Exchange and transport

Examples of things which need to be interchanged between an organism and its environment include:

- Respiratory gases
- Nutrients
- Excretory products
- Heat

This exchange can take place in two ways:

- Passively by diffusion and osmosis
- Actively by active transport

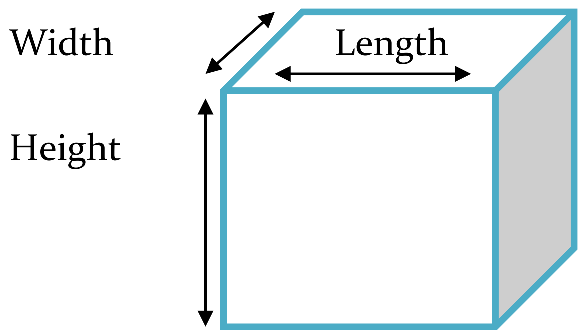
Surface area to volume ratio

For exchange to be effective, the surface area of the organism must be large compared to the volume.
As organisms become larger, their volume increases at a father rate than their surface area.

To overcome the problem organisms have evolved some of the following features:
- A flattened shape so no cell is far from the surface.
- Specialised exchange surfaces with large area to increase the surface area to volume ratio.

Features of specialised exchange surfaces:

- A large surface area to volume ratio to increase the rate of exchange.
- Thin so the diffusion path is short.
- Partially permeable to allow selected materials to cross.
- Movement of the environmental medium.
- Movement of the internal medium.



Gas exchange in single-celled organisms and insects

Gas exchange in single-celled organisms:

Oxygen is absorbed by diffusion across their body surface.
Carbon dioxide from respiration diffuses out across their body surface.

Gas exchange in insects

The problem for all terrestrial organisms is that water easily evaporates from the surface of their bodies and they become dehydrated.

To reduce water loss, terrestrial organisms exhibit two features:

- ***Waterproof coverings*** *rigid outer skeleton in insects.*
- ***Small surface area to volume ratio*** *to minimise the area over which water is lost.*

These features mean insects can't use their body surface to diffuse respiratory gases. They have therefore developed an internal network of tubes called **tracheae.** These are supported by **strengthened rings** to prevent them from collapsing. The tracheae divide into smaller tubes called **tracheoles**. The tracheoles extend through the body tissues.

Respiratory gases move in and out of the tracheal system in two ways:

- **Along a diffusion gradient:** During respiration, oxygen is used and the concentration at the ends of the tracheoles decreases. This creates a diffusion gradient that causes gaseous oxygen to diffuse from the atmosphere along the tracheae and tracheoles to cells.
Carbon dioxide is produced during respiration which creates a diffusion gradient in the opposite direction. This causes gaseous carbon dioxide to diffuse along the tracheoles and tracheae from cells to the atmosphere.
- **Ventilation:** The movement of muscles in insects can create mass movements of air in and out of the tracheae.

Gases enter and leave tracheae through **spiracles**. These may be opened and closed by a valve. When they are open water can evaporate so most of the time they are close to prevent water loss.

Gas exchange in fish

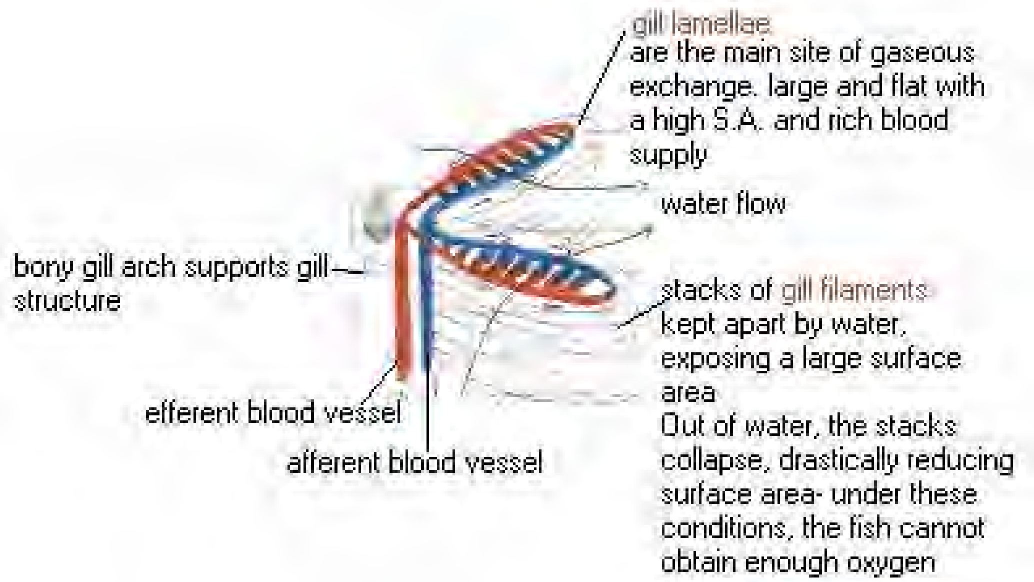
Fish have a waterproof, gas-tight outer covering. They also have a small surface area to volume ratio. Their body surface is not adequate to supply and remove their respiratory gases and so they have developed a specialised internal gas exchange surface.

Structure of the gills

The gills are located in the body of the fish behind the head. They are made up of **gill filaments.** These are stacked up in a pile and at right angles to the filaments are **gill lamellae**, which increase surface area of the gills.

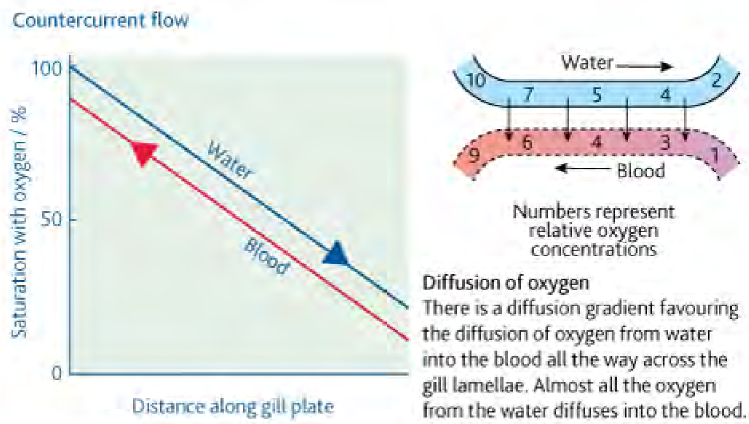
Water is taken in through the mouth, forced over the gills and through an opening on the side of the body.

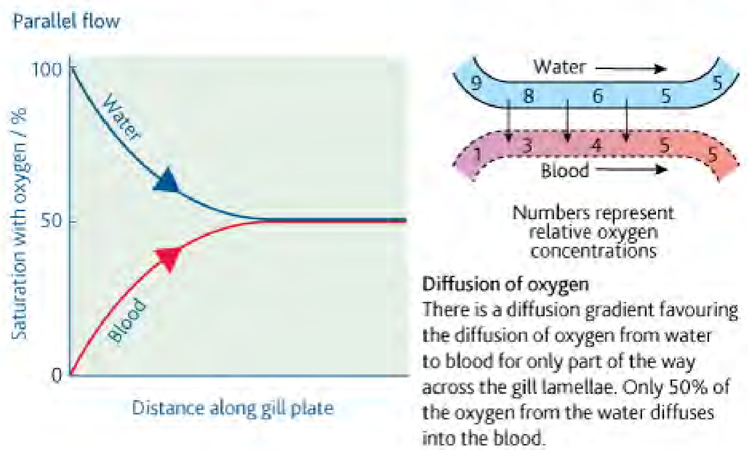
The flow of water over the gill lamellae and the blood within them are in opposite directions which is known as **counter current flow**.



The counter current exchange principle

- Blood is already well loaded with oxygen meets water which has its max concentration of oxygen. This means diffusion of oxygen from water to blood takes place.
- Blood with little or no oxygen meets water which has had most but not all of its oxygen removed. Diffusion of oxygen from water to blood takes place.





Gas exchange in the leaf of a plant

When photosynthesis is taking place some carbon dioxide comes from respiration of cells. Most of it is obtained from external air in the same way oxygen from photosynthesis is used in respiration but most diffuses out of the plant.

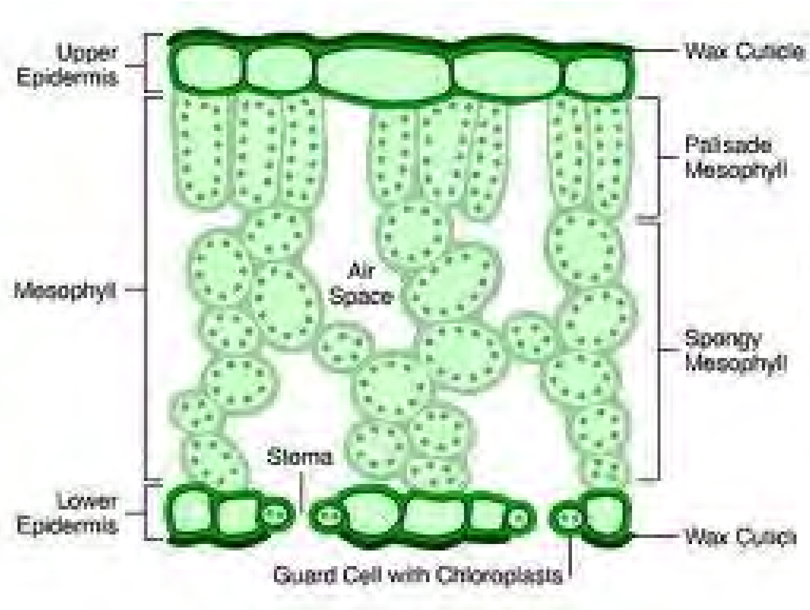
When photosynthesis is not occurring, oxygen diffuses into the leaf as it is constantly being used by cells during respiration. In the same way carbon dioxide diffuses out during respiration.

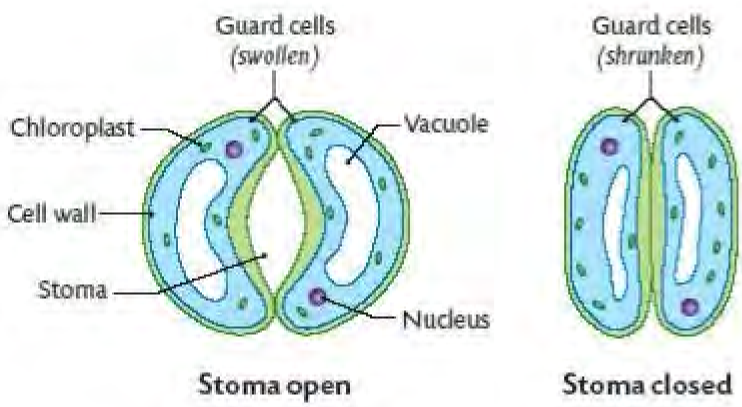
Structure of a plant leaf and gas exchange

There is a short diffusion pathways and a plant leaf has a very large surface area to volume ratio.
Most gaseous exchange occurs in leaves which show the following adaptations for quick diffusion:
- Thin, flat shape that provides a large surface area.
- Stomata, mostly in the lower epidermis.
- Interconnecting air-spaces that occur throughout the mesophyll.

Stomata

These are minute pores which occur mainly in the leaves. Each stoma is surrounded by a pair of special cells (guard cells). These can open and close the stomatal pore. Therefore they can control the rate of gaseous exchange.





Circulatory system of a mammal

Why large organisms need a transport system

With increasing size, the surface area to volume ration decreases so the needs of the organism cannot be met by the body surface.

A specialist exchange surface is needed to absorb nutrients and respiratory gases and to remove excretory products. These are located in specific regions of the organism.

A transport system is required to take materials from cells to exchange surfaces and vice versa.

Whether of not there is a specialised transport medium and whether or not It's circulated by a pump depends on 2 factors:

- The surface area to volume ratio.
- How active the organism is.

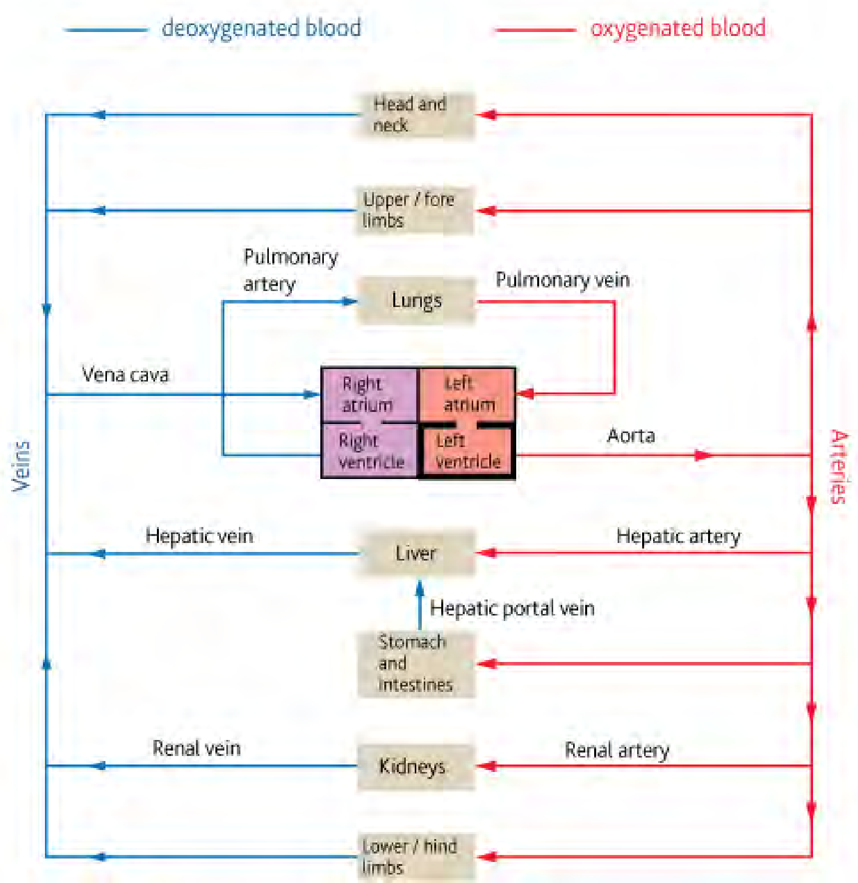
Features of transport systems

- A suitable medium to carry materials (normally liquid based on water).
- Form of mass transport.
- A closed system of tubular vessels that contains the transport medium and forms a branching network to distribute it.
- A mechanism for moving the transport medium within the vessels.
  (a) Animals use muscular contraction.
  (b) Plants rely on physical processes.
- A mechanism to maintain the mass flow in one direction.
- A means of controlling the flow of the transport medium.

Transport systems in mammals.

Mammals have a close blood system where blood is confined to vessels. The heart circulates the blood around the body.

Mammals have a double circulatory system; this means blood passes twice through the heart for each complete circuit.



Blood vessels and their functions

Structure of blood vessels

- **Arteries** carry blood away from the heart into the arterioles.
- **Arterioles** are smaller arteries that control blood flow from arteries to capillaries.
- **Capillaries** are tiny vessels that link arterioles to veins.
- **Veins** carry blood from capillaries back to the heart.

Arteries, arterioles and veins all have the same layered structure:

- **Tough outer layer**- resists pressure changes.
- **Muscle layer**- contract and control the flow of blood.
- **Elastic layer**- maintains blood pressure by stretching and springing back.
- **Thin inner lining**- prevents friction and allows diffusion.
- **Lumen**- central cavity of the blood vessel where blood flows.

Artery structure related to function

- **Muscle layer is thicker than veins:** Smaller arteries can be constricted and dilated to control the volume of blood passing through.
- **Elastic layer is thicker than veins:** The wall is stretched at the beat of the heart and springs back when the heart relaxes. This helps maintain a high pressure.
- **Overall thickness of the wall is large:** Resists the vessel bursting under pressure.
- **There are no valves:** Because blood is under constant high pressure.

Arteriole structure related to function

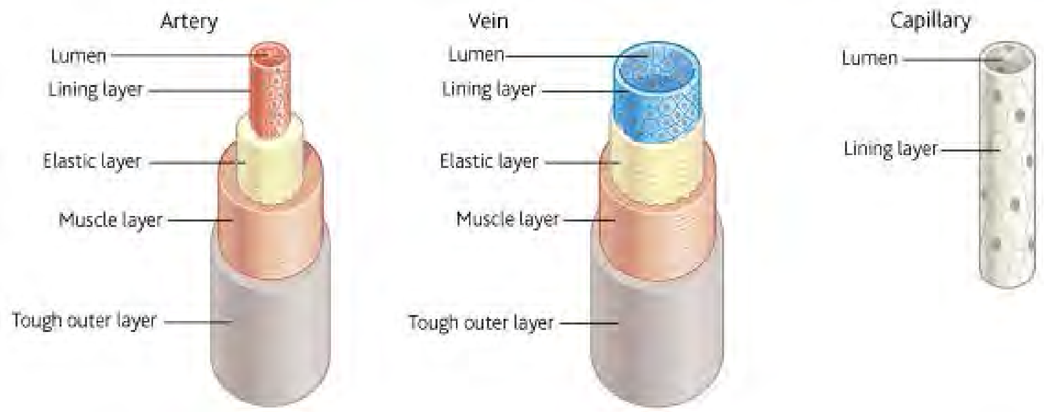
- **Muscle layer is thicker than arteries:** The contraction of this layer allows constriction of the lumen. This restricts the flow of blood and controls its movement.
- **Elastic layer is thinner than arteries:** Because blood pressure is lower.

Vein structure related to function

- **Muscle layer is thin:** Because veins carry blood away from tissues.
- **Elastic layer is thin:** Because low pressure of blood will not cause them to burst.
- **Thickness of wall is thin:** As pressure is low.
- **There are valves:** To prevent backflow.

Capillary structure

- **Walls consist of lining layer:** For short diffusion distance.
- **Numerous and highly branched:** Large surface area.
- **Narrow diameter:** Permeate tissues.
- **Lumen is narrow:** Reduces diffusion distance.
- **Spaces between lining:** So white blood cells can escape.



<u>Tissue fluid and its formation</u>
Tissue fluid contains glucose, amino acids, fatty acids, salts and oxygen.
It's formed in the blood plasma.

Blood pumped around the heart creates hydrostatic pressure at the arterial end of the capillaries which forces tissue fluid out of blood plasma.

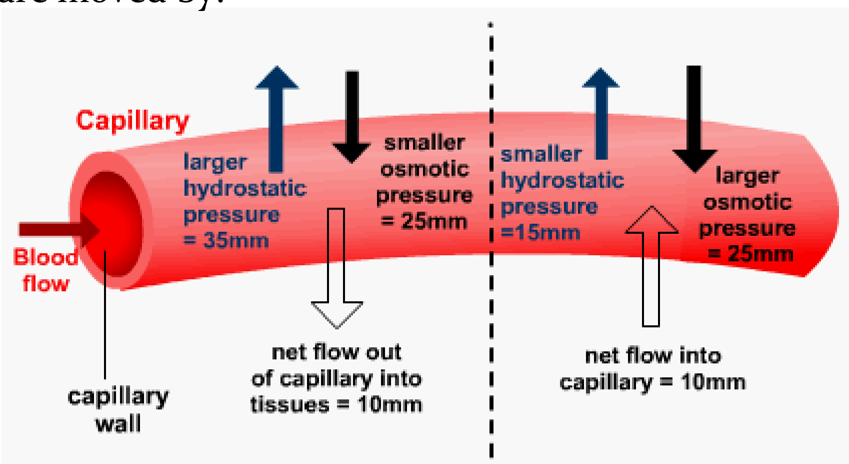
The outward pressure is opposed by:
- Hydrostatic pressure of tissue fluid outside capillaries
- Lower water potential of the blood.

The pressure is only enough to force small molecules out leaving cells and proteins in the blood. This is called **ultra filtration.**

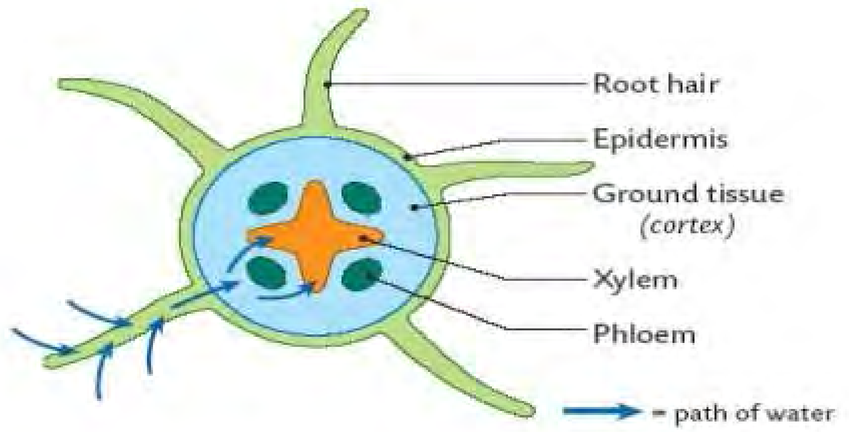
<u>Return of tissue fluid to the circulatory system.</u>
- The loss of the tissue fluid from the capillaries reduces the hydrostatic pressure inside.
- By the time the blood reaches the venous end the hydrostatic pressure is less than the tissue fluid outside of it.
- Tissue fluid is forced back into the capillaries.
-Osmotic forces pull water back into the capillaries.

Not all the tissue fluid can return to the capillaries so the remainder is carried back via the lymphatic system.
This is a system of vessels that begin in the tissues.

The contents of the lymphatic system are moved by:
- **Hydrostatic pressure**
- **Contraction of body muscles.**



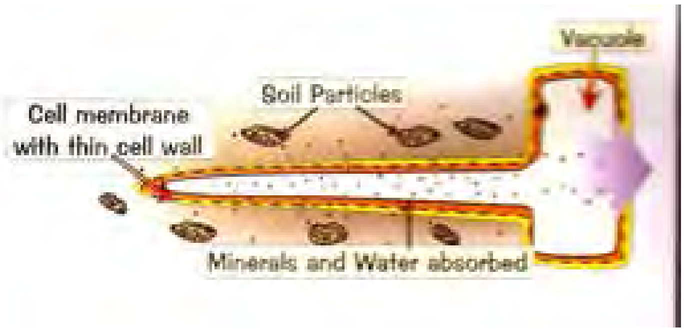
Movement of water through roots



<u>Uptake of water by root hairs</u>

Each root hair is a long, thin extension of a root epidermal cell. They are efficient surfaces for the exchange of water and mineral ions because:

- They provide a large surface area as they are long.
- They have a thin surface layer.



Root hair cells arise from epidermal cells. They grow into the spaces around soil particles. In damp conditions they are surrounded by a soil solution which contains mineral ions.
The solution has a high water potential.

Root hairs have sugars, amino acids and mineral ions dissolved inside of them. Therefore they have a lower water potential. Water then moves by osmosis from the soil into the root-hair cells down the water potential gradient.

<u>The apoplastic pathway:</u>

As water is drawn into endodermal cells, it pulls more water along due to the cohesive properties of the water molecules.
This creates a tension that draws water along the cell walls. The mesh-like structure of the cellulose cell walls has water-filled spaces so there is little resistance to the pull of water.

<u>The symplastic pathway:</u>

This takes place across the cytoplasm as a result of osmosis.
The water passes through the cell walls along the plasmodesmata. Each plasmodesma is filled with cytoplasm.

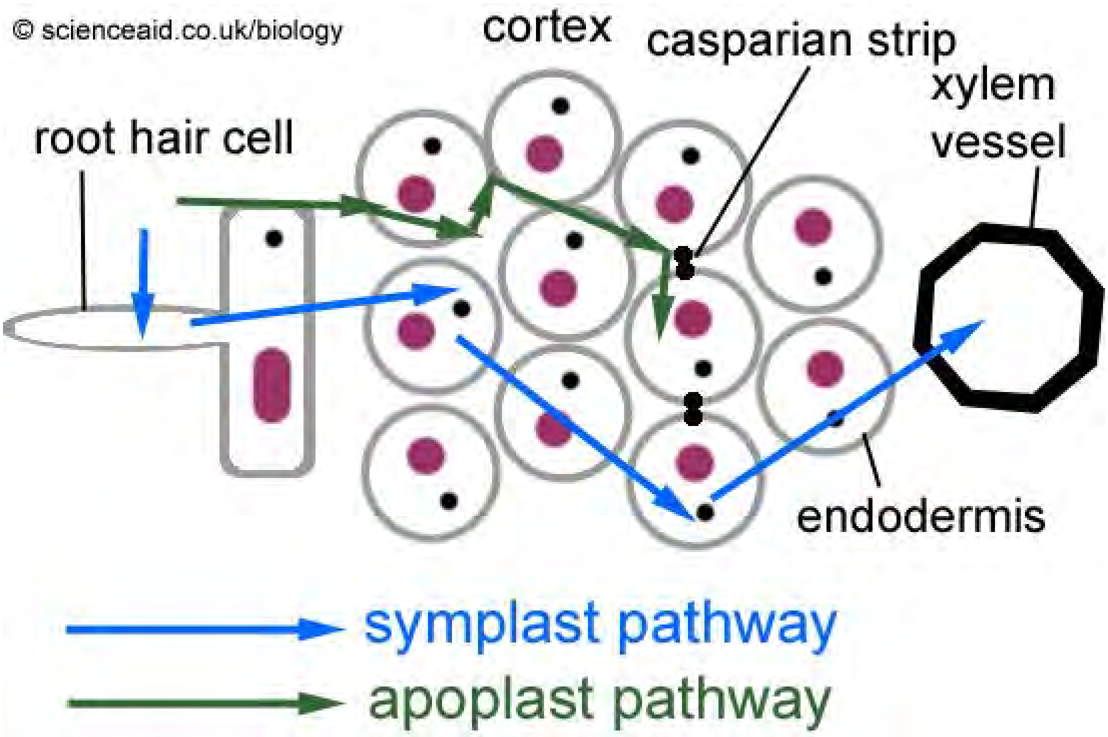
1) Water entering by osmosis increases the water potential of the r.h.c.
2) The r.h.c has a higher w.p than the first cell in the cortex.
3) Water moves from the r.h.c to the first cell by osmosis.
4) The first cell has a higher w.p than its neighbour in the stem.
5) Water moves into the neighbour.
6) The neighbour has a higher w.p so it moves to the 3rd cell.
7) The loss of water from the first cell lowers its water potential causing more water to enter.
8) A water potential gradient is set up which carries water along the cytoplasm to the endodermis.

<u>Passage of water into the xylem</u>

When the water reaches the endodermis the waterproof band making up the Casparian strip prevents it progressing. Water is then forced into the protoplast where it joins water that's arrived by the symplastic pathway.

Active transport of salts is most likely to allow water into the xylem. This requires energy and takes place along carrier proteins.

The active transport of mineral ions creates lower water potential in the xylem. Water moves into the xylem by osmosis which creates a force to move water up the plant (root pressure).



Movement of water up stems

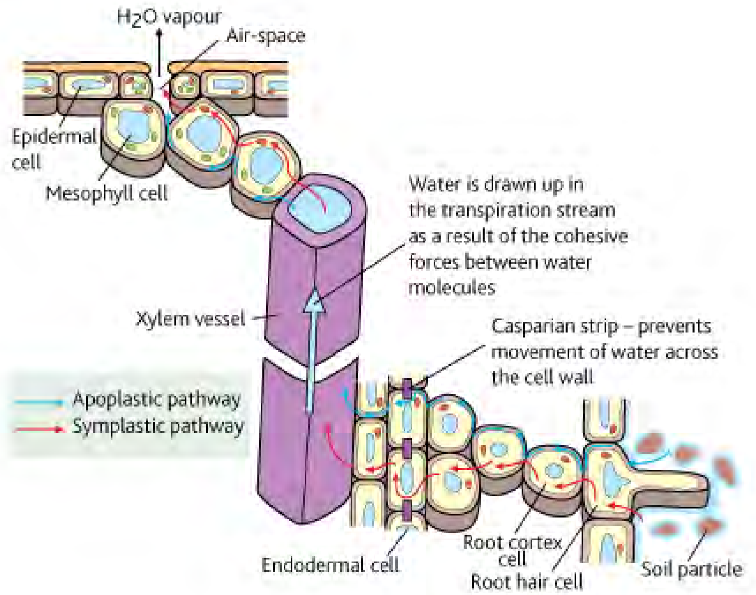
The force that pulls water up the stem of a plant is a process called transpiration.

Movement of water out through stomata

The humidity of the atmosphere is less than of the air spaces next to the stomata. If the stomata are open, water vapour molecules diffuse out into surrounding air. Water lost from the air spaces is replaced by evaporating water from cell walls of the mesophyll cells.

Movement of water across the cells of a leaf

Water is lost from mesophyll cells by evaporation to the air spaces of the leaf. This is replaced by water reaching the mesophyll cells from the xylem by either the apoplastic or symplastic pathways.



In the case of the symplastic pathway, the water movement occurs because:

- Mesophyll cells lose water to air spaces.
- The cells have lower water potential so water enters.
- Loss of water from neighbouring cells lowers their water potential.
- They take in water from their neighbours by osmosis.

Movement of water up the stem in the xylem

The two main factors responsible for the movement of water up the xylem are **cohesion-tension** and **root pressure.** The cohesion-tension theory operates as follows:

1) Water evaporates from leaves by transpiration.
2) Water molecules form H bonds and stick together (cohesion).
3) Water forms a continuous pathway across mesophyll cells and down the xylem.
4) As water evaporates from the mesophyll cells more molecules are drawn up.
5) Water is pulled up the xylem (transpirational pull)
6) Transpirational pull puts xylem under tension.

There are several pieces of evidence to support the theory:

- Change in diameter of trunks (day= more tension night=less tension= trunk shrinks)
- If xylem vessel is broken tree can't draw up water.
- If vessel is broken water doesn't leak out.

Transpirational pull is passive so it doesn't require energy. The xylem vessels are dead so can't actively move the water.

Transpiration and factors affecting it

Role of transpiration

Leaves have a large surface area to absorb light and stomata allow inward diffusion of CO_2. Both features result in loss of water. Transpiration is not essential because osmosis could achieve this.

Materials e.g. mineral ions, sugars and hormones are moved around the plant. The water carrying them is carried up the plant by transpirational pull.

Factors affecting transpiration

- ***Light:*** *Stomata are the openings where CO_2 diffuses. Photosynthesis only occurs when there's light so stomata are open and close in the dark. When open water leaves into the atmosphere. Increase in light increases the rate of transpiration.*

- ***Temperature:*** *This affects how much water air can hold and the speed at which water molecules move. A rise in temperature increases kinetic energy and speed of water molecules therefore increasing evaporation. It also decreases the amount of water air can hold.*

- ***Humidity:*** *This is the measure of the number of water molecules in the air. Humidity affects the water potential gradient between the air outside + inside the leaf. When air outside has high humidity the gradient is reduced and rate of transpiration is lower.*

- ***Air movement:*** *As water diffuses through stomata, it collects as vapour around them on the inside of the leaf. The water potential is therefore increased which reduces the water potential gradient between the atmosphere and air spaces. The transpiration rate is therefore reduced.*

Factor	How it affects transpiration	Increase in transpiration caused by:	Decrease in transpiration caused by:
Light	Stomata open in light and close in the dark.	Higher light intensity.	Lower light intensity.
Temperature	Alters kinetic energy of water molecules and the humidity of the air.	Higher temperature.	Lower temperature.
Humidity	Affects water potential gradient between air-spaces in leaf and the atmosphere	Lower humidity.	Higher humidity.
Air movement	Changes water potential gradient by altering rate that moist air is removed.	More air movement.	Less air movement.

Limiting water loss in plants

Xerophytic plants

Plants that do not have a plentiful water supply have developed a range of other adaptations to limit water loss through transpiration. These plants are called **xerophytes.**

These are plants that are adapted to living in areas where their water losses due to transpiration may exceed their water uptake. Their modifications to reduce water loss include:

- **Thick cuticle:** The thicker the cuticle, the less water can escape. Many evergreen plants for example holly have thick cuticles to reduce water loss especially during winter.

- **Rolling up of leaves:** Most leaves have their stomata confined to the lower epidermis. The rolling of leaves protects the lower epidermis from the outside and helps trap a region of still air. The region becomes saturated with water vapour so there is no water potential gradient between the inside and outside. Plants such as marram grass roll their leaves.

- **Hairy leaves:** A thick layer of hairs on leaves help trap moist air next to the leaf surface. The water potential gradient between inside and outside is reduced therefore less water is lost through transpiration. One type of heather plant has this.

- **Stomata in pits or grooves:** These also trap moist air and reduce the water potential gradient. Pine trees use this modification.

- **Reduced surface area to volume ratio of the leaves:** By having leaves that are small and roughly circular in cross-section e.g. pin needles, the rate of water loss can be reduced.