Transport of substances in plants

We have already looked at why many organisms need transport systems – with special reference to surface area and volume.

The larger the **volume : surface area** ratio, the more likely it is that the organism will need a transport system.

So we know that it is important to have transport systems…now we have to actually look at them! And of course, we must start with plants (yay(!)).

For many organisms, it is necessary to move things in a **mass flow** system. This means that the substances are moved **as a single body** (or all **flowing** at the same rate). Examples include blood circulation (in humans…) and transport of water with dissolved substances (in plants).

This relies upon the cohesion of water molecules to each other and adhesion to the vessel's wall by hydrogen bonding. If an air bubble occurs the flow will be stopped as the column is broken and the pressure difference in the vessel cannot be transmitted. This is called an air lock.

**Transport in flowering plants**

Plants, like animals, need to transport substances, including food (nutrients) and water, around their “bodies”.

There are two types of vessel that are used for these purposes:

a. **Xylem** vessels: these are used to transport water and dissolved minerals from the roots to the leaves

b. **Phloem** vessels: these are used to transport sucrose from the leaves, where it is made in photosynthesis, around the plant to where it is needed.

Xylem vessels are composed of dead cells with no cell walls in between. They sometimes become thickened with **lignin** which also has a **support** function in the plant.

Phloem vessels are made up of living cells which have **companion cells** to provide for their needs.

Mineral ions such as sodium, nitrates and phosphates dissolve in water in the soil. They enter the root hair cells and are transported in the xylem. The mineral ions are normally present in higher concentrations inside the root hair cells and so they must be brought into the root hair cell by **active transport**.

The main substance moved in the phloem is sucrose. This is a disaccharide sugar and is transported by dissolving it in water – the resultant liquid is called **sap**. It is then taken to parts of the plant where it is needed as energy for respiration or for the manufacture of materials such as roots or the stem. It may also be stored as starch.
The cell grows and then dies. At this point, all the organelles in the cytoplasm and the cytoplasm itself leaves the cell – creating a hollow lignified tube through which water can flow.

Lignin is a polysaccharide like cellulose but a lot tougher (wood)

Xylem and phloem vessels are found together in structures called **vascular bundles**. At the leaves, the main bundles branch to form **veins** that run close to all the cells. Vascular bundles are arranged in a ring around the plant stem. This arrangement helps to **strengthen** and **support** the plant stem.
In the root, the vascular bundles are arranged in the centre of the root rather than around the edges. This prevents damage to the bundles as the roots force their way through the soil.

Write about the process of transpiration:

- Water from the soil enters the root hair cells of the plant by **osmosis**. This occurs because the concentration of the water in the root hair cells is less than the concentration of the water in the soil. Water moves down the concentration gradient.
- Water moves from cell to cell by osmosis until it reaches the xylem vessels.
- Once in the xylem, the water is drawn up the stem towards the leaves.
- Water that is transported to the leaves is used as a raw material in photosynthesis.
- Water constantly evaporates from the leaves into the atmosphere in a process called **TRANSPIRATION**.

**Transpiration**

Water is lost through the stomata. The stomata are gaps in the leaves created so that the gases needed for photosynthesis can enter and the waste gases can leave the leaf. These are mainly on the underside of the leaf so that the plant does not lose too much water and die. The stomata close at night to reduce water loss — as the plant does not need the gases to photosynthesise.

Transpiration is the loss of water by evaporation from the leaves through the stomata. The source of water for the plants is soil water. It is taken up by root hair cells by osmosis. Once in the root hair cell, water moves by osmosis from cell to cell through the endodermis into the Xylem. The water is then pulled under pressure through the transpiration stream up the Xylem (a long hollow tube) to the leaves.

The water moves by osmosis into the palisade cells and will saturate the air spaces in the leaves. Water is lost from air spaces within stomata to outside.
Transpiration Stream

This is a force. The evaporation of water from the leaves causes a type of suction, which pulls (this is the force!) water up the stream from the roots. The water travels in the xylem vessels of the vascular bundles.

Water will move out of the xylem by osmosis to ensure the cell vacuoles are full of water (turgid). In the leaf, the air spaces are saturated with water. This allows cell membranes to be moist, to allow rapid diffusion. There are several factors assisting the water from the root to the leaf:

i. Root pressure  The constant movement of water into the base of the xylem forces the water to move upward.

ii. Cohesion tension  Water molecules stick to each other (surface/cohesion tension) and pull each other up the stem in a column.

iii. Capillarity  Water molecules stick to the walls of the thin xylem tubes and move up the tubes

iv. Evaporation of water at the leaf surface  
The process of transpiration means that the water is constantly lost from the leaf surface. Water in the xylem is therefore pulled up by a suction-like force. Transpiration is fastest when it is HOT, SUNNY and WINDY.

Importance of transpiration

Transpiration is important for the plant for numerous reasons (obviously – otherwise why would we be studying it….well, to be fair you could probably ask that anyway….but whatever):

1. Supplies water to leaf for photosynthesis

2. Supplies mineral ions in solution to leaf (e.g. magnesium for chlorophyll)

3. Cooling for leaf

4. For turgor shape

5. Moist cell membranes (gases only pass through solution)
## Factors affecting transpiration

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Increased Transpiration</td>
<td>Stomata are open</td>
</tr>
<tr>
<td>Dark</td>
<td>Decreased Transpiration</td>
<td>Stomata are closed</td>
</tr>
<tr>
<td>High temperature</td>
<td>Increased Transpiration</td>
<td>Any given volume of air requires more water to saturate at high temperature (i.e. greater evaporation rate)</td>
</tr>
<tr>
<td>Low temperature</td>
<td>Decreased Transpiration</td>
<td>Less evaporation</td>
</tr>
<tr>
<td>High wind</td>
<td>Increased Transpiration</td>
<td>Water molecules moved away from stomata, which increases gradient in favour of diffusion of water from leaves.</td>
</tr>
<tr>
<td>Low wind</td>
<td>Decreased Transpiration</td>
<td>Less gradient formed</td>
</tr>
<tr>
<td>High humidity (moist air)</td>
<td>Decreased Transpiration</td>
<td>Moisture in air reduces gradient</td>
</tr>
<tr>
<td>Low humidity (dry air)</td>
<td>Increased Transpiration</td>
<td>Greater gradient in favour of evaporation</td>
</tr>
<tr>
<td>Defoliation</td>
<td>Decreased Transpiration</td>
<td>Reduced surface area/fewer stomata from which water can evaporate</td>
</tr>
<tr>
<td>Availability of water</td>
<td>Reduced water loss</td>
<td>At times of drought, plants can close their stomata to prevent water loss.</td>
</tr>
</tbody>
</table>

### Adaptation of leaves of plants to reduce water loss (normally in arid conditions) - Xerophytes

- surface area : volume ratios **reduced** (opposite to animals)
  - smaller surface area means less stomata – so less water is lost by transpiration

- leaves reduced to spines
  - again, this means less/no stomata: i.e. no water vapour is lost

- stem is main photosynthetic organ
  - because the leaves are spines, they are unable to absorb sunlight; the stem can

- reduced transpiration:
  - waxy cuticle
  - reduced number of stomata – only open at night
  - sunken stomata – not open to the wind – meaning less water vapour lost
  - epidermal hairs around stomata: trap humid air: reducing water potential gradient
  - rolled leaf – to hide stomata, to trap humid air: specialised cells known as **hinge cells**, when they lose water, cause the leaf to roll up
  - thin leaves – giving a low heat capacity

  - the reason for this is because too much heat would damage the enzymes which are used for photosynthesis
Root Transport

Flowering plants have two distinct transport systems. (Seeing as you did this earlier, you should know these two standing on your head. We would do that but I’m sure there would be complaints about even the slight bit of movements from your seat…)

**xylem**: movement of water and mineral ions from the soil to stem and leaves

**phloem**: transport of sugars and other products of photosynthesis to where they are needed (e.g. in developing shoots, flowers, fruit and roots)

**Structure of a root**

- roots anchor the plant
- they also provide a surface through which water is taken up
- thousands of root hairs are present on each root-tip to increase surface area

To understand the way in which water is transported, it is important to look at the structure of a root.
The single layer of cells around the outside of the root is called the **epidermis**.

A root hair is an extension of a single epidermal cell – it can be up to 4mm long. The root hairs penetrate the soil particles and are in close contact with the soil water. There are thousands of root hairs near each root tip and greatly increase the surface area for absorption.

The central part of the root contains the **xylem**, which provides a system for water and dissolved mineral ion transport.

The xylem and phloem are enclosed in a cylinder made of cells called **endodermis**. Between the endodermis and the xylem and phloem are unspecialised cells with thin walls.

Between the endodermis and epidermis, there are several layers of large cells called **parenchyma**, forming the **cortex**. The walls of the parenchyma are permeable to water and also dissolved solutes.

Air spaces are present in the cortex, which allow the diffusion of oxygen across the root for respiration.

**Adaptations of root hair cell**

- long and thin: this gives a large surface area for uptake of...

  o water by **osmosis**:
    ▪ water moves from an area for less negative water potential to an area of more negative water potential
    ▪ concentration of cell sap in root hair is greater than that in soil water

  o mineral ions by **active transport**:
    ▪ energy required to supplement process
    ▪ gradient maintained by water moving up xylem
    ▪ concentration in xylem lower than in soil water
**Uptake of water**

- Water is mainly taken up by younger parts of the roots
- The water concentration in most soils is close to zero because of the very low concentrations of solutes (e.g. mineral ions) in the soil
- The mineral ion concentration is less in the soil than in the cells
- So, to take up these mineral ions, active transport is used
- As the concentration of mineral ions in the soil is so low, the water potential is very high (in comparison to the cells), so water moves into the cells by osmosis.
- Once inside the root, the water and the mineral ions can move from the cell to cell across the cortex of the root from the epidermis to the central tissues by two main pathways:

  **Apoplast Pathway**
  - probably most important route:
  - water passes through cell walls in adjacent cells
  - there are no barriers to movement, so diffusion is free

  **Symplast Pathway**
  - water passes from cytoplasm to cytoplasm
  - the cytoplasms of each cell are not completely separate from each other
  - there is a fine channel in the cell wall called *plasmodesmata* through which the cytoplasm continues

The symplastic route is slower because resistance in the cytoplasm is four times greater than that of the cell wall. Water can move through the cells in either of these two ways.
Movement towards the centre of the root by apoplastic pathway is stopped when the water reaches the endodermis.

This is due to a waterproof layer on the endodermis called the Casparian strip. This strip contains suberin, which is a waxy compound impermeable to water. So, instead of passing through the endodermal cell walls, the water must pass through the plasma membrane and into the cytoplasm.

The Casparian strip forces water to take the symplast pathway through endodermal cells.

This is important when looking at root pressure.

Water travels from the roots to the leaves via the stem. The xylem and phloem are vascular tissue and are grouped into vascular bundles in stems such as that of a buttercup. They are arranged in a ring.

Xylem and phloem run the whole length of the plant – from roots to the midrib and veins of the leaves.