TRANSPORT OF MATERIALS

Movement of materials in and out of the cells is vital in all living organisms. Unicellular organisms and multicellular organisms like hydra have simple methods of transporting materials across the cell. This is mainly by simple diffusion. Such organisms possess a large surface area to volume ratio and each cell can exchange useful materials and waste products directly to the external environment.

In higher organisms, both plants and animal tissues are bulky and the body is complex. Diffusion alone cannot efficiently supply the body's requirements. Such organisms involve a highly vascularized conducting muscular tissue to enable movement of important materials through the body.

The transport system/circulatory system consists of the following:

- Tubular tissue in which substances move
- Fluid that dissolves the substance
- Pumping organ for circulatory of materials

Plants do not have a pumping organ and a vascular tissue is separated by space whereby the xylem tissue which transports water and mineral salts has no direct contact with the phloem tissue which translocate dissolved food substances. In both water is the fluid in which materials are dissolved.

Animals have a pumping organ that enables the circulation of the fluid in the blood vessels so that materials can be supplied to the whole body. Animals therefore have a circulatory system. There are several functions of the transport system;

- Transport of materials from one part of the body to another.
- Transport of waste products.
- Movement of important substances i.e. water, hormones, enzymes, etc.
- Movement of respiratory gases.

The transport system in all higher organisms forms a system of vessels which forms a complex network.

TRANSPORT OF MATERIALS IN PLANTS

Plants require adequate supply of CO_2, O_2, mineral salts and water for normal growth. Lower plants like algae move materials in and out of their bodies by diffusion and active transport because they have a large surface area to volume ratio. Higher plants have a vascular system which helps in translocation.

The vascular tissues have several adaptations to perform their functions.

Adaptations of the xylem tissue

i) Has long cells joined end to end in order to form a continuous column for the flow of water.
ii) End walls break down to form an uninterrupted structure to ensure smooth flow of water from vessels to leaves in tracheid. Where end walls are not present, large pits are formed to reduce the resistance to flow.
iii) There are pits at particular places where lignin is deposited. These pits allow natural flow of water where this is necessary to prevent air bubbles from blocking the vessels.
iv) Deposition of cellulose walls with lignin increases the adhesive forces between water molecules and the tissue wall and it enables water to raise up by capillarity.
v) The xylem tissue especially the vessels have very narrow lumen of about 0.01-0.02mm in diameter. This increases capillarity forces for the uptake of water.
vi) Each xylem element has a wall made up cellulose and lignin. Lignin is water proof and a very strong material which helps in maintaining water inside the xylem element.

Adaptations of the phloem to its function

The phloem has tissues that are well adapted to movement of materials in the following ways:

i) Possess cytoplasmic strands over which materials can flow.
ii) Possess end walls called sieve plates which are perforated by numerous pores to allow passage of substances from one sieve element to the next.
iii) The cytoplasm of the sieve elements is structurally simple with no or few organelles like endoplasmic reticulum. This provides large space for the movement of materials.
iv) Besides each sieve element is a companion cell which possesses nucleus, mitochondria, endoplasmic reticulum, etc., which is a site for intense metabolism. The mitochondria provides the energy required.
v) Cells have plasmadesmata pits that allow movement of materials between sieve elements.

vi) The phloem tissue in leaves have transfer cells responsible for moving products of photosynthesis from the mesophyll cells to the sieve tubes.

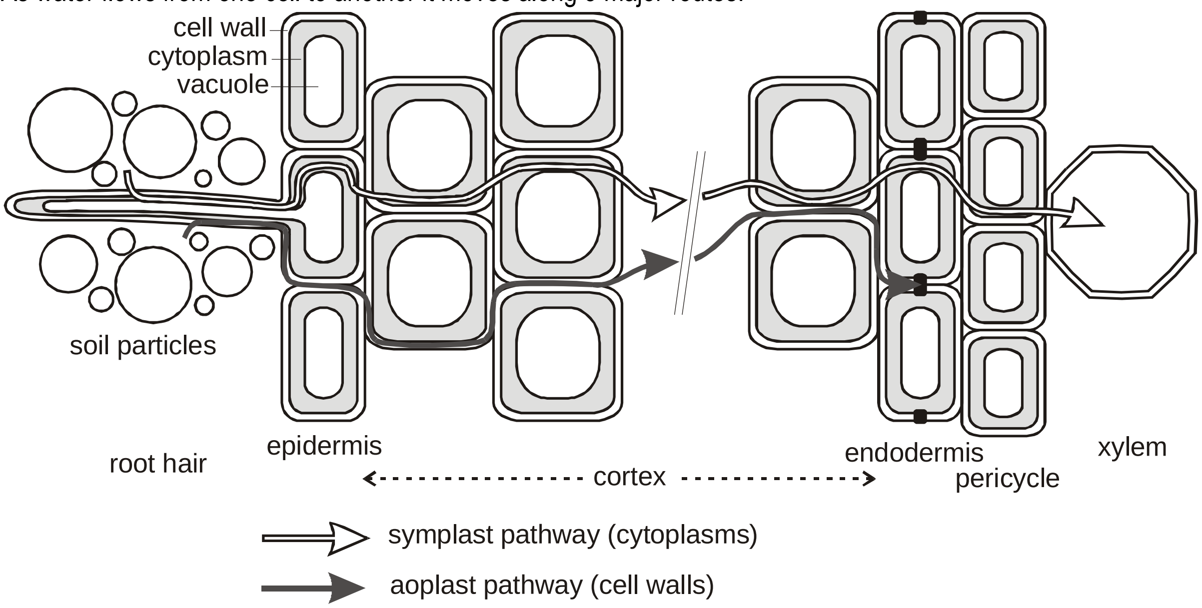
Absorption of water from the soil by plant roots.

In plants the principle surface for absorption of water are roots. Not all parts of the root are useful but only the tip between 20 -200mm from the tip. As the root grows older the cells become impermeable to water due to deposition of lignin, suberin and cutin. Root hairs have several adaptations that enables them to absorb water.

i) They are very small and numerous thus increase surface area to volume ratio.
ii) They are slender and flexible so they can penetrate through the soil.
iii) They have large concentrated vacuoles which provide an osmotic gradient.
iv) The outer cell of the root hairs is fully permeable to water.

Root hairs absorb water from the soil by osmosis and thus water moves from the root hair cells to xylem by osmosis. The cortex cells neighboring the root hair cells have a high osmotic pressure therefore water moves the root hair cell to the cortex cells by osmosis.

As water flows from one cell to another it moves along 3 major routes:



Apoplast pathway:
This is where water flows along the cell walls between the different cortex cells. Along this route, there is less resistance to water flow.

Symplast pathway:
Here water moves from cytoplasm to cytoplasm through plasmadesmata. There is some resistance along this route.

Vacuolar pathway:
Water moves from vacuole to vacuole. The resistance to water flow is too high due to high concentration of the vacuole. A limited amount of water moves to the xylem through this route.

Towards the xylem tissue, there is an epidermal layer with casparian strip. The strip is made of suberin which impermeable to water. The strip prevents flow of water through the Apoplast pathway. Water is therefore forced to pass through the cytoplasm of endodermal cells. Some endodermal cells secret materials close and into the xylem tissue which increases the osmotic pressure along the region. This increases the flow of water into the xylem tissue from the cortex region.

Uptake of water in the xylem tissue

As water is absorbed from the soil, it accumulates in the xylem. There are several forces that ensure its movement upwards. These include; cohesion, tension, root pressure, adhesion, transpiration pull and capillarity.

1. Movement of water up the plant may be due to capillary forces because of the narrow xylem vessels and tracheid. These provide capillary forces to raise water up the stem. The level at which the water raises depends on the height of the plant. In very tall trees, capillary may not be enough to raise water to the leaves.

2. Cohesion-tension forces; as water molecules raise, they attract and pull other water molecules to cause an upward movement of water in a continuous column. This is mainly due to high cohesion forces between the water molecules, in case of any blockage of water column, lateral flow of water between xylem and tracheid through pits will prevent creation of bubbles to ensure that the continuous water column is maintained.
3. Adhesion forces; forces of attraction between water molecules and walls of the xylem tissues enables water to raise up the stem.
4. Root pressure; continuous absorption of water from the soil by the root cortex creates a pushing force in the xylem tissue as more water enters the xylem. This makes a considerable contribution of the movement of water upwards especially in herbaceous plants but its effects are less significant especially in tall woody plants.
5. Transpiration pull; this is the most important force responsible for the uptake of water in tall woody plants. As water is lost by evaporation from the mesophyll cells in the leaves, such cells become concentrated and absorb more water from the leaf veins due to high osmotic gradient by transpiration. More water moves up from the stem to the leaf veins to replace lost water. This would eventually create a continuous flow of water moving up the plant called the transpiration stream. The pulling force generated in the leaves is called the transpiration pull and is the one responsible for the flow of water.

Uptake of ions

Ions are absorbed into the root hairs, transported across the root, and then into the xylem. They then travel in solution in water to all parts of the plant.

The mechanism by which ions are taken up by root hairs depends on their concentration in the soil solution. If a particular type of ion is in a higher concentration in the soil than inside the root hair cell, then it will be absorbed by ***facilitated diffusion***. This does not require any energy input by the plant. If, however, the concentration of the ion in the soil is lower than that inside the root hair cell, then it must be absorbed by ***active transport***. Specific transporter proteins use energy derived from the hydrolysis of ATP to move ions through the cell membrane into the cytoplasm.

TRANSPIRATION

This is the loss of water inform of water vapour from the aerial parts of the plant to the atmosphere. Transpiration is as a result of evaporation of water from the mesophyll cells into the air spaces then out of the leaf through the stoma. It normally occurs over the leaves that have numerous pores (stoma). It can also occur at the bark where there are lenticels and some water can be lost through the cuticle.

Importance of transpiration in plants

Transpiration has been described as a *necessary evil* because it is an inevitable but potentially harmful consequence of the existence of moist cell walls from which evaporation occurs. Water vapour escapes along the routes used for gaseous exchange between the plant and its environment which is essential for the process of photosynthesis and respiration.

Loss of water can lead to wilting, cause desiccation and kill the plant if conditions of drought are experienced. Evidence shows that even mild water stress results in reduced growth rate. However, despite its inevitability, it is worth to note that there are some advantages associated with transpiration.

i) It cools down the plant.
ii) It helps in the movement of water and mineral salts through transpiration pull.
iii) It leads to remove of excess water.
iv) Keeping mesophyll cells moist ensures that gaseous exchange occurs especially in leaves.

Factors affecting transpiration

Anything that increases the water potential gradient between the air spaces in the leaf and air outside, or that speeds up the movement of the water molecules, will increase the rate of transpiration.

i) **Humidity:** humidity is a measure of how much water vapour is held in the air. In conditions of low humidity – that is, when the air is dry – there is a steep water potential gradient between the leaf and the air. Transpiration rates are therefore greater in low humidity than in high humidity.
ii) **Temperature:** an increase in temperature causes an increase in the kinetic energy of water molecules. This increases the rate of evaporation of water from the cell walls into the air spaces, and also the rate of diffusion of the water vapour out of the leaf. An increase in temperature therefore increases the rate of transpiration.

iii) **Light intensity:** light does not normally have any direct effect on the rate of transpiration during the daytime. However, many plants close their stomata at night, when it is dark and they are unable to photosynthesis and so do not need to use carbon dioxide from the air.

iv) **Air movements:** the more the air around the plant's leaves is moving, the faster the humid air surrounding them is carried away. This helps to prevent the leaf becoming surrounded by air that is saturated with water vapour, and maintains a water potential gradient from the air spaces inside the leaf to the air outside. Transpiration therefore happens faster on a windy day than on a still day. ***Fig.1***.

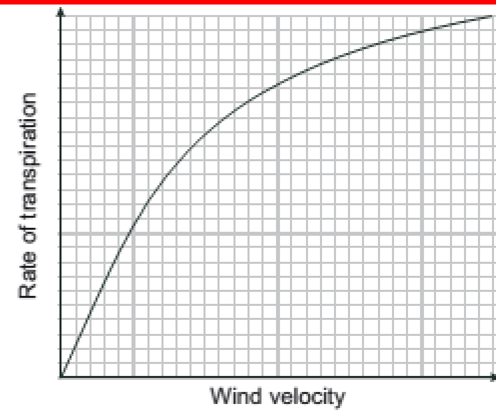


Fig.1: How wind affects the rate of transpiration

v) **Stomatal aperture:** in many plants, stomata close at night. In the graph (***fig.2***) stomatal closure has occurred at night.
In especially dry conditions, the plant may close its stomata even when light levels are ideal for photosynthesis, to avoid losing too much water from its leaves. There is often a compromise to be reached between allowing in enough carbon dioxide for photosynthesis, and not letting out too much water vapour. The rate of transpiration is higher at larger aperture.
However, if you look at the graph in ***fig.3***, you will see that in still air, the increase in the rate of transpiration is very little at larger apertures, whereas in windy conditions, the rate continues to increase even with larger apertures.

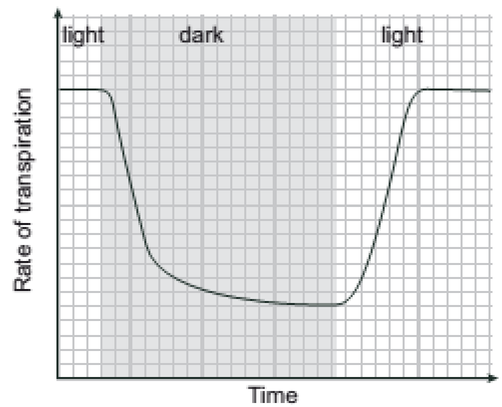


Fig.2: How stomatal closure affects transpiration

vi) **Plant structure:** transpiration occurs from the surface of leaves and green stems. For plants that need to conserve water, reducing the area of these surfaces will limit the rate of transpiration. This can be done by dropping leaves in dry seasons, having small leaves or having no leaves (relying on green stems for photosynthesis).

vii) **Leaf anatomy:** a number of structural features can reduce the rate of transpiration, even when stomata are open. All of these features act by trapping still air outside the stoma. This increases the distance water has to diffuse before it can be carried away in the mass flow of air in the wind. The further the distance water has to diffuse, the slower the rate of transpiration.
This is achieved by one of the following; having stomata set in pits, having stomata on a leaf surface that is on the inside of a rolled leaf, having dense hairs on the leaf surface or having a thick layer of wax on the leaf.

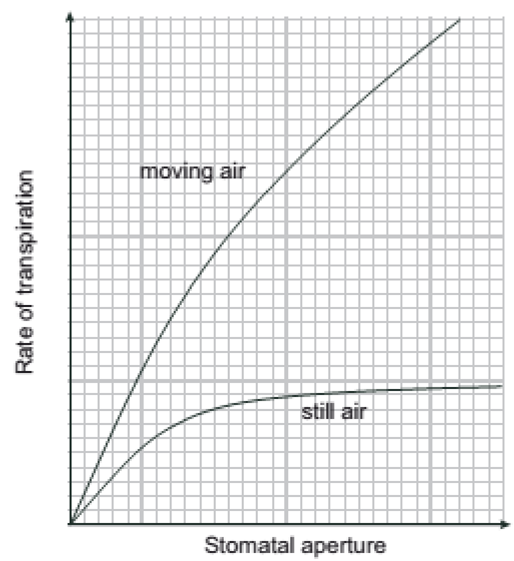
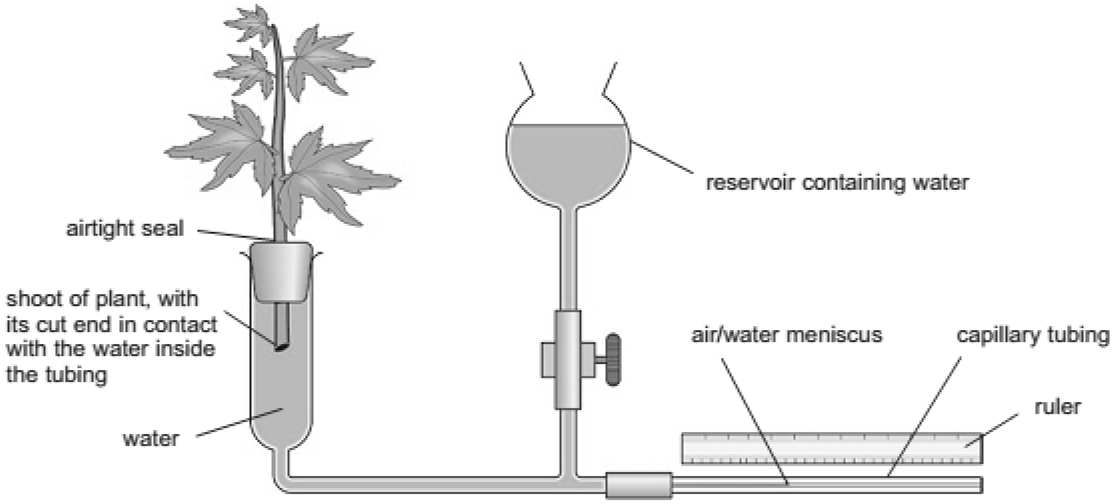


***Fig.3:* The effects of wind velocity and stomatal aperture on the rate of transpiration**

Measuring/comparing the rate of transpiration

It is not easy to measure the rate at which water vapour is leaving a plant's leaves. This makes it very difficult to investigate directly how different factors, such as light or air movement, affect the rate of transpiration. However, it is relatively easy to measure the rate at which a plant stem takes up water. A very high proportion of the water taken up by a stem is lost in transpiration. As the rate at which transpiration is happening directly affects the rate of water uptake, this measurement can give a very good approximation of the rate of transpiration. The apparatus used for this is called a ***potometer.***



It is essential that everything in the potometer is completely watertight and airtight, so that no leakage of water occurs and so that no air bubbles break the continuous water column.
To achieve this, it helps if you can insert the plant stem into the apparatus with everything submerged in water, so that air bubbles cannot enter the xylem when you cut the stem. It also helps to cut the end of the stem with a slanting cut, as air bubbles are less likely to get trapped against it.
As water evaporates from the leaves, more water is drawn into the xylem vessels that are exposed at the cut end of the stem. Water is drawn along the capillary tubing. If you record the position of the meniscus at set time intervals, you can plot a graph of distance moved against time. If you expose the plant to different conditions, you can compare the rate of water uptake.

Adaptations of plants to prevent water loss

- Reduction of leaves to fine spines
- Small leaves
- Stem with hard thick epidermis covered with waxy cuticle.
- Ability to fix CO_2 at night so that the stomata can be closed during the day.
- Possession of thick succulent leaves that can store water.
- They have organ pipe-like stem that point vertically upwards to minimize the surface area exposed to the midday sun.
- They have sunken stomata reduced in number and confined to the surface of the leaf.
- Have a layer of stiff interlocking hairs in the inter-epidermis that reduces transparency by trapping air within the leaf.
- Have shallow but extensive root system so they allow efficient absorption of water.

Transport in phloem

The transport of soluble organic substances within a plant is called **translocation**. These substances are sometimes called assimilates. The main substance transported in phloem is **sucrose**.
Assimilates are transported in sieve elements. Sieve elements and companion cells work closely together to achieve translocation.
There are several hypotheses put forward to explain movement of materials through the phloem. The most widely accepted is the mass flow hypothesis, however, the other mechanisms are cytoplasmic streaming, electro-osmosis, active transport and surface spreading.

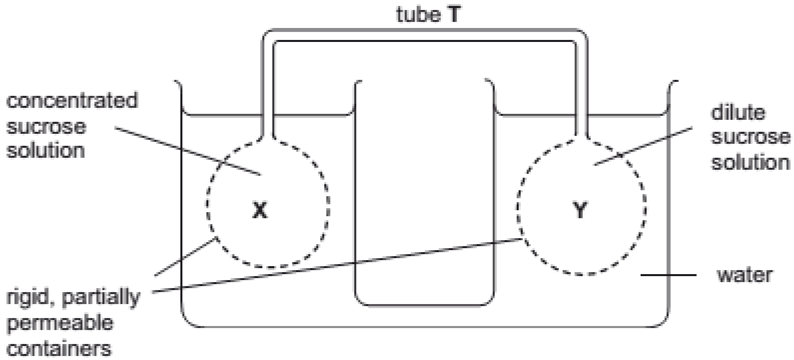
1. Mass flow

Mass flow hypothesis explains translocation as a result of photosynthetic products moving through the phloem tissue from the leaves to the roots due to the turgor pressure gradient.
In the leaves, turgor pressure is high due to manufacture of food substances and materials produced e.g. sucrose increases the osmotic pressure of mesophyll cells which when absorbed would result into increase in turgor pressure.
In the roots, turgor pressure is very low because food substances respired to release energy.

The difference in turgor pressure enables food substances to flow from the source to the sinks. Any area of a plant from which sucrose is loaded into the phloem is called a **source**. An area that takes sucrose out of the phloem is called a **sink**.
There are several evidences to show that mass flow occurs in plants. These include;

- There is flow of food substances/solution; there is flow of sap from a cut stem.
- There is flow of sap from aphid stylets.
- There is a difference in the concentration of sucrose between the leaves and roots. Concentration of sucrose is higher in leaves than the roots therefore turgor pressure gradient occurs.
- Some viruses and growth substances applied to the leaves move through the phloem to the roots.

Munch demonstrated mass flow as a physical process as illustrated below;



The model above illustrates mass flow i.e. bulk movement of food substances from higher turgor pressure to a lower turgor pressure.
Flask X contains a concentrated solution which in plants may stand for leaves. Flask Y contains a dilute solution which in plants may be roots. Fluid flows from flask X to flask Y through the delivery tube T. The delivery tube may represent phloem tissue which connects the source to the sink.

Shortcomings of the mass flow hypothesis

Although the mass flow hypothesis is widely accepted, there are some observation that regard translocation that it can't explain.

i) Different solutes have been observed to move at different speeds since the sieve tubes are not equally permeable to all solutes. The ratios of concentrations of various solutes changes as the solutes move along the sieve tube resulting in a change in their rate of flow.
ii) Materials have been observed to move up and down at the same time in the phloem tissue, mass flow can't account for bi-directional flow.
iii) In some plants, gradients of turgor pressure are insufficient to overcome the resistance caused by the sieve pores and plates to move the food substances.

2. Cytoplasmic streaming

Within the phloem tissue, there are cytoplasmic strands or filaments which are proteins in nature and they are continuous from one sieve element to another via the pores. Food substances are able to move along these strands due to wave-like contractions generated by the filaments. The sieve elements use energy provided by the companion cells to carry out such contractions.
Cytoplasmic streaming enables some food substances to move upwards while others downwards. It therefore accounts for the bi-directional flow of substances observed in the phloem tissue.

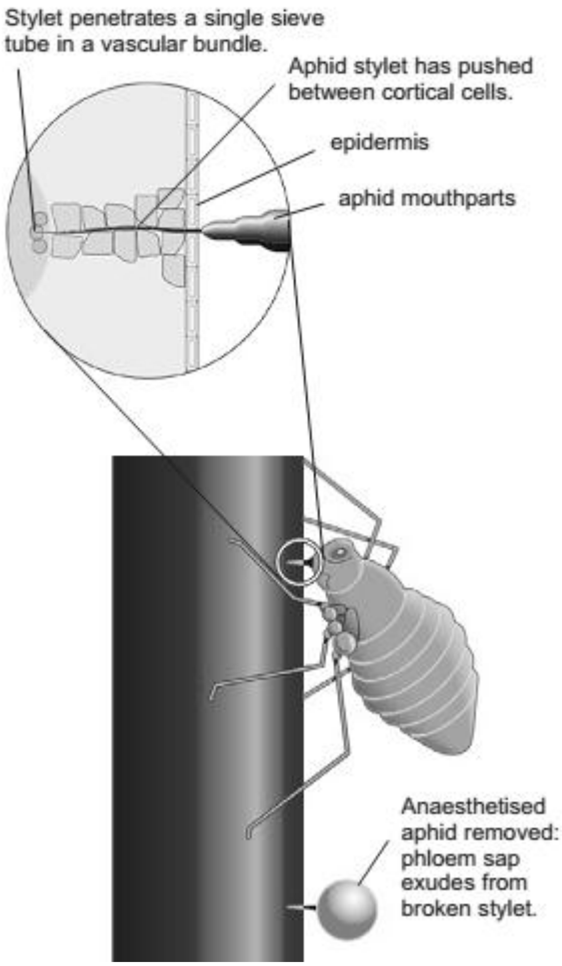
Shortcomings/criticisms:

Plants would require a lot of energy to transport the observed food units of food substances.

Evidence to support the fact that translocation of materials occurs via the phloem

1. Ringing experiment:

In natural tree trunks, the phloem is confined to the bark. If a ring is cut round the bark and stripped off a tree trunk, the sucrose concentration increases above the ring and decreases below, indicating that downwards the movement of sucrose is blocked at that point.



The feeding aphid

2. Radioactive tracers:

If a plant is exposed to CO_2 labelled with radioactive ^{14}C, the ^{14}C becomes incorporated into the end products of photosynthesis which are subsequently detected in the stem. That these substances are confined to the phloem and can be shown by cutting sections of the stem, placing the sections in contact with photographic film and auto radiographing, it is found that the sites of radioactivity correspond precisely to the position of the phloem.

3. Feeding aphid:

Aphids are a good way of collecting sap. Aphids, such as greenfly, feed by inserting their tubular mouthparts, called stylets, into the phloem of plant stems and leaves. Phloem sap flows through the stylet into the aphid. If the stylet is cut near the aphid's head, the sap continues to flow.

TRANSPORT IN ANIMALS

The unicellular organisms like amoeba, paramecium transport of materials in and out of the body is by simple diffusion since the bodies of such organisms are too small. They have a large surface area to volume ratio so that simple diffusion is efficient to transport substances in and out of their bodies. Such organisms therefore have no any specific vascular systems.

Vascular systems in multicellular organisms such as animals share the following basic features:

1. A circulatory fluid: most common one is blood though higher organisms contain lymph as an addition.
2. A pump organ: the heart
3. A system of tubes through which the circulatory fluid can move.

Types of circulatory systems in animals

There are two types and these include; water circulatory system and blood circulatory system.

Water circulatory system

It exists in lower animals like sponges and hydra where water from the surrounding medium acts as a circulatory fluid.

i) Canal system:

It exists in poriferans like sponges. They have a system of tubes called canal system which could be simple or complex depending on the organization of the sponge. All canals ultimately communicate to the exterior through the numerous pores called Ostia. The body of the sponge is in form of a cylinder enclosing a cavity called spongocoel with a large opening called osculum.

The beating of flagella lining the canals causes the current of water to enter through Ostia which are like inhalant siphon. The current of water bring in food and oxygen for the sponge. As the water moves through the various canals, food is taken in and wastes are given out and finally the water leaves the sponge through the osculum i.e. exhalent siphon.

Water in → ostia → canals → spongocoel → osculum → water out

ii) **Coelenterons water filled cavity**:

All coelenterates possess a single large cavity called coelenteron lined by endodermal cells. This cavity has a single opening through which water enters and leaves the animal.

The water carrying food and oxygen passes in through the mouth and circulates through the coelenteron. After collecting the wastes and carbon dioxide the water leaves the coelenteron through the same mouth opening. The flagellated cells of the endoderm direct the movement of water.

Function of White Blood Cells

They defend the body against disease causing organisms (antigens) by producing antibodies. The antibodies defend the body by:

The antibodies defend the body by.

i) **Agglutination:**
Some antibodies have many binding sites and can join the antigens of many different pathogens. In this way, the pathogens can be joined together in clumps making them vulnerable to attack from other types of antibody.

ii) **Precipitation:**
Some antibodies bind together soluble antigens into large units which are thus precipitated out of solution. As such, they are more easily ingested by phagocytes.

iii) **Neutralization:**
Certain antibodies bind toxic molecules produced by pathogens and in doing neutralize their harmful effects.

iv) **Opsonisation:**
Antibodies bind cell surface antigens on bacteria cells and make them more susceptible to being digested by phagocytes.

v) **Lysis:**
Some breakdown pathogens' membranes and cell walls if they have them leading to water getting into it by pinocytosis. The pathogens swell and burst in the process called lysis.

They also defend the body by engulfing foreign materials (phagocytosis/endocytosis).

NB: The number of white blood cells increases during infection because the body manufactures more white blood cells to attack the disease causing organisms and prevent the infection from proceeding.

Platelets (thrombocytes)

They are cell fragments

They lack nuclei

Functions

They play a role in blood clotting which protects the body against excessive loss of blood and entry of pathogens through the injured part.

The Process of Blood Clotting

Blood clotting is brought about by a soluble plasma protein called **fibrinogen when it is converted to an insoluble form called fibrin.**

The process begins when platelets exposed to air at the injured part break down releasing **Thromboplastin.**

Thromboplastin converts **prothrombin** to **thrombin** in presence of **calcium ions** and **vitamin K**.

Thrombin is an enzyme which catalyzes the conversion of **fibrinogen** to **fibrin** which fibrin forms a mesh that forms the blood clot. *(Use the acronym **TPTFF** to remember the sequence with **P** to **T** occurring in presence of **calcium ions** and **vitamin K**)*

Blood plasma

This is the fluid part of blood. It is made up of;

i) A soluble protein called **fibrinogen** that plays a role in blood clotting.

ii) Serum, a watery fluid containing a variety of substances transported from one part of the body to another e.g. hormones, lipids, enzymes, urea carbon dioxide, plasma, proteins, amino acids etc.

Its function is transport of materials and substances around the body

BLOOD GROUPS AND BLOOD TRANSFUSION

There are basically two blood group systems; ABO system and the Rhesus factor system. Both systems have to be considered during blood transfusion

ABO system

Under this system, there are four blood groups:

i) Blood group A
ii) Blood Group B
iii) Blood Group AB
iv) Blood Group O

A person's type of blood is determined by carbohydrate or protein structures located on the extracellular surface of the Red blood cell membrane. These structures are called **antigens.** So if a person is of;

i) **Blood group A**, he or she has the **A type antigens**
ii) **Blood group B**, he or she has the **B type antigens**
iii) **Blood group AB**, he or she has the **A and B types of antigens**
iv) **Blood group O**, he or she **lacks antigens** on his or her red blood cells.

The antigens of an individual's red blood cells have corresponding antibodies in the plasma of blood which are different from the antigens in that;

a) A person of **blood group A** has **antibodies of type b**.
b) A person of **blood group B**, has **antibodies of type a**.
c) A person of blood group AB, has no antibodies to any ABO blood group antigens.
d) A person of **blood group O** has **antibodies of type b** and **a.**

During blood transfusion, the blood of the recipient should not have antibodies against antigens of blood donated by the donor otherwise *agglutination* will occur.

NB: Blood transfusion is the blood transfer process from the donor to the receiver.

Agglutination is the formation of a blood clot due to a reaction between the antigens in the donor's blood and antibodies in the recipient's blood.

Assignment: *a table showing blood compatibilities (fill in the table below relevant answers to the gaps)*

Recipient's	**Antibodies in recipient's blood**	**Donor's Blood Group**			
		A	B	AB	O
A					
B					
AB					
O					

Use key:

√ **-** Represents safe transfusion. **X -** Represents agglutination will occur.

A person with blood group O is universal donor because he/ she lacks antigens A and B on the surface of his or her blood cells and his or her blood can be donated to any other person having any blood group without agglutination occurring.

A person of blood group AB is a universal recipient because he/ she lacks antibodies b and a in the plasma of his or her blood and can be transfused with blood of a donor having any blood group without agglutination occurring.

Assignment: *a table summarizing the information above (fill the table below)*

Blood group	**Antigens**	**Antibodies**	**Can donate to**	**Can receive from**
A	A	b		
B	B	a		
AB	A and B	-		
O	-	a and b		

"RHESUS FACTOR" System

Rhesus factor is a protein (antigen) also found on the cell membranes of the red blood cells.

Many individuals have the Rhesus factor and are said to be rhesus positive (Rh^+) while a few do not have the Rhesus factor and are said to be Rhesus negative (Rh^-).

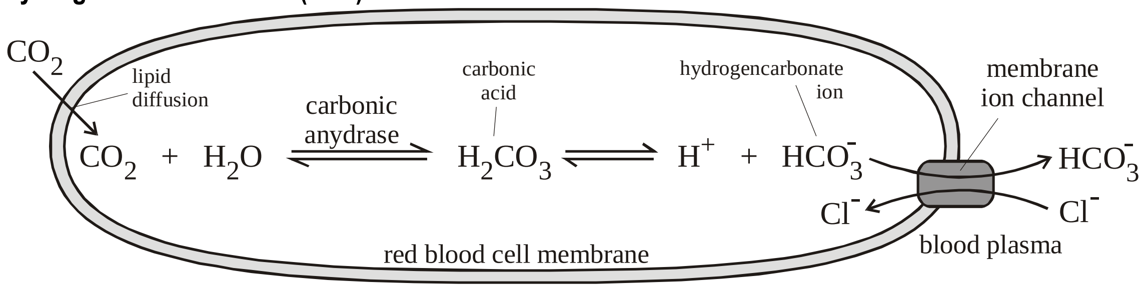
The Rhesus factor was first discovered in a Rhesus Monkey hence its name.

A person who is Rhesus factor positive can receive a successful blood donation without agglutination from a person of Rhesus positive and a person of Rhesus negative.

However, a person who is Rhesus negative can only receive a successful blood donation without agglutination from his fellow Rhesus negative person though he can be transfused with blood which is Rhesus positive quite successfully only once and after this transfusion, his body produces antibodies against the Rhesus factor. Such antibodies attack the Rhesus factor with subsequent transfusion of Rhesus positive blood leading to agglutination.

The same concept can be applied to *pregnancy* in that a Rhesus positive woman can successfully carry on a pregnancy where the fetus is Rhesus positive or Rhesus negative.

3. **As dissolved gas in blood plasma (2%)**
   Very little travels this way as CO_2 is not very soluble in water (about 0.02%)
4. **As Carbamino Haemoglobin (13%)**
   Carbon dioxide can bind to amino groups in haemoglobin molecules, forming carbamate ions:
   $$Hb—NH_2 + CO_2 \rightleftharpoons Hb—NHCOO^- + H^+$$
   Since there are so many haemoglobin molecules in red blood cells, and each one has many amino groups, quite a lot of CO_2 can be carried this way.
5. **As Hydrogen carbonate ions (85%)**



Carbon dioxide diffuses through the cell membrane into red blood cell and reacts with water to form carbonic acid, which immediately dissociates to form a hydrogen carbonate (or bicarbonate) ion and a proton. This proton binds to haemoglobin, as in the cause of the Bohr Effect. Hydrogen carbonate is very soluble, so most CO_2 is carried this way. The reaction in water is very slow, but red blood cells contain the enzyme carbonic anhydrase, which catalyzes the reaction with water.

In respiring tissues CO_2 produced by respiration diffuses into the red blood cells and forms hydrogen carbonate, which diffuses out of the cell into the blood plasma through an ion channel in the red blood cell membrane. This channel carries one chloride ion into the cell for every hydrogen carbonate ion it carries out, and this helps to keep the charge in the cell constant (***chloride shift***).
Chloride shift *is the movement of chloride ions into red blood cells as bicarbonate ions leave during the picking up of carbon dioxide from the tissues by the blood. It helps to restore electronegativity within the red blood cells in tissue capillaries when bicarbonate ions diffuse into plasma.*
In the lungs the reverse happens: hydrogen carbonate diffuses back into the red blood cell through the channel (and chloride goes out) and CO_2 is formed by carbonic anhydrase (remember enzymes will catalyze reactions in either direction), which diffuses into the plasma and into the alveoli.
In all three cases the direction of the reactions is governed by the CO_2 concentration. So in the tissues, where CO_2 is high, the reactions go to the right, while in the lungs, where CO_2 is low, the reactions go to the left.

The Principle of immunology

Immunology is the study of the immune system. Immunity is defined as the capacity to recognize the entry of foreign materials in the body and to mobilize cells to help and remove the foreign particles immediately it enters the body or before they enter the body.

Antigen:
Molecule that stimulates an immune response. Usually proteins (polysaccharides, nucleic acid, lipids can also act as antigens) and other inorganic molecules important for self-recognition.
Self-antigen: Only found on the host's own cells and does **not** trigger an immune response. There is only 1:4 change that siblings will possess an identical antigen.
Non-self-antigen: Found on cells entering the body (e.g. bacteria, viruses, and another person's cell) and can cause an immune response.

Antibody (immunoglobin protein):
Secreted by B-lymphocytes and produced in response to a specific (foreign) non-self-antigen. B-lymphocyte's receptor site matches the non-self-antigen.
Each antibody is produced by one type of B-lymphocyte for only one type of antigen

An antibody is Y-shaped

- The two ends of the Y are called the Fab fragments
- The other end is called the Fc fragment
- Fab fragment is responsible for the antigen-binding properties
- Fc fragment is the effector component and triggers the immune response

B cells divide and form memory cells and antibody-secreting plasma cells:

- Agglutination makes pathogens clump together.
- Antitoxins neutralize toxins produced by bacteria.
- Lysis digests bacterial membrane, killing the bacterium.
- Opsonisation coats pathogen in protein that identifies them as foreign cells.

Types of Immune Response

The immune system defends the body in the following ways:

Non-specific way

This works by attacking anything foreign. It involves:

1. **First line of defense**: this is a barrier that helps prevent pathogens from entering the body. The body has several different types of barriers:
   - Tears = wash germs away, kill germs
   - Skin = Germs can only enter skin when you have a cut, burn or Scrape.
   - Mucous Membranes = in your nose, mouth, and throat secrete a fluid called mucus that traps germs.
   - Saliva = washes germs from your teeth and helps keep your mouth clean.
   - Gastric juice = destroys germs that enter through food or drink.

2. **Second line of defense**: microbes that get into the body encounter the second line of non-specific defense. It is meant to limit the spread of invaders in advance of specific immune responses. There are 3 types:
   i) Inflammatory response: works in two ways;
      - Histamine triggers vasodilation which increase blood supply to that area, bringing more phagocytes to engulf germs. Histamine is also responsible for the symptoms of the common cold, sneezing, coughing, redness and itching and runny nose and eyes - all attempt to rid the body of invaders.
      - Increased body temperature speeds up the immune system and makes it more difficult for microbes to function.

Inflammation:

This is a localized reaction which occurs at the site where a wound has been formed. It causes swelling and a lot of pain. The site appears red due to increased blood flow. Capillary network dilate and become more permeable to lymph and release lymphocytes. Chemical substances called histamines are released to bind the pathogens (agglutination) for easy recognition by lymphocytes. Fibrinogen also present to assist blood clotting if necessary.

   ii) Phagocytes
   iii) Interferon: chemicals released by the immune system to block against viral infections.

Specific immune response

Lymphocytes undergo maturating before birth, producing different types of lymphocytes

i) Humoral response - B lymphocytes
- Produce and release antibodies into blood plasma
- Produce antibodies from B plasma cells
- Recognize foreign antigen directly

ii) Cellular response - T lymphocytes
- Bind to antigen carrying cells and destroy them and/or activate the humoral response.
- Recognize foreign antigens displayed on the surface of normal body cells
- They promote inflammation
- They stimulate B cells to make antibodies.

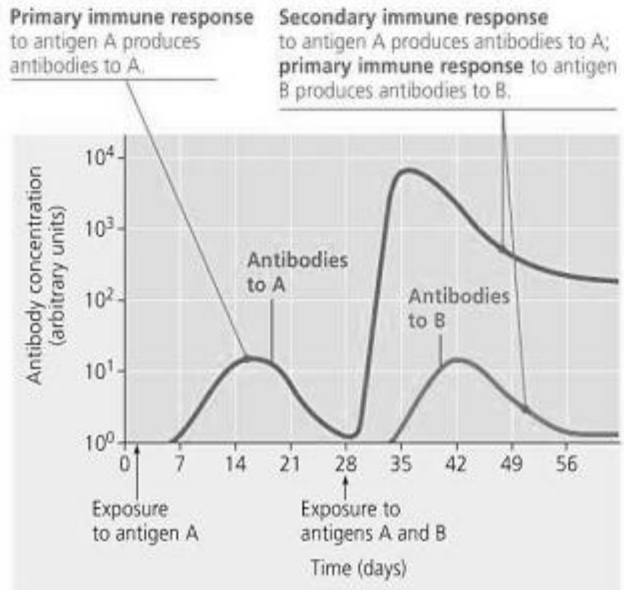
iii) **Primary response** produces memory cells which remain in the circulation.

iv) **Secondary response** new invasion by same antigen at a lower state. Immediate recognition and distraction by memory cells - faster and larger response usually prevents harm.

B-Lymphocytes: The Humoral Response

Response for pathogens not entering our cells i.e. antibodies defend against infection in body fluids. (E.g. bacterium).
Each B-lymphocyte recognizes only one specific antigen or need T-helper cell to be activated.
Mature B-cells develop to give many different variants of specific immune system responding to any type of pathogen entering the body.

1. **Primary response:**
   Pathogen is ingested by macrophages / macrophage displays the pathogens surface non-self-antigen on its surface (antigen presentation).
   It then joins with specific T-helper cells and B lymphocytes that have membrane receptors and are complementary in shape to the non-self-antigen.
   T-helper cells will release cytokines to activate selected B-cell/lymphocyte:
   i) Secretes antibodies of the same type into the blood
   ii) Divided by mitosis to produce a clone
   iii) Cells grow to form plasma cells producing masses of free antibodies
   Some of the cells remain in the blood as memory cells.
2. **Secondary response:** this occurs if an individual is exposed again to the same antigen. There is immediate recognition and distraction - faster, larger response usually prevents harm. Antibodies are produced more rapidly and in larger amounts.



▲ **Figure 43.15 The specificity of immunological memory.** Long-lived memory cells generated in the primary response to antigen A give rise to a heightened secondary response to the same antigen, but do not affect the primary response to a different antigen (B).

T-Lymphocytes: Cell-Mediated Response

Cytotoxic lymphocytes defend against infection in body cells. This occurs when a Virus enters a cell thus more difficult to remove.
No antibodies involved / work directly on the infected cell by destroying it.
Special proteins called Major Histocompability Complex (MHC) are present on all human cells. Non-self-antigen interacts with MHC as human cell becomes infected by a pathogen.

- ✓ Specific T-lymphocyte recognizes specific non-self-antigen only with a chemical marker next to it (MHC)
- ✓ Activated T-lymphocytes multiply by mitosis and enter circulation
- ✓ Cells differentiate into different types of cell.
  i) **Cytotoxic T-Cells**: destroy pathogens and infected cells by enzyme action, and secrete chemicals which attract and stimulate phagocytes.
  ii) **Helper T-Cells:** stimulate the activity of the cytotoxic T-Cells and B-lymphocytes by releasing chemicals (cytokines and interleukins). It's the one destroyed by HIV.
  iii) **Suppressor T-Cells**: switch off the T and B cell responses when infection clears
  iv) **Memory T-Cells**: Some activated T-Cells remain in the circulation and can respond quickly when same pathogen enters body again.

Different types of immunity

	Active (Antibodies made by the human immune system, long term acting due to memory cells)	**Passive** (Given-Antibodies, short term acting)
Natural	- Response to disease - Rejecting transplant	- Acquired antibodies (via placenta, breast milk)
Artificial (immunization)	- Vaccination (Injection of the antigen in a weakened form)	- Injection of antibodies from an artificial source, e.g. anti-venom against snake bite
Differences	- Antibody in response to antigen - Production of memory cells - Long lasting	- Antibodies provided - No memory cells - Short lasting

How vaccines produce responses by the immune system (Artificial active immunity)

Types of vaccine

1. Vaccine containing dead pathogens. Antigen is still recognized and an immune response made
    - Salk polio vaccine (Polio vaccine is injected)
    - Influenza
    - Whooping cough
2. Vaccine containing a toxin
    - Diphtheria
    - Tetanus
3. Vaccine containing an attenuated (modified or weakened) organism which is alive but has been modified so that it is not harmful
    - Sabin polio vaccine (Taken orally, often sugar pumps)
4. Purified antigen - genetically engineered vaccine.
    - Hepatitis B (A gene coding for a surface protein of the hepatitis B virus has been inserted into yeast cells which produce the protein when grown in fermenters)

Transplantation

This is the replacement of diseased tissue or organs by healthy ones through a surgery. It's less successful than blood transfusion because the organ contains more antigens than blood so they are likely to be rejected by the body's immune system. Tissue rejection has been perfectly overcome by:

- Careful tissue typing i.e. using tissue which meets the donor and recipient antigens as exactly as possible.
- Use of immune suppressive drugs which suppress the recipient's immunity in order to increase the chances of transplant success.

Tissue typing can be effected through the following ways;

i) **Autograft**; the tissue is grafted from one area to another on the same individual. E.g. skin. Rejection is not a problem.
ii) **Isograft**; a graft between two genetically identical individuals' e.g. identical twins. Rejection is not a problem.
iii) **Allograft**; a tissue from individual to individual but the two must be closely attached or related though of different genetic constitution. In case of rejection, immune suppressive drugs can be used.
iv) **Xenograft**; a graft between individuals of different species such as from sheep to human.

"Life's battles don't always go to the stronger or faster man, but soon or later, the man who wins is the man who thinks he can".