Bio Factsheet

Number 64

Transpiration

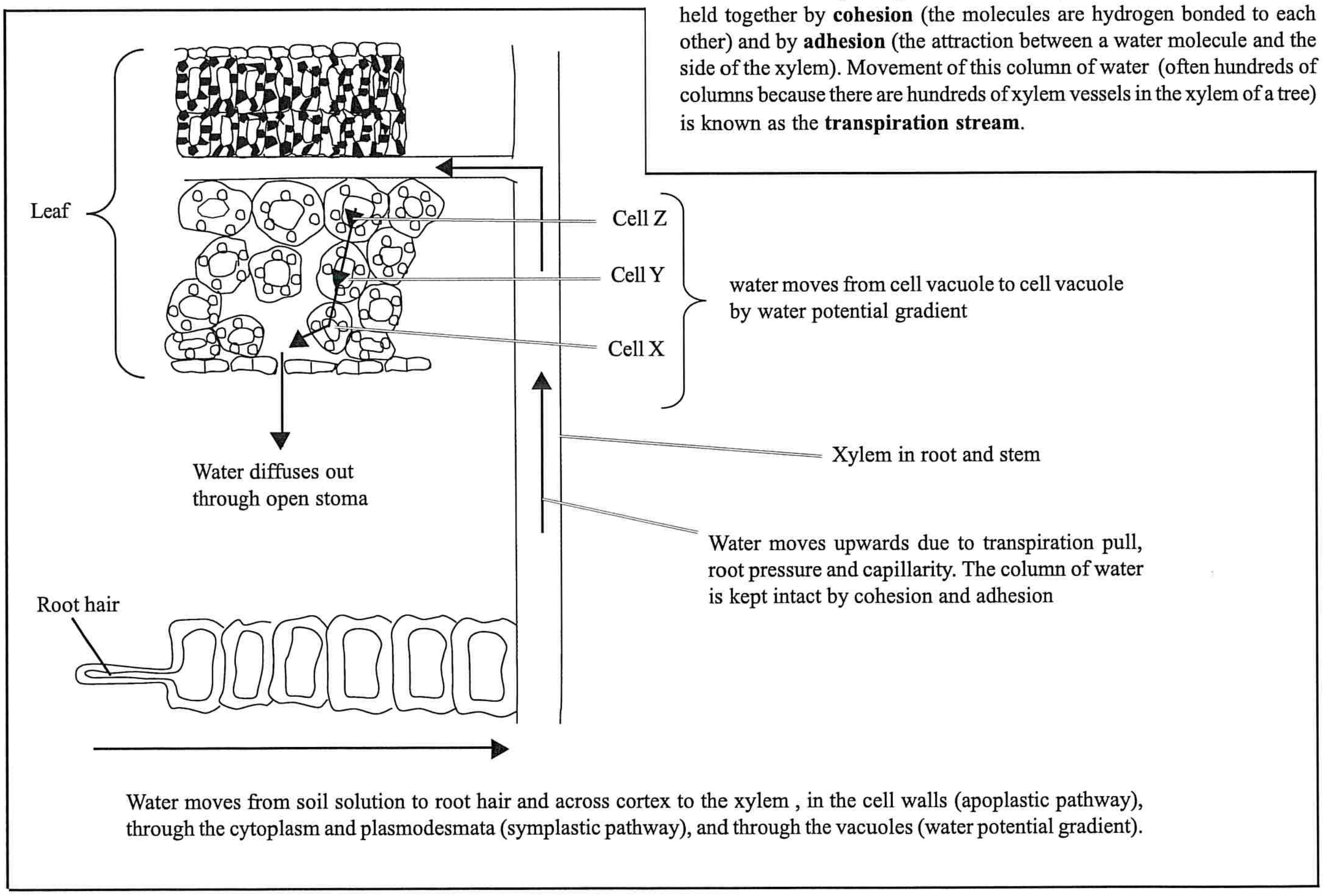
Transpiration is the loss of water from the aerial parts of a plant. It aids transport of water and salts throughout the plant from the soil to the leaves and helps to keep the leaves cool.

Water is essential in the life of a plant (Table 1).

Table 1. Functions of water in plants

Function	Explanation
Turgidity	Keeps stems and leaves rigid, increases light absorption and photosynthesis
Photosynthesis	Provides hydrogen for reduction of NADP
Enzyme Reactions	All metabolic processes must occur in solution
Transport	Ions, eg. Mg^{2+} are absorbed in solution and transported in the xylem. Sugars, hormones etc. are transported in solution in the phloem

Fig 1. Passage of water through the plant



Plants absorb water through their roots. Despite the fact that plants have adaptations – such as waxy cuticles on their leaves – 95% of this water will be lost by evaporation, mainly from the stomata. Some water is also lost via evaporation through the cuticle and through pores in the stem known as lenticels. Wherever it occurs, the evaporation of water from the plant is called **transpiration**.

How is water transported up stems?

There are 3 hypotheses put forward to explain how water is transported up stems. The most important of these is the **cohesion tension hypothesis**. To understand this hypothesis, consider Fig 1.

Water evaporates from spongy mesophyll cells into the air spaces of the leaf. Water then diffuses out of the leaf via the stomata. The loss of water from cell X (Fig 1.) means that the water potential of that cell decreases. Since water always moves from a region of high water potential to a region of low water potential, water now moves from cell Y to cell X. This causes the water potential of cell Y to decrease. In turn, this means that the water from cell Z now moves into cell Y, and so on, all the way back to the xylem. The loss of water from the xylem causes a negative pressure or tension which lifts water up the xylem. Within the xylem the columns of water are held together by **cohesion** (the molecules are hydrogen bonded to each other) and by **adhesion** (the attraction between a water molecule and the side of the xylem). Movement of this column of water (often hundreds of columns because there are hundreds of xylem vessels in the xylem of a tree) is known as the **transpiration stream**.

There are two other forces which are thought to contribute to the transpiration stream. The first of these is **capillarity**. This results from the adhesion of water to the sides of the microscopic xylem vessels and tracheids. The maximum upward movement of water by such capillarity in vessels is about 1 metre. The third process put forward to explain upward movement of water in a stem is **root pressure**. This can be summarised as follows:

1. Minerals are actively absorbed at night and pumped into the xylem tissue.
2. Water potential of the xylem cells decreases.
3. Water, therefore, moves in by osmosis.
4. This increases pressure within the system since the stomata are closed.
5. Water is forced out of the leaves by guttation. Root pressures of this kind can push water several centimetres up a plant.

Environmental factors affecting transpiration

The factors which affect the rate of transpiration are summarised in Table 2.

Evidence that the transpiration stream occurs in the xylem

1. Tree ringing - removing a ring of bark from a tree does not significantly alter transpiration, however, because it removes the phloem, it stops translocation.
   If the xylem is removed as well, transpiration stops, proving that the water moves through the xylem.
2. When roots absorb a soluble dye all of the xylem elements in the stem are stained but no other components in the plant are stained
3. The system of xylem vessels provides the only open 'pipe system' in the plant.

Table 2. Factors affecting rate of transpiration

Environmental Factors	Effect
Soil moisture	Inadequate soil moisture can cause damage to the roots which decreases their ability to absorb water and this will decrease the rate of transpiration.
Temperature	1. An increase of temperature increases the rate of movement of water molecules, so diffusion increases and transpiration increases. 2. Increases in temperature provides energy for the latent heat of vaporisation so increasing temperature increases evaporation which increases rate of transpiration. 3. However, if transpiration increases drastically, stomata close, enzymes may become denatured and transpiration will decrease. 4. Temperature also affects the normal 24 hour (circadian rhythm) of stomatal opening and closing. Normally stomata open just before the light period and remain open during the day and then close at night.
Light intensity	Light intensity affects stomatal opening – they close in darkness or extremely bright light.
Water potential gradient	The greater the water potential gradient between the air in the leaf and the atmosphere outside the stomata, the greater the rate of diffusion hence the greater the rate of transpiration. Winds effectively blow away moisture which may build up in the boundary layer - the layer of still air around a leaf. This effectively increases the diffusion gradient increasing the rate of transpiration.
Carbon dioxide concentration	Carbon dioxide concentrations will influence the circadian rhythms of the plant (responses which seem synchronised for the length of the day or the night).

Exam hint *- The questions on the transpiration stream usually offer:*
1. 1 mark for describing an upwardly moving column of water
2. 1 mark for mentioning in the xylem vessels or tracheids
3. 1 mark for mentioning cohesion and adhesion
4. 1 mark for mentioning water potential gradients

Mechanism of stomatal opening

This relies on the fact that the inner walls of the guard cells are thickened. Thus when the guard cells are turgid the pore between the inner walls is opened, due to unequal wall stretching.

There are 2 commonly examined hypotheses for how the cells become turgid.

Hypothesis 1

1. Photosynthesis occurs in chloroplasts in guard cells making sugars.
2. Sugars reduce water potential.
3. Water enters guard cells which become turgid.
4. The guard cell expands so because of irregular walls the pore opens.

Limitations

1. Not all guard cells have chloroplasts.
2. Guard cells chloroplasts don't possess all the enzymes needed in the Calvin cycle to produce sugars.

Hypothesis 2

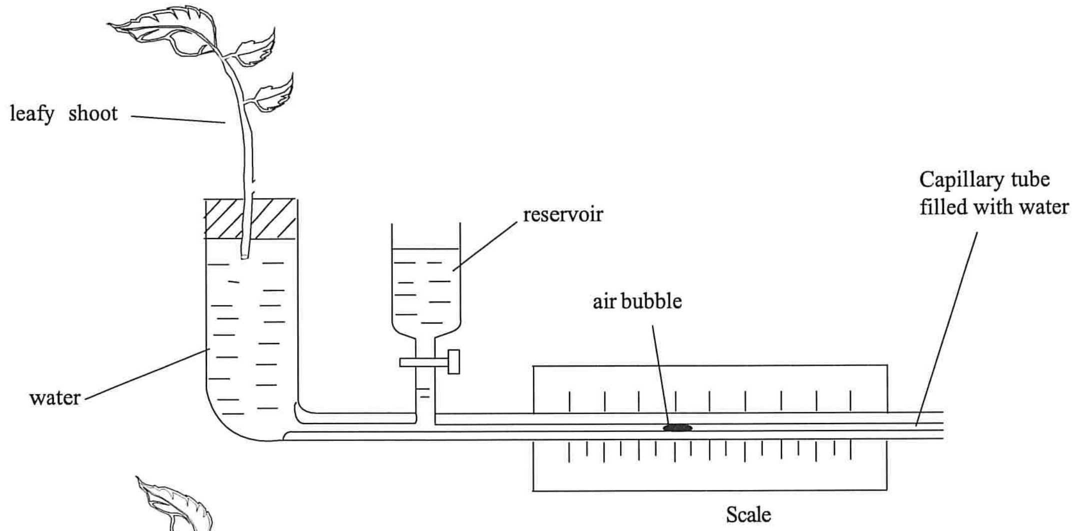
1. The light reaction of photosynthesis produces ATP.
2. ATP provides energy for the absorption of K^+ ions by the guard cells.
3. Chloride (Cl^-) ions are absorbed and maintain electroneutrality.
4. K^+ ions decrease the water potential hence water enters.
5. Thus cells become turgid and open.

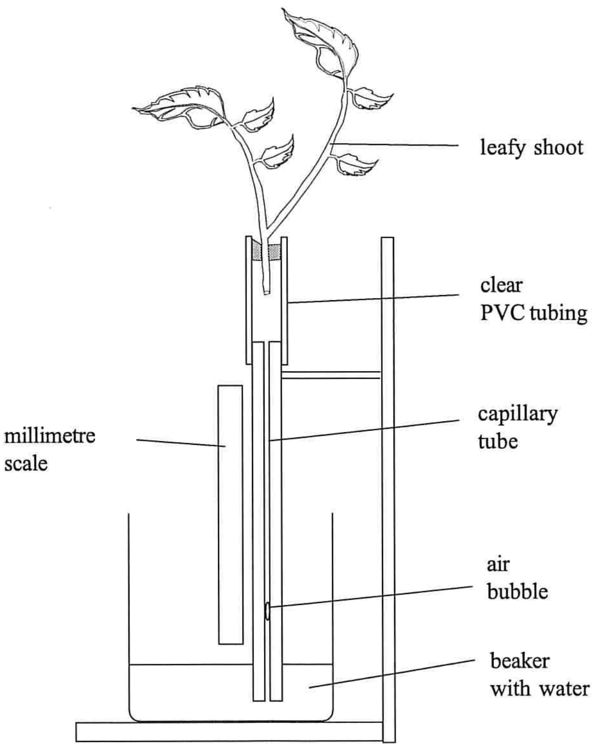
Practical exam questions on transpiration

Questions are sometimes set which test candidates' knowledge of how transpiration can be measured practically. Transpiration is measured using a potometer. There are several designs of potometer (Fig 2).

> ***Exam Hint*** *- Questions often ask candidates to describe the method of using a potometer and to describe the precautions which need to be taken when setting up the apparatus.*

Fig 2. Two types of potometer





Suggestions for practical investigations

1. To measure the effect of air currents or temperature change on the rate of transpiration.
2. To compare transpiration rates in hairy and hairless leaves.
3. To compare transpiration rates in deciduous and evergreen shoots.
4. To assess the affects of metabolic inhibitors on transpiration rate. (If transpiration is completely passive they should have no effect).

Examples of precautions which can be taken when setting up and using the potometer are:

- ensure system is air tight by connecting capillary tube and PVC tube together under water.
- cut shoot under water and connect to PVC tube under water.
- grease all joints.
- use hairless leaves as hairs can severely reduce transpiration.
- remove excess moisture from leaf surfaces by blotting.
- maintain air tight system.
- to introduce bubble into system:
  1. lift potometer from water.
  2. gently blot the end to the tube capillary tube to create a small air bubble.
  3. lower capillary tube back into water.
- wait until bubble is at suitable position and start clock.
- record bubble position at suitable time intervals eg 30 secs, 60 secs
- have eye at same level as bubble
- when bubble reaches top of mm scale, gently squeeze PVC tube and continue.