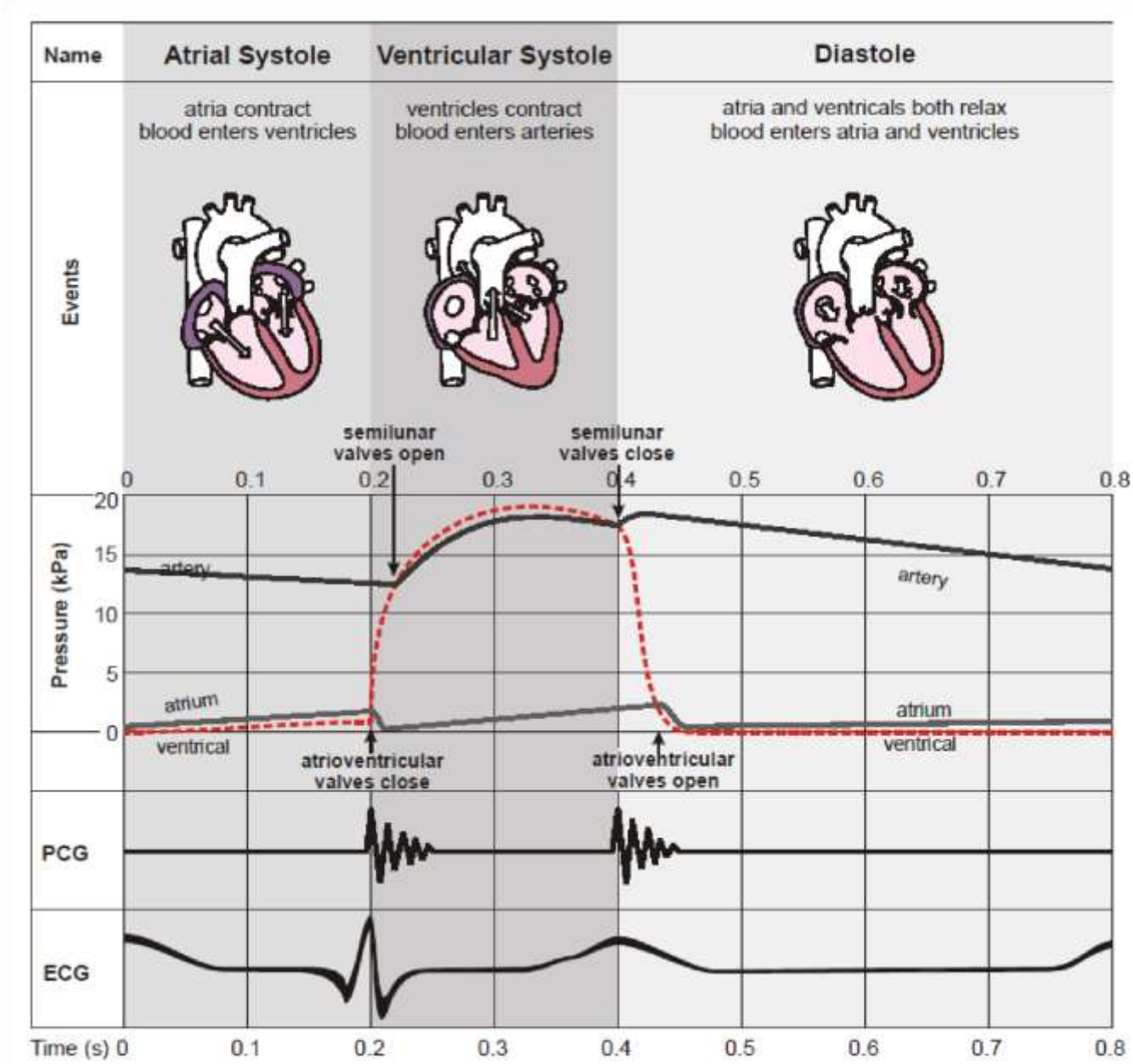
junction at the boundary of the atria, they excite another specialised plexus of other cardiac muscle chambers known as **Atrio Ventricular**

Node (AVN)

When excited, the AVN sends waves of electrical excitations down to another bundle of cardiac muscle of fibres formed along the inter-ventricular septum called the Purkinje tissue or Bundle of His to the apex of the heart. This conducts and spreads the excitement to both ventricles which eventually pump blood into the arteries.

NOTE;

1. The closing of the atrioventricular valves during ventricular systole produces the first heart sound, described as ***lub.***
2. The closing of the semi lunar valves causes the second heart sound, described as ***dub.***
3. The pulse in the arteries is due to ventricular systole and elastic recoil of the arteries due to high pressure of blood.
4. The pulse is more pronounced in the arteries
5. The PCG (phonocardiogram) is a recording of the sound the heart makes. The cardiac muscle itself is silent and the sounds are made by the valves when closing. The first sound (lub) is the atrioventricular valves closing and the second sound (dub) it is the semi lunar valves closing.
6. The ECG (electrocardiogram is a recording of the electrical activity of the heart. There are characteristic waves of electrical activity marking each phase of the cardiac cycle. It begins with a P wave, atrial depolarisation and the spread of the through the atria. The QRS complex indicates ventricular depolarisation. The T wave represents ventricular repolarisation. Changes in these ECG waves can be used to help diagnose problems with heart.



The cardiac cycle (Sequence of the heart beat)

This is the sequence of events of heart beat by which blood is pumped around the body. The pumping action of the heart consists of alternate contractions of heart muscles (cardiac muscles) called **systoles** and relaxations called **diastoles**. The term cardiac output refers to the volume of blood pumped from each ventricle.

The cardiac cycle begins with the contractions of the atria i.e. **atrial systole,** which is initiated by SAnode and it which causes the atria volume to decrease and the atria pressure increases. As the atria contracts, the ventricles relax i.e. undergo ventricular diastole, causing the bicuspid and tricuspid valves to close. The contraction of the atria due to blood entering the atria forces the bicuspid and tricuspid valves to open so that blood moves from atria into the ventricles.

Contraction of atria walls has an effect of sealing off the venacava and pulmonary veins, thereby preventing the back flow of blood into the vessels as the blood pressure rises within the atria. It takes 0.1 seconds.

When the ventricles are filled with blood from atria, their walls contract simultaneously i.e. **ventricular systole**, and the atria relax i.e. **atrial diastole.** Ventricular systole is initiated by impulses from AVnode to the bundle of His, Purkije fibres and rapidly through the ventricle muscles. The ventricles' volume reduces while the pressure increases, forcing the bicuspid and tricuspid valves to close and prevent the back flow of blood into the atria. The increased pressure in the ventricles also forces blood to be pumped into the pulmonary artery via the open semi lunar valves from the ventricles. This enables the blood to be pumped into the lungs via the pulmonary artery and into the body tissue via the aorta.

The ventricular systole is more powerful than the atrial systole because the ventricles are more muscular than the atria and therefore generate more pressure. The powerful ventricular systole forces blood into the atria and pulmonary artery.

After ventricular systole, there's a short period of simultaneous atrial and ventricular relaxations. In the **ventricular diastole**, the high pressure developed in the ventricles causes a slight back flow of blood which closes the semi lunar valves, thereby reducing blood back flow.

Relaxation of the atrial wall and contraction of the ventricle, initiates the refilling of the atria by blood under relatively low pressure i.e. deoxygenated blood in the venacava flows into the right atrium and oxygenated blood from the lungs flows into the left atrium via the pulmonary vein.

Intrinsic control of the heart beat

The cardiac muscle in the heart is myogenic. It contracts and relaxes automatically and does not depend on stimulation by nerves. The initial stimulus originates from the sino-atrial node (SAN), often called the pacemaker. The pacemaker is found in the right atrium wall at the entrance of the superior venacava. The membranes of the cells of the SAnode are permeable to sodium ions. Sodium ions enter into these cells and the cell membranes are depolarized.

An excitatory wave of depolarization is generated which spreads rapidly from the SA node across the two atria causing them to contract simultaneously. A slowing down occurs as depolarization of the atrio-ventricluar node (AVN) is delayed for about 0.1s to allow the atria to complete their contraction and empty the blood into the ventricles. Impulses from the AV node are conducted by specialized muscle fibres called bundle of His in the inter-ventricular septum towards the heart apex. Impulses are conducted by Purkinje fibres (Purkyne tissue) throughout the ventricular walls. This causes the contraction of both ventricles forcing blood into the pulmonary arteries and the aorta.

Characteristics of the cardiac muscle in relation to excitation and contraction

1. The absolute relative refractory period is longer than that of other muscles i.e. the heart cannot be fatigued easily
2. The generation of the wave from the SAN has a refractory period between contraction of the heart and relaxation of the heart i.e. the waves are not generated continuously.

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Hormonal control of the heat rate

A number of hormones affect the heart rate by stimulating the SAnode, either directly or indirectly.

Those with a direct effect are considered

a) **Adrenaline hormone**. Adrenaline is secreted by the medulla (middle) of the adrenal glands. The adrenal medulla also secretes smaller amounts of hormone noradrenaline which has similar effects to adrenaline. Both stimulate the heart, although adrenaline is more effective. Cardiac output and blood pressure are increased heart rate. The two hormones also have other effects on the body which prepare the body for action (the 'flight or fight' response).

b) **Thyroxine**. This is produced by the thyroid gland which raises the basal metabolic rate. This in turn leads to greater demand for oxygen production of more heat. As a result, vasodilation (dilation of the blood vessels) followed by increased blood flow occurs, and this leads in turn to increased cardiac output. Heart rate is also directly stimulated by thyroxine.

Control of the rate of the heart beat

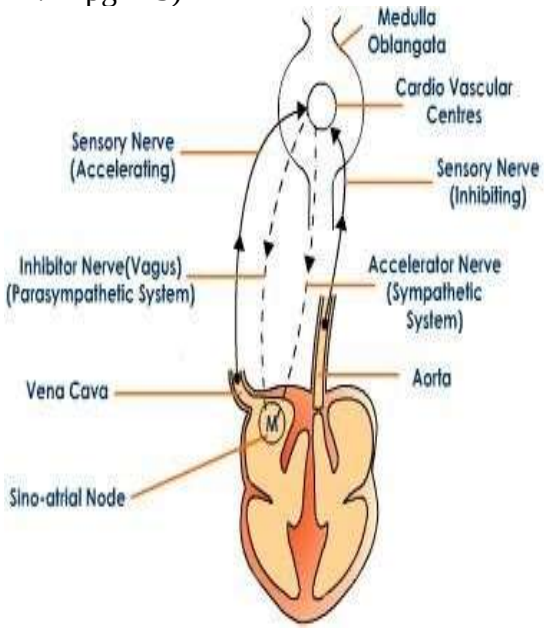
Through the initiation of the contraction of cardiac muscle and hence initiation of heart beat are not under the control of the central nervous system, the rate at which the heart beats to pump blood is under the control of the autonomic (Involuntary) nervous system.

The heart is innervated by the sympathetic nerve from the sympathetic autonomic nervous system and by the vagus nerve, a branch of a parasympathetic autonomic nervous system. The nerves modify the rate at which the pace maker gives waves of electrical excitations hence controlling the speeding up or slowing down of the rate of the rate of heart beat.

When the rate of heart beat increases beyond the normal rate, the vagus nerve (parasympathetic nerve) is stimulated to release **acetylcholine** such that it lowers rate of the heart beat back to normal

If however, the rate of the heart beat lowers below the normal rate or if there's need for higher rate of heart beat the sympathetic nerve releases **noradrenaline** to bring back or increase to the cardiac frequency usually to the normal rate. Therefore the sympathetic and vagus nerves are antagonistic, functionally.

(Clegg fig 17.13 pg 350 OR Soper fig 14.24 pg 475)



Cardiac output

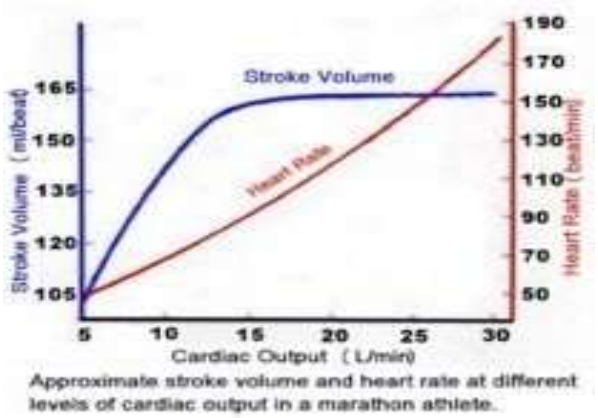
It refers to the volume of blood pumped out from the heart, per minute by one ventricle.

Cardiac output (volume of blood going out of the heart) = **Rate of heart beat X Cardiac frequency**

a) **Stroke volume** is the strength of the heart beat measured in volume of blood per heart beat
b) **Heart rate** is the number of heart beats per minute

Cardiac output is regulated by the autonomic nervous system. The output increases when there is an increase in body activity. This serves to supply more oxygen and glucose to respiring cells and remove waste products.

Soper fig 14.25 pg 476



Approximate stroke volume and heart rate at different levels of cardiac output in a marathon athlete.

Prolonged athletic training strengthens the heart, increasing the heart muscles and enlarging the heart chamber. This leads to an increase in strength of cardiac muscle contraction and an increase in the stroke volume. Thus, at rest, the trained athlete has a higher cardiac output than an untrained person Explain the relationship between;

troke volume and heart beats

ardiac output and heart beats **Short term effects of exercise on the cardiovascular system**

a) Cardiac output increases
b) Vasodilation or vasoconstriction of different blood arterioles redistributes the blood towards muscles and away from organs such as kidneys and intestines, whose need is less immediate. The heart needs more blood to maintain the higher cardiac output and the brain must continue

to function normally in order to coordinate activities – its supply is therefore largely unchanged during exercise. As exercise generates heat, the blood supply to the skin is increased during exercise to help dissipate this heat to the environmet.

c) Increase in systolic blood pressure although diastolic pressure is largely unchanged.

Long term effects of exercise

a) Hypertrophy of the heart i.e. increase in size of the heart (cardiac muscle)
b) Increase in the stroke volume
c) Decrease in the resting heart rate
d) Increased maximum cardiac output
e) Increased volume of blood
f) Decrease in blood pressure when at rest
g) Increased in the number of blood capillaries

Internal factors affecting the heart beat

1. Body temperature
2. Blood pH
3. Carbon dioxide concentration
4. Partial pressure of oxygen
5. Hormonal balance
6. Salt balance
7. Blood pressure
8. Emotional situations
9. Impulses from the venacava and aorta

QN. Explain how change in each of the above factors may affect the heart beat

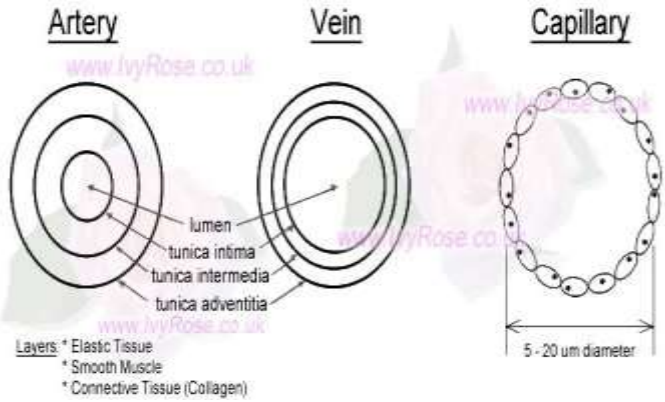
BLOOD VESSELS

There are three main types of blood vessels; arteries, veins and capillaries. The walls of these blood vessels occur in three layers, namely; **(1)** Tunica externa (outer most layer), **(2)** Tunica media (middle layer) & **(3)** Tunica interna (inner most layer)

Tunica externa, this is the outermost layer which is tough and made up of thick collagen fibres which provide strength and prevents extensive stretching.

Tunica media is the middle layer which consists of smooth muscles, collagen and elastic fibres. The structural proteins allow for the stretching of the walls of blood vessels during vasodilation. The smooth muscles allow for the distension and constriction of the walls of the blood vessels.

Diagrams showing the transverse sections of the vein, artery and capillary



Tunica interna is the innermost layer composed of a single layer of squamous endothelium. It is found in all walls of blood vessels. Capillaries have only the tunica interna

Arteries transport oxygenated blood from the heart to the tissues except the pulmonary artery which transports deoxygenated blood from the heart to the lungs while veins transport deoxygenated blood from tissues to the heart except the pulmonary vein which transports oxygenated blood from the lungs to the heart. Therefore ***arteries*** can be defined as blood vessels which transport blood away from the heart and ***veins*** are defined as blood vessels which transport blood from the tissues to the heart.

Comparison between arteries and veins

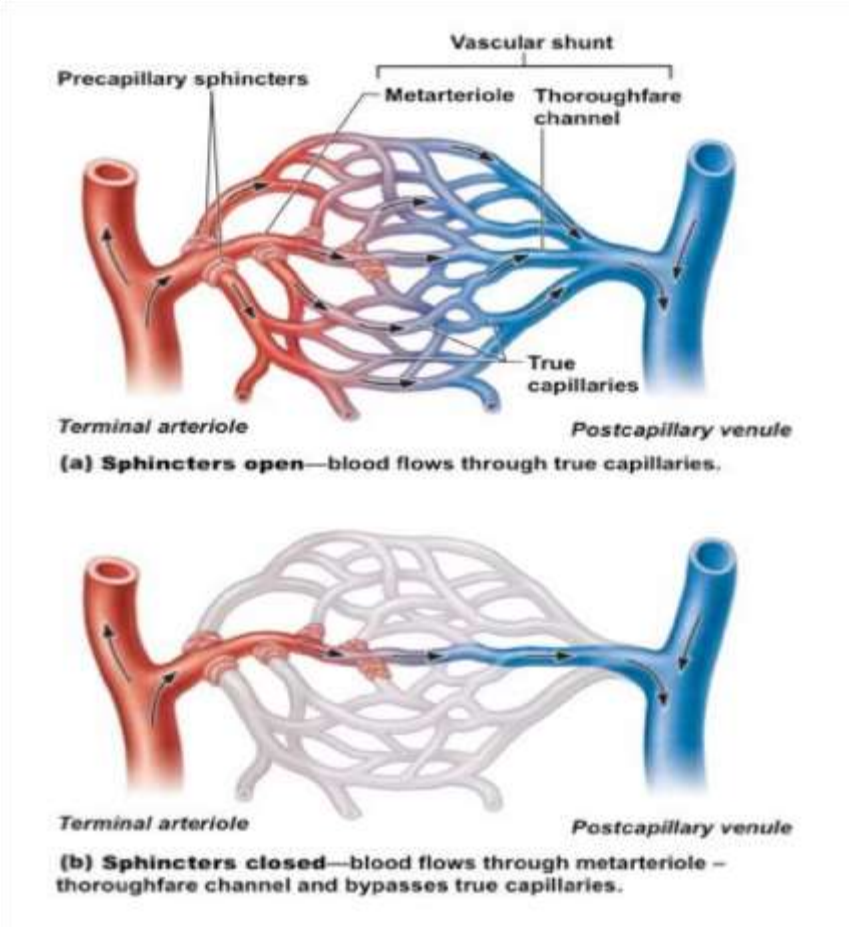
1. Both tunica media and tunica externa are more developed in arteries than veins and therefore arteries have thicker walls than those of veins. Arteries have thicker walls than veins because blood flows through them at a higher pressure than in the veins, due to the pumping action of blood by the heart. Arteries therefore have thicker walls to counteract the pressure by which blood moves through them. The capillaries lack both the tunica externa and the tunica media.
2. In addition the walls of the arteries are more elastic than those of veins, in order to overcome the pressure by which blood flows through them by rapidly stretching without bursting.
3. Also arteries have a narrower lumen than veins, which increases the pressure of the blood flowing through them.
4. Arteries also lack valves while veins haves valves which prevent the backflow of blood in veins. However, arteries do not need valves since they transport blood under high pressure, which pressure ensures that blood flows forward

Adaptations of blood Diagram showing the capillary network capillaries Clegg fig 17.18 pg 353

1. They possess the capillary sphincter muscles which contract and relax so as to regulate the amount of blood entering into the capillary network.
2. Some capillaries have a bypass arterio-venous shunt vessel which links the arterioles and venules directly so as to regulate the amount of blood which flows through the capillary network e.g. in the capillaries of the feet, hands, stomach e.t.c.
3. They are numerous in number to provide a large surface area which increases the rate of diffusion and allows rapid

exchange of materials between blood and the tissue fluid.

4. The capillary network offers maximum resistance to blood flowing through them hence decreasing the speed of blood flow which allows the maximum diffusion and exchange of materials between blood and the tissues. Blood capillaries are the smallest blood vessels found in close contact with tissues in form of a dense network which allows a high rate of diffusion of materials during their exchange between the blood circulatory system and the tissues.



5. They have a thin and permeable membrane which is made up of thin flattened pavement cells which allow rapid diffusion and exchange of materials between blood and tissues with minimum resistance.

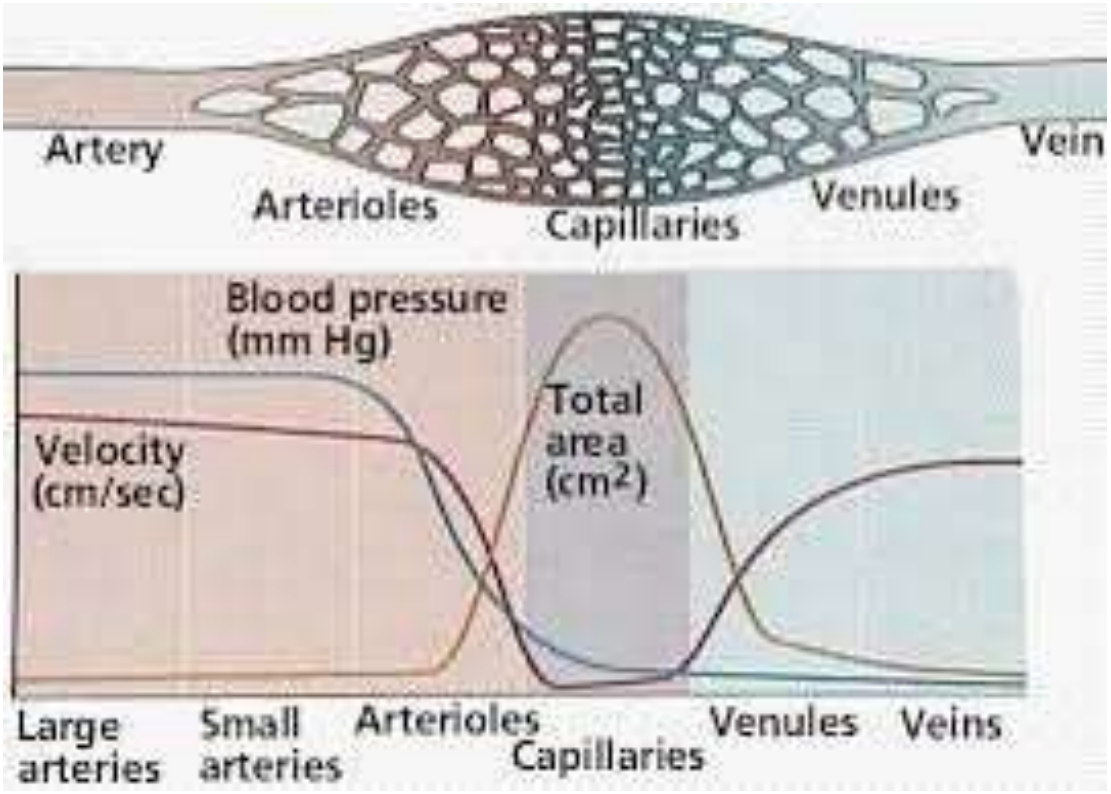
Adaptations of veins to their function

1. The elastic layer is relatively thin because blood is under low pressure, cant cause them to burst and the pressure is too low to create a recoil action
2. The muscular wall is relatively thin because veins carry blood away from tissues and therefore their dilation and constriction cannot control the flow of blood to the tissues
3. The collagen fibres provide a tough outer layer in order to prevent the veins bursting from the external forces
4. There are semilunar valves throughout to ensure that blood does not flow backwards, which it might otherwise do because the pressure is so low.
5. The overall thickness of the wall is small because there's no need for a thick wall as the pressure within the veins is too low to create any risk of bursting.
6.

Blood flow velocity

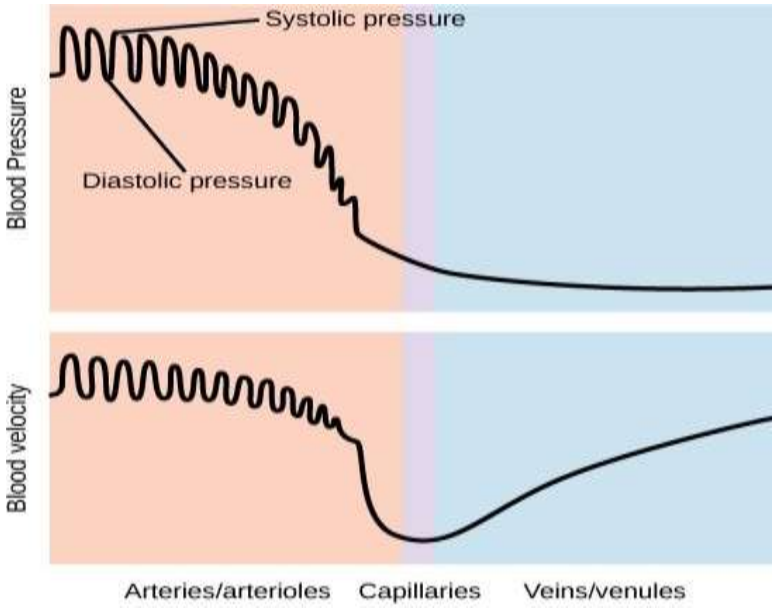
The speed of blood flow reduces as it moves from arteries to arterioles to capillaries. Each artery conveys blood to so many capillaries that the total cross-sectional area is much greater in capillary beds than in the arteries or any part of the circulatory system. The result is an decrease in velocity from the arteries to capillaries than in the aorta.

The reduced velocity of blood flow in capillaries is critical to the function of the circulatory system. Capillaries are the only vessels with walls thin enough to permit the transfer of substances between the blood and interstitial fluid. The slower flow of blood through these tiny vessels allows time for exchange to occur. After passing through the capillaries, the blood speeds up as it enters the venules and veins, which have smaller total-sectional areas

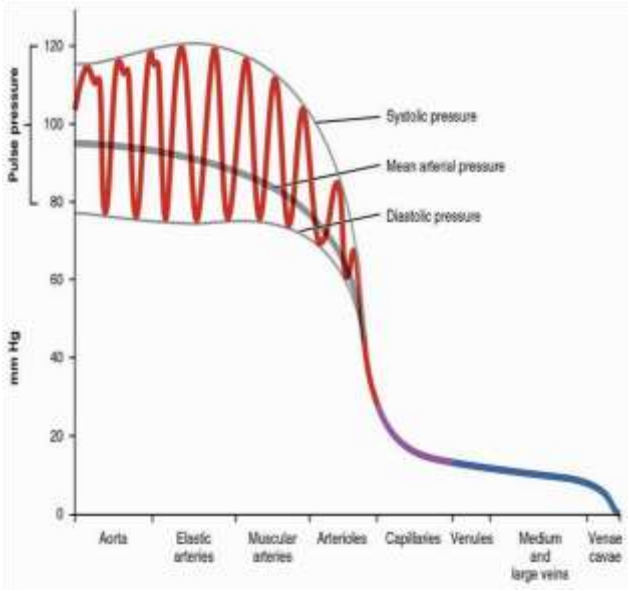


Blood pressure

Contraction of the heart ventricle generates blood pressure, which exerts a force in all directions. The force directed lengthwise in artery causes the blood to flow away from the heart, the site of highest pressure. The force exerted against the elastic wall of an artery stretches the wall, and the recoil of the arterial wall plays a critical role in maintaining blood pressure, and hence blood flow, throughout the cardiac cycle. The numerous arterioles and capillaries offer resistance to blood flow hence reducing the blood pressure.



Changes in blood pressure during the cardiac cycle Blood in arteries moves inform of **pulses** while in veins is flows smoothly without any pulse. ***A pulse*** is a series of waves of dilation that pass along the arteries caused by the pressure of the blood pumped from the heart through contractions of the left ventricle. Arterial blood pressure is highest when the heart contracts during ventricular systole, this is systolic pressure, which causes the expansion of the arterial wall. This is also due to the narrow openings of arterioles impeding the exit of blood from arteries. Hence, when the heart contracts, blood enters the arteries faster than it can leave, and the vessels stretch from the rise in pressure.



During diastole, the elastic walls of the arteries snap back. As consequence, there's a lower but still substantial blood pressure when ventricles are relaxed (diastolic pressure). Before enough blood has flowed into the arteries to completely relieve pressure in the arteries, the heart contracts again. Because the arteries remain pressurized throughout the cardiac cycle blood continuously flows into arterioles and capillaries.

NOTE:

Blood is expelled from the heart only when it contracts. Blood flow through the arteries is therefore *intermittent*, the blood flowing rapidly during systole and slowly during diastole. However, by the time the blood reaches the capillaries it is flowing evenly. The gradual change from intermittent to

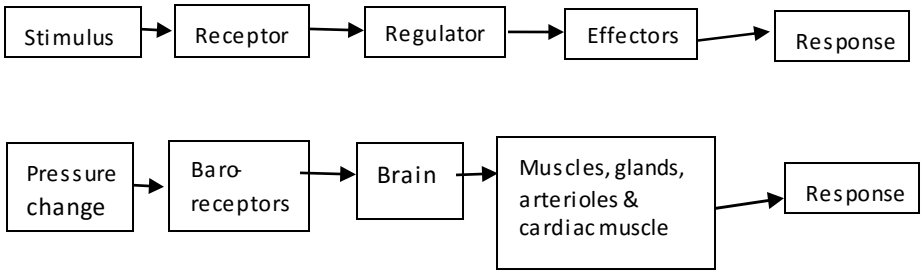
even flow is made possible by the elasticity of the of the arterial walls which contain elastic tissue and smooth muscles

Control of blood pressure

Small receptors which are sensitive to stretching, called **baro receptors** are found in the walls of aortic arc, carotid sinuses, vena cava and the right atrium become stimulated when blood pressure increases above the norm. They fire impulses to the vasomotor centre and cardio vascular centre found in the medulla oblongata of the brain via the afferent nerves (sympathetic nerves). The cardio vascular centre sends impulses to the heart via the efferent nerves (vagus nerves), which results into reduction of the cardiac output. The vasomotor centre on receiving impulses, its sympathetic output is suppressed and this lowers the blood pressure by causing vasodilation of the arterioles

When the blood pressure lowers below the norm, the baro receptors stop being stimulated and this leads to impulses being fired from the cardio vascular centre to heart. The cardiac output is then increased. Decrease in blood pressure also increases the vasomotor centre sympathetic output which results into vasoconstriction of the arterioles hence increasing the blood pressure back to normal.

NOTE: When the arterioles constrict (vasoconstriction) blood pressure is raised and when they dilate (expand) the blood pressure decreases.



The brain includes the vasomotor, cardiovascular

Note:-Blood pressure depends on the following factors;centre and the medulla oblongata

1. Blood volume
2. Force of the heart
3. Blood vessel radius/ diameter of the lumen
4. Blood volume is adjusted to some extent through contraction of the spleen and liver which bring stored blood into circulation. The stored blood is due to the regulation of the fluid intake and fluid loss by organs such as the kidney and the skin during homeostasis.

Blood vessels offer resistance Clegg fig 17.17 pg 352 OR Soper fig 14.26 pg 477]

(R) to blood flow. The resistance is inversely proportional to the fourth power of the radius **(r)** of the vessel **($R \alpha \frac{1}{r^4}$).** Therefore,

the resistance increases as the vessel becomes narrower and since we are dealing with the fourth power of the radius, small changes in the arterioles radius will make a large difference to the resistance.

Note:-Blood pressure depends on the following factors;

- Blood volume
- Force of the heart (cardiac output) i.e. blood from the ventricles
- Blood vessel radius/ diameter of the lumen i.e. resistance to blood flow

Blood volume is adjusted to some extent through contraction of the spleen and liver which bring stored blood into circulation. The stored blood is due to the regulation of the fluid intake and fluid loss by organs such as the kidney and the skin during homeostasis.

Blood vessels offer resistance **(R)** to blood flow. The resistance is inversely proportional to the fourth power of the radius **(r)** of the vessel **($R \alpha \frac{1}{r^4}$).** Therefore, the resistance increases as the vessel becomes narrower and since we are dealing with the fourth power of the radius, small changes in the arterioles radius will make a large difference to the resistance.

Blood pressure is **increased** by;	Blood pressure is **decreased** by;
1. Increased cardiac output e.g. during exercise	1. decreased cardiac output e.g. during sleep or rest
2. Increased resistance to blood flow e.g. vasoconstriction and atherosclerosis	2. decreased resistance to blood flow e.g. vasodilation
3. Increased blood volume e.g. due to retention of water by the kidney under the influence of ADH	3. decreased blood volume e.g. during loss of blood due to injury

DEFENCE AGAINST DISEASES

Every mammal is equipped with a complex system of defensive mechanisms which are designed to enable it prevent the entry of microbes into it, to withstand attacks by pathogens (disease causing micro-organisms) and to remove foreign materials from the system.

The defensive mechanisms of blood include the following;

1. Clotting of blood
2. Phagocytosis
3. Immune response to infection

Clotting of blood

When a tissue is wounded, blood flows from it and eventually coagulates to form a blood clot which covers the entire wound. This prevents further blood loss and entry of pathogens. The process of blood clotting is described below.

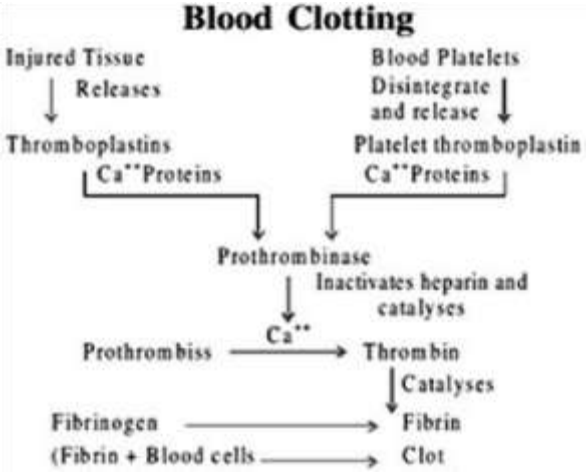
When blood platelets and damaged tissues are exposed to air, the platelets disintegrate and release an enzyme called **thromboplastin** or **thrombokinase,** which in the presence of plasma proteins and calcium ions catalyses

Thrombin is a proteolytic enzyme that hydrolyses a plasma protein called **fibrinogen** into an insoluble protein called Fibrin forms fibres at the wounded area. Within the fibrous network of fibrin blood cells become trapped, thereby forming a fibrin clot or a blood clot. The clot not only prevents further blood loss, but also prevents the entry of bacteria and other microbes which might otherwise cause infection

Note:
Heparin is an anticoagulant which inhibits the conversion of prothrombin to thrombin thereby preventing blood clotting.
Apart from blood clotting, the entry of microbes into the body can be prevented by the following;

1. Using impermeable skin and its protective fluid called sebum (oily secretion in the skin)
2. Using mucus and cilia to trap the microbes and then remove them
3. By using hydrochloric acid in the stomach
4. By using lysozyme enzyme in the tears and nasal fluids
5. By vomiting and sneezing

(Clegg fig 17.41 pg 365)



Why blood does not clot in the vessels

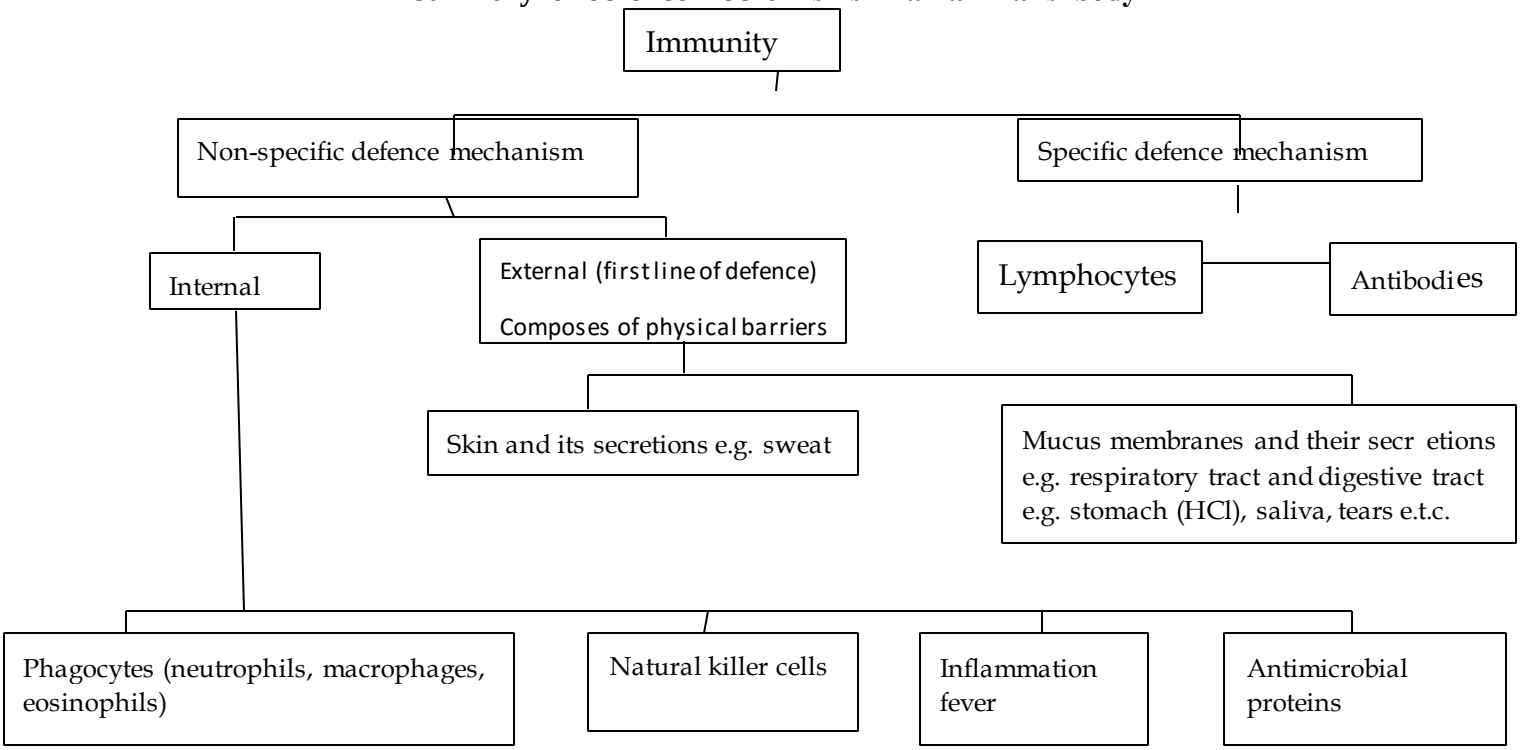
Connective tissue plus the liver produce chemical, heparin, which prevents the conversion of prothrombin to thrombin, and fibrinogen to fibrin.

Blood vessels are smooth to the flow of blood. Damage to the vessel's endothelium can lead to platelets breakdown which leads to clotting of blood.

BODY DEFENCE SYSTEM AND MECHANISM IN MAMMALS (HUMANS)

An animal must defend itself against unwelcome intruders e.g. dangerous viruses and other pathogens it encounters in the air, water and food. The body also deals with abnormal cells (cancer cells) that develop periodically in the animal's body.

A summary of defence mechanisms in an animal's body



Two comparative defensive systems are used to fight pathogenic and abnormal cells in the body. One of the system is **non-specific** in nature i.e. it does not distinguish one infectious agent from another. The other defence system is **specific** in nature and constitutes the **immune system**. The non-specific system includes two lines of defence which an invader encounters in sequence. The first line of defence is external comprising of epithelial tissues that cover and line our bodies (skin and mucus membranes) and other secretions these tissues produce. The second line of non-specific defence is internal. It is triggered by chemical signals and uses antimicrobial proteins and phagocytic cells that indiscriminately attack any invader that penetrates the body's outer barrier (inflammation is a sign that the second line of defence has been deployed).

The immune system constitutes a third line of defence which comes into place simultaneously with the second line of specific defence. However, the immune system responds specifically to a particular type of invader. This immune response includes the production of specific defence proteins called **antibodies**. It also involves participation of several different types of cells that are derived from the white blood cells called **lymphocytes**.

NOTE: the non-specific defence system which involves use of phagocytes, natural killer cells and antimicrobial proteins is said to offer innate immunity (defence) which is abroad defence mechanism against infection. The immune response offers a specific defence against infection. It is also described as **acquired immunity**. Immunity is the ability of an organism to resist infection or to counter the harmful effects of toxins produced by infecting organisms.

NON SPECIFIC DEFENCE MECHANISM

The non-specific defence mechanism act in 6 ways i.e

1. Through physical barriers e.g. skin.
2. Phagocytosis.
3. Natural killer cell.
4. Anti-microbial proteins.
5. Inflammation.
6. Fever

THE SKIN AND MEMBRANES

This is the first line of defence and it takes a different number of forms.

The intact skin is a **(1) barrier** that cannot be penetrated by bacteria or viruses, although minute abrasions allow their passage [some pathogens such as the malarial parasite *Plasmodium*, use a vector, the mosquito, to penetrate this covering and so gain entry to the body]. In the same way, the **(2) (a) mucus membranes** which line the digestive, respiratory and urinal genital tracts prevent the entry of potentially harmful microbes [such areas cannot be covered by a thick layer of skin due to the body's need to obtain and lose substances by diffusion]. Mucus, which is a viscous secreted by cells of the mucus membranes also traps particles that contact it. Microbes entering the upper respiratory system are caught in the mucus and are then swallowed or expelled. The lining of the trachea has specialized epithelial cells equipped with cilia which sweep out microbes and other particles trapped by mucus, preventing them from entering the lungs.

Apart from their role as physical barriers, the skin and mucus membranes produce secretion that counter pathogens e.g. in humans, secretions from the **(b) oil and sweat gland** give the skin a pH ranging from 3-5 which is acidic enough to discourage micro-organism from colonizing there, bacteria that make the normal flora of the skin are adapted to its acidic relatively dry environment. **(c) Saliva, tears** and mucus secretions that bathe the surface of the exposed epithelia wash away many potential invaders and in addition to these secretions contain various antimicrobial proteins. For example the enzyme cysozyme which digests the cell walls of many bacteria, destroys many microbes entering the upper respiratory system and openings around the eyes.

Microbes present in food or trapped in swallowed mucus, from the upper respiratory system pass, through the highly **(3) acidic gastric juice** produced by the stomach lining which denatures the enzymes of most of the macrobes before entering the intestinal tract.

Despite these precautions, **pathogens** still frequently gain entry and therefore the body has a second line of defence, a series of specific cellular and chemical defecnces designed to;

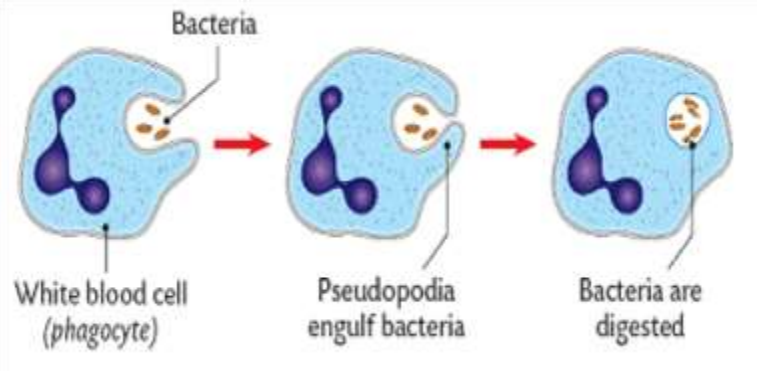
- neutralise any toxins produced by the pathogens
- prevent the pathogen multiplying
- kill the pathogen
- remove any remains of the pathogen

Phagocytic defence mechanism

Phagocytosis is the process by which large particles are taken up by cells, in the form of vesicles formed from the cells surface membrane. **Two types of white blood cells (1) neutrophils** and **(2) monocytes** are attracted by chemicals released by body cells which have been damaged by invading pathogens. These white blood cells show **amoeboid movements** which engulf, ingest and destroy

pathogens. They are known as **phagocytes** and are produced in the marrow of the long bones. Neutrophils can squeeze through blood capillary walls a process called **diapedesis** and move about in tissue spaces. The monocytes migrate out of blood stream then become larger white blood cells (leucocytes) called **macrophages**. Some macrophages are permanently located in tissues and organs such as the liver, spleen, kidney and lymph nodes while other circulate throughout the body. The term macrophage means "**big eater**" and these cells are long lived phagocytes which even engulf much larger particles like old red blood cells and protozoan parasites.

- **Antibodies** attach themselves to **A drawing to summarize the phagocytic process antigens** on the surface of the **affected by neutrophil, macrophage or monocytes.**



bacterium

- Proteins, found in the plasma, attach themselves to the antibodies
- As a result of a series of reactions, the surface of the bacterium becomes coated with proteins called **opsonins**. This process is called **opsonisation**.
- Complement proteins and any chemical products of the bacterium act as attractants, causing neutrophils to move towards the bacterium.
- Neutrophils attach themselves to the opsonins on the surface of the bacterium Neutrophils engulf the bacterium to form a vesicle, known as a **phagosome.**
- **Lysosomes** move towards the vesicle and fuse with it
- The enzymes within the lysosomes breakdown the bacterium into smaller, soluble materials
- The soluble products from the breakdown of the bacterium are absorbed into the cytoplasm of the neutrophils.

Note: The **eosinophils** have low phagocytic activity but are critical to defence against multicellular parasitic invaders such as the blood fluke (*Schistosoma mansoni*) they rarely engulf such a large parasite but position themselves against the parasites body and then discharge destructive enzymes which damage the invader

Inflammation

An inflammation is a localized non-specific response initiated by the defence system of the body due to physical damage to the skin or mucus membranes by bacteria. This physical damage causes **(1)** release of chemical signals such as **histamine** and **prostaglandins**. **(2)**The chemical signals induce increased permeability of the blood capillaries to blood components and **(3)** the flow of blood to the affected area respectively [having increased blood flow causes the area to swell]. **(4)** They also attract phagocytic cells and lymphocytes which on arrival at the site of injury, the **phagocytes** consume pathogen (the area becomes warm and pale red in colour) and the cells debris and consequently the tissue heals

Note. it is the damaged cells and certain leucocytes that produce histamine and prostaglandins. The histamine cause vasodilatation i.e. the capillaries dilate and the walls become leaky. As more fluid collects around the wound, the site becomes red, swollen and warm. The localized swelling is called **oedema**. The prostaglandins are the ones that promote blood flow to the site of injury and increase the sensation of pain.

Natural killer (N.K) cells

This is a class of white blood cells which attack virus injected body cells and abnormal cells that could form tumours.

The virus infected cells have viral proteins displayed on their surfaces and these are recognized by the natural killer cells contains perforin – filled vesicle.

When an N.K encounters a virus infected cell, perforin molecules are released by exocytosis. Perforin molecules make large holes of pores in the turgid cells plasma membrane, causing leakage of the cytoplasmic contents. This results into cell death. The membrane of NK cell is not affected by these membranes dissolving molecules

FEVER

Fever refers to increase in body temperature. It is triggered if microbes infect larger areas of the body in response to infection, certain leucocytes releases pyrogens which are also anti-microbial protein of the complement system. The pyrogen stimulate the hypothalamus to rise the body temperature set point from its normal value about 39^0C hence casing a fever. The fever has several beneficial effects; It increases the activity of phagocytes which then attack the invading microbes more efficiently. It increases the production of interferon in virus infected cells. Interferons are proteins which inhibit viral replication, activate natural killer and stimulate macrophages to destroy tumour cells and virus infected cell

ANTIMICROBIAL PROTEINS

These are proteins that function in the mechanisms by attacking microbes directly of by impeding the production e.g. lysozyme.

Other antimicrobial proteins include about 30 serum proteins that make up the complement system proteins through a sequence of stops, leading to lysis (bursting) of invading cells.

Some complement proteins initiate inflammation and also play a role in acquired defence

(specific defence system) interferon is one of the proteins of the complement system which provides innate defence against viral infection the interferon protein is secreted by virus infected body cells and induce neighbouring uninfected to produce other substances that inhibit viral reproduction. In this way, inteferons limit the cells spread of viruses in the body helping control of viral infections such as colds and influenza.

SPECIFIC DEFENCE SYSTEM /IMMUNE SYSTEM

The specific immune response confers immunity against specific microbes and it depends on a type of whte blood cells called **lymphocytes**. Immunity is the capacity of an organism's body to

recognize the intrusion of foreign materials in the body and mobilize cells and cell products (**antibodies)** to remove a particular sort of foreign material to a greater speed and effectiveness. The specific defence system involves immune system whose response result from the interaction among several types of lymphocytes, the molecules they produce (antibodies) and the foreign material introduced by microbes (**antigens**)

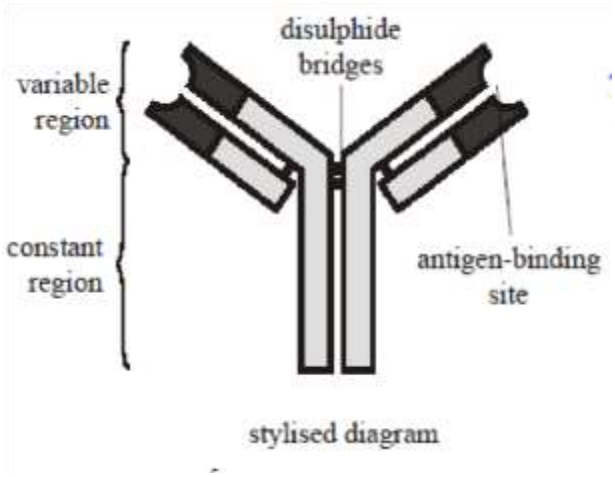
Molecules of the immune system

a) Antigens

An antigen is any organism or substance that is recognised as non-self (foreign) by the immune system and provokes an immune response. Antigens are usually proteins that make up the cell surface membranes of invading cells, such as microorganisms, or diseased ones, such as cancer cells. The presence of an antigen triggers the production of an antibody as part of the body's defence system.

b) Antibody

This is a specific protein (immunoglobin) which recognizes and binds to specific antigens. Antibodies either neutralise antigens or tag cells that are antigens for easy attack by macrophages. They are synthesised by cells in the blood called **B-lymphocytes**.
Note: Macrophages are also taken to be part of the immune response i.e. involved in specific defence mechanism through indirectly since they are phagocytes which destroy microbes and alert other immune cells the infection.



stylised diagram

How antibodies work

An antibody does not directly destroy an antigenic invader. However specific antibodies bind to specific antigens, in the same way a key fits a lock, to form an antigen antibody complex which is the basis for several effector mechanisms which make macrophages recognize the antigens and destroy them. The binding of antibodies to antigens is very specific and takes various forms, some of which include the following:

- **Neutralisation**

Here the antibody blocks certain sites on an antigen or **toxins** (chemicals that cause many of the symptoms of a disease) making it ineffective. Antibodies neutrallise a virus by attaching to the sites the virus uses to bind to its host cell. Also bacterial toxins become coated with antibodies hence getting neutralised, eventually, phagocytic cells (macrophages) destroy these antigen-antibody complexes.

- **Agglutination** (**clumping**)

This is when antibodies cross link adjacent antigens. This is made possible because certain antibodies possess at least two antigen binding sites. The clumping of antigens e.g. bacteria

makes it possible to be recognized by macrophages and other phagocytes which destroy the antibody-antigen complex

- **Precipitation**

This is a similar mechanism to agglutinations, except that here the antibody-antigen complexes are formed with soluble antigen molecules rather than cells are linked to form immobile precipitates which are captured by phagocytes and macrophages that destroy them i.e. soluble antigens are precipitated out so that they are easily destroyed by phagocytes.

- **Opsonisation**

Here, the antibody molecule oats the surface of a microbe making it easier for **phagocyte** and **leucocytes** to engulf it.

- **Lysis**

Having attached themselves to antigens on foreign cells, antibodies then attract other compound which bind to them. These include enzymes which help to break down the foreign cells.

- **Complement fixation**

Here, the antibodies activate the complement proteins which then leads to lysis of foreign cells.

c) **Epitopes**

These are antigens determinants with specific sequences of amino acids that confer as specific shape to the antigen molecules which is then recognized by an antibody or T-cell receptor. An antigen can have several different epitopes on its surface and different antibodies can therefore bind a single antigen.

d) **Cytokines** (**lymphokines**)

These are peptides and proteins that regulate many cell activities (growth and repair) and act as signal in both the specific and non-specific immune responses

Examples of cytokines include

 Interferons Interleukin

e) **Complement system.**

This is a group of about 20 proteins found in plasma and other body fluid. These are inactive until the body is exposed to antigens e.g. histamines.

Mechanism of immune responses

The immune response depends on a type of white blood cell called a **lymphocyte** formed in stem cells found in the bone marrow. There are two types of lymphocytes each with its own immune response to antigens, namely:

a) **B lymphocytes** (**B cells**) - **humoral response** which involves antibodies which are present in body fluids or 'humour'. B-cells mature in the **B**one marrow.

b) **T lymphocytes** (**T cells**) - **cell-mediated response**. Which involves cells. T cells mature in the **T**hymus gland

Humoral response

The humoral immunity results in the production of antibodies which are secreted by B-cells, the antibodies circulate as soluble proteins in blood plasma and lymph, the fluids that were once called **humors**.

There are many different types of B- lymphocytes (close to 10 million) each producing a specific/different antibody which respond to one antigen.

When an antigen, e.g. a protein on the surface of a pathogen cells, enters the blood, or tissue fluids, it encounters numerous B cells. A few of these will carry the appropriate immunoglobin on their surface membrane and will attach to antigens on the surface of the pathogen or toxin. This attachment has a dramatic effect on the B-cell. If given the right signal from the T-helper cells, the B-cell divides rapidly by mitosis to produce a large number of daughter cells i.e. **a clone**. This is referred to as **polyclonal activation**. Some of these daughter cells develop into **plasma cells** which produce and secrete up to 2000 molecules of their specific antibody per second. These antibodies destroy the pathogen, and any toxins it produces. The plasma cells are therefore responsible for the immediate defence of the body against infection. This is known as the **primary immune response**. Finally some daughter cells develop into **memory cells** which remain in the circulation without secreting antibodies. They can live for decades circulating in the blood and tissue fluid until they encounter the same antigen at some future date.

Memory and secondary immune response

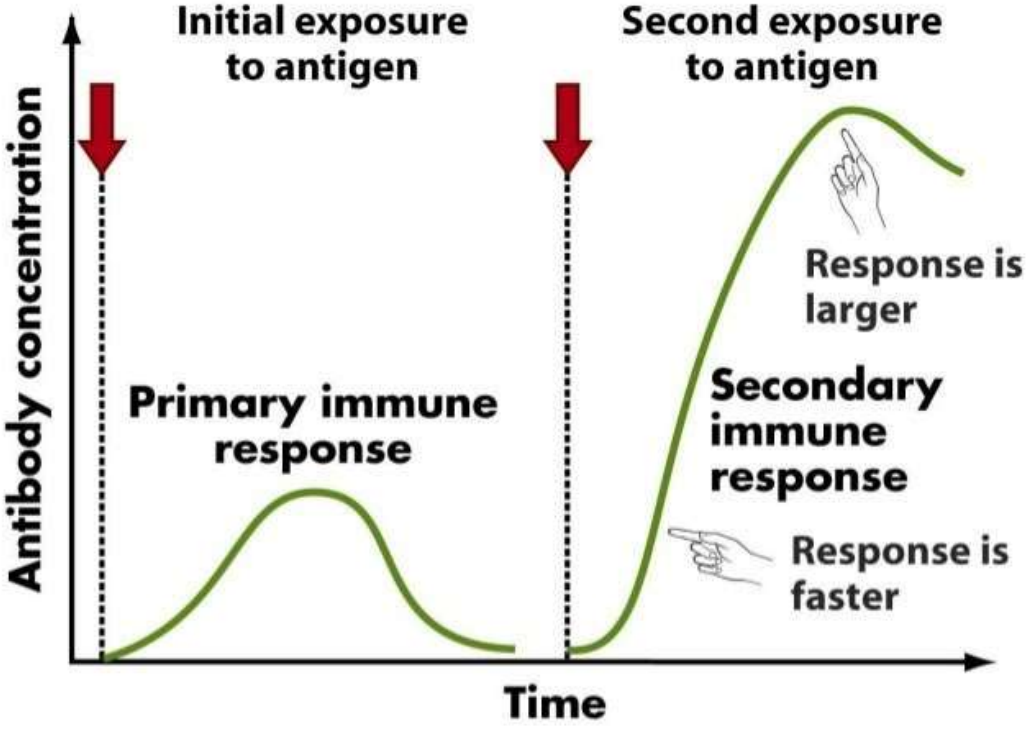
Memory cells function in secondary immune response. In primary immune response there is **selective proliferation** (multiplication) of lymphocytes to form clones of effector cell upon the first exposure to an antigen. Here there is a lag period between initial exposure to an antigen and maximum production of effector cells. During the lag period, the lymphocytes secreted by the antigen differentiates into effector T-cells

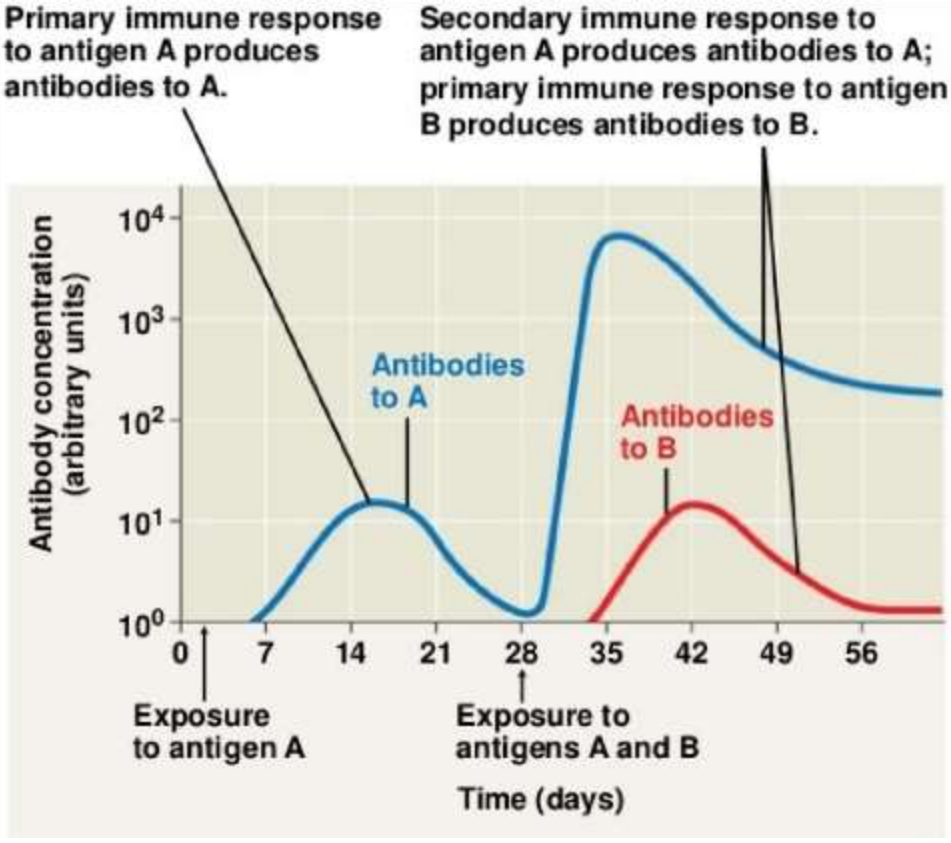
(TH and TC) and antibody producing plasma cells. If the body is exposed to the same antigen at a later time, the response is faster one/more prolonged than the primary immune response. This is the secondary immune response.

Secondary immune response is the rapid response that results in faster production of effector T cells and antibody-producing plasma cells, when the body is exposed to subsequent infection of the same antigen that has ever invaded the body. Antibodies produced during the secondary immune response are more effective in binding to the antigen than those produced during the primary immune response. The immune systems' ability to recognize an antigen as previously encountered is called **immunological memory**. The ability is based on long lived effector cells of the immune response, **memory cells.** These cells are not active, survive for long periods and proliferate rapidly when expose to the same antigen that caused their formation. Secondary immune gives rise to a new clone of memory cells as well as effector cells.

Graph to illustrate changes in antibody concentration during primary and secondary immune

responses to antigens





Cell mediated immune response.

In the cell mediated response, the immunity depends on the direct action of the T-lymphocytes rather than antibodies. T-lymphocytes only respond to antigens that are attached to a body cell (rather than

those within body fluids). T lymphocytes respond to an organism's own cells that been invaded by non-self material e.g. virus or cancer cell. They also respond to transplanted materials, which is genetically different. Invader cells are distinguished from the normal cells because:

a) macrophage cells that have engulfed a pathogen and broken it down, present some of the proteins produced on their own surface
b) body cells invaded by a virus also manage to present some of the viral proteins on their own cell surface membrane, as a sign of distress
c) cancer cells likewise display non-self proteins on their cell surface membrane. The non-self materials on the surface of these cells act as **antigens** therefore the term **antigenpresenting cells** is used to describe them. There are many different versions of the two main types of T lymphocytes each with a different receptor protein on its surface. Although these receptors function in a similar way, they are **not antibodies**, because they remain attached to cell rather than being released into the blood plasma.

Note: The circulating antibodies of the humoral branch of the immune response defends the body against toxins, free bacteria and viruses present in the body fluids. In contrast, lymphocytes of the cell mediated branch are active against bacteria and viruses inside the body's cells and against fungi, protozoa and worms. The cell mediated immunity is also involved in attacks on transplanted tissue and cancer cells both of which are perceived as non self.

Major cells in the immune system.

1. B-cells (B-lymphocytes)

These are lymphocytes that produce antibodies when stimulated. They are produced and mature in the bone marrows from the **stem cells**. They have glycoprotein receptors on their cell surface membranes which bind specific antigens. Mature B-cells become plasma cells and memory cells produce much more antibodies in terms of quantity and effectiveness than plasma cells.

2. T-cells (**T-lymphocytes**)

The T-lymphocytes regulate the immune response (in case of T_H-cells) or kill certain types of cells (Tc-cells) the T cells are produced in the bone marrow but mature in the thymus gland where they develop specific receptors which recognise specific antigens. These are two main categories of T cell namely:

a) **T cytotoxic cells (T killer cells)**, recognize and destroy cells with foreign antigens on their surface. They mainly attack virus infected cells, cancerous body cells and foreign grafted tissues. They kill not by phagocytosis but by making holes in the cell surface membrane using proteins called **perforins**. These holes allow water to rush into the cell, causing it to burst. Since viruses need living cells within which to reproduce, this sacrifice of body cells prevents viruses multiplying.
b) **T-helper cells**, play a key in the immune system. When they attach to an antigen-presenting cell, T helper cells secrete chemicals called **cytokines**. These cytokines:
    - stimulate macrophage cells to engulf pathogens by phagocytosis
    - stimulate B lymphocytes to divided and develop into antibody producing plasma cells activate T cytotoxic cells (T killer cells)

Both T helper and T cytotoxic cells produce their own type of memory cells, which circulate in the blood in readiness to respond to future invasions by the same pathogen.

Another type of T lymphocyte is the **T suppressor cells,** suppress the activity of the killer T-cells and B-cells after the microbes have been cleared out of the body to prevent these cells from attacking and destroying the body cells. Suppressor T-cells therefore regulate the immune response and prevents antibodies from being produced by the B-cells.

3. Memory cells

These are derived from B cells and T-cells. They are long lived and confer future immunity against subsequent infections by the same antigen i.e. they are the ones responsible for causing the secondary immune response.

Characteristics of the immune system

The immune system develops specific response against each type of foreign microbes, toxin or transplanted tissues.

The immune system has 4 features i.e.

a. Specificity. c. Memory

b. Diversity d. Self/non self-recognition.

a. **Specificity**

The immune system has the ability to recognize and eliminate particular microorganism, and foreign molecules. The immune system responds to an antigen by activating specialized lymphocytes and producing specific proteins called antibodies.

Antigens that trigger an immune response include molecules belonging to viruses, bacteria, fungi, protozoa and parasitic worms.

Anti-bodes recognize antigens using epitopes which are antigenic determinants on the surfaces of the antigens. If an antigen has several epitopes, it stimulates several different B cells which secrete specific distinct antibodies against it. Therefore each antigen has a unique molecular shape and stimulate the production of the very type of antibody that defends against that specific defences, each response the immune system targets a specific invader distinguishing it from other foreign molecules that may be very similar. b. **Diversity**

The immune system has the ability to respond to very many kids of invaders each recognized by its antigenic markers. This diversity of response is possible because the immune system is equipped with an enormous variety of lymphocyte population among the antibody producing lymphocytes (Blymphocytes) each population is stimulated by a specific antigen and response synthesizing and secreting the appropriate type of antibody.

c. **Memory**

The immune system has the ability to "remember" antigen encountered and react more promptly and effectively on the subsequent exposures. This characteristics also known as acquired immunity. d. **Self/non self-recognition**

The immune system distinguishes the body's own molecules from foreign molecules (antigens). Failure of self/non self-recognition leads to anti immune disorders in which the immune system destroys the body's own tissues

Types of immunity

The ability of an organism to resist infection may be naturally acquired or artificially induced. **Natural immunity** is immunity which is either inherited, or acquired as part of normal life processes, e.g. as a result of having had a disease. **Artificial immunity** is the immunity acquired as a result of deliberate exposure of the body to **antibodies** or **antigens** in nan-natural circumstances e.g. vaccines. Both natural and artificial immunity may be passively or actively acquired.

Types of natural immunity

a. Natural passive immunity

This involves passing antibodies in the body of an organism into the body of another organism of the same species e.g. from the mother to the foetus via to the placenta to defend the body against disease and also via the first milk called **colostrum** to the child. This type of immunity is temporary.

b. Natural active immunity

This is the immunity that involves formation of antibodies by the body of an organism in the presence of certain antigens.

This type of immunity is permanent because during the immune response, memory B-cells are produced which recognize the microbes on reinfection (second infection) and then stimulate the rapid production of large amounts of antibodies to curb down the microbes before causing significant damage. Memory B-cells stay for long in blood. It is for this reason that many people suffer diseases such as measles only once in a life time.

Artificial immunity

There are two types of acquired immunity namely:

a. **Artificial active immunity** depends on the response of a person's own immune system. Here the individual organism produces antibodies using the B-lymphocytes against the infectious agent. Active immunity is naturally acquired but it can also be artificially acquired by vaccination.
b. **Artificial passive immunity**. Occurs when antibodies from another individual are injected as in the treatment of tetanus.

NB. Passive immunity can also be transferred artificially by introducing antibodies from an animal or human who is already immune to the disease e.g. rabies is treated in humans by injecting antibodies from people who have been vaccinated against rabies. This produces an immediate immunity which is important because rabies progress rapidly and the response to vaccination would take too long.

EXPLANATION OF HOW THE KEY FEATURES OF AN IMMUNE SYSTEM ARE REALIZED DURING THE SPECIFIC DEFENCE MECHANISM.

SPECIFITY AND DIVERSITY

Immunological specificity and diversity is based on clonal selection of lymphocytes if the antigen enters the body and binds to receptors on the specific lymphocytes, the nasal those lymphocytes are activated to mount an immune response. The selected cells proliferate by cell division and develop into a large number of identical effector cells known a clone. This clone of cells combat the very antigen that provoked the response e.g. plasma cells that develop from that function as the antigen receptor on the original B-cell. Which first encountered the antigen. The antigen specific selection and cloning of lymphocytes is called clonal selection.

In clonal selection, each antigen by binding to specific receptors selectively activate a tiny traction of cells from the body's diverse pool of lymphocytes. These relatively small numbers of selected cells, all dedicated to eliminating the specific antigen that stimulated the humoral or cell mediated immune response.

N.B. Antigens are molecules (usually proteins, polysaccharides or glycoproteins carried on the surface of cells which cause antibody formation. All cells have antigen makers on their cell surface membranes but the body can distinguish between its own antigen (self) and foreign antigen (non self)

Self and non-self-recognition

Here, molecular markers on cell surface, function in self and non-self-recognition. The antigen receptors on the surface of lymphocytes are responsible for detecting molecules that enter the body. Normally, there are no lymphocytes that are reactive against the body's own molecules. Selftolerance begins to develop as T and B lymphocytes bearing antigen receptors mature in the thymus and bone marrow and continues to develop with receptors for molecules present in the body are destroyed or rendered passive (non-functional) leaving only lymphocytes that are reactive against foreign molecules tolerated by an individual's immune system, are a collection of molecules encoded by a family of genes called the Major Histocompatibility complex (MHC) two main classes of MHC molecules mark cells as self. Class 2 MHC molecules are restricted to a few specialised cell types of the body's defence system e.g. macrophages, B-cells and activated T-cells.

NB. Class 2 MHC molecules play an important role in interaction between cells of the immune system.

ABNORMAL IMMUNE FUNCTION

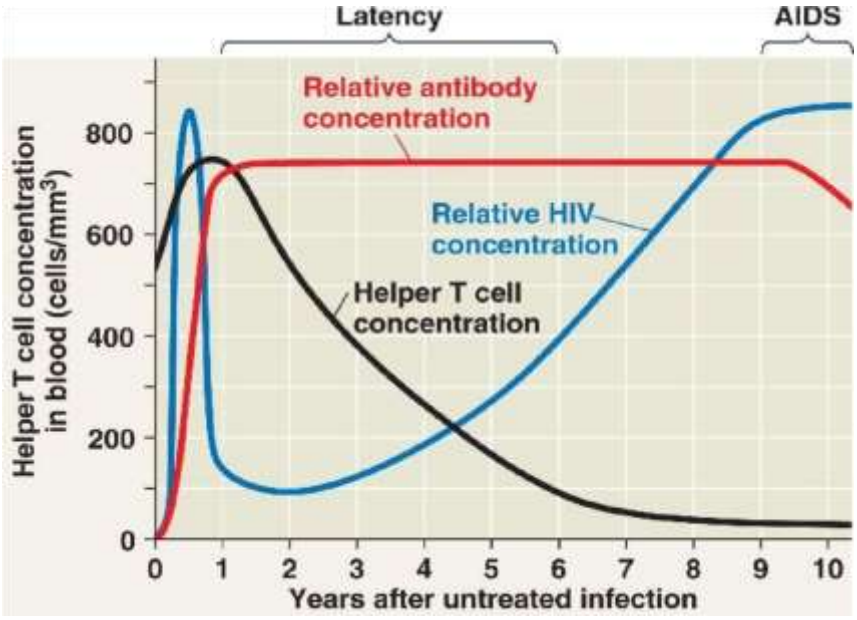
Sometimes, the immune system fails to defend the animal against intruders instead turns against the components of the body which leads to certain disease. Conditions immune system abnormalities include;

1. Auto immune disease.
2. Allergy.
3. Immune deficiency.

Acquired Immunodeficiency Syndrome (AIDS). AIDS is a disease caused by a virus called the **Human Immunodeficiency Virus** (**HIV**). HIV infects certain T cells, including helper T-cells, which carry a receptor called CD4 on their surface. Other cells with CD4 receptors include

macrophages and some B lymphocytes. Glycoproteins on the HIV envelope bind specifically to this receptor. Following attachment, the virus enters the cells and disintegrates, releasing RNA and an enzyme called **reverse transcriptase**. The enzyme causes the cell to translate the viral RNA into DNA. The viral DNA enters the nucleus and is incorporated into the cell's own DNA. Thus a gene representing the HIV becomes a permanent part of the infected person's CD4 lymphocyte cells. Newly formed viruses bud from the host cell, circulate, and infect other cells. The infected cells may produce new viruses by exocytosis for an extended time or may be killed quickly, either by the virus or by the response of the immune system. HIV may also remain latent for many years as a **provirus** assimilated into the genome of an infected cell. When the infected cell divides, it also makes a copy of the viral DNA. The provirus is invisible to the immune system because it does not produce viral proteins and infects the cells of the immune system itself, so impairing its ability to respond i.e. cannot be destroyed by circulating antibodies.

The ability of HIV to remain latent is one of the reasons why anti-HIV antibodies fail to eradicate the disease. Probably more important, however, are the extremely rapid mutational changes in antigens the virus undergoes during the infection. Indeed, every HIV probably differs in atleast one small way from its parent. The immune system responds effectively against HIV infection at first, but it is eventually overwhelmed by the accumulation of more resistant variants. In the ***figure below*** notice that the number of viruses gradually increase as the helper T-cell population (and hence the body's protection,) decreases. When the damage to the immune system reaches a certain point, cellmediated immunity collapses and secondary infections (opportunistic infections) e.g. Kaposi's sarcoma and pneumonia are established in the patient. [Remember that the major destructive cells of the immune system, T-cytotic and B cells, depend on stimulation by the T helper cells for their activity, inactivation of T helper cells knocks out the whole immune system]. Such infections are established in the late stages of HIV infection and are defined by a specified reduction of T- cells. These infections are called AIDS. The time from infection to AIDS varies, but it averages about 10 years. Death usually results from the opportunistic infections The progress of the disease from HIV infection to AIDS can be categorised into four phases.



(a) First phase Most individuals have no symptoms, although some may have flu-like symptoms, skin rash and swollen lymph glands.

(b) Second phase

Production of anti-HIV rises in the blood stream. Although the level of HIV in the blood falls, HIV replication continues in the lymph nodes. This phase may last from a few weeks to 13 or more years.

(c) Third phase

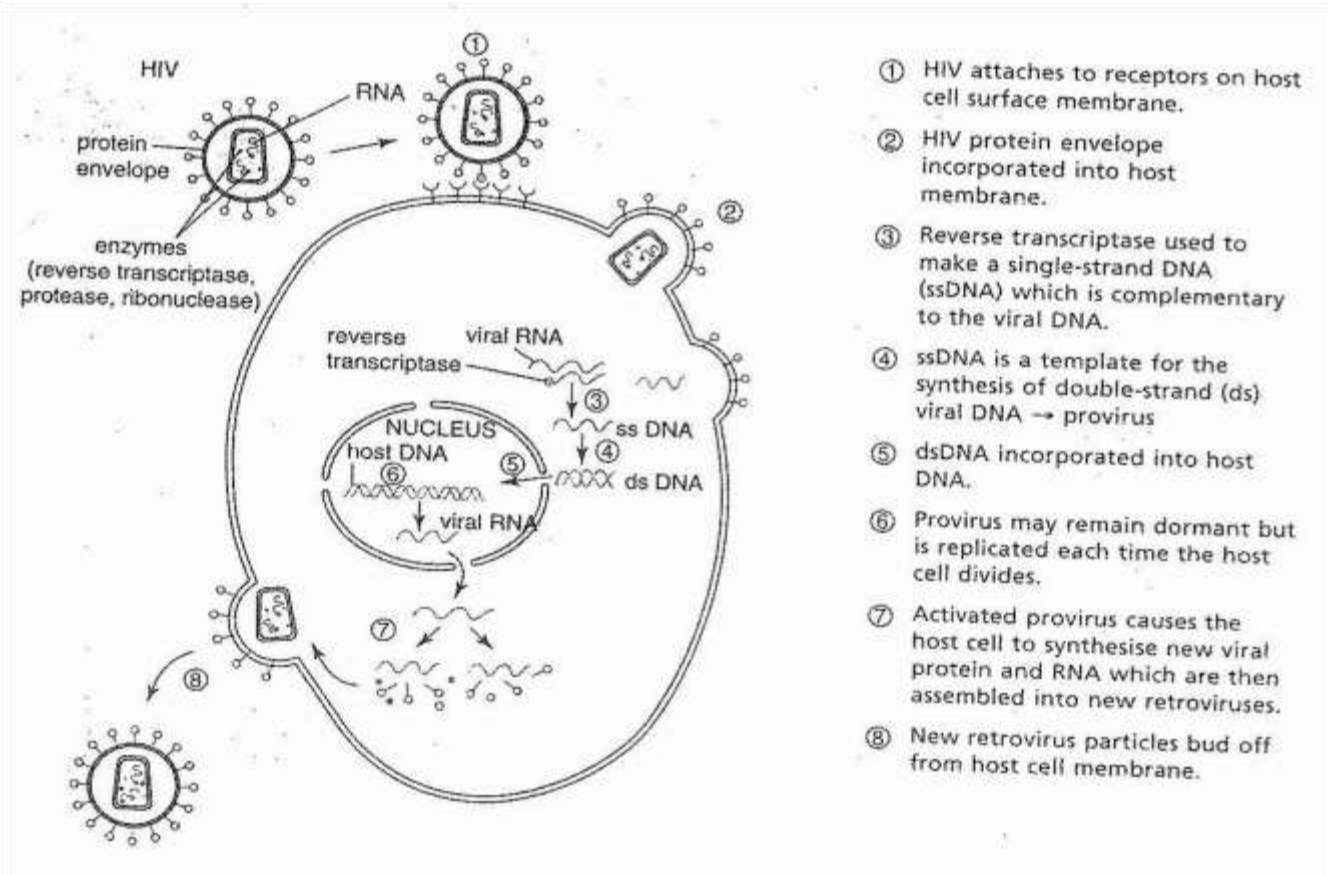
AIDS-related complex refers to the many **opportunistic** infections which affect the patient. These include common bacterial, fungal and viral infections such as oral and genital herpes and athlete's foot. The patient may lose weight and there is a significant drop I the number of T-helpers cells.

(d) Fourth phase

More opportunistic infections and the development of secondary cancers e.g. Kaposi's sarcoma. By this time, there is almost total loss of cellular immunity.

Note:

1. HIV can only survive in body fluids such as semen or blood
2. Individuals who have been exposed to HIV have circulating antibodies against the virus, and detection of these antibodies is the most common method for identifying infected individuals who are said to be **HIV-positive**.
3. HIV is not transmitted by causal contact or even kissing
4. At this time, AIDS is incurable.
5. For the present, the best approach for slowing the spread of AIDS seems to be to educate people about the practices that transmit HIV, such as unprotected sex (without a condom) and sharing needles. *Anyone* who has sex – vaginal, oral, or anal- with a partner who may have had unprotected sex with another individual during the past 15 years risks exposure to HIV.
6. Breast milk has transmitted the disease from mother to nursing infants.
7. We should avoid discriminating those of HIV i.e. stigmatism, rather we should offer help to them in any way that you can.



THE LYMPHATIC SYSTEM

The lymphatic system returns tissue fluid to the blood and also plays a role in the body defence. As blood passes through the capillaries, there is accumulative loss of fluid which is effected by

ultrafiltration of blood and this forms tissues fluid that bathes cells. The lost fluid is similar to blood in composition except that of lacks blood plasma proteins and cells. The lost fluid returns the blood via the lymphatic system. It enters the system by diffusion into tiny lymph capillaries which are intermingled among the capillaries of the cardio vascular system. Once inside the lymphatic system, the fluid is called lymph. The lymphatic system drains into the circulator system near the shoulders where it pours its contents on the **subclavian vein** that leads to the anterior vena cava.

Along the lymph vessels are specialized swellings called lymph nodes. These filter the lymph and attack bacteria, virus infected cells and other antigens using the lymphocytes in them.

When the body is infected by an antigen the cells in the **lymph nodes** multiply rapidly and the lymph nodes become swollen and tender. Like the veins of the cardio vascular system lymph vessels have valves which prevent back flow of fluids towards the capillaries. In the same way, lymph vessels depend on the movement of skeletal muscles to squeeze the fluid along the vessel.

N.B the lymphatic system serves to;

a) Defend the body against infection.

b) Maintains the level of interstitial fluid (tissue fluid).

c) Transports fats from the digestive tract to the circulatory system (the lymph capillaries called lacteals) penetrate the villi of the small intestine which absorb the fatty acids and glycerol. Whenever the interstitial fluid accumulates rather than being returned to the blood by lymphatic system, the tissues and body cavities become swollen a condition known as oedema.

Vaccines

Vaccines are toxic chemicals or killed or attenuated (weakened) microbes introduced into the body of an organism to make it produce very many antibodies against a certain pathogen.

The killed microbes are usually viruses and bacteria. The attenuated microbes are living microbes which are inactivated and they lack powers to infect the body due to the chemical or temperature treatment given to them.

Note; toxins are toxic chemicals produced by microbes and therefore can work as antigens

BLOOD TRANSFUSION

This is the transfer of compatible blood from the donor to the recipient.

Blood transfusion based on the ABO system of grouping blood

Blood group A has antigen A on the surface of its red blood cells and antibody b in the blood plasma of that person. Blood group B has antigen B on the surface of its red blood cells and antibody a in the blood plasma of that person. Blood group AB has antigen B and A on the surface of its red blood cells and no antibody in the blood plasma of that person. Blood group O has no antigen on the surface of its red blood cells and both antibody b and a in the blood plasma of that person.

Blood group	Antigen on the red blood cell membrane	Antibody in plasma
A	A	b
B	B	a
AB	A and B	Lacks antibodies
O	No antigens	a and b

Blood plasma permanently contains antibodies depending on a particular blood group. However these antibodies do not correspond to a specific antigen, if they correspond then agglutination occurs (precipitation of blood).

That is why an individual with blood A having antigen b cannot donate blood to an individual with blood group B having antibody a in the plasma which corresponds to antigen A to cause agglutination. Similarly, blood groups A and B cannot donate blood to an individual of blood group O because antigen A will be attacked by antibody a in blood group O and antigen B will be attacked by antibody b in blood group O to precipitate the recipient's blood. The table below summarizes the possible blood transfusions and the impossible ones.

Individuals with blood group AB posses antigen B which stimulates blood group B of the recipient to produce antibody a that reacts with antigen A in the donor's blood to cause agglutination and therefore this transfusion from AB to B is impossible. Similarly blood group O individuals can donate blood to blood group A because the donor's blood has no antigens which would react with antigen A in the recipient's blood and therefore agglutination is impossible.

Blood group compatibilities

Recipient		Donor's blood group			
Blood group	**Antibody in plasma**	**A**	**B**	**AB**	**O**
A	b	✓	X	X	✓
B	a	X	✓	X	✓
AB	None	✓	✓	✓	✓
O	a and b	X	X	X	✓

✓ = compatible with recipients blood **X** = Incompatible with recipient i.e. agglutination occurs

Individuals with blood group O are called **universal donors** because they lack antigens which would react with the corresponding antibodies in the recipient's blood. Individuals with blood group AB are called **universal recipients** because they lack antibodies in their blood plasma which would have reacted with the corresponding antigens in the donor's blood.

NOTE; the recipient's antibody is the one expected to attack and react with the corresponding antigen in the donor's blood. Whenever the antigen of the donor corresponds with the antibody of the recipient's blood group, an antibody-antigen reaction occurs, leading to agglutination (precipitation or clotting of blood)

RHESUS FACTOR (D-Antigens)

These are antigens which were first observed in the bodies of the Rhesus monkeys. These antigens are also carried on the surface of the erythrocytes of some human beings. Those people with D-antigens on the surface of their red blood cells are called Rhesus positive (Rh^+) while individuals missing such D-antigens are called Rhesus negative (Rh^-).

The bodies of individuals do not have already manufactured antibodies against the D-antigens. When an expectant mother who is Rh^- bears the foetus with which is Rh^+, some foetal erythrocytes with Dantigens will cross the placenta and enter into the blood circulation of the Rh^- mother towards the end of the gestation period (pregnancy). It is also possible for the blood of the foetus to mix with that of the mother during birth so that the mother gets Rh^+ by getting the D-antigens from the child.

The D-antigens that have entered the mother's blood circulation stimulate the maternal body to manufacture corresponding antibodies (antibody-d or anti-D antibodies) which attack and react with the D-antigens in the mother. Some formed antibodies-d can also pass via the placenta and enter the foetal blood circulation where they attack and react with the D-antigens which results into clumping together and bursting of the foetal red blood cells, a condition called **erythroblastosis foetalis** (Haemolytic disease of the new born). This disease results into acute anaemia which can lead to death of the feotus.

The first born rarely dies because the time is too short for the mother to produce enough antibodies that can pass to the foetus to cause death but subsequent Rh^+ foetus can die due to the many antibodies of the mother entering its circulation to cause agglutination.

To prevent this disease, pregnant mothers are always given anti-D chemicals 72hours to delivery, to render her immune system insensitive towards the D-antigen i.e. the mother may be infected with antibody-d within 70-72hours to delivery or within 72 hours after her first born. Also the blood of the foetus can be transfused with normal blood to dilute antibody-D so as to save the child.

NOTE: if a rhesus negative mother of blood group O is carrying a rhesus positive child of any blood group other than O, the problem will not arise. This is because if fetal cells enter the mother's circulation, the mother's **a** and **b** antibodies will destroy the blood cells before the mother has time to manufacture anti-rhesus antibodies.

UPTAKE AND TRANSPORT IN PLANTS

Water and mineral salts are necessary for photosynthetic reactions and other metabolic processes; hence they must be absorbed in sufficient quantities by using the root system and transporting them through the xylem to the mesophyll cells of leaves where photosynthesis takes place. Leaves have a large surface area to absorb light, and stomata to allow adequate inward diffusion of carbon dioxide, both result in an immerse loss of water.

Water is lost from the mesophyll cells into sub-stomatal air chambers and then eventually lost into the atmosphere of water vapour through tiny pores called "stomata" by a process known as **transpiration**.

TRANSPIRATION

This is the process of water loss inform of water vapour to the atmosphere from the plant mainly through the stomata pores.

Types of transpiration

There are three types of transpiration which include the following **(a)** Stomatal transpiration **(b)** Cuticular transpiration & **(c)** Lenticular transpiration

Stomatal transpiration

This is the loss of water vapour to the atmosphere through the stomatal pores of the leaves. This contributes 90% of the total water loss from a leafy shoot. This is because leaves contain a large number of stomata for gaseous exchange where this water vapour can pass and also there's little resistance to the movement of water vapour through the stomatal pores. In addition, leaves also have a large surface area over which water vapour can evaporate rapidly to the atmosphere.

Cuticular transpiration

This is the loss of water vapour to the atmosphere directly through the epidermis coated with a cuticle layer. It contributes 5% to the total water loss from the leafy shoot. This is because the cuticle is hard, waxy and less permeable to most diffusing molecules including water vapour molecules.

Lenticular transpiration

This is the loss of water vapour through a mass of loosely packed cells known as lenticels found scattered on the stems. It also contributes 5% of the total water loss to the atmosphere in a leafy shoot. It is because the lenticels are usually few in number and not directly exposed to environmental conditions. Lenticular transpiration is the main source of water loss from deciduous plants after shading off their leaves. Because there are more stomata on the leaves than elsewhere in the shoot system, it is evidence that most of the water vapour is lost from the leaves.

In order to establish that transpiration occurs mostly in the leaves, an experiment using absorptive paper, dipped Cobalt II Chloride solution or Cobalt II thiocynate solution is carried out. The paper is covered on the surface of both sides of the leaves and then clamped with glass slides. After some time, the blue cobalt thiocynate paper changes to pink, indicating the evaporation of water molecules from the leaf by transpiration. The rate of change from blue to pink is higher at the lower epidermis than the upper epidermis. This is because structurally there are more stomata on the lower epidermis to prevent excessive loss of water by transpiration due to direct solar radiation

Measuring the rate of transpiration

The rate of transpiration can be measured by either determining the rate of transpiration at which the plant loses mass due to water loss or the rate at which the plant takes in water (water uptake), using an instrument called a potometer.

Determining the rate of transpiration using

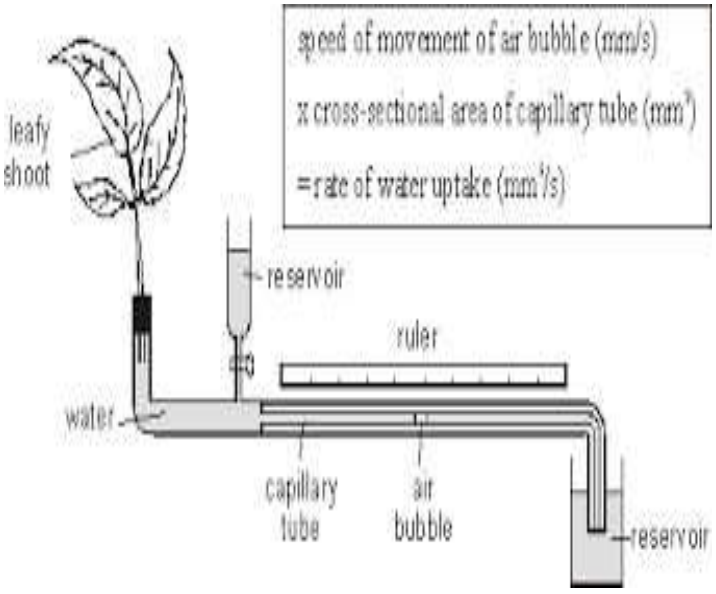
a. the weighing method

The rate of mass loss by the plant can be determined by using the potted plant placed on an automatic weighing balance whereby the change in mass is noted over a given period of time. Using this method, it is assumed that the mass loss is only due to water loss by transpiration. However, the whole pot must be enclosed in a polythene bag to prevent water from evaporating from the soil. In addition, the soil must be well watered before the beginning of the experiment so that the plant has enough water throughout the experiment. The rate of transpiration is then expressed in terms of mass lost per unit time

b. the potometer

The potometer is used to measure the rate of water uptake by the shoot of the leafy plant.

(Kent Fig 2 pg 276, Soper Fig 13.10 pg 439, Toole fig 22.12 pg 457)



However, since most of the water taken up is lost by transpiration, it is assumed that water uptake ≈ water loss. The leafy shoot is cut under water to prevent the air bubbles from entering and blocking the xylem vessels. The cut leafy shoot is immediately fixed in the sealed vessel and connected to the capillary tube. The rate of water uptake is then measured by introducing an air bubble at the end of the graduated capillary tube and the distance moved by the air bubble per unit time is noted.

To drive the air bubble back to the original position, water is introduced into the capillary tube from the reservoir by opening the tap on the reservoir.

The leafy area is also established by tracing the outline of the leaves on a squared graph paper and then counting the number of complete and incomplete squares enclosed in the outline

$$\text{Total area of leaves} = \text{Number of complete squares} + \text{Number of incomplete squares} \times \frac{1}{2}$$

The rate of transpiration is therefore expressed in terms of the volume of water taken up by the leafy shoot per unit time per unit leaf area. The structure of a potometer is shown in the diagram above.

Precautions taken when using a potometer

a. The leafy shoot used should have a significant water loss by having very many leaves
b. The stem of the leaf shoot must be cut under water to prevent air from entering and blocking the xylem vessels
c. The setup must have plenty of water
d. Ensure that only one bubble is present in the capillary tube
e. A well graduated scale must be used e.g. a ruler, so that clear readings are taken
f. The air bubble should always be reset to zero mark before the potometer is used again under different conditions
g. The water reservoir should be filled with water when setting the air bubble at the zero mark
h. The cut leafy shoot must be in contact with water in the sealed vessel

How to use a potometer

a. The leafy shoot is cut under water to prevent air bubbles from entering and blocking the xylem vessels. The cut leafy shoot is immediately fixed in the sealed vessel of water connected to a capillary tube. Allow time (5 minutes) for the apparatus to equilibrate. The rate of water uptake is measured by introducing the air bubble at the end of the graduated capillary tube and the distance moved by the air bubble per unit time is noted.
b. To drive the air bubble back to the original point, water is introduced into the capillary tube from the reservoir by opening the tap.
c. The leafy area is then established by tracing the outline of the leaves on squared papers and then counting the number of complete and incomplete squares in the outline of the leaves.
d. The rate of transpiration is therefore expressed in terms of the volume of water taken up by the leafy shoot per unit time per leafy area.

NOTE; since most of the water taken up by the potometer is lost by transpiration, it is assumed that water uptake = water loss.

Advantages of transpiration

a. It allows the uptake of water from the roots to leaves in form of a transpiration stream. This is due to a transpiration pull created in the leaves. This ensures proper distribution of water throughout the plant to keep it alive.
b. It facilitates the uptake of the absorbed mineral salts within the xylem vessels from roots to leaves
c. It brings about the cooling of the plant since as water evaporates to the atmosphere, excessive heat is also lost as heat of vaporization, which results into the cooling of the plant
d. It brings about mechanical support in non-woody or herbaceous plants, due to water uptake which provides turgidity to the parenchyma cells of the stem and leaves
e. It is important for cloud formation via evapotranspiration hence resulting into rainfall

Disadvantages of transpiration

a. It causes wilting of plants in case of excessive transpiration
b. It may eventually cause death of the plant, when the plant loses water excessively due to excessive transpiration

NOTE: **wilting is** the drooping of leaves and stems as a result of plant cells losing water osmotically and becoming flaccid. Evaporation occurs at rate greater than that at which it is absorbed, resulting into reduction in turgor pressure and dropping of the plant. It always takes place in hot and dry areas. Wilting also results into the closure of the stomata which cuts off gaseous exchange and therefore may cause death if it persists.

FACTORS AFFECTING TRANSPIRATION

The potometer may be used to investigate the effect of environmental factors on the rate of transpiration i.e. it can be moved to a windy place or a place which is dark. Transpiration is affected by both environmental and non-environmental factors.

ENVIRONMENTAL FACTORS

1. Humidity

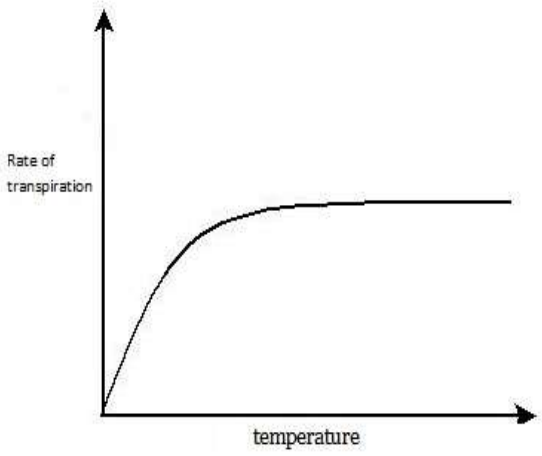
The humidity of the atmosphere affects the gradient of water vapour between the sub-stomatal air chamber and the atmosphere around the leaf i.e. it affects the rate of diffusion of water vapour. Low humidity (low water vapour pressure) outside the leaf increases the rate of transpiration because it makes the diffusion gradient of water vapour from the moist sub-stomatal air chamber to external atmosphere steeper.

When humidity is high in the atmosphere, the diffusion gradient or the water vapour pressure gradient is greatly reduced between the sub-stomatal air chamber and the atmosphere which results into reduction in the rate of transpiration.

In areas where humidity is too high, plants loose liquid water from their leaves via structures/glands on their leaf margins known as hydathodes, a process known as guttation. **Guttation** is the loss of liquid water from plant leaves (exudation) through hydathodes due to excessive humidity in the atmosphere. Guttation is common in young grass seedlings and rain forest plants due to the dim light and high humidity.

2. Temperature

Increase in temperature increases the rate of water loss by the leaves via transpiration. A decrease in temperature lowers the rate of water loss by the plant leaves via transpiration. This is because **(a)** increase in temperature increases the heat energy which provides the latent heat of vaporization of water molecules hence the water molecules evaporate rapidly to the sub-stomatal chambers and eventually to the atmosphere via the stomata **(b)** increase in temperature also lowers humidity outside the leaf by increasing the random thermal movement of molecules in the water vapour which further increases the rate of transpiration.



In extremely hot conditions, the stomata of some plants close, an adaptation to prevent water loss by transpiration.

3. Air movements

In still air (no wind), layers of highly saturated vapour build up around the stomatal pores of the leaf and reduces diffusion gradient between the stomatal air chamber and the external atmosphere, thereby reducing the rate of diffusion of water vapour from the leaf.

The layers of highly saturated water vapour which (Soper fig 13.9 pg 439) build up around the stomatal pores of the leaf are called **diffusion shells.**

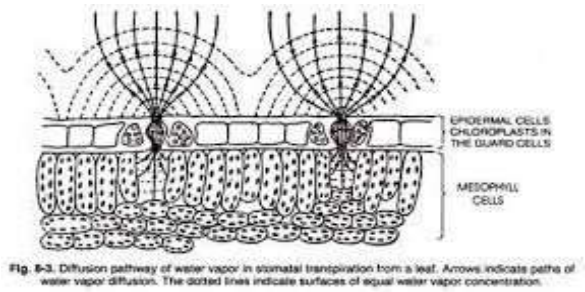


Fig. 8-3. Diffusion pathway of water vapor in stomatal transpiration from a leaf. Arrows indicate paths of water vapor diffusion. The dotted lines indicate surfaces of equal water vapor concentration.

Windy conditions result in increased transpiration rates because the wind sweeps away the diffusion shells around the leaf, thereby creating a steep diffusion gradient which leads to a high the transpiration rate

4. Atmospheric pressure

Water vapour and the atmospheric pressure decreases with increasing altitude.

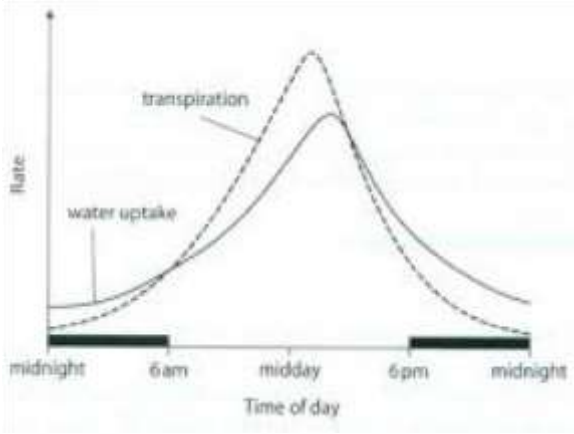
The lower the atmospheric pressure the greater the rate of evaporation of water from the substomatal air chamber. This implies that plants growing on a mountain have a higher rate of transpiration than those growing in low land areas.

However, when the atmospheric pressure is high e.g. in the lowland areas, the evaporation of water vapour from the sub-stomatal air chamber to the atmosphere decreases, thereby decreasing the rate of transpiration.

5. Water availability

For water vapour to diffuse out of the sub-stomatal air chamber to the atmosphere, the mesophyll cells must be thoroughly wet. Shortage of water in the soil or any mechanism which hinders the uptake of water by the plant leads to **wilting** of the plant hence the closure of the stomata.

When water is supplied in large amounts, too much water evaporates to the atmosphere and therefore a high rate of transpiration. However, when the water supply to the mesophyll cells is low, less water evaporates from the sub-stomatal to the atmosphere, hence a low rate of evaporation.



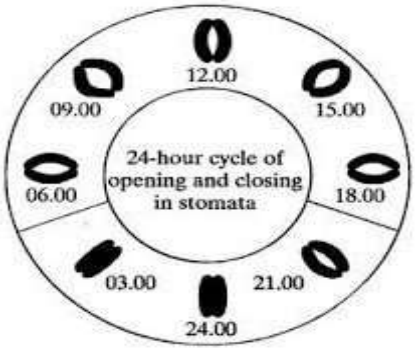
QN. What is the relationship between transpiration and water up take?

6. Light intensity

It affects transpiration indirectly by affecting the closure and opening of the stomata, which usually opens in bright sunlight to allow evaporation of water to the atmosphere. Therefore sunlight increases the rate of transpiration.

At night and in darkness, the stomata close and therefore there is no evaporation of water from the sub-stomatal air spaces to the atmosphere. This greatly lowers the rate of transpiration in the plant.

Differences between transpiration and guttation



Transpiration	Guttation
1. Water is lost in form of vapour	1. Water is lost in form of droplets
2. Occurs through the stomata, cuticle and lenticels	2. Occurs through the hydathodes
3. Occurs during bright light and high temperatures	3. Occurs during dim light and low temperatures
4. Enhanced by low humidity	4. Enhanced by high humidity
5. Water lost is pure without mineral salts	5. Water lost is mineral water with sugars, salts and amino acids
6. Increased transpiration causes wilting	6. Increased guttation does not cause wilting

NON-ENVIRONMENTAL FACTORS

Leaf area

The larger the leaf surface area on the plant, the higher the rate of water loss by transpiration. In addition, broad leaves provide a large surface area over which water vapour diffuses to the atmosphere as compared to the narrow leaves.

Cuticle

The thinner the cuticle, the higher the rate of water loss by transpiration and the thicker the cuticle, the lower the rate of water loss from the plant to the atmosphere by transpiration. This is because this offers a significant resistance towards the diffusion of water vapour from the plant to the atmosphere

Number of stomata

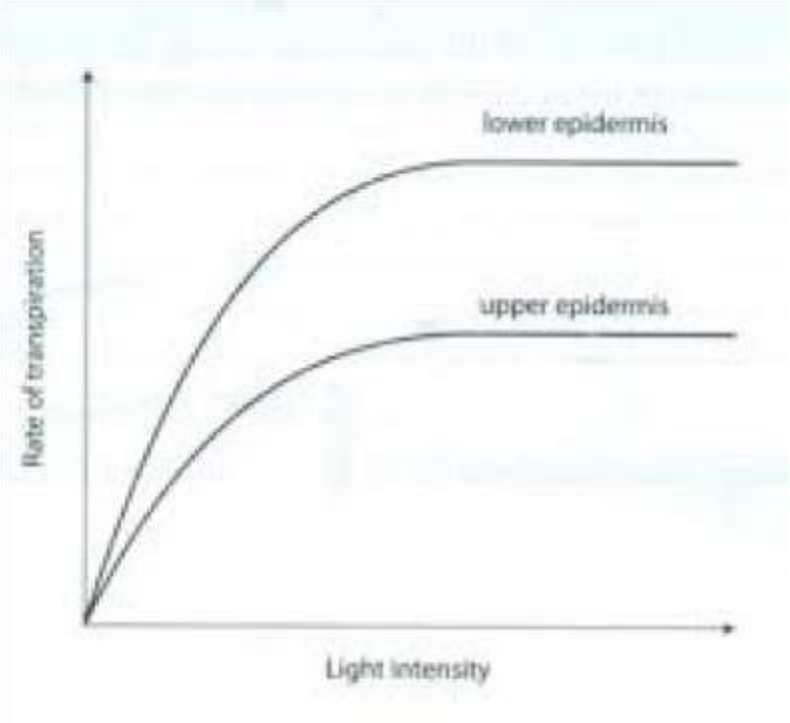
The larger the number of stomata on the plant, the higher rate of water loss by transpiration and the lower the number of stomata, the lower the rate of transpiration. However, a very large number of stomata so close to each other may instead reduce the rate of transpiration especially in still air due to the accumulation of water vapour around the whole stomata pore.

Distribution of stomata

The upper surface is more exposed to environmental factors that increase the rate of transpiration.

Xerophytic adaptations of leaves that reduce transpiration

Xerophytes (xero = dry, phyte = plant) are plants that are adapted to living in areas where water losses due to transpiration may exceed their water uptake. Similar adaptations may also be seen in plants found in dry, windy places, where rainfall is high and temperature relatively low. As the vast majority of transpiration occurs through the leaves, it is these organs that show most modifications.



Examples include;

a) Having a thick cuticle. The thicker the cuticle, the less water can escape by this means.
b) Curling up of leaves. A region of still air is trapped within the curled leaf. This region becomes saturated with water vapour and so there is no water potential gradient between the substomatal air space and the outside, and so transpiration is considerably reduced.
c) Having hairy leaves. A thick layer of hair, especially on the lower epidermis, traps moist air next to the leaf surface which reduces the water potential gradient between the inside and the outside of the leaf, therefore less water is lost.
d) Having stomata in pits or grooves. These trap moist air next to the leaf and reduce the water potential gradient.
e) Reducing the surface area to volume ratio e.g. the cacti leaves are in form of thorns
f) Closing stomata when transpiration rate is very high. This is done by the release of abscisic acid.

STOMATA

In terrestrial plants, gaseous exchange takes place predominantly in the leaves. The epidermis of the leaves contains small pores called stomata (singular. stoma). Through stomata, gaseous exchange between the inside of the leaf and the outside air takes place by diffusion.

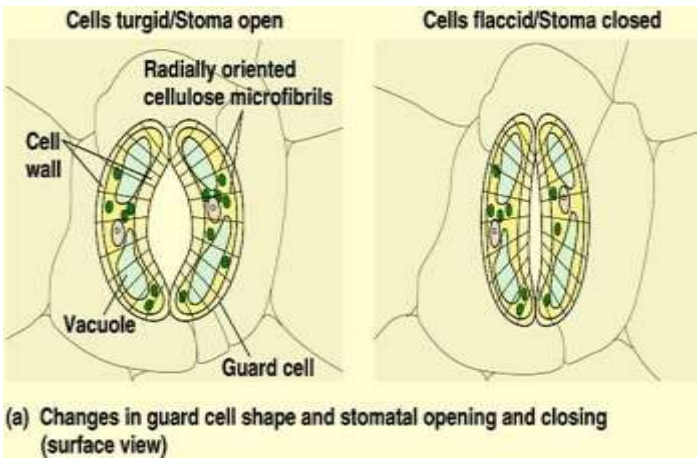
The broad leafed shape of the leaf offers a large surface for diffusion of gases, its thinness reduces the distances over which diffusion of gases from the atmosphere to the inner most cells.

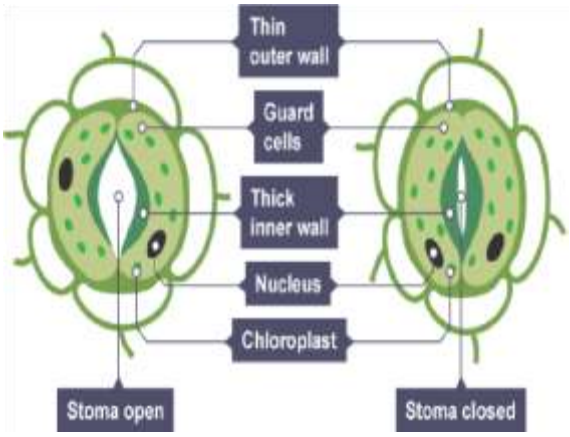
In most terrestrial plants, stomata are more abundant on the lower side than the upper surface of the leaf. This reduces water loss through transpiration since the upper surface is exposed to direct sunlight. The number of stomata in leaves vary from one plant species to another. They are normally absent in submerged leaves of water plants.

Structure of the stoma

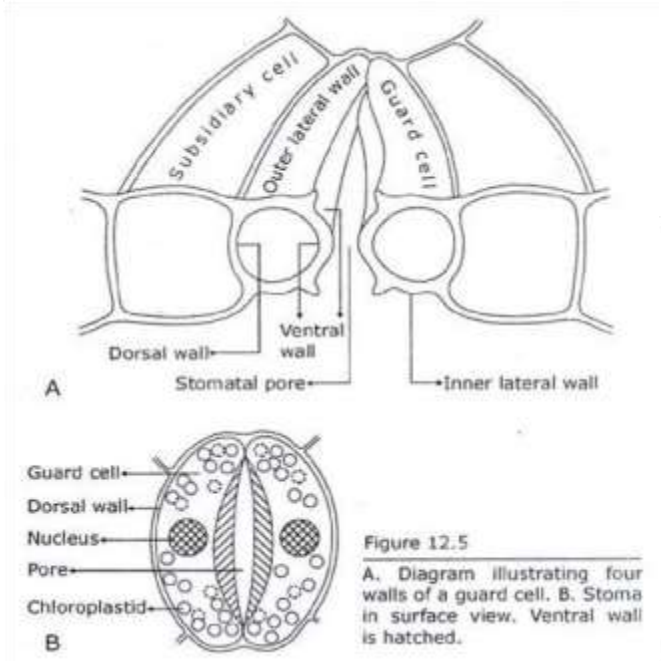
Each stoma consists of a stomatal pore, bordered by a pair of crescent or bean-shaped cells called guard cells. Unlike epidermal cells, guard cells contain chlorophyll. The inner cell wall of guard cells is thicker and less elastic than the outer wall. Microfibrils are radially orientated in the cell wall and the guard cells are joined at the ends. The epidermal cells surrounding the guard cells are subsidiary cells.

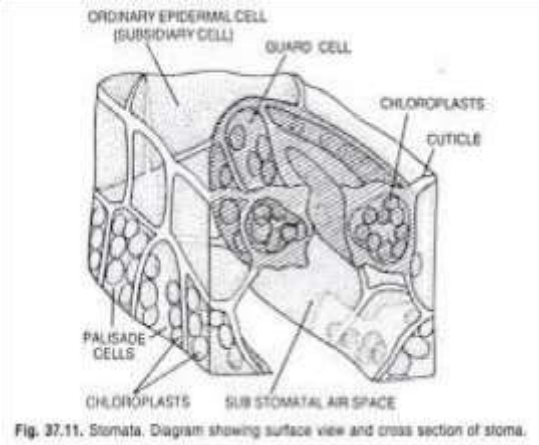
(Toole fig 22.7a pg 452) (Toole fig 22.7b pg 452)





(Soper fig 13.15 pg 444)





Ventilation (opening and closing of stomata)

The opening and closing of stomata occurs as a result of changes in the shape of the guard cells. When guard cells take in water by osmosis, they expand and become turgid. However, they do not expand uniformly in all directions. The thick inelastic inner wall makes the guard cells to curve away from each other, opening the stoma. When the guard cells lose water, they become flaccid and collapse, closing the stomata.

The closing and opening is controlled mainly by the intensity of light. They are normally open during daylight and closed during the night.

Several theories have been put forward to explain how the light intensity influences the opening and closing of stomata.

a. Starch sugar inter conversion

This is one of the earliest theories that attempted to explain the control of stomata closure.

- Photosynthesis by mesophyll cells during daylight would remove carbon dioxide from air spaces within the leaf
- Since carbondioxide is an acidic gas, removal of carbon diode raises the pH of the guard cells
- Starch hydrolyzing enzymes in the guard cells work better in alkaline conditions, and they convert starch to sugar
- Accumulation of sugar makes the water potential of the guard cells more negative, causing a net influx of water into the guard cells and opening the stomata.

  Note: a starch hydrolyzing enzyme, starch phosphorylase that is affected by pH was found **but** some plants e.g. the onion do not form starch at all.

b. Photosynthetic product theory -

Guard cells have chloroplast.

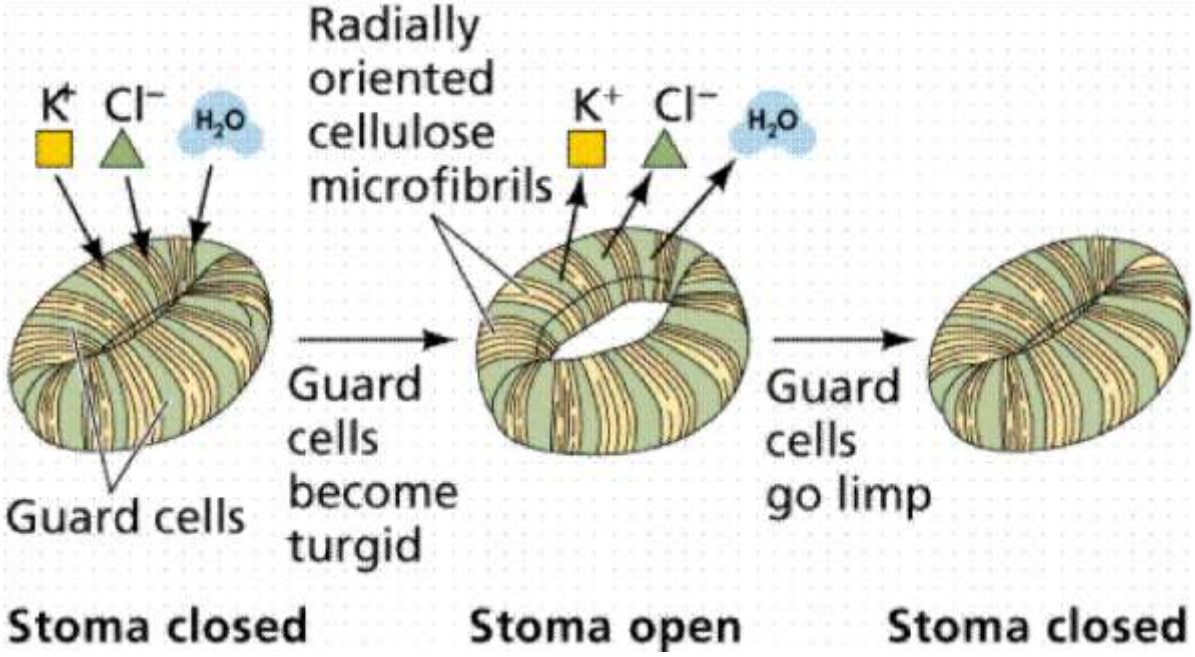
- During day light, they carry out photosynthesis producing sugar.
- The sugar increases the osmotic pressure of the cell sap. This causes water to move into the guard cells from neighbouring epidermal cells by osmosis. The result is an expansion and increase in turgidity of the guard cells containing the stomata to open.
- In darkness, photosynthesis stops and the sugar in the guard cells is converted to starch. This lowers the osmotic pressure of guard cells causing them to lose water to neighboring cells by osmosis.
- The guard cells become flaccid and the stomata close.

Note; this theory does not explain how the low rate of glucose formation can account for the rapid opening of stomata

c. Potassium ion (K^+) mechanism (mineral ion concentration)

- When guard cells are exposed to light, the light energy activates the ATPase enzyme, hence their chloroplasts manufacture ATP.
- The ATP drives a K^+ - pump on the cell membrane of the guard cells. This causes an active uptake of K^+ ions in the guard cells from the surrounding epidermal cells.
- Accumulation of K^+ in the guard cells increases the osmotic pressure of their cell sap. This causes water to move into the guard cells from neighboring epidermal cells by osmosis. The result is an expansion and increase in turgidity of the guard cells causing the stomata to open because when they become turgid, they expend but not uniformly since the inner wall is inelastic, making the guard cells curve away from each other.
- At the onset of darkness, ATP concentration in guard cells falls rapidly stopping the K^+ pump. K^+ migrates from the guard cells to neighboring epidermal cells by diffusion. This lowers the osmotic pressure of guard cells causing them to lose water to neighboring cells by osmosis.
- The guard cells become flaccid and the stomata close.

Note; the above theory is the most widely accepted theory today. It is supported by the fact that the opening of stomata is prevented by metabolic poisons which inhibit active transport. (Toole fig 22.8 pg 452 OR Kent fig 3 pg 281)



The above theories can be summarised into a single mechanism of stomata opening and closing as described below;

Stomata opening

a. Stomata opening is promoted by high light intensity and low mesophyll carbon dioxide levels. Guard cells generate ATP by photophosphorylation during photosynthesis. .

b. Blue light is absorbed by blue-light photoreceptors which activate a proton-pump (H^+-ATPase) in the cell membrane of the guard cell

c. ATPs generated by the light-dependent reaction of photosynthesis are hydrolysed to provide energy to drive the proton-pump. As protons (H^+) are pumped out of the guard cells, the cells become increasingly negatively charged. Potassium channels are activated and K^+ ions diffuse from subsidiary cells through the channels down this electrochemical gradient into guard cells. Chloride ions (Cl^-) then enter to balance the charge.

d. In some plants the starch is converted to malate.

e. The accumulation of K^+ (and malate ions) causes the water potential in the guard cells to become more negative. Water enters by osmosis from the neighbouring subsidiary cells into the guard cells. The guard cells become turgid.

f. The outer wall of the guard cells is thinner and more elastic than the thicker inner wall. There are cellulose micro fibrils which are radially arranged around the cell wall and the ends of the two guard cells are joined

g. The increased turgor pressure therefore causes the guard cells to curve outward and the stoma opens

Stomata closure

a. Stomata closure can be triggered by water stress, high temperature, increasing carbon dioxide levels in the leaf mesophyll and low light intensity (night time)
b. The hormone abscisic acid (ABA) is secreted by plant cells when transpiration rate is high and soil water is low.
c. ABA binds to receptors at the cell membrane of the guard cells. This increase the permeability of calcium channels in the cell membrane. Calcium ions (Ca^+) enter into the guard cell. The influx of calcium ions also triggers the release of Ca^+ from the cell vacuole into the cytosol.
d. Potassium ions (K^+) move out of the guard cells into the subsidiary cells
e. In some plants (Cl^-) and certain organic ions e.g. malate ions also move out of the guard cells
f. The water potential in the guard cells increase. Water diffuses out to neighbouring subsidiary cells by osmosis. The turgor pressure in the guard cells decreases, the cells become flaccid and the stoma closes.
g. At night the chloroplasts in the guard cells do not photosynthesise, less ATP is produced and there's no active uptake of K^+ ions. Instead, the K^+ ions diffuse out of the guard cells. The cells become flaccid and the stoma closes.

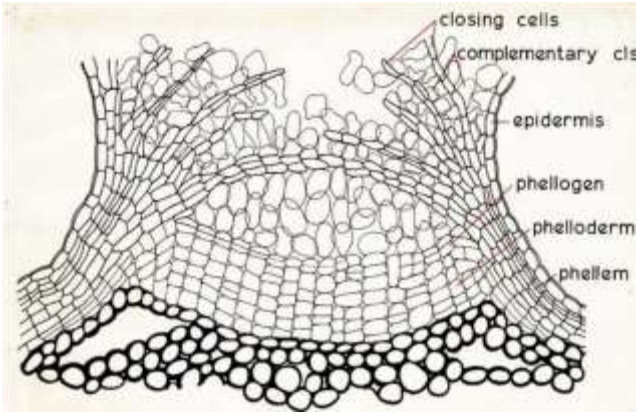
Importance of stomata

1. Stomata allow gaseous exchange of carbon dioxide (for photosynthesis) and oxygen (for respiration) between the plant and the surrounding
2. Stomata regulate the rate of transpiration and control water loss by the plant
3. When water is lost through the stomata, it creates a transpiration pull which can pull the water and mineral salts from the roots to the higher parts of the plant. Transpiration also has a cooling effect on the plant.

LENTICELS

A small extent of gaseous exchange takes place through structures called lenticels. The small gaps in the stem, usually circular or oval slightly raised on the bark surface. The cells in this area are thin walled and loosely parked, leaving air spaces which communicate with air spaces in the cortex. Here oxygen for respiration is taken up and carbon dioxide is given out.

Structure of the lenticel



ROOT EPIDERMAL CELLS

Root cells can also take in oxygen for respiration and give out carbon dioxide. Gaseous exchange takes place by diffusion between the epidermal cells of roots and the air spaces in the soil. Most of the exchange takes place at the root hairs which provide a large surface area.

Water logged soils have their air spaces occupied by water, thereby reducing respiration in the roots which may subsequently die. This would obviously kill the whole plant.

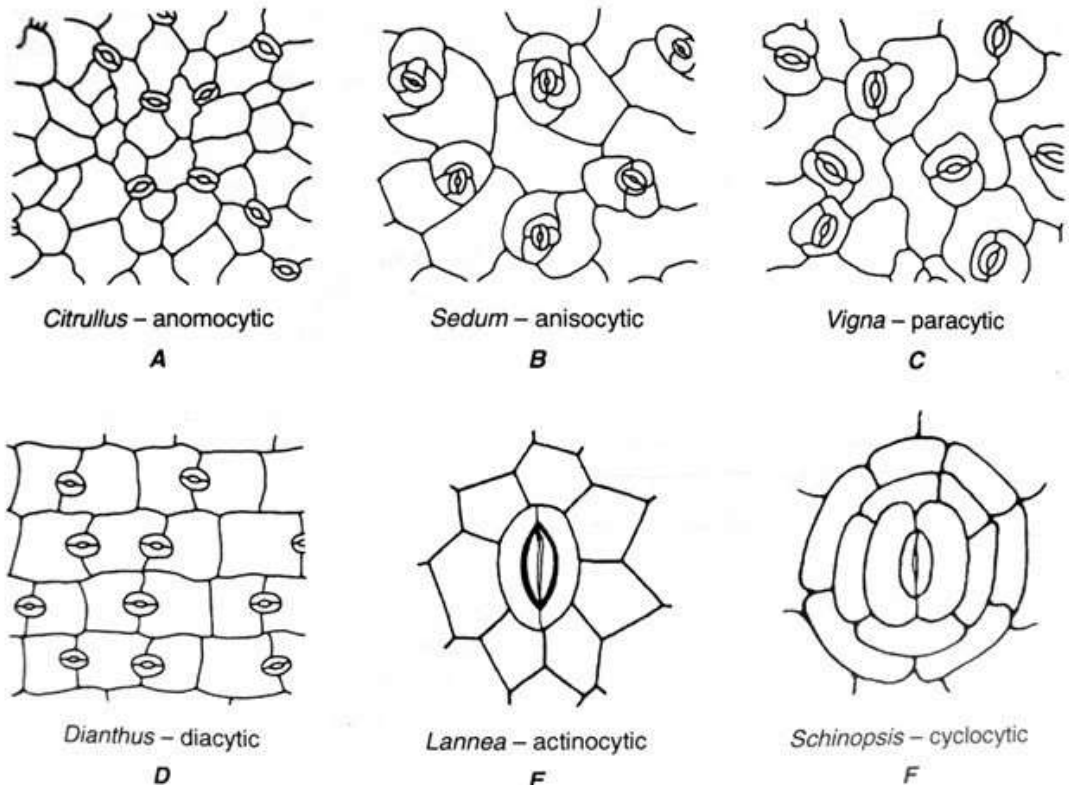
Some aquatic plants, like pond weeds and multi cellular algae are completely submerged in water. These obtain their gaseous requirements by diffusion from the surrounding water. Epidermal cells of such plants have no cuticle and gasses diffuse directly across it.

Others like rice and water lilies are partially submerged in water. Their aerial parts obtain carbon dioxide and oxygen in the same manner as terrestrial plants. The submerged parts may face the problems of obtaining adequate oxygen for their respiratory requirement. However such plants have large air spaces in their stems and roots which store oxygen obtained from the aerial parts and that formed during photosynthesis. Floating leaves of such plants have stomata on the upper surfaces only.

In swampy environments, root systems give rise to breathing roots or pneumatophores. These grow out of the water and op into the air. Oxygen diffuses into them and aerates the submerged parts of the root system.

EXPERIMENT TO OBSERVE STOMATA

Obtain a leaf a leaf of comelina. Hold it in such a way that the lower surface is facing you. Slowly tear the leaf as you would tear a piece of paper by moving the right hand towards the body. This produces a thin, transparent membrane-like tissue along the edge of the tear on the part of the leaf in the left hand. This is the lower epidermis. Using forceps, remove a small section of the epidermis and mount it in a drop of water on a slide and cover it with a cover slip. Observe under low power and then under the high power of a microscope. Identify the guard cells and the normal epidermal cells. Observe a closed stoma and an open stoma under low and high power. Draw each of these



WATER UPTAKE BY THE ROOTS

Internal structure of the root

The root consists of various tissues which occur in concentric layers. The cells at the surface of the young root forming the peliferous layer are so called because it is by the root hairs. As the roots get older, they increase in girth (thickness or diameter) and the peliferous layer (breaks) raptures and peels off leaving the outer most layer of cells known as epiblem, to become the functional outer layer. Next to the epiblem is the thicker layer of loosely packed parenchyma cells, known as **cortex**. Adjacent to the cortex is a layer of cells known as endodermis.

The endodermal cells have their radial and horizontal walls coated with a corky band called **casparian strip**. This strip is made up of a substance called **suberin.** The Casparian strip is impermeable to water and solutes due to the suberin that it contains and therefore prevents water and solutes to pass through the cell walls to the endodermis. The endodermis also contains starch grains.

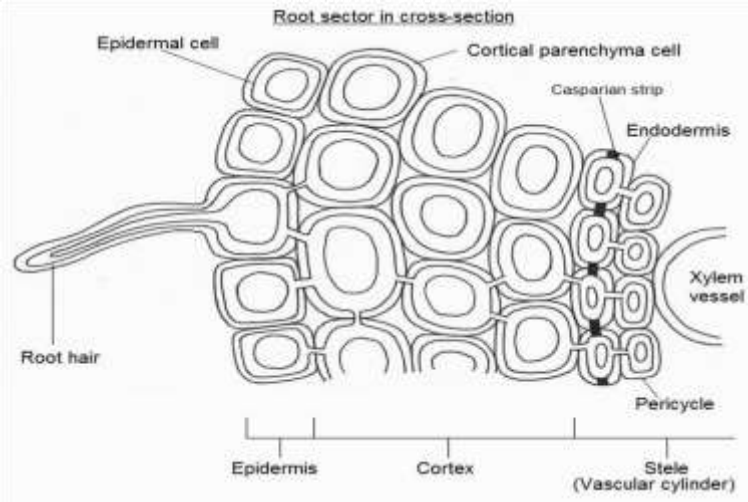
Next to the endodermis is another layer of cells known as pericycle from which lateral roots develop. The pericycle, that is made up of parenchyma cells which encloses the vascular bundles (xylem and phloem) in the centre of the root.

Diagram showing the internal structure of the root

(Toole fig 22.13a pg 462)

(Toole fig 22.13b pg 462)

Longitudinal section through a root



Mechanism of water uptake by the roots

For water to be transported up to the leaves through the stem, it must be absorbed from the soil by the tiny root hairs. Water absorption into the root hairs occurs by **osmosis**. This is due to the water potential of the cell sap of the root hairs being lower than that of the soil solution (water content) due to the very low concentration of mineral ions in water and the soil particles. The cells of the root hairs have a relatively higher concentration of ions, sugars and organic acids within their vacuoles and cytoplasm hence a lower water potential (more negative).

When the root hair absorbs water, its water potential increases and becomes higher than that of the adjacent cells of the root. This facilitates the flow of water from the root hairs to the endodermal cells across a water potential gradient.

The water flow is also due to the root pressure developed by the cell cortex and endodermis which ensures that water flows from the root hairs to the xylem vessels and upwards to the leaves.

Water flows by osmosis form the root hairs to the endodermal cells using three pathways, namely; **(a)** Apoplast (cell wall) pathway, **(b)** Symplast (cytoplasm) pathway & **(c)** Vacuolar pathway

Apoplast pathway

This is the pathway in which water moves through the **spaces** between the cellulose fibres in the cell wall of one cell to the cell wall of the adjacent cells. The **cohesive** forces between the water molecules enable the stream of water to be pulled along the apoplast pathway.

However, this movement does not occur within the endodermal cells because they possess the impermeable water proof band of **suberin** that makes up the **casparian strip**. The casparian strip prevents water and solutes flow through the cell walls of the endodermal cells. This means that water and solutes flow through the cell walls of the endodermal cells via the Symplast and the vacuolar pathways only.

The significance of this casparian strip is that endodermal cells actively pump salts (ions) from the cytoplasm into the xylem vessels which creates a high solute concentration in the xylem, thereby greatly lowering the water potential in the xylem than in the endodermis. This makes the water potential of the xylem vessels more negative (very low) and results into rapid osmotic flow of water from the endodermal cells to the xylem vessels, due to the steep water potential gradient between the endodermal cells and the xylem vessels. This positive hydrostatic pressure is known as the **root pressure**.

The casparian strip facilitates the pushing of water upwards through the xylem vessels by root pressure up to the leaves due to its active pumping of the salts. In addition, this active pumping of the salts into the xylem vessels prevents leakage of salts (ions) out of the xylem vessels so as to maintain a low water potential in this vessel.

Note, in some short herbaceous plants, root pressure is strong at times e.g. at night when humidity is high to cause exudation of water droplets from hydathodes at the edges of leaves. This is known as **guttation.**

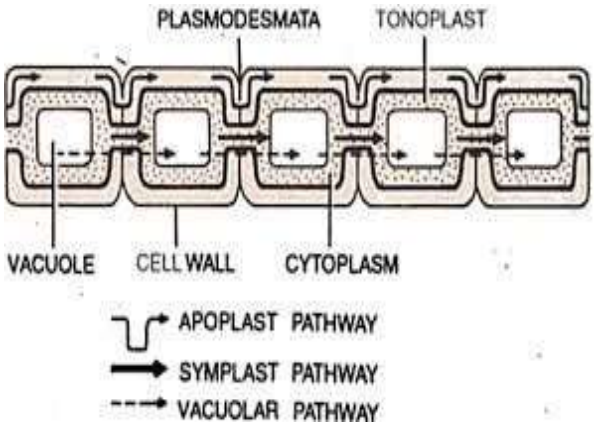


Diagram showing the three pathways of water in the root

(Soper fig 13.18a pg 448)

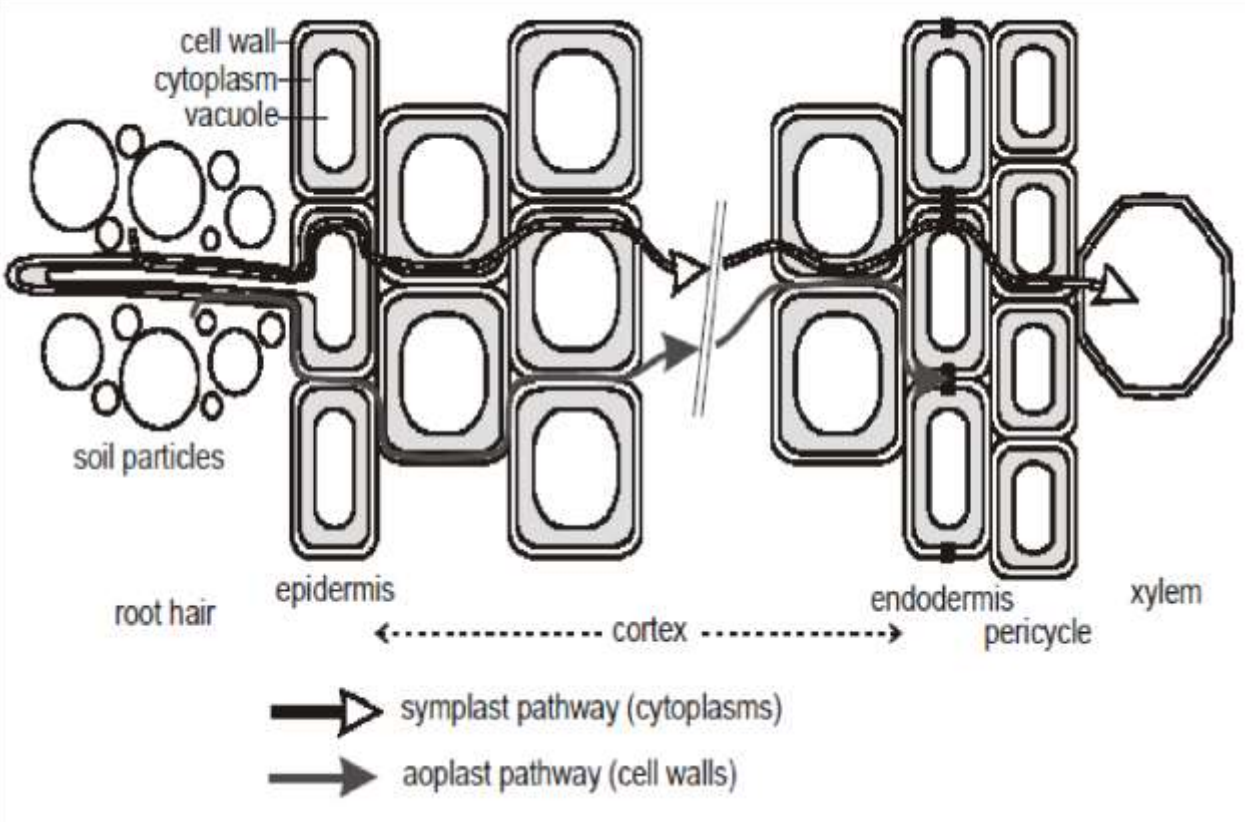
Symplast pathway

This is the movement of water through the cytoplasm of one cell to the cytoplasm of the adjacent cell via plasmodesmata along a water potential gradient. Water leaving the pericycle cells to enter the xylem causes the water potential of these cells to become more negative (more dilute). This facilitates the flow of water by osmosis from the adjacent cells into these cells. In this way the water potential gradient from the root hairs to the xylem is established and maintained across the root. This pathway offers a significant resistance to the flow of water unlike the apoplast pathway.

Vacuolar pathway

This is the movement of water from the sap vacuole of one cell to the sap vacuole of the adjacent cell through the cytoplasm, vacuoles as well as the cell wall following a water potential gradient. This is achieved by maintaining a steep water potential gradient. However, this also offers a reasonable level of resistance towards water flow in comparison to the Symplast pathway.

Note; the apoplast is the most appropriate pathway in plants because it provides less resistance to water flow in the plant.



To ensure maximum absorption of water, the root hairs have the following adaptations

a. They are numerous in number so as to provide a large surface area for the maximum absorption of water by osmosis.
b. They are slender and flexible for easy penetration between the soil particles so as to absorb water.
c. The lack a cuticle and this enhances the passive osmotic absorption of water without any resistance
d. They have a thin and permeable membrane which allows the absorption of water by osmosis.
e. They have a water potential lower than that of the soil solution which facilitates a net osmotic flow of water from the soil
f.

Vascular tissues

The transport system in plants is made up of the **xylem** (which carries water from roots, up the plant from the aerial parts) and **phloem** (which carries sugars produced by leaves to other parts of the plant). The two tissues occur together throughout the plant, sometimes associated tissues, such as **sclerechyma fibres**, to form discrete areas, known as **vascular bundles**.

a) Distribution of vascular tissues in a leaf

The vascular tissues in a dicotyledonous leaf form a network of tiny vascular bundles throughout the blade, or **lamina**, of the leaf. These tiny bundles fuse to give a series of **side veins** that run parallel with one another. These side veins then merge into a central **main vein**. The main vein runs along the centre of the leaf, increasing in diameter towards the petiole, or leaf stalk. Within in each, or vascular bundle, there is an area of xylem towards the upper surface of the leaf and an area of phloem towards the lower surface.

b) Distribution of vascular tissues in a stem

The xylem and phloem in a dicotyledonous stem form vascular bundles that are arranged towards the outside of the stem. The reason for this is that the vascular bundles, along with associated sclerechyma fibres, not only transport materials but also provide support in **herbaceous plants**. The main forces acting on stems are lateral one caused by the action of wind on them. Such forces are best resisted by an outer cylinder of supporting tissue. Hence the vascular bundles form a discontinuous ring towards the edge of them. Being discontinuous, this ring of supporting tissues allows the stems to be flexible and to bend in wind. Within the vascular bundles, the xylem is to the inside of the stem and the phloem towards the outside. Between the two is a thin layer of dividing cells called cambium, which give rise to both phloem and xylem.

c) Distribution of vascular tissues in a root

The vascular tissue in the root of a dicotyledonous plant is situated centrally rather than towards the outer edge, as in a stem. This is because roots are subject to pulling forces in a vertical direction, rather than in a lateral direction, as experienced by stems. Vertical forces are better resisted by a central column of supporting tissues, such as xylem, rather than an outer cylinder of tissue. The xylem is typically arranged in a star-shaped block of tissue at the centre of the root, with the phloem situated in separate groups between each of the points of the star-shaped xylem. Around both is the **pericycle** and **endodermis**.

The xylem.

The xylem is the principle water-conducting tissue in vascular plants. It also provides support for plants. The **sclerechyma fibres** in the xylem contribute to support whereas **vessels** and **tracheids** have both support and transport roles.

a) **xylem fibres** are elongated sclerechyma cells with walls that are thickened with **lignin**; these features suit them for their role of support

b) **vessels** vary in structure, depending on the type and amount of thickening of their cell walls, but are all hollow and elongated. As they mature, their walls become impregnated with lignin, which causes them to die. The end walls breakdown to form a perforation plate which allows the cells form a continuous tube. The lignin maybe spiral/network/reticulate or annular/ring in form; these arrangements are better than continuous thickening, because allows elongation of vessels as the plant grows. There are areas of the lignified wall where lignin is absent, called **pits**. They are not completely open as there is still a cellulose cell wall across them. Pits allows lateral (sideways) movement of water. In angiosperms, vessels are the structures through which the vast majority of water is transported.

c)

Adaptations of the xylem structure to its function

- the cells are long and arranged end to end to form a continuous column the cell contents die when mature, which means that:
    - there is no nucleus or cytoplasm to prevent water flow
    - the end walls break down, so that there is no barrier to water flow between adjacent cells
- cells are thickened with lignin, which
    - makes them more rigid and therefore less likely to collapse under the tension created by the transpiration pull
    - increases the **adhesion** of water molecules, enabling them to rise by capillarity
- annular, reticulate and spiral thickening allow xylem vessels to elongate during growth, and make them more flexible, so that branches can bend in the wind
- there are pits throughout the cells, to allow lateral movement of water
- the large **lumen** of the vessels allows a large volume of the water to be transported

Other xylem tissues

a) **Xylem parenchyma** is composed of unspecialized cells that act as packing tissue around the other components of the xylem. They are roughly spherical in shape, but when they are turgid they press upon and flatten each other in places. In this way they provide support.

b) **Tracheids** have similar structures to vessels except that they are longer and thinner, and have tapering ends. They, too, are thickened with lignin and therefore die when mature. As with vessels, the end walls break down, and their side walls possess pits which allow lateral movement of water between adjacent cells. Tracheids are found in all plants and are the major conduction tissues in ferns and conifers.

ROOT PRESSURE

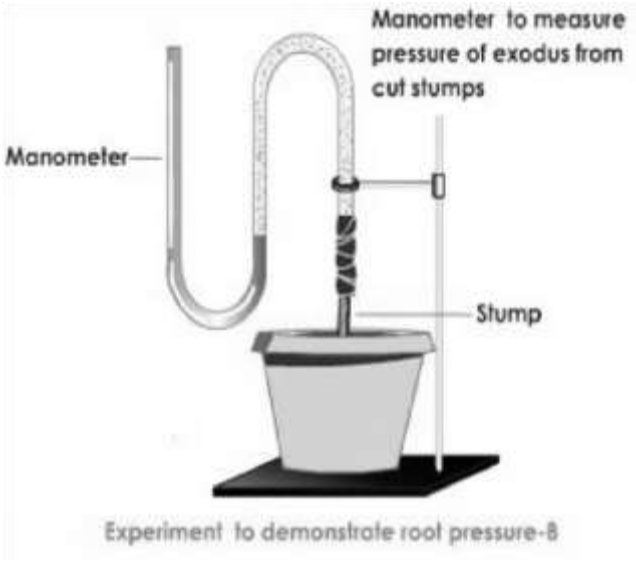
Root pressure is the force developed by cells of the roots which forces water from the endodermal cells into the xylem vessels of the root and constantly forces water upwards through the stem to leaves. This process is active and involves utilization of many ATP molecules. Root pressure occurs as a result of endodermal cells actively secreting salts into the xylem sap from their cytoplasm, which greatly lowers the water potential in the xylem.

In some plants, root pressure maybe large enough to force liquid water through pores called hydathodes of the leaves in a process called **guttation**

The following is the evidence to show that water moves by pressure in a plant.

a. When the stem of a plant is cut water continues to exude from the xylem vessels of the plant stem. The continuous exudation of water from the xylem vessels of the cut stem is due to root pressure because the leafy shoot is cut off, meaning that water not only moves upwards by transpiration pull, but also due to pressure and other forces.

b. Root pressure can be measured using a mercury manometer whose diagram is shown on the right



Experiment to demonstrate root pressure-8

c. Though it is true that water moves from the roots through the stem to the leaves by transpiration pull, root pressure partly contributes towards the movement of water from the parenchyma cells to the xylem of the root, to the stem and eventually up to the leaves

The following is the evidence to support the mechanism of water uptake from the endodermis into the xylem vessel as an active process

a. There are numerous starch grains in endodermal cells which could act as an energy source for active transport.
b. Lowering the temperature reduces the rate of water exudation (given out) from the cut stem as it prevents root pressure, an active process.
c. Treating the roots with metabolic poisons e.g. potassium cyanide also prevents water from being exuded from the cut stems. This is because the poisons kill the cells thereby preventing aerobic respiration, a source of ATP molecules.
d. Depriving roots of oxygen prevents water from being exuded from the cut stems. This shows that water was being pushed upwards in the cut stem by root pressure, an active pressure.

THE UPTAKE OF WATER FROM THE ROOTS TO THE LEAVES

The movement of water from the roots to the leaves, via the stem, is by combination of different forces which include the following; **(1)** Root pressure, **(2)** Transpiration pull (cohesion force) & **(3)** Capillarity

Root pressure

This enables movement of water from the parenchyma cells of the main root into the xylem tissue due to the active pumping of cells from endodermal cells into the xylem tissue.

Root pressure also ensures upward movement of water through the xylem tissues to the leaves.

Transpiration pull (cohesive force/cohesion-tension theory of water uptake)

This offers an explanation for the continuous flow of water upwards through the xylem of the plant i.e. from the root xylem to the stem xylem and finally to the leaf xylem. Water is removed from the plant leaves by transpiration which creates a tension within the leaf xylem vessels that pulls water in the xylem tubes upwards in a single unbroken column or string held together by the cohesive forces of attraction between water molecules.

According to the cohesion-tension theory, evaporation of water from the mesophyll cells of the leaf to the sub-stomatal air chamber and eventually to the atmosphere via the stomata by transpiration, is responsible for the rising of water from the roots to the leaves. This is because the evaporated water molecules get replaced by neighbouring water molecules which in turn attract their other neighbours and this attraction continues until the root is reached.

Evaporation of water results in a reduced water potential in the cells next to the leaf xylem. Water therefore enters these mesophyll cells by osmosis from the xylem sap which has the higher water potential. Once in the mesophyll cells water moves using the three pathways namely; apoplast, Symplast and vacuolar pathways from one cell to another by osmosis across a water gradient. When water leaves the leaf xylem to the mesophyll cells by osmosis, a tension is developed within the xylem tubes of water which is transmitted to the roots by cohesive forces of water molecules. The tension develops in the xylem vessels and builds up to a force capable of pulling the whole column of water molecules upwards by means of mass flow and water enters the base of these columns from neighbouring root cells. Because such a force is due to water loss by osmosis by transpiration, it is referred to as **transpiration pull**.

The upward movement of water through the xylem tissue from the roots to leaves is also facilitated by the cohesive forces of attraction which holds the water molecules firmly together, due to the hydrogen bonds which exist between them. This enables water to have a high tensile strength which enables it to move upwards in a continuous stream without breaking. In addition, the upward movement of water from roots to leaves is also facilitated by adhesive forces which hold the water molecules on the xylem walls so that it continues moving upwards.

Capillarity

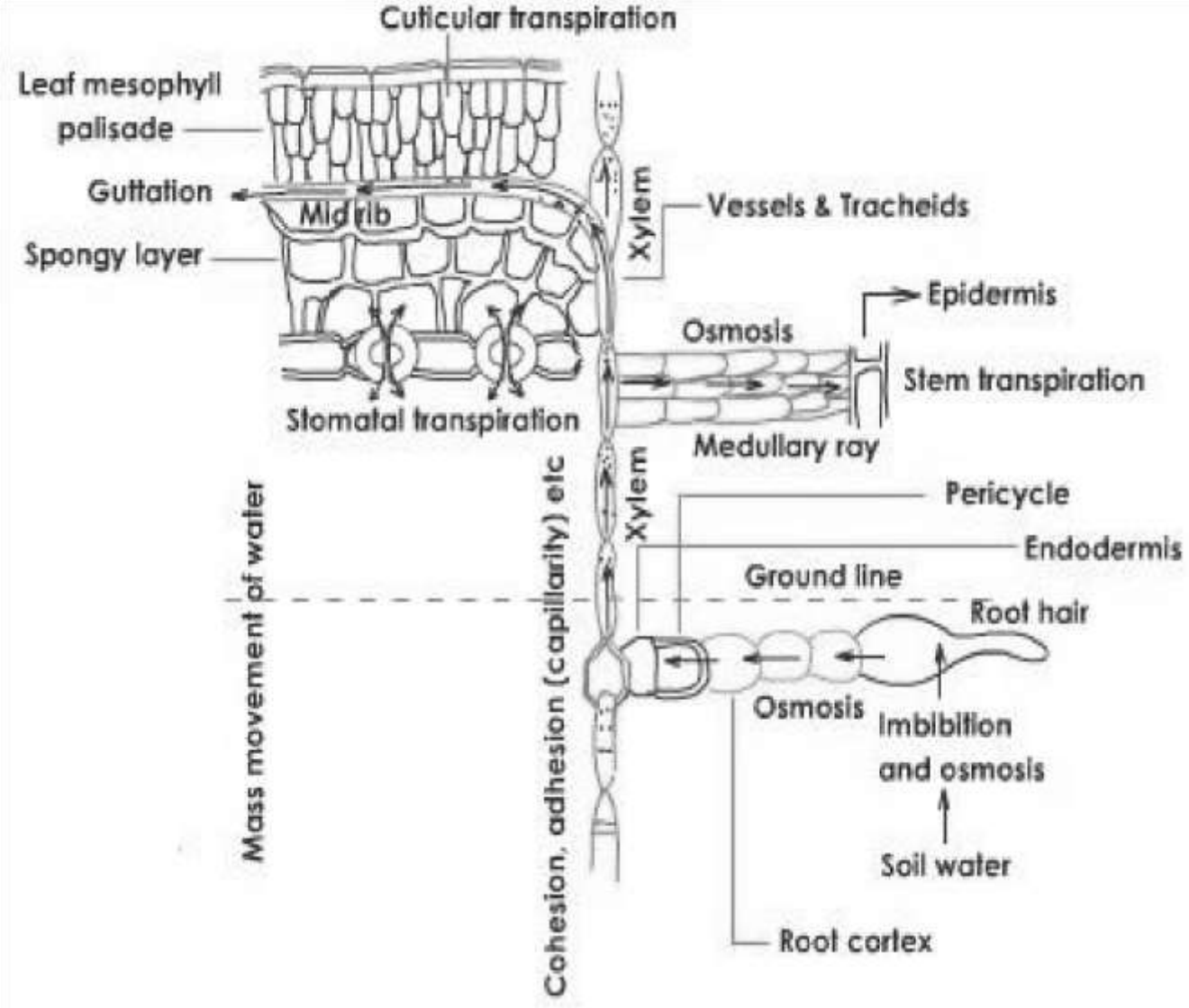
Since the water rises upwards through narrow leaves, it is also facilitated by capillarity through the stem. This is because the xylem vessels are too narrow and the flow of water is maintained without breaking by both the cohesive forces (between the water molecules) and adhesive forces (between the water molecules and the hydrophilic surface of the walls of the xylem).

NOTE

The continuous mass flow of water through the xylem vessels from the roots to the leaves in a stream without breaking, due to the transpiration pull is called the transpiration stream

Adhesion is the force of attraction between molecules of different substances while cohesion is the force of attraction between molecules of the same substance

The diagram below shows the upward movement of water from the soil up to the leaves.



In summary

Movement of water across the leaf The humidity of the atmosphere is usually less than that of the sub-stomatal air-space and so, provided that the stomata are open, water diffuses out of the airspaces into the surrounding air. Water lost from the airspaces is replaced by water vapour evaporating from the cell wall of the surrounding **spongy mesophyll** cells. By *changing the size of the stomatal pores, plants can control water loss*. Water vapour evaporating from the cell walls of spongy cells is replaced by water reaching them from xylem by either the apoplast or symplast pathways. In case of the symplast pathway, the water movement occurs because, once the spongy mesophyll cells have lost water to the sub-stomatal air-space, they have a lower (more negative) **water potential.** Water therefore enters by **osmosis** from the adjacent cells. The loss of water from these adjacent cells cause them to have a lower water potential and so they, in turn, take in water from the neighbours by osmosis. In this way, a water potential gradient is established that pulls water from the xylem, across the leaf mesophyll, and finally out into atmosphere.

Evidence for the cohesion-tension theory

Movement of water up the stem in the xylem

The main mechanism by which water moves up the xylem is known as the **cohesion-tension theory**. It operates as follows;

- Water evaporates from leaves as a result of transpiration

- Water molecules form **hydrogen bonds** between one another and hence tend to stick together i.e. **cohesion**
- Water forms a continuous, unbroken path across the mesophyll cells and down the xylem
- As water evaporates from mesophyll cells in the leaf into the sub-stomatal air space, more molecules of water are drawn up behind it as a result of this cohesion
- Water is hence pulled up the xylem as a result of transpiration. This is called the **transpiration pull**.
- The transpiration pull puts the xylem under tension, i.e. there is a negative pressure within the xylem.

a) The changes which occur in the diameter of trees according to the rate of transpiration. During the day, when transpiration is at its greatest, there is more tension (more negative pressure) in the xylem. This causes the trunk to shrink in diameter. At night, when transpiration is at its lowest, there is less tension in the xylem and so the diameter of the trunk increases

b) When a xylem vessel is broken, water does not leak out which would be the case if it were under pressure, but rather air is pulled in, which is consistent with it being under tension.

UPTAKE AND TRANSLOCATION OF MINERAL IONS

Translocation is the movement of mineral salts and chemical compounds within a plant.

There are two main processes of translocation which include;

a. The uptake of soluble minerals from the soil and their passage upwards from the roots to the various organs via the xylem tubes.

b. The transfer of organic compounds synthesized by the leaves both upwards and downwards to various organs via the phloem tubes

Mechanism of mineral ion uptake

Minerals such as nitrates, phosphates, sulphates e.t.c. may be absorbed either actively or passively.

Active absorption of minerals

Most minerals are absorbed from the soil solution having the less mineral concentration into the root hairs with the higher mineral concentration, selectively by using active transport which uses a lot of energy.

The rate of active absorption of minerals into the root hairs depends on the rate of root respiration. Factors such as oxygen supply and temperature will affect the rate of ion uptake. The addition of respiratory poison has shown to inhibit uptake of mineral ions.

(Soper Fig 13.19 pg 449)	(Soper Fig 13.20 pg 450)

Passive absorption

If the concentration of a mineral in a soil solution is greater than its concentration in the root hair cell, the mineral may enter the root hair cell by diffusion.

Mass flow or diffusion occurs once the minerals are absorbed by the root hairs so that they move along cell walls (apoplast pathway).

In mass flow, the mineral ions are carried along in solution by water being pulled upwards in the plant in the transpiration stream, due to the transpiration pull i.e. the mineral ions dissolve in water and move within the water columns being pulled upwards.

The mineral ions can also move from one cell of the root to another against the concentration gradient by using energy inform of ATP. This is achieved by the use of special **carrier proteins**. Two important mineral ions in plants are nitrates and magnesium. Nitrate ions provide nitrogen is a component of:

- amino acids (make up proteins)
- nucleotides (make up DNA and RNA)
- auxins (are plant growth factors)

Magnesium is a component of chlorophyll and activator of ATPase enzyme.

The mineral ions can also move through the Symplast pathway i.e. from one cell cytoplasm to another. When the minerals reach the endodermis of the root, the Casparian strip prevents their further movement along the cell walls (apoplast pathway). Instead the mineral ions enter the cytoplasm of the cell (Symplast pathway) where they are mainly pumped by active transport into the xylem tissues and also by diffusion to the xylem tissues.

Once in the xylem, the minerals are carried up the plant by means of mass flow of the transpiration stream. From the xylem tissues, minerals reach the places where they are utilised called **sinks** by diffusion and active transport i.e. the minerals move laterally (sideways) through pits in the xylem tissue to the sinks by diffusion and active transport.

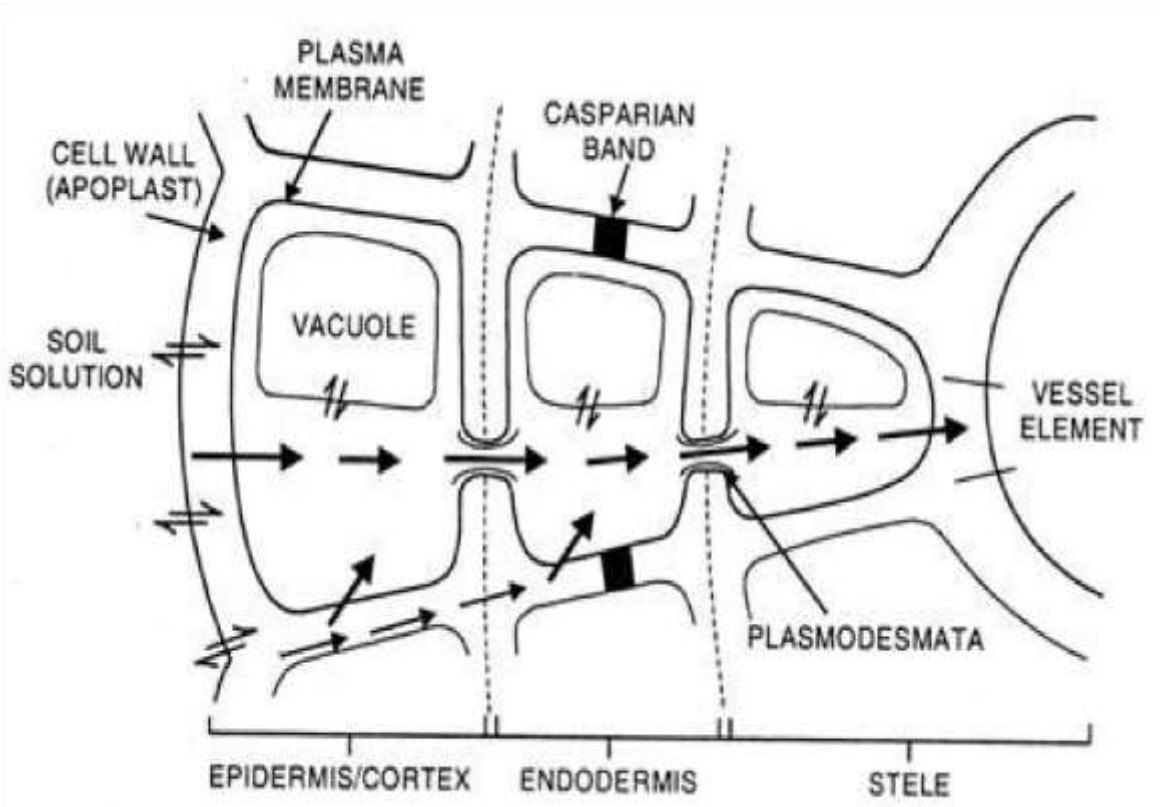


Fig. 7.5. Radial paths of movement of mineral nutrient ions in root

The following is the evidence to show that most mineral ions are absorbed actively by the root hairs

1. Increase in temperature around the plant increases the rate of mineral ion uptake from the soil as it increases respiration that can provide energy for active transport
2. Treating the root with respiratory inhibitors such as potassium cyanide prevents active mineral ion uptake leaving only absorption by diffusion. This is because the rate of mineral ion uptake greatly reduces when potassium cyanide is applied to the plant.
3. Depriving the root hairs of oxygen prevents active uptake of minerals by the roots and as a result very few ions enter the plant by diffusion.

The following is the evidence for supporting the role of the xylem in transporting minerals

1. The presence of mineral ions in the xylem sap i.e. many mineral ions have been found to be present in the xylem sap.
2. There's a similarity between the rate of mineral ion transport and the rate of transpiration i.e. if there's no transpiration, then there's no mineral ion transport and if transpiration increases, the rate of mineral ion transport also increases.
3. There's evidence that other solutes e.g. the dye, eosin, when applied to the plant roots, it is carried in the xylem vessels

4. By using radioactive tracers e.g. phosphorous-32. When a plant is grown into a culture solution containing radioactive phosphorous-32, phosphorous -32 is found to have reached all the xylem vessels but not the phloem tubes.

(The interpretation of these elements is that where lateral transfer of minerals can take place minerals pass from the xylem to the phloem and where lateral transfer is prevented, the transport of minerals takes place in the xylem)

NOTE; Some plants absorb mineral salts by using mutualistic associations between their roots and other organisms e.g. the association between the fungus and the higher plant roots called **mycorrhiza**.

TRASLOCATION OF ORGANIC MOLECULES

(Food molecules in the phloem)

The organic materials produced as a result of photosynthesis; need to be transported to other regions of the plant where they are used for growth or storage. This movement takes place in the phloem tissue particularly in the sieve tubes.

Structure of the phloem

The phloem of composed of a number of cell types:

- **Sieve tube elements** are elongated structures that are joined end to end to form long tubes. The cells are living and retain a thin layer of cytoplasm within their cell surface membrane, which lie against the cellulose cell wall. Within the cytoplasm are mitochondria and a modified form of endoplasmic reticulum. However, unlike most cells, there is no nucleus or Golgi apparatus and there are no ribosomes. These are broken down in order to make the sieve tubes more hollow and so reduce resistance to the flow of liquid within them. The end walls of the sieve tubes are perforated by large pores, to form **sieve plates**. The central space within the sieve tube is called the **lumen**.
- **Companion cells** are always associated with sieve elements and both come from the same cell division. As the sieve tube elements lack structures such as a nucleus, Golgi apparatus and ribosomes, they are unable to carry out many of the metabolic processes essential for their survival. The companion cells are the sites for these processes. Materials can easily pass through the many **plasmodesmata** that link the two types of cells. At the tips of veins in the leaf, companion cells have very folded cell walls and cell surface membranes. These special types of companion cells are called **transfer cells** and their large surface area increases the rate of transfer of sucrose into sieve tube elements. (fig 11.19 page 238 Clegg and Mackean)

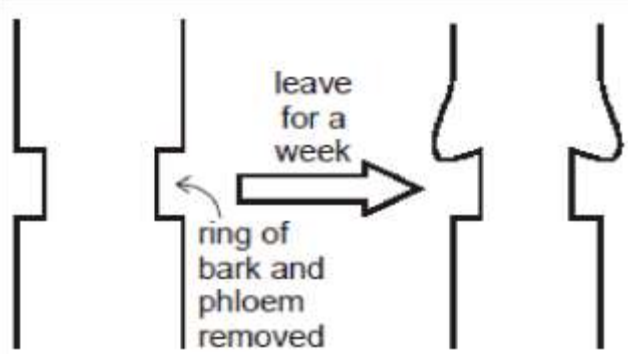
  How structure phloem is related to its function

1. Sieve tube elements are elongated and arranged end to end to form a continuous column
2. The nucleus and many of the organelles are located in the companion cells, leaving the lumen of the sieve tube elements more open so reducing resistance to the flow of liquid
3. Sieve plates are perforated with sieve pores, reducing resistance to liquid flow
4. Sieve tubes hold the walls of sieve tube elements together and prevent them from bursting
5. The walls contain cellulose microfibrils that run around cells, giving strength and preventing the tubes bursting under pressure
6. The walls are thin to allow easy entry of water at the source so as to build up pressure

7. Companion cells have many mitochondria to release the ATP needed for translocation of organic materials
8. Companion cells have numerous ingrowths of their cell walls to increase the surface area for active uptake of solutes .i.e. the transfer cells
9. Plasmodesmata allow easy movement of substances to and from companion cells
10.

Evidence to support that organic molecules of photosynthesis are transported in the phloem

1. When the phloem is cut, the sap which exudes out of it is rich in organic food materials especially sucrose and amino acids.
2. Removal of a complete ring of phloem around the phloem causes an accumulation of sugar around the ring, which results into the swelling of the stem above the ring. This indicates that the downward movement of the sugars has been interrupted and results into the part below the ring failing to grow and may dry out. This is called the **ringing experiment.**



3. The sugar content of the phloem varies in relation to environmental conditions. When the conditions favor photosynthesis, the concentration of the sugar in the phloem increases and when they not favor photosynthesis and concentration of the sugar in the phloem reduces
4. The use of radioactive tracers. If radioactive carbon dioxide-14 is given to plants as a photosynthetic substrate, the sugars later found in the phloem contain carbon-14. When the phloem and the xylem are separated by waxed paper, the carbon-14 is found to be almost entirely in the phloem.
5. Aphids have needle like proboscis with which they penetrate the phloem so as to suck the sugars. If a feeding aphid is anaesthetized using carbon dioxide or any other chemical e.g. chloroform and then its mouth parts cut from the main body, some tiny tubes called the proboscis remain fixed within the phloem sieve tubes from which samples of the phloem content exudes
6. When the contents of the phloem are analyzed, they are confirmed to be containing carbohydrates, amino acids, vitamins e.t.c. which further confirms that the phloem transports manufactured foods
7. When small sections of the pierced stems are cut following the proboscis penetration, the tips of the proboscis are found within the phloem sieve tubes.

MECHANISM OF TRANSLOCATION IN THE PHLOEM

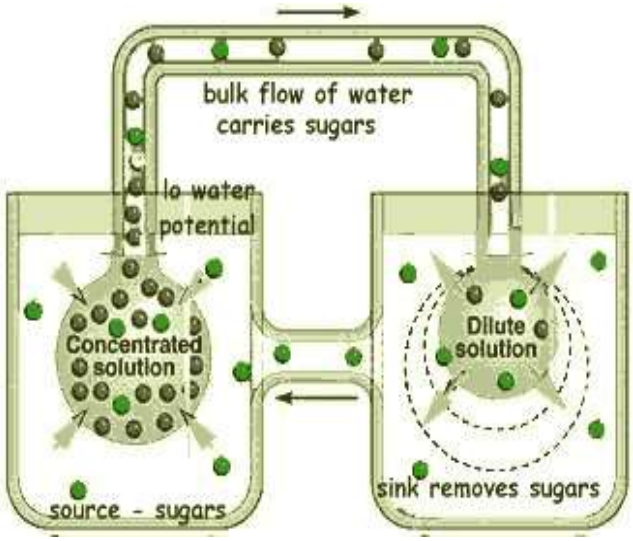
It was found out that organic materials do not move through the phloem sieve tubes by diffusion because the rate of flow of these materials is too fast for diffusion to be the cause. The mechanism of translocation of food in the phloem is explained by the following theories or hypothesis; **(a)** The mass flow or pressure flow hypothesis (i.e. Much's hypothesis), **(b)** Electro-osmosis & **(c)** Cytoplasmic streaming

Mass flow or pressure flow hypothesis

Mass flow is the movement of large quantities of water and solutes in the same directions.

According to this theory, photosynthesis forms soluble carbohydrates like sucrose in the leaves. The photosynthesizing cells in the leaf therefore have their water potential lowered due to the accumulation of this sucrose. Sucrose diffuses down a concentration gradient from the photosynthesising cells into the companion cells. Hydrogen ions are actively pumped from companion cells into the apoplast (spaces within cell walls) using ATP. These hydrogen ions then flow down a concentration gradient through carrier proteins into the sieve tube elements. Sucrose molecules are transported along with the hydrogen ions, a process called co-transport. The carrier proteins are therefore also known as cotransport proteins.

Sucrose is actively pumped into the phloem sieve cells of the leaf via transfer cells. As a result, water which has been transported up to the stem xylem enters these mesophyll cells by osmosis due to the accumulation of sucrose. This causes an increase in the pressure potential of the leaf cells including the leaf sieve tube elements more than that in the cells in the sink i.e. the mesophyll cells where the sugars are manufactured are referred to as the **source** while the other parts of the plant such as the roots where food is utilized are referred to as the **sink**.



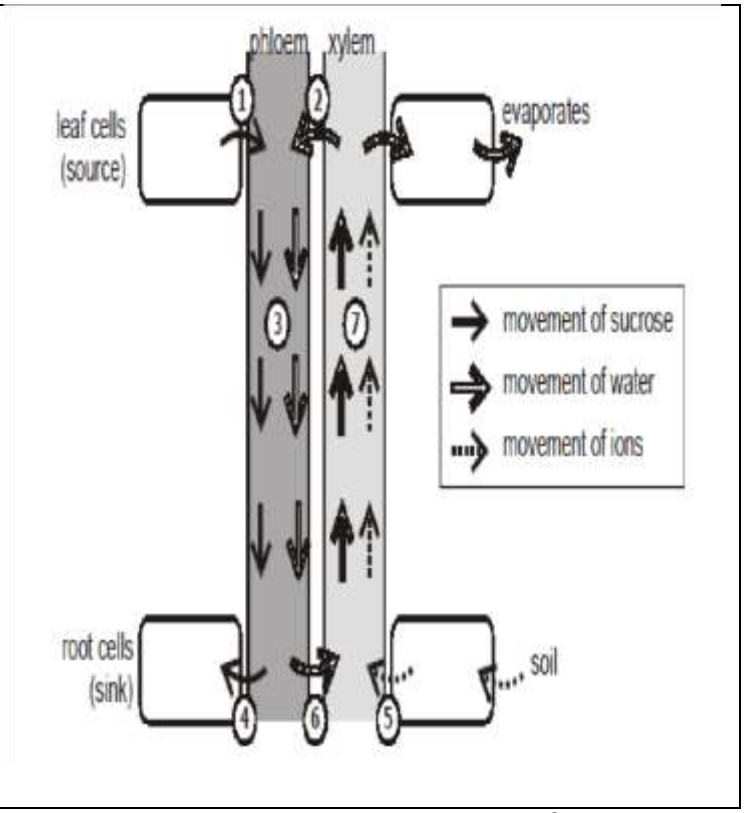
A diagram showing movement of the products of photosynthesis by mass flow (Toole fig 22.23 pg 470, Kent fig 2 pg 286)

The food solution in the sieve tubes then moves from a region of higher pressure potential in the leaves to that of lower pressure potential in the sink such as roots following a hydrostatic pressure gradient. At the other parts of the plant which form the sink e.g. the roots, sucrose is either being utilized as a respiratory substrate or it is being converted into insoluble starch for storage, after being actively removed from the sieve tubes and channeled into the tissues where they are required. The soluble content of the sink cells therefore is low and this gives them a higher water potential and consequently lower pressure potential exists between the source (leaves) and the sink such as roots and other tissues

The sink and the source are linked by the phloem sieve tubes and as a result the solution flows from the leaves to other tissues (sinks) along the sieve tube elements

Evidence supporting the mass flow theory

1. When the phloem is cut, the sap exudes out of it by mass flow
2. There's rapid and confirmed exudation of the phloem's sap from the cut mouth parts of the aphids which shows that the content of the sieve tubes move out at high pressure.
3. Most researchers have observed mass flow in microscopic sections of the sieve tube elements.
4. There's some evidence of concentration gradient of sucrose and other materials with high concentration in the leaves and lower concentration in the roots.



5. Any process that can reduce the rate of photosynthesis indirectly reduces the rate of translocation of food.
6. Certain viruses are removed from the phloem in the phloem translocation stream indicating that mass flow rather than diffusion, since the virus is incapable of locomotion.

Criticism of mass flow

1. By this method all organic solutes would be expected to move in the same direction and at the same speed. It was however observed that the organic solutes move in different directions and at different speeds.
2. The phloem has a relatively high rate of oxygen consumption which this theory does not explain.
3. When a metabolic poison such as potassium cyanide enters the phloem, the rate of translocation is greatly reduced, implying that translocation is not a passive process, but an active one.
4. The mass flow hypothesis does not mention any translocation of solutes with influence of transfer cells and Indole Acetic Acid (IAA) hormone that loads the sugars or solutes into the sieve tubes and also unload it into the cells of the sink.
5. The sieve plates offer a resistance which is greater than what could be overcome by the pressure potential of the phloem sap. This implies that the pressure would sweep away the sieve plates during this transport.
6. Higher pressure potential is required to squeeze the sap through the partially blocked pores in the sieve plates than the pressure which has been found in the sieve tubes

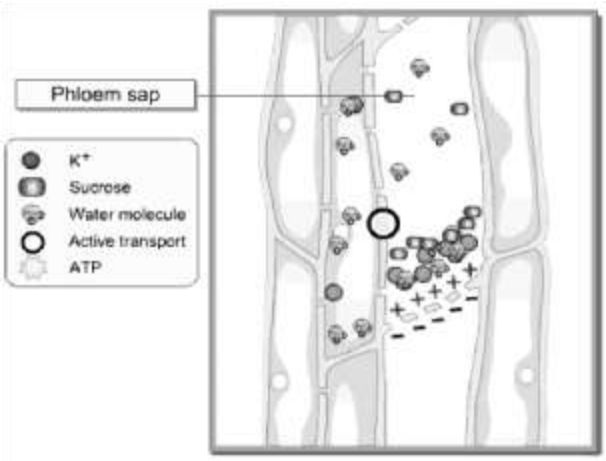
NOTE: the mass flow theory is considered to be the most probable theory in conjunction with electroosmosis

Electro-Osmosis

This is the passage of water across a charged membrane.

This membrane is charged because positively charged ions e.g. K^+, actively pumped by the companion cells across the sieve plate into the sieve tube element using energy from ATP of the companion cells. Potassium ions accumulate on the upper side of the sieve plate thereby making it positively charged. Negatively charged ions accumulate on the lower sides of the sieve plate thereby making it negatively charged.

The positive potential above the sieve plate is (Clegg fig 16.39b pg 341) further increased by hydrogen ions, actively pumped from the wall to the upper sieve tube element into its cytoplasm.



Organic solutes such as sucrose are transported across the sieve plates due to an electrical potential difference between the upper and the lower side of the sieve plate whereby the lower side is more negative than the upper side i.e. solutes move from the upper sieve tube element which is positively charged to the lower sieve element which is negatively charged.

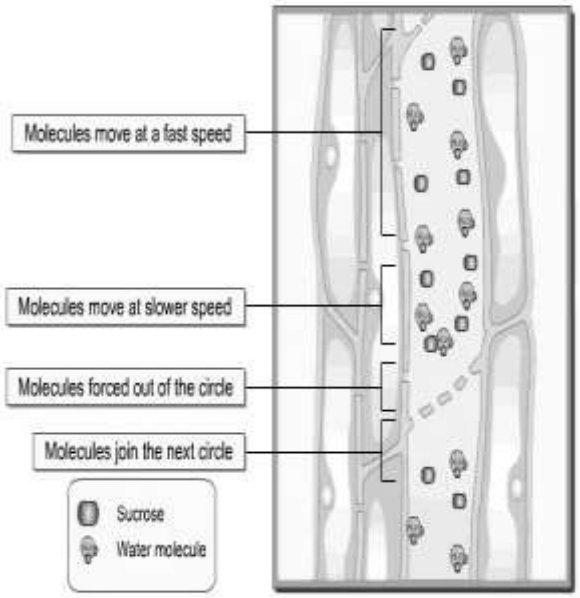
The electrical potential difference is maintained across the plate by active pumping of positive ions, mainly potassium ions, in an upward direction. The energy used is produced by the companion cells. The movement of K^+ ions through the pores of the sieve plates rapidly draws molecules of water and dissolved solutes through the sieve pores, to enter the lower cell.

Evidence to support the electro-osmosis theory

1. K^+ ions stimulate the loading of the phloem in the leaves with sugars during photosynthesis.
2. Numerous mitochondria produce a lot of energy for translocation, an indicator that translocation is an active process. If however, the phloem tissues are treated with a metabolic poison, the rate of translocation reduces.

Cytoplasmic streaming theory

This suggests that the protoplasm circulates using energy from sieve tubes elements or companion cells through the sieve tube elements from cell to cell via the sieve pores of the sieve plates. As the protoplasm circulates, it carries the whole range of the transported organic materials with it. The solutes are moved in both directions along the trans-cellular strands by peristaltic waves of contraction, such that they move from one sieve tube element to another using energy in from of ATP. The proteins in the strands contract in a wave form, pushing the solutes from one sieve tube element to another, using energy in form of ATP.

Evidence supporting the cytoplasmic streaming theory	*Diagram showing Cytoplasmic streaming* (Kent fig 3 pg 287)
1. It has been found that the solute materials move in both directions in the phloem tissue 2. The theory explains the existence of the trans-cellular strands in the phloem tissue as well as many mitochondria in the companion cells 3. Presence of a sieve plate where a potential difference can be developed across the plate 4. Criticism of the Cytoplasmic Streaming Theory 5. Cytoplasmic streaming has not been reported in mature sieve tube elements but only in young sieve tubes. 6. The rate at which the protoplasm streams is far slower than the rate of translocation	

SAMPLE QUESTIONS

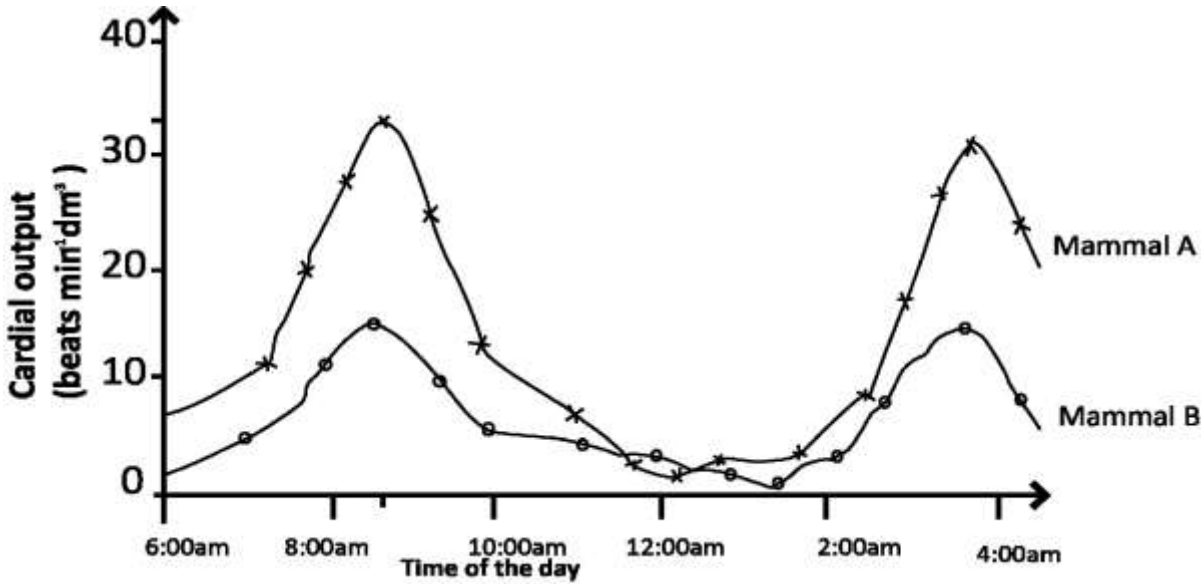
1. Distinguish between the terms **immunity** and **autoimmunity** (02 marks)

(b) Suggest **three** key roles played by the body's immune system (03 marks)

(c) State **three** ways body openings are protected from entry of pathogens (03 marks)

(d) State **two** human diseases resulting from autoimmune disorders (02 marks).

2. The figure shows the changes in the cardiac output of two individual Mammals and A and B of different sizes, determined from 6:00a.m up to 4:00p.m in the evening when the mammals were given a hot drink.



i. Compare the cardiac output of both mammals. (04marks)
ii. Explain the effect of day time on the cardiac output of both mammals. (08marks)
iii. Comment on the difference in the cardiac output both mammals. (04marks)
iv. Suggest factors that are likely to affect the cardiac output of a mammal. (03marks)

b) The table below shows the volume of blood flowing from the left vertical side of the heart of various parts of the body in one minute at rest and during a heavy exercise.

Organ	**Volume of blood/cm^3**	
	Rest	**Exercise**
Brain	750	750
Hear Muscle	250	750
Skeletal muscle	1,200	1,250
Skin	500	1,900
Kidney	1,100	600
Other organs	2,000	1,000

i. Calculate the percentage increase in blood flow from rest to exercise in skeletal muscle.(03 mark ii. Give three ways in which the increase in b(i) is achieved. (03 marks) iii. Explain the changes in volume of blood flow rest to exercise to various parts of the body. (11 ma

iv. Suggest with reasons the likely changes in composition of blood as it flows through the kidney.(04

3. In an investigation pea plants were dug up from the field and washed thoroughly. The nodules were removed surface sterilized and transferred aseptically to a sterile liquid culture medium. After two weeks incubation, small samples of culture media were removed and added to trays each containing a batch of pea plants growing in an inert medium. Each batch was watered regularly with a nutrient solution containing a particular concentration of sodium nitrate for four weeks, at the end of four weeks the mean number of root nodules and biomass were obtained from the investigation are shown in the table below.

Nitrate concentration of nutrient solution (arbitrary units)	**Mean number of nodules per plant**	**Biomass of pea plants /gm^{-2}**

0	82	140
1	70	200
2	68	230
3	40	350
3.5	20	400
4	10	460
5	0	440
5.5	0	400
6	0	350

(a) Represent the results of the table above graphically (**08 marks**)

(b) Explain the changes in mean number of nodules per plant and changes in the biomass of pea plants with increasing nitrate concentration of nutrient solution (**20 marks**)

(c) How was accuracy of results to be obtained ensured throughout the experiment (**05 marks**)

(d) (i) on the graph draw a graph to represent the plot for biomass you would expect if the experiment was repeated and in this case the sample culture medium was not added to the trays containing pea plants (**02 marks**)

(ii) Suggest reason(s) for the appearance of the graph drawn in d (i) above (**03 marks**)

(e) How can the information from the investigation be beneficial in crop production? (**02 marks**

4. In an experiment to investigate the effect of light intensity on the rate of transpiration and stomatal opening a leafy herbaceous plant was used. A potometer with the stem of a herbaceous plant was placed in an open grassland, the following results were obtained.

Light intensity in µm	Number of open stomata per branch	Rate of transpiration in $mgm^{-2}h^{-1}$
10	30	28
30	50	36
40	62	41
60	90	50
80	51	33
90	28	20
100	0	7

(a) Represent the above results graphically on the same axes (09 marks)

(b) Compare the effect of light intensity on the rate of transpiration and the number of open stomata (06 marks)

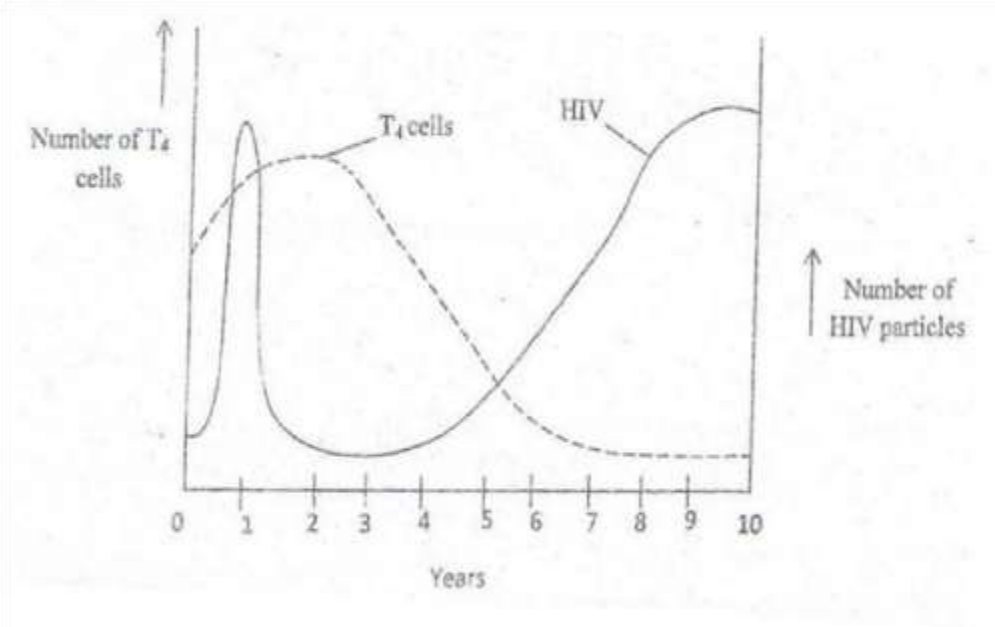
(c) Explain the effect of light intensity on the number of open stomata (14 marks)

(d) (i) State the relationship between the number of open stomata and the rate of transpiration *(02 marks)*

(ii) Explain the relationship stated in (c) (i) above (06 marks)

(e) Explain the results obtained at 100μm of light intensity (03 marks)

5. (a) The human immune deficiency Virus (HIV) is a retrovirus that suppresses the immune system resulting into Acquired Immune Deficiency Syndrome (AIDS). **Figure 1** below shows the development of an infection with HIV over a period of 10 years and the changes in the number of T-lymphocytes that activate other cells of the immune system. Use this information and **figure 1** to answer the questions
that follows



(i) Describe the Variation in the number of HIV particles and T-lymphocytes for the period of ten (10) years. (05 marks)

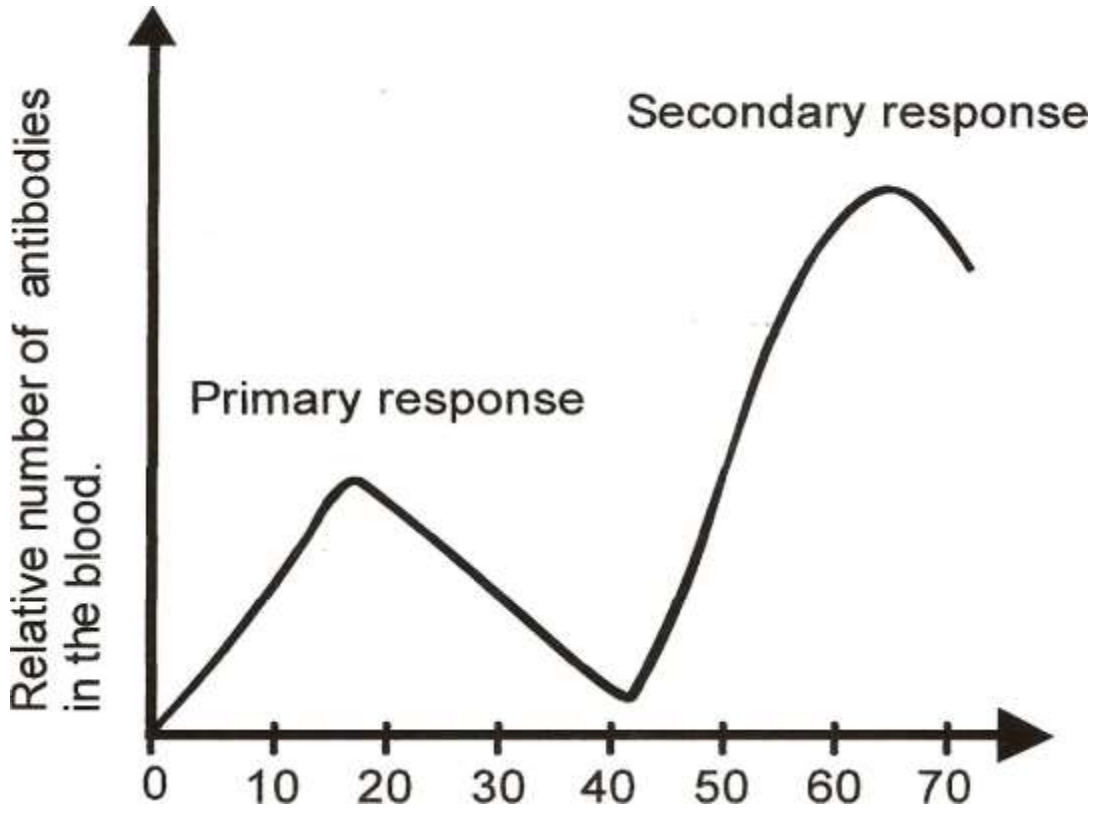
(ii) Explain the relationship between number of HIV particles and T-lymphocytes for the period shown. (09 marks)

(iii) From the figure; what evidence shows that HIV suppresses the immune system. (03 marks)

(iv) Predict with a reason what would happen if the development of an infection continued for another five years. (03 marks)

(v) Suggest a reason why it has taken long to obtain a vaccine for HIV. (04 marks)

(b) **Figure 2** below shows the comparison of antibodies produced to the same antigen during primary and secondary response.



(i) Compare the primary and secondary response (03 marks)

(ii) Explain how each response is being stimulated. (08 marks)

(iii)From figure 2, what is the significance of a secondary response in the immune system of an individual. (03 marks) (iv) Suggest other ways in which the body defends its self against diseases causing organisms.

(02 marks)

6. Differentiate between natural active immunity and artificial active immunity. (02 mark)

(b) What are the different ways in which the mammalian body naturally defends itself against pathogens? [12 marks]

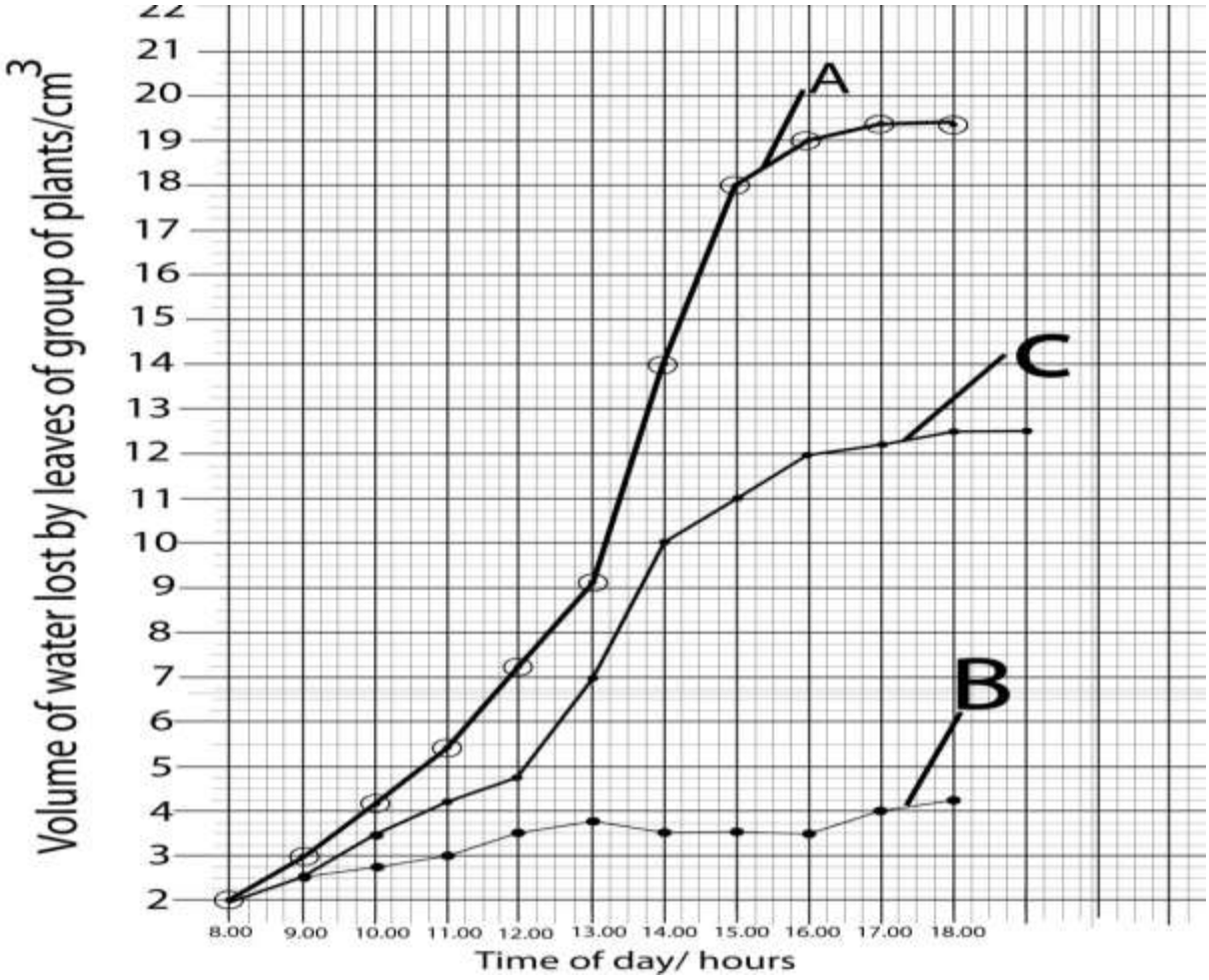
(c) Explain how artificial active immunity occurs. [06 marks]

7. An experiment was carried out to investigate the rate of water loss by three groups of leafy plants under different conditions. Twelve leafy plants of approximately the same age, leaf surface area and of the same species were used in the experiment. Four plants were placed in each group and treated simultaneously as follows:

Group 1: Plants completely covered with transparent polythene bags. Group 2: Plants fanned with an electric fan.

Group 3: Plants placed in still air in the open

The figure below shows the results of the experiments and the mean volume in cubic centimetres of water lost through evaporation over the leaf surfaces of groups of plants recorded. Each group of plants is represented as A, B and C in the figure 1 below



(a) Compare the volume of water lost by the leaves of different groups of plants shown in figure 1 above. (12 m)

(b) (i) From the curves drawn, identify the experimental conditions to which each group of plants **A**, **B** and **C** were placed. (03 marks)

(ii) With respect to group of plants **A** and **B**, suggest reasons for the observed difference in the two curves drawn. (07 marks)

(c) Why were the plants of the same age, leaf surface area and same species used in the experiment? (05 marks)
Suggest

(i) a hypothesis which this experiment was designed to test. (01 mark)

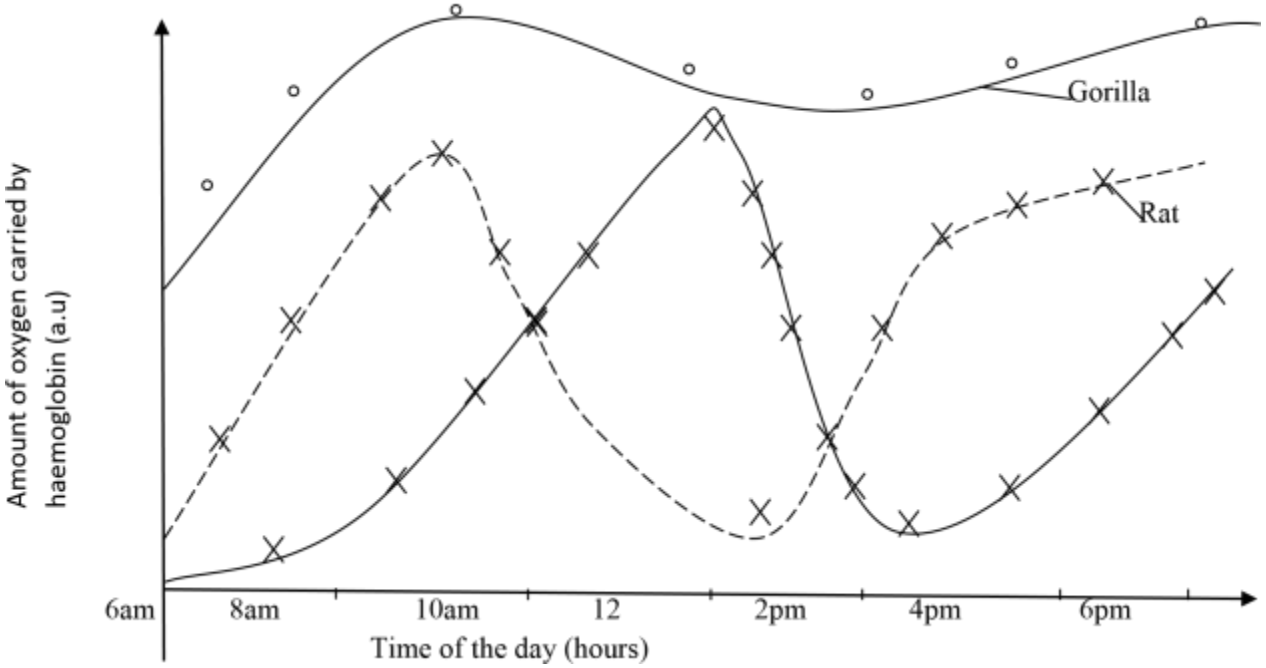
(ii) the name of the apparatus commonly used in this type of experiment. (01 mark)

(d) (i) Calculate the rate of water loss over the leaf surfaces by evaporation in group **C** between the time of the day 12:00 – 14:00 hours and 16:00 – 18 hour (03 marks)

(ii) Explain the difference in the rate of water loss by the same group of plants at various times of the day. (08 marks)

8. The figure below shows the amount of oxygen carried by haemoglobin in three different mammals during

the course of the day.



(i) Outline the differences in the amount of oxygen carried by haemoglobin of a rat with that of a human. (04marks)

(ii) Explain the trend of oxygen carried by haemoglobin for the;

- Gorilla (05 marks)
- Human (06 marks)
- Rat (06 marks)

b) Table 1 below shows the data obtained during an investigation on the effect of altitude on the amount of oxygen carried by haemoglobin and the rate of oxygen delivery to body tissues, for a person with sickle cell trait.

Altitude (metres)	Amount of oxygen carried by haemoglobin/cm^3	Rate of oxygen delivery to blood tissues (cm^3/minute)
0	85	20
100	80	5
200	73	11
300	48	20
400	32	45
500	20	60

600	15	75
700	13	85
800	11	88
900	8	90
1000	7	93

(i) Represent the above information on the graph paper. (06 marks)

(ii) Explain the relationship between altitude and the;

- the rate of oxygen delivery to body tissues. (05 marks)
- amount of oxygen carried by haemoglobin (06 marks)

c) What possible conclusion can be made from figure 1 and the graph plotted? (02 marks)

9. (a) What is meant by the term **human specific defence system**? (02 marks)

(b) Describe the role played by the thymus glands in the human specific defence system (12 m (c) Of what importance is memory and diversity to a defence system? (06 marks)

10. Differentiate between Natural active immunity and Artificial active immunity (02 marks)

b) State the different ways in which the mammalian body naturally prevents pathogens from accessing its internal environment (11 marks)

c) What is the significance of the high body temperature experienced when the mammalian body is attacked by *Plasmodium Spp?* (07 marks) a) What is meant by the term chloride shift? (03 marks)

11. Account for the relative position of the oxygen dissociation curves of the human and rat haemoglobin

(b)Explain the rapid dissociation of oxyhaemoglobin of a rat during a vigorous activity (07 marks)

(c) Describe the events which occur during the heart beat (16 marks) (d)Outline the features which ensure efficient flow of blood within the mammalian body (04 marks)

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12. What are the essential features of the immune system in mammals?

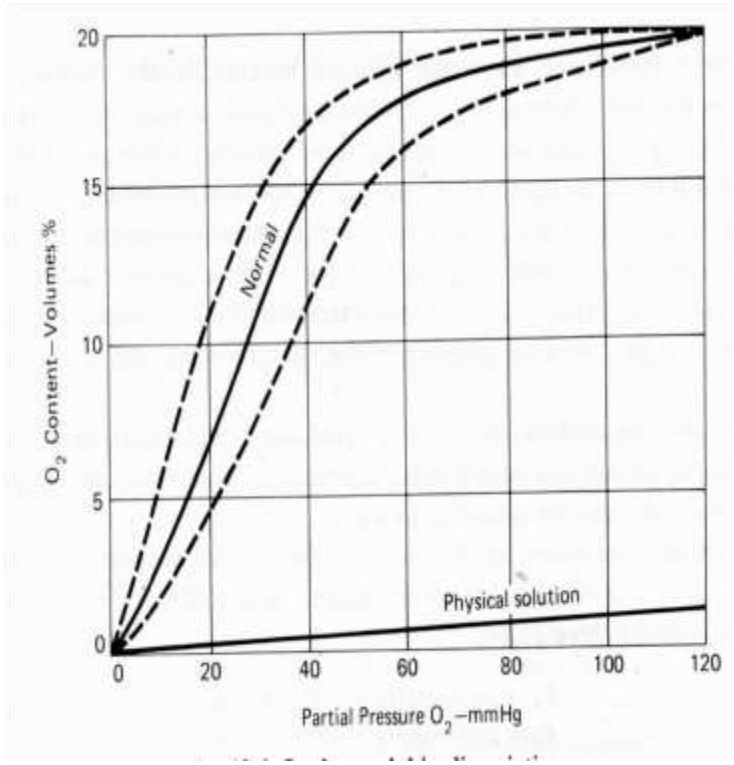
b) (i) Give an account of the ABO blood group system in humans, and explain how certain ABO group donations cause agglutinations with the recipients, while others do not.

(ii) Besides blood, other tissues can be transplanted from one individual to another. Mention problems associated with them, and steps taken to minimize the transplant failure

13. (a) What is the physiological significance of the Bohr effect in animals? (08 marks)

(b) Discuss the factors that may alter the rate of heart beat in mammals (12 marks

14. Figure 3 shows the union of oxygen and haemoglobin in three different physiological conditions



The straight line near the bottom of the graph shows the uptake of oxygen by a solution when hemoglobin is not present while the dotted curves on either side of the solid curve shows the formation of oxyhaemoglobin under two different levels of carbon dioxide

(a) Label the curves of blood in

(i) veins and muscles and

(ii) arteries and lungs (02 marks).

(b) Explain the importance of the positions suggested above in the physiology of the animal (04 marks).

(c) Explain the difference in the variation of the oxygen content of normal and physiological solutions(03 ma

15. Give an account of the structures involved in the translocation of organic solutes between the different parts of a flowering plant.

(b) Briefly describe how dissolved blood carbon dioxide is expelled in gaseous form by the lungs.

16. In fish, oxygen is transported in the blood in the form of oxyhaemoglobin. The table below shows the percentage saturation of blood with oxygen of a teleost (bony) fish after equilibrating with oxygen of different partial pressures. The experiment was carried out at two different partial pressures of carbon dioxide.

Partial pressure of oxygen in Pa	Percentage saturation of blood with oxygen	
	Partial pressure of carbon dioxide at 500 Pa	Partial pressure of carbon dioxide at 2600 Pa

500	30	5
1000	70	13
2000	90	24
3000	96	33
4000	98	41
5000	99	48
7000	100	60
9000	100	69
11000	100	76
13000	100	81

(a) Present the data in a suitable graphical form.

(b) Calculate the difference of percentage saturation of blood with oxygen at the two different partial pressures of carbon dioxide at oxygen partial pressures of 500 Pa.

(c) With reference to the graph, describe the effects of different partial pressure of carbon dioxide on the percentage saturation of blood with oxygen.

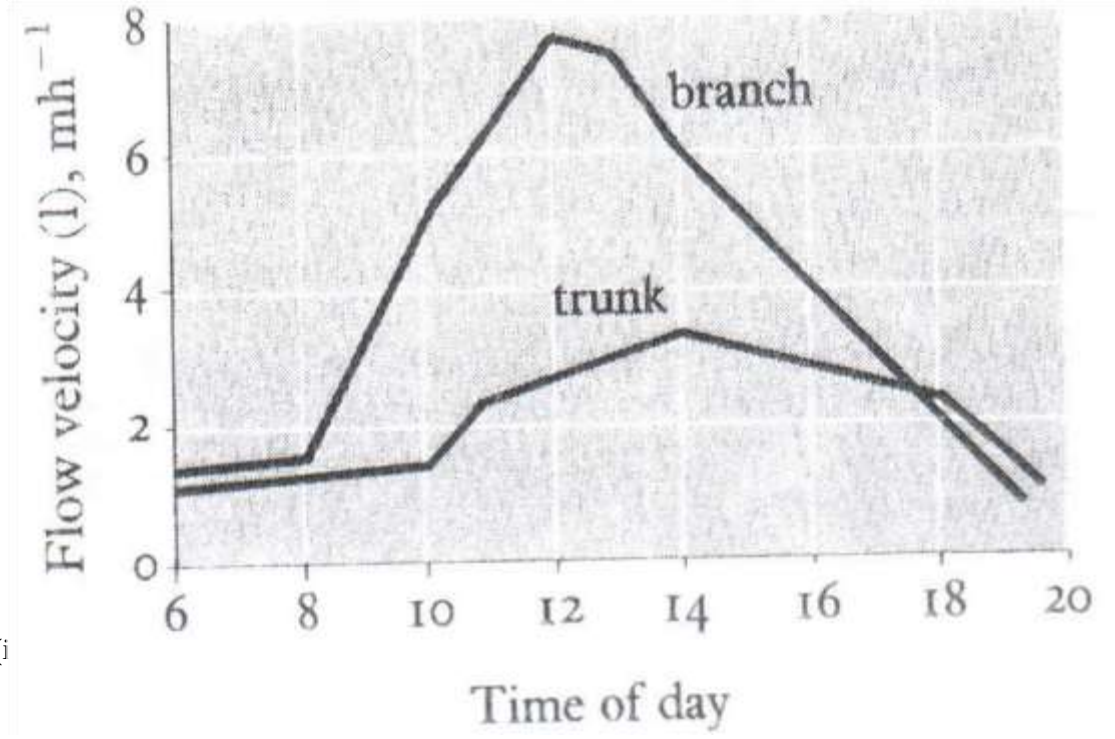
(d) Explain how changes in oxygen content of blood at different partial pressure of carbon dioxide are important in the release of oxygen to the tissues of fish.

(e) What information do such experiments give about the environmental conditions in which fish would maintain a high level of growth as required in commercial fish farming?

(f) Explain how the properties of haemoglobin molecule are affected by changes in the oxygen and carbon dioxide partial pressures.

17. The linear velocity of flow of sap through the xylem of a tree was measured in mh^{-1} in the trunk and in one of the small branches at the top of the tree. Measurements were taken at two-hourly intervals (07 marks)

during a hot day. The results are shown in the below.



(i

(ii) Explain the difference obtained in the flow velocity for the trunk and branch at 14:00 hours. (04 marks)

(iii) Briefly explain the difference would you expect in the circumference of the trunk measured at 14:00 hour when compared with that measures at 18:00 hrs?(04 marks)

(iv) Explain how the results would change if the experiment was carried out on a cold day (03 days)

(b) Table 1 shows the relative number of stomata and relative rate of transpiration, in your difference plant species.

Table 1

Plant Species	**A**	**B**	**C**	**D**
Relative number of stomata mm^{-2} of leaf (upper : lower surface)	5:30	0.80	10:15	0.50
Relative transpiration rate (upper: lower surface)	10:12	0:4	15:30	20:50

(i) Comment on the distribution of stomata in the four species (06 marks)

(ii) Explain the relationship between the distribution of stomata and the rate of transpiration in;

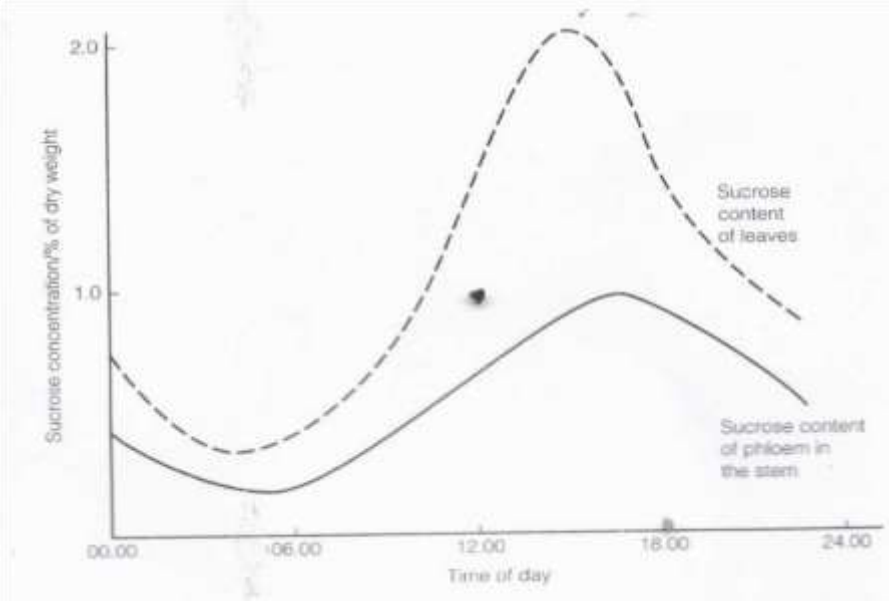
- Species **B**. (04 marks)
- Species **D**. (03 marks)

(iii) From the data, what conclusions can be drawn about the difference between the upper leaf surface of species **B** and **D**.? (03 marks)

(c) (i) Describe how cohesive and adhesive forces ensure a continuous water column up the xylem vessels. (03 marks)

(ii) How does bulk flow in the xylem differ from diffusion (03 marks)

18. Figure 1 below shows the diurnal variation in the sugar content of leaves and the phloem in stems.



(i) Compare the trend in sucrose concentration in the leaves and the stem. (08 marks)

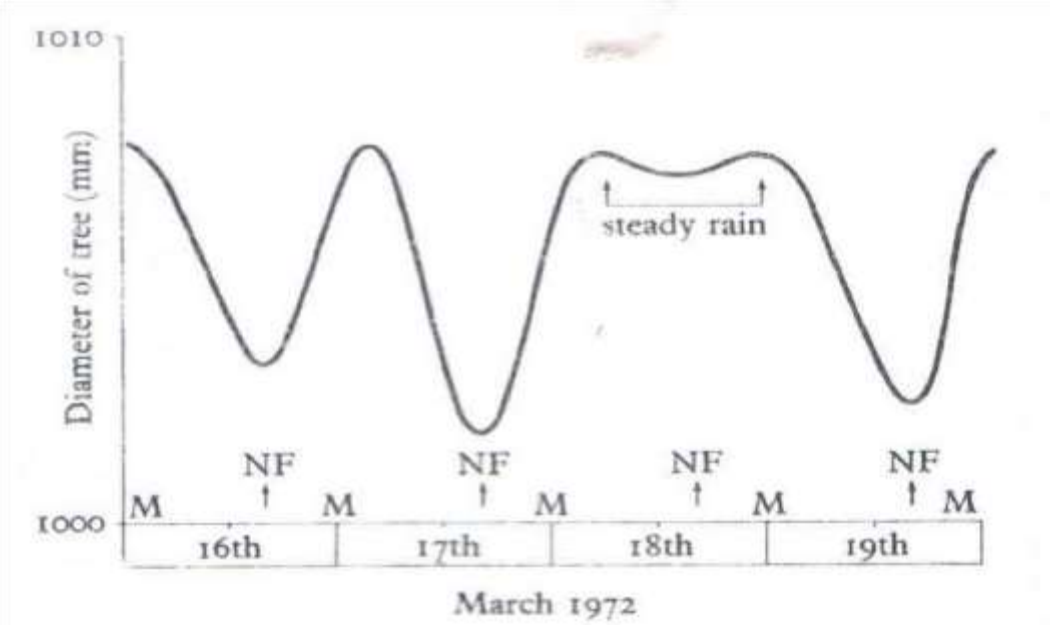
(ii) Account for changes in sucrose concentration between 00.00hrs and 16:00 hr (10 ma

(iii) Describe the relationship between sucrose content of leaves and sucrose content of phloem in the stem. (03 marks)

(iv) Explain the relationship described in (a) (iii) above. (06 marks)

(b) In an experiment, a scientist used very sensitive recording equipment to observe the diameter of certain very large trunks.

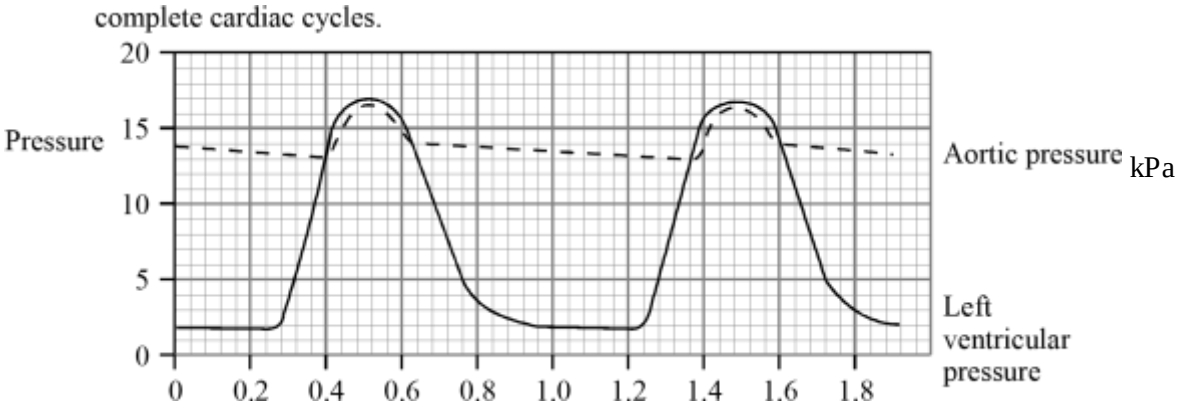
Figure 2 shows the results obtained when changes the trunk diameter of one of the trees was measured for a period of about four days



(i) Explain the effect of time of day on the diameter of the trunk between 16th and 17th of March. (08 days)

(ii) Explain the effect of steady rain on the diameter of tree as seen on the 18th day. (05 days)

19. The figure below shows changes in the blood pressure in the aorta and the left ventricle during two /



Time /s

(a) On the graph, draw an arrow to show when the left atrioventricular (mitral) valve closes.(01 mark

(b) Use the information in the graph to calculate the heart rate. Show your working. (02 marks

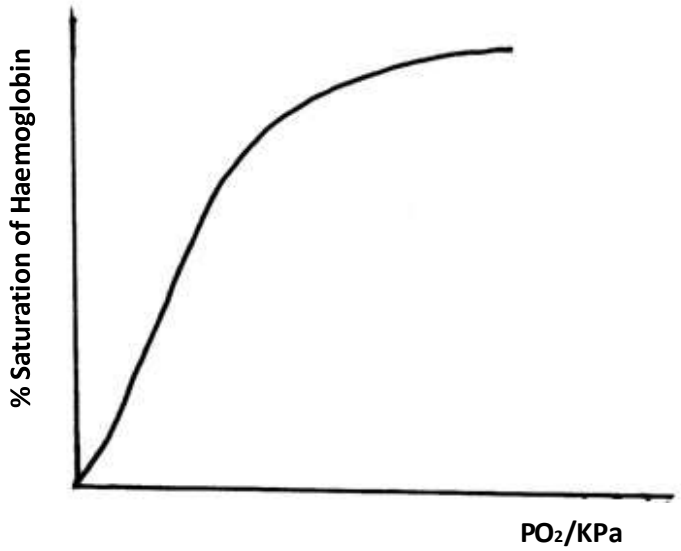
(c) During the cardiac cycle, the pressure in the left ventricle falls to a much lower level than in the aorta. Suggest an explanation for this difference. (03 marks)

(d) During the cardiac cycle, the pressure in the right ventricle rises to a maximum of about 3.3 KPa. Suggest reasons for the difference between this pressure and the maximum pressure in the left ventricle.(03 marks)

20. Blood that is fully saturated with oxygen carries 105cm^3 of oxygen in 1 dm^3(liter) of blood

(a) Calculate the volume of oxygen released from 1 dm^3 of blood when blood that has become 90% saturated at 38^0C reaches a part of the body where the partial pressure is 18% (03 marks)

The figure below shows the oxygen dissociation curve of hemoglobin from a mammal at 38^0C.



(b) Draw the curve of hemoglobin when the body temperature is raised to 43^0C(01 mark)

(c) Name one change in the conditions in the tissues which has the same effect on the oxygen dissociation curve as change in temperature (01 mark)

(d) Explain the effect of increased body temperature on the oxygen dissociation curve for hemoglobin in mammals(03 marks)

(e) State how this effect of temperature on the oxygen dissociation curve of hemoglobin might be advantageous to the mammal (03 marks)

21. The table below shows the results of an experiment on the rate of absorption of sugars by a mammalian intestine. Study it carefully and answer the questions that follow.

Sugar		Relative rates of absorption taking normal glucose uptake as 100	
		By living intestine	By intestine poisoned with cyanide
Hexose sugars	Glucose	100	30
	Galactose	106	35
Pentose sugars	Xylose	32	32
	Arabinose	30	31

(a) Suggest a reason for the difference between the rates of absorption of hexose and pentose sugars in the living intestines (03 marks)

(b) Mention the mechanism by which hexose sugars are absorbed by living intestines ($0\frac{1}{2}$ mark)

(c) What is the advantage to the individual of having hexose sugars absorbed in the way mentioned above?

(d) What could be the effect of cyanide on the mechanism of hexose absorption? (02 marks)

(e) In an intact mammal, absorption of fatty acids is drastically curtailed by any clinical condition which leads to a reduction in bile salt excretion or release. Explain why this is so. (03 marks)

22. (a) What is meant by the term **Bohr's effect**? (02 marks)

(b) Briefly explain the following observations;

The oxygen dissociation curve of,

i. man shifts to the right during exercise (03 marks)

ii. the elephant is on th e left of the oxygen dissociation curve of a mouse? (03 marks)

iii. the lungworm is on the left of that of man? (03 marks)

c) Explain three factors that influence the affinity of haemoglobin for oxygen (06 marks)

23. The table below shows the difference in percentage saturation in blood with oxygen at varying partial pressure of oxygen between a pregnant woman and that of the fetus developing in her uterus.

Partial pressure of oxygen /mmHg	**Percentage saturation of blood with oxygen**	
	mother	**Fetus**
1.3	**8**	**10**
2.7	**20**	**30**
3.9	**40**	**60**
5.3	**65**	**77**
6.6	**77**	**85**
8.0	**84**	**90**
9.3	**90**	**92**
10.6	**92**	**92**

i) Plot the results in a suitable graphical form. (08 marks)

ii) Compare the percentage saturation of blood for the mother and that of the fetus.(04 marks) iii) State and explain the shape of the curve for the mother. (07 marks) iv) Explain the physiological significance of the position of the fetal curve (05 marks)

b) Explain what is meant by: (06 Marks)

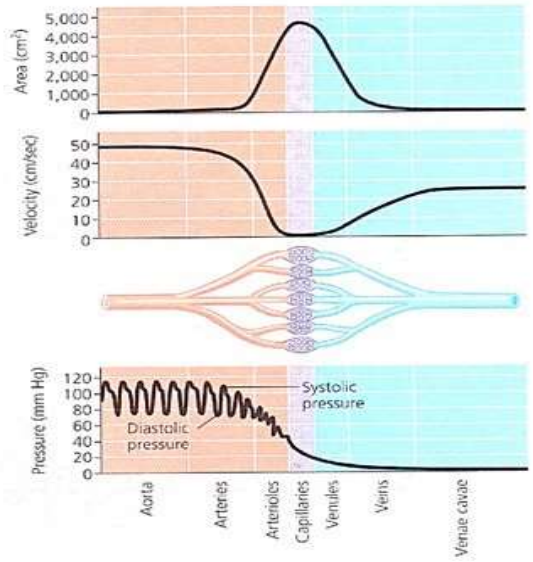
i) Bohr's effect iii) Un loading tension ii) Loading tension

24. What fundamental physical constraints necessitate a circulatory system in large organisms? *(02*

b) State **one** advantage and **one** disadvantage of a closed circulatory systems *(02 marks)*

c) State **two** physiological advantages of separate pulmonary and systemic circuits in a mammalian circulatory system *(02 marks)*

d) Figure 6 shows the interrelationship of blood flow velocity, cross sectional area of



Explain the relationship between **area** and **velocity** in the arteries

REFERENCES

1. D.T.Taylor, N.P.O. Green, G.W. Stout and **R. Soper**. Biological Science, 3rd edition, Cambridge University Press
2. M.B.V.**Roberts**, Biology a Functional approach, 4th edition, Nelson
3. C.J.Clegg with D.G.Mackean, ADVANCED BIOLOGY PRICIPLES AND APPLICATIONS, 2nd EDITION, HODDER EDUCATION
4. Glenn and Susan **Toole**, NEW UNDERSTANDING BIOLOGY for advanced level, 2nd edition, Nelson thornes
5. Michael **Kent**, Advanced BIOLOGY, OXFORD UNIVERSITY PRESS
6. Michael Roberts, Michael Reiss and Grace **Monger**, ADVANCED BIOLOGY
7. J.SIMPKINS & J.I.WILLIAMS. ADVANCED BIOLOGY