DP IB Biology: HL

Your notes

9.1 Transport in the Xylem of Plants

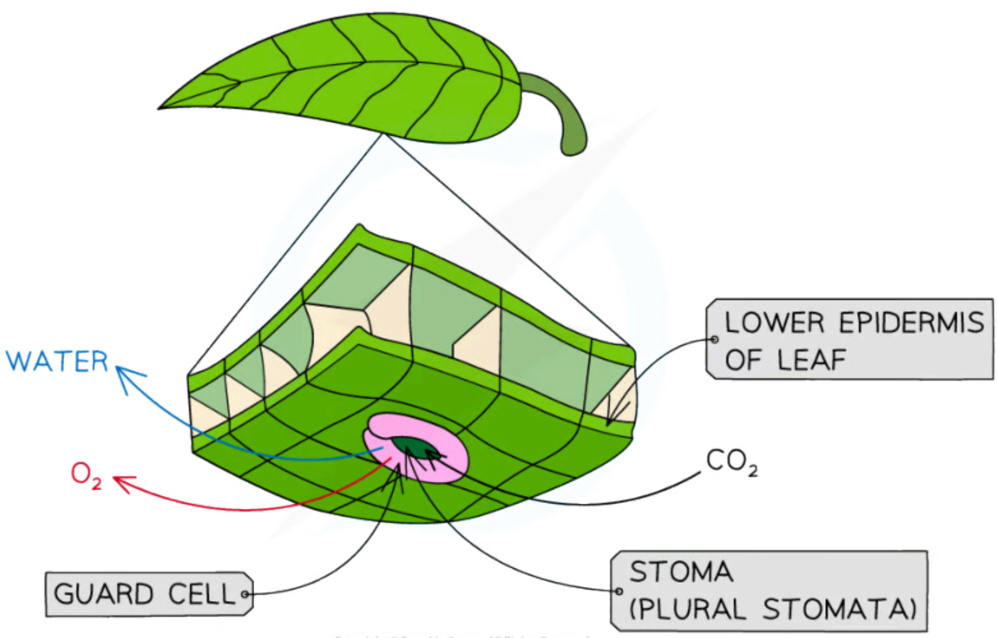
Contents

9.1.1 Transpiration in Plants

Your notes

Transpiration & Gas Exchange

- The majority of photosynthesis takes place in the **leaves** of plants
  - Some plants are able to carry out photosynthesis in the cells of their stems
- During photosynthesis, **carbon dioxide is taken in by the leaf and oxygen is released**
  - The **pores in the epidermis of the leaf** through which this gas exchange takes place are known as stomata (singular stoma)
  - The stomata need to be open all the time in order for **gas exchange, and therefore photosynthesis, to continue**
- The problem for plants is that as the stomata open to allow gas exchange to occur, **water in the form of water vapour is also lost through the stomata**
  - This water loss is known as **transpiration**
  - Most plants can use cells called **guard cells to close their stomata** in order to **reduce water loss**, but this will also reduce gas exchange and therefore their rate of photosynthesis
  - Transpiration is the inevitable consequence of gas exchange in the leaf
- There are some advantages to the process of transpiration
  - It provides a means of **cooling** the plant via **evaporation**
  - The transpiration stream is helpful in the **uptake of mineral ions**
  - The turgor pressure of the cells, due to the presence of water as it moves up the plant, provides **support** to the leaves and to the stems of non-woody plants
    - Leaves with high turgor pressure do not wilt and therefore have an increased surface area for photosynthesis



The loss of water vapour from leaves by evaporation through the stomata is unavoidable as gas exchange for photosynthesis can only occur when the stomata are open

Your notes

Your notes

9.1.2 The Transpiration Stream

Water Transport Within The Xylem

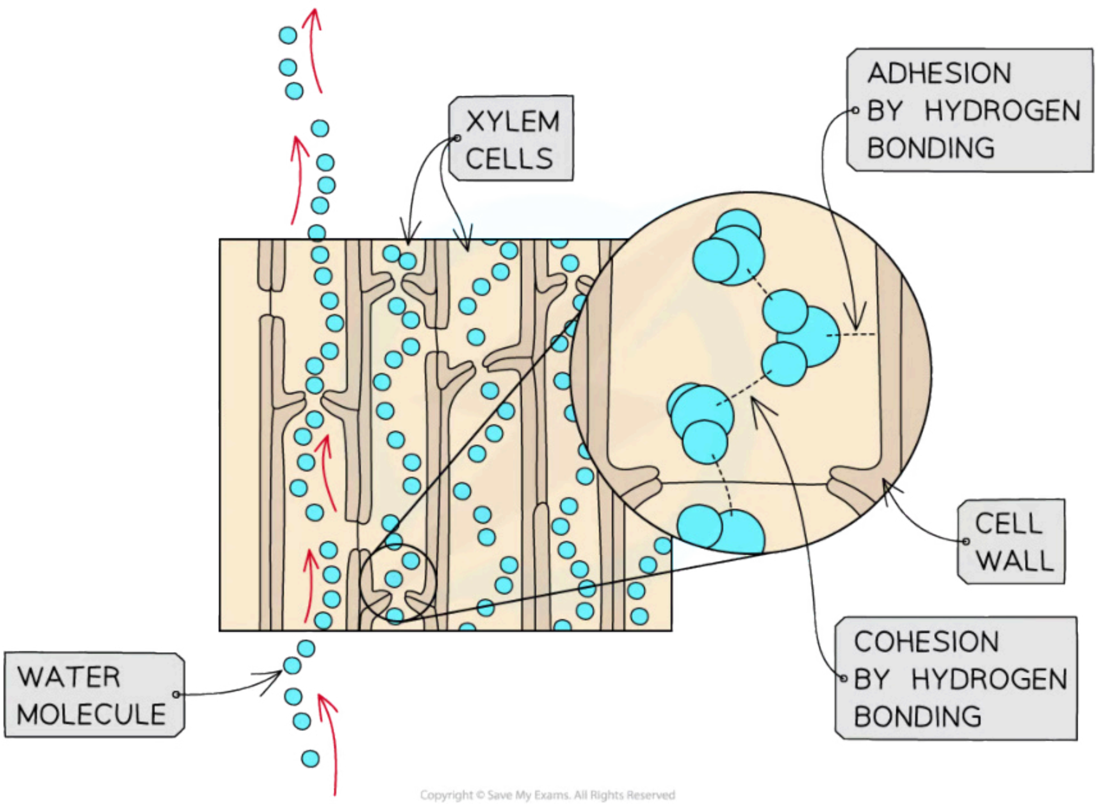
- The transport of water occurs in xylem vessels, one of the vascular tissues found within plants
- The cohesive property of water, together with the structure of the xylem vessels, allows water to be transported under tension from the soil to the leaves

Cohesion between water molecules

- Within water molecules the **oxygen atom has a slight negative charge** while the **hydrogen atoms have a slight positive charge**; this difference in charge across the molecule means that water is a **polar molecule**
- As a result of the polarity of water, **hydrogen bonds form between the positive and negatively charged** regions of adjacent water molecules
  - This force of attraction between water molecules is known as **cohesion**
- Water molecules are also **attracted to the hydrophilic surface of the cell walls** on the interior of xylem vessels
  - This attraction between molecules of a different type is known as **adhesion**

Xylem vessels

- Xylem vessels are formed from **long lines of cells** that are connected at each end
- As the xylem vessels develop, the **cell walls between the connected cells degrade** and the **cell contents are broken down**
  - This forms **mature xylem vessels** that are **long, continuous, hollow tubes**
  - Mature xylem vessels are **non-living** cells
- The walls of xylem vessels are **thickened with cellulose** and **strengthened with a polymer called lignin**
  - This means xylem vessels are extremely tough and can **withstand very low internal pressures**, i.e. negative pressure caused by suction, **without collapsing** in on themselves

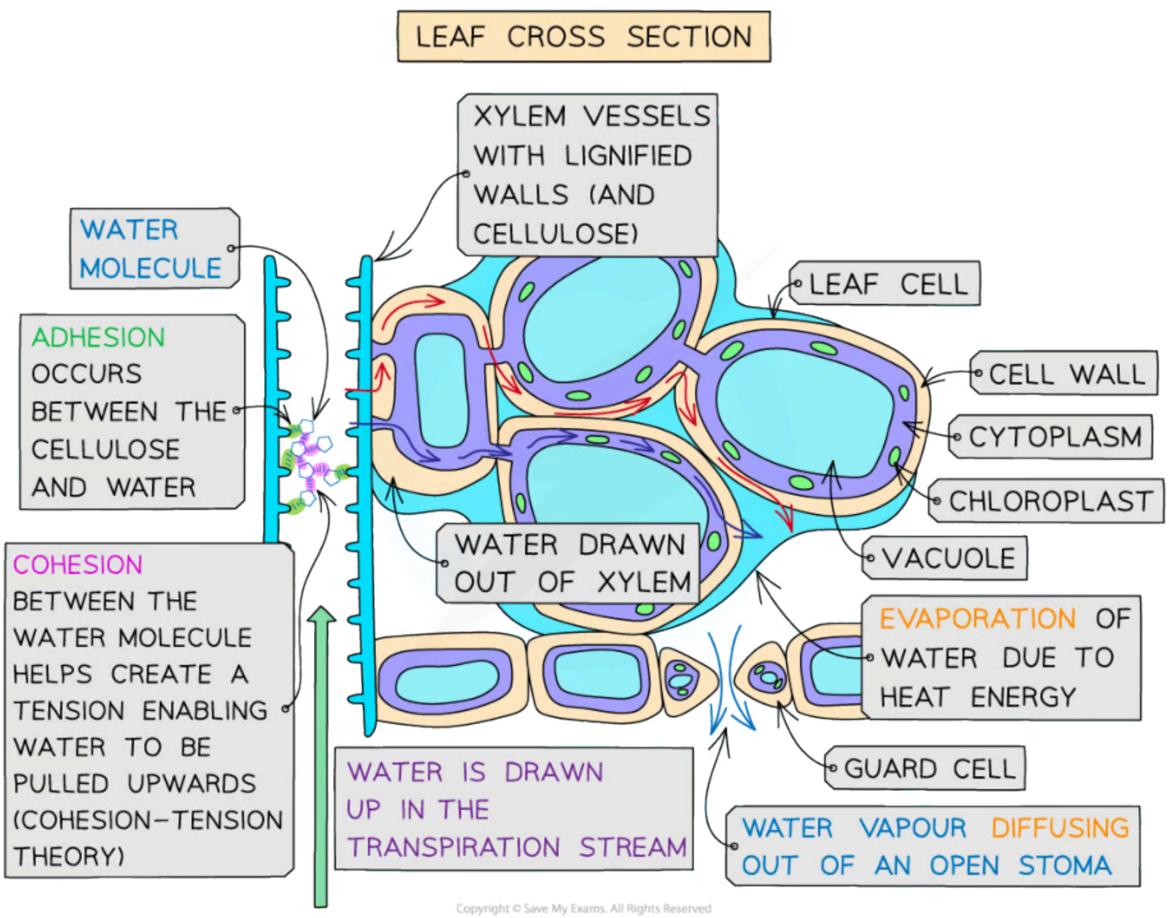


Cohesion between water molecules and adhesion of water molecules to xylem cell walls allow water to be pulled up xylem vessels in one continuous column

Your notes

The Transpiration Stream

- When water **evaporates** from the surfaces of cells inside a leaf during transpiration, more water is **drawn from the nearest xylem vessels** to **replace the water lost** by evaporation
  - Water molecules **adhere to the cell walls of plant cells** in the leaf, enabling water to move through the cell walls
    - e.g. water moves through the cell walls of the xylem into other cells of the leaf
  - The loss of water from the xylem vessels **generates low pressure** within the xylem
- The **low pressure generated in the xylem** when water moves into the cells in the leaves creates a **pulling force throughout the xylem vessels** that is transmitted, via **cohesion between water molecules**, all the way **down the stem of the plant and to the ends of the xylem in the roots**
  - This is known as **transpiration-pull** and it **allows water to be moved upwards through the plant**, against the force of gravity
  - This is sometimes known as the cohesion-tension theory of transpiration
- At the same time, **forces of adhesion** between the water molecules and the walls of the xylem vessels **ensure that there are no air bubbles or spaces inside the xylem vessels**
- This continuous upwards flow of water in the xylem vessels of plants is known as the **transpiration stream**



Your notes

The movement of water through xylem vessels is due to the evaporation of water vapour from the leaves and the cohesive and adhesive properties exhibited by water molecules

Your notes

Your notes

Modelling Water Transport in Plants

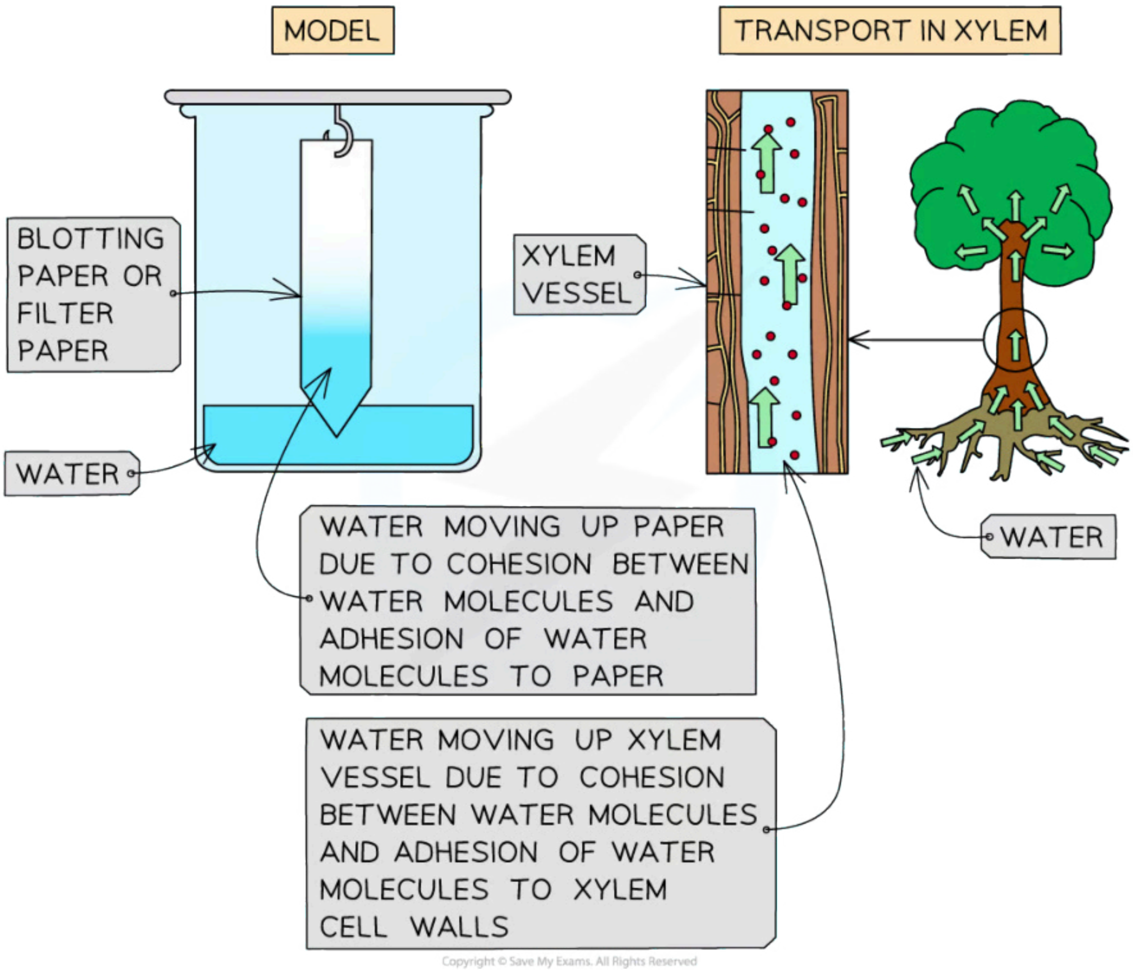
NOS: Use models as representations of the real world; mechanisms involved in water transport in the xylem can be investigated using apparatus and materials that show similarities in structure to plant tissues

- Models are often used to study complex **living systems** which may be **too complicated** to observe in reality, or to **demonstrate the mechanisms** behind the processes that take place inside living systems
- It is possible to **model the mechanisms involved in water transport in the xylem** using simple apparatus including
  - Blotting paper or filter paper
  - Porous pots
  - Capillary tubing

Blotting or filter paper

- Blotting paper or filter paper has the ability to **absorb water**
- When a piece of blotting paper or filter paper is placed with the end touching the water, the water will **rise up** along the length of the paper
  - **Adhesive** and **cohesive** forces cause water to be **drawn into and through the paper**
- This can be **compared to the movement of water up a xylem vessel**
- A strength of this model is that, like xylem vessels, **the paper is made of cellulose**
  - Adhesion occurs **between water molecules and the interior cellulose surface** of xylem vessels

Your notes

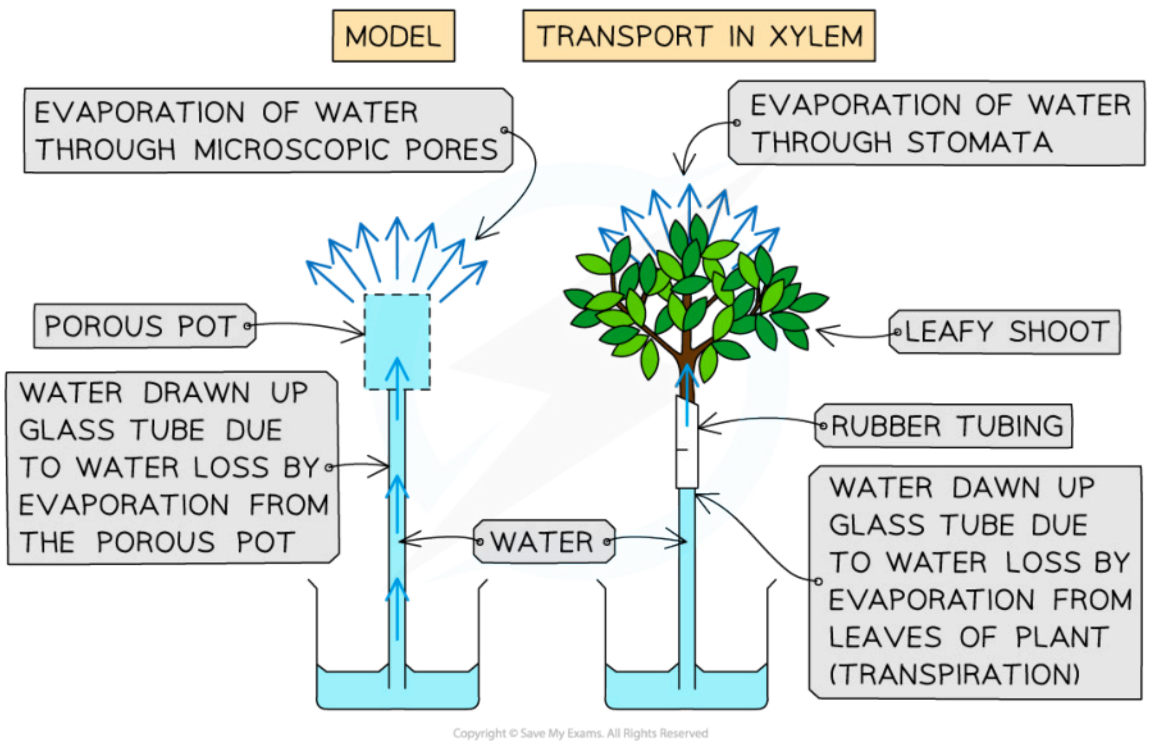


Water transport in the xylem can be modelled using blotting paper or filter paper

Porous pots

- A porous pot is a **partially permeable container** made from a material full of **microscopic pores** through which water can pass
  - An example of a material containing these pores is terracotta clay that has been fired
- Porous pots can be used to **model the evaporation of water that occurs from the leaves of a plant**
  - If the porous pot is filled with water, **adhesion between water molecules and the material of the pot occurs**, causing water to fill the pores within the material, from where it can evaporate
    - This is similar to the way that water molecules **adhere to cell walls** inside a leaf
  - If the porous pot is connected to a water filled glass tube that is also dipped in a container of water, the **negative pressure created by water evaporating** from the surface of the pot, together with **cohesion**, causes water to be **drawn up the glass tub**e, just as it would to form the transpiration stream within a xylem vessel

Your notes

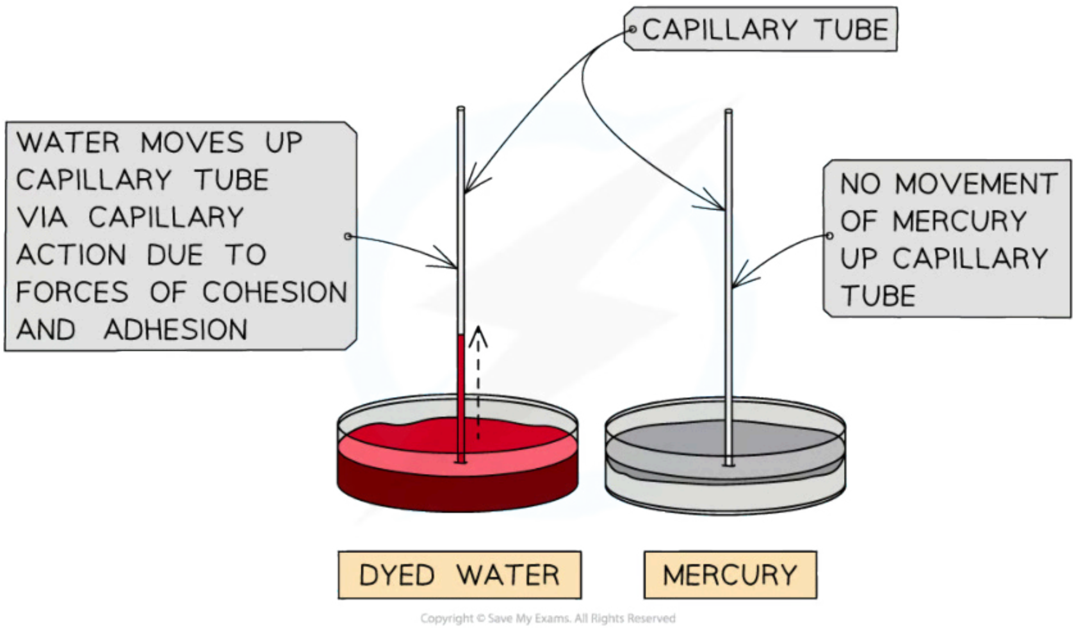


Water transport in the xylem can be modelled using porous pots

Capillary tubing

- When a very narrow glass tube known as a **capillary tube** is dipped into water, **water can flow up the tube** despite the opposing force of gravity purely due to the **adhesion of water molecules with the inner surface of the tube** and **cohesion between water molecules**
  - This phenomenon is known as capillary action
  - The thinner the tube, the higher the water will rise
- Although the movement of water up xylem vessels is also driven by **evaporation of water from the cells of the leaf**, which is not reflected by this model, and xylem vessels are **much thinner** than a capillary tube, this model still **shows how important adhesion and cohesion are** in the transport of water up xylem vessels
- The fact that water has these properties can be further demonstrated by
  - Dipping one capillary tube in **dyed water** and another capillary tube into **liquid mercury**
    - As adhesion **does not occur between mercury and the glass of the capillary tube**, and there is **no cohesion between mercury atoms**, capillary action in this tube cannot occur and **mercury does not rise up the tube**

Your notes



Modelling the mechanisms involved in water transport in the xylem using capillary tubing

9.1.3 The Roots & Water Transport

Your notes

Active Transport of Minerals in the Roots

- Within a plant, **mineral ions** are **dissolved in water** and transported in the **xylem vessels**
  - Mineral ions needed by plants include nitrates, phosphates, and potassium ions
- **Plant roots** are responsible for the **uptake of both water and mineral ions**
  - Root hair cells increase the available **surface area** for these processes
- The **uptake of water** is a **passive** process and occurs by osmosis as a result of the active transport **of mineral ions** into root cells
  - Mineral ion uptake **raises the solute concentration**, or osmolarity **of the root cells**, causing water **to move from an area of lower osmolarity** in the soil **to an area of higher osmolarity inside the root cells**

Mineral ion uptake

- The soil surrounding root cells contains **low concentrations of mineral ions in relation to the root cell contents**, so several mechanisms are required to maintain an adequate supply of mineral ions to roots
  - Mineral ions are **actively transported** into root cells by the action of **specific transporter proteins** in their cell surface membranes
    - These proteins are sometimes known as **protein pumps**
    - Note that active transport acts **against a concentration gradient**, so mineral ions are transported from an area of **relatively low concentration** in the soil to an area of **relatively high concentration** inside the root cells
  - The movement of water in the surrounding soil and into the spaces within the cell walls of the root cells **brings mineral ions into contact with their specific pump proteins**
    - Note that this is **not** referring to the movement of water by osmosis, but to the flow of water that results e.g. when it rains and water flows through the soil
  - Some plants have a mutualistic **relationship with soil fungi** in which the fungus grows on, and sometimes into, the roots of the plant; the fungi cells spread out into the surrounding soil and **absorbs mineral ions** that the plant's roots may not be able to access, passing them on to the plant
    - In return the plant provides the fungus with sugars

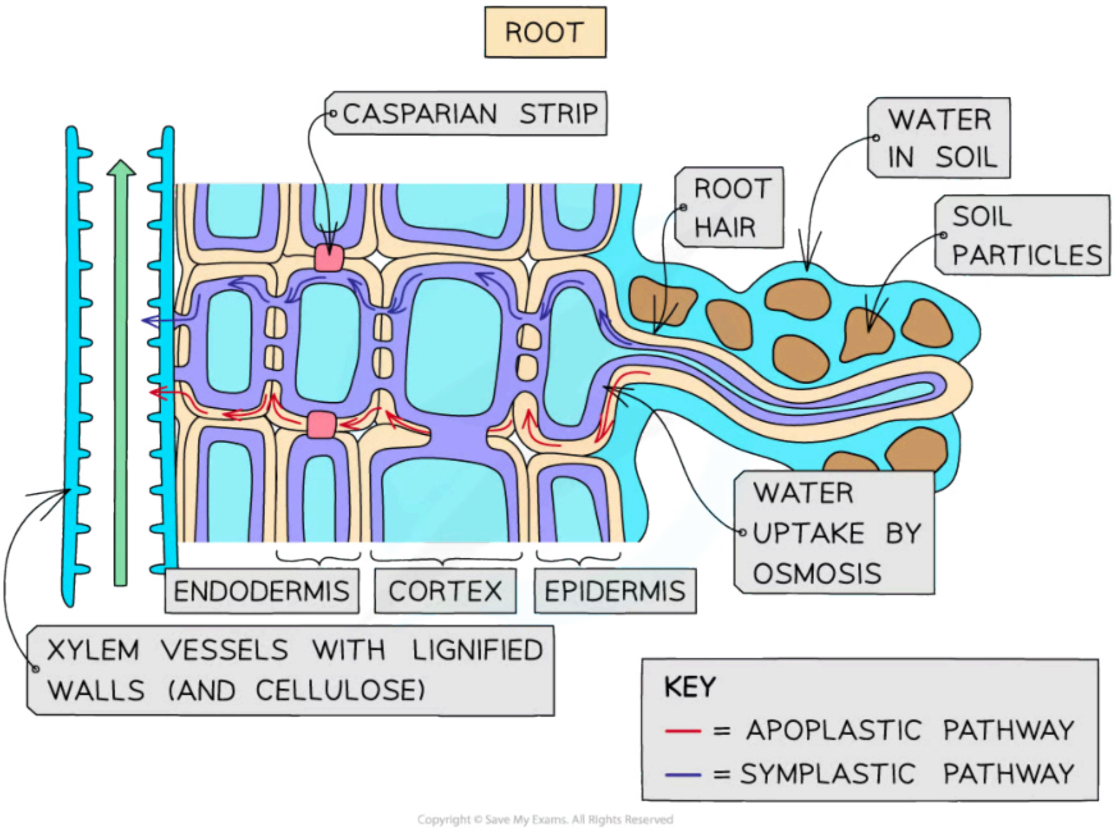
Replacing Losses from Transpiration

Your notes

- Plants transport water from roots to leaves **to replace losses from transpiration**
- Water needs to move across the root, up the stem, and across the leaves

Water movement across the root

- There is more than one pathway that water and dissolved minerals can take as they move across the central region of the root, known as the root **cortex**
  - **Apoplastic,** or **apoplast, pathway**
    - This involves the series of **spaces** running through the **cellulose cell walls** of the root cells
      - The water does not move by osmosis here as there are no cell membranes to cross
    - The movement of water through the apoplast pathway occurs **rapidly**
    - When the water reaches the layer of cells that surrounds the vascular tissue in the centre of the root, it encounters a waterproof layer called the **casparian strip** which forces the water out of the cell walls and into the interiors of the cells
      - This forces the water to pass **through the plant cell membranes** and so **increases the control** that the plant has over substances entering its cells
  - **Symplastic,** or **symplast, pathway**
    - This involves the **cytoplasm** of the cells
    - The water moves by **osmosis** into and out of the cells
    - The movement of water in the symplast pathway is **slower** than the apoplast pathway
    - **Less water** travels by the symplast pathway than by the apoplast pathway
    - Water that encounters the casparian strip is forced out of the apoplast pathway and **into the symplast pathway**

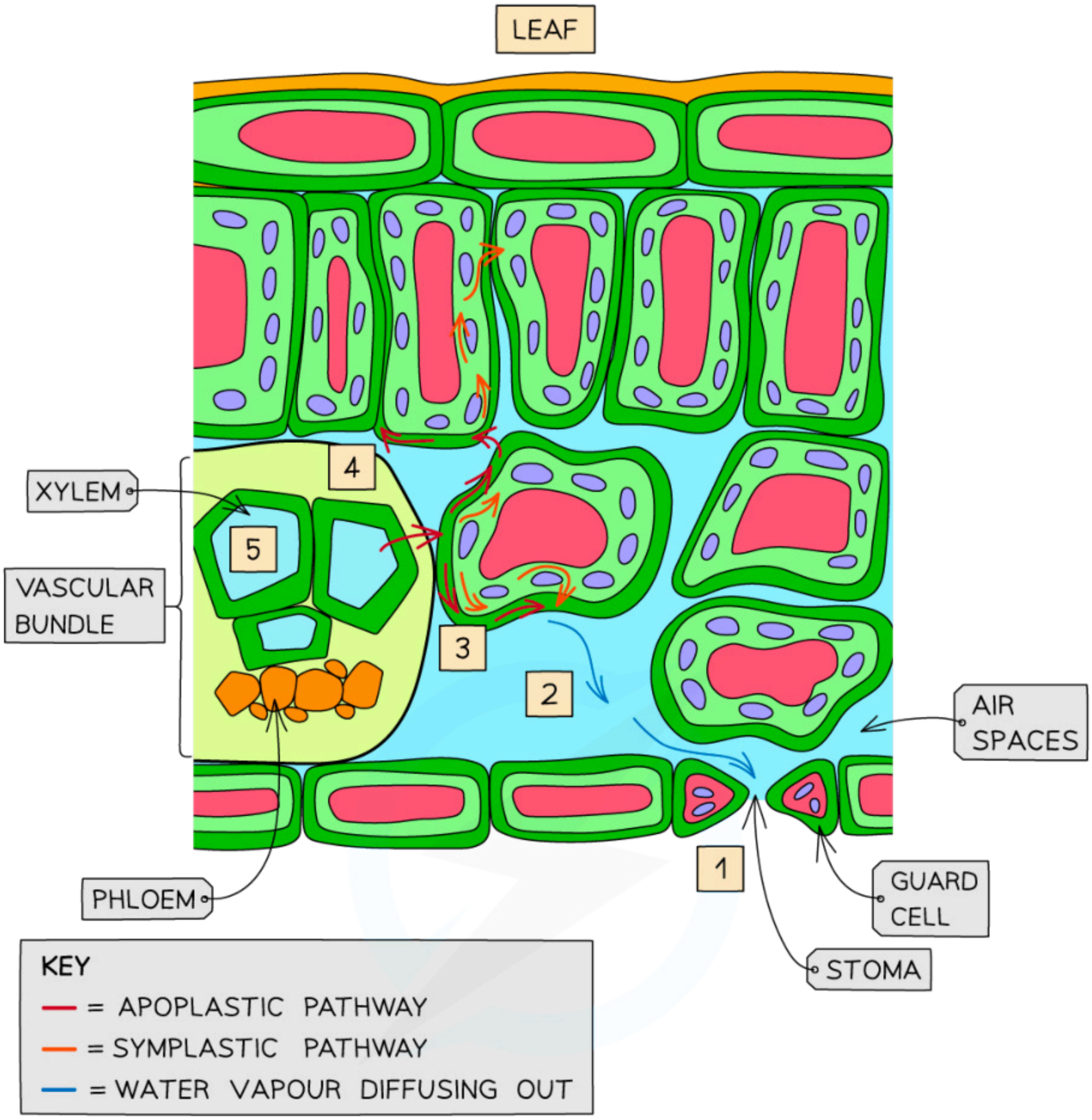


Water can move across the root to the xylem by the apoplast or symplast pathways. Note that the layer of cells surrounding the vascular tissue that contains the casparian strip is labelled here as the endodermis.

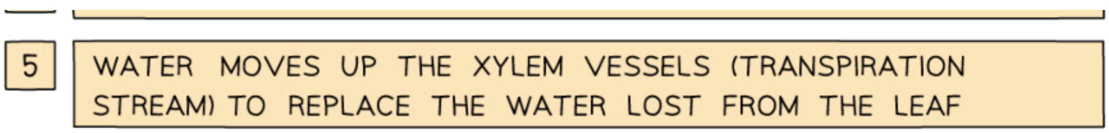
Movement of water across the leaves

- As transpiration occurs at the stomata, **water vapour is removed from air spaces** surrounding the leaf cells, creating a water vapour **concentration gradient** between the air spaces and nearby cells
- The water within the cell walls of the leaf cells lining the air spaces **evaporates** into the air spaces, generating **transpiration pull** that draws water into these cells from neighbouring cells
  - Transpiration pull occurs because of **cohesive forces** between water molecules
- This transpiration pull results in **water moving across the leaves** from the xylem towards the stomata
  - Water moving across the leaf can move via either the apoplast or symplast pathways

Your notes



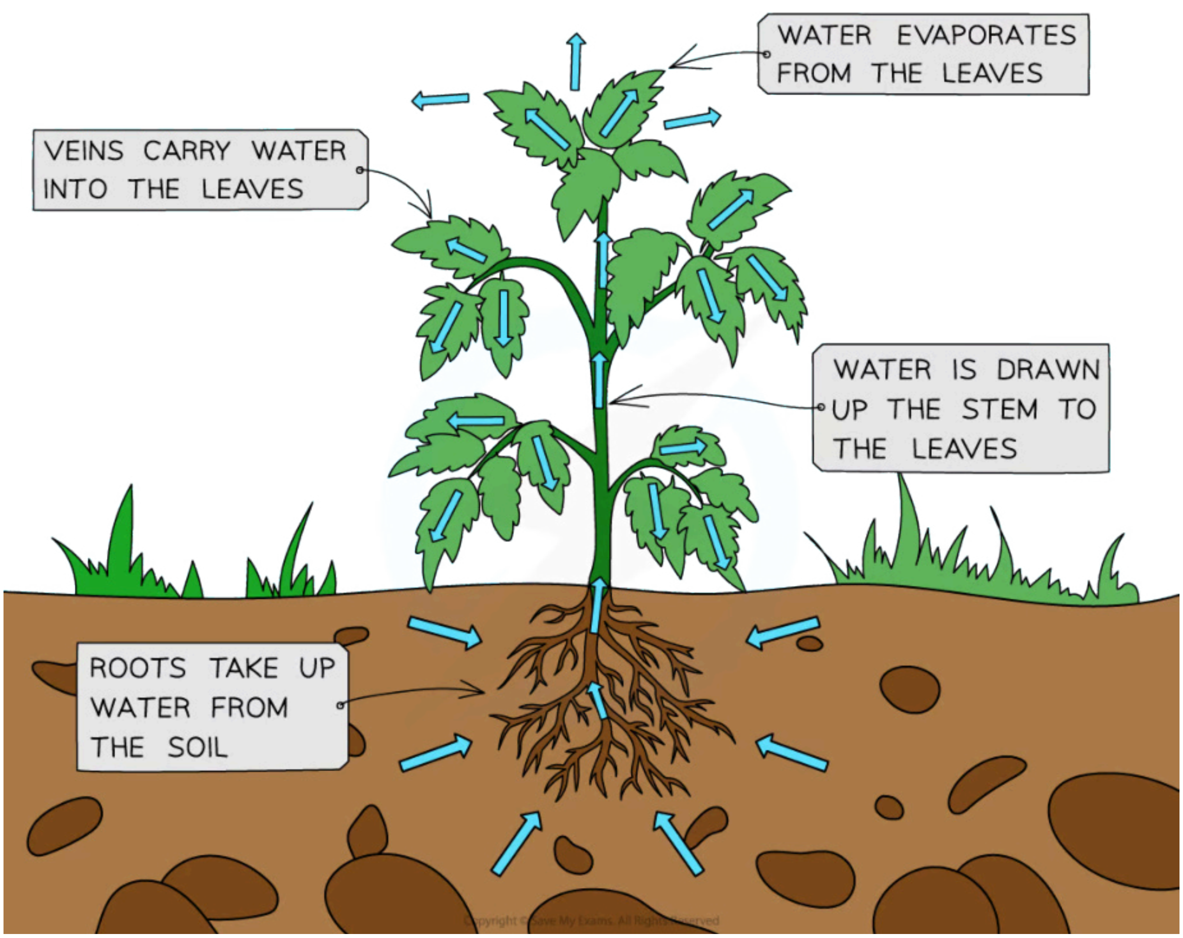
1	WATER VAPOUR DIFFUSES FROM AIR SPACES THROUGH A STOMA BY A PROCESS CALLED TRANSPIRATION
2	WATER EVAPORATES FROM A MESOPHYLL CELL WALL LINING THE AIR SPACES, CREATING A TRANSPIRATION PULL
3	WATER MOVES THROUGH THE APOPLAST OR SYMPLAST PATHWAY DUE TO TRANSPIRATION PULL
4	WATER LEAVES A XYLEM VESSEL DUE TO TRANSPIRATION PULL



Water moves across a leaf from the xylem to the stomata due to transpiration pull. Note that some water enters the leaf cells to be used in photosynthesis.

Water movement up the stem

- Water moves up the stem in the xylem vessels **to replace the water that is lost at the leaves by transpiration**
  - The transpiration pull generated in the leaves **is transmitted down the xylem** due to the **forces of cohesion and adhesion** acting on water molecules
- The evaporation of water vapour from the leaves together with the cohesive and adhesive properties exhibited by water molecules result in water being **continuously drawn up through xylem vessels** within the plant



Your notes

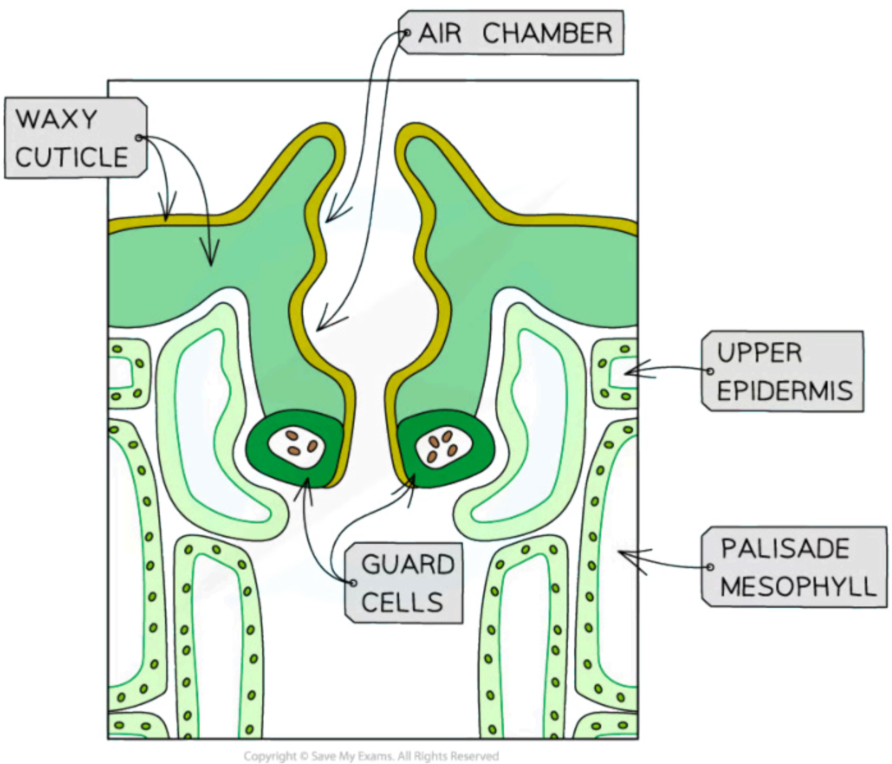
The loss of water vapour from the leaves of plants by transpiration results in a transpiration pull that causes water to move upwards through the xylem vessels of the plant

9.1.4 Adaptations of Xerophytes

Your notes

Adaptations of Xerophytes

- Plants that live in conditions with a **plentiful supply of fresh water** have leaves with a **short diffusion distance through to the stomata** and a **large surface area** provided by the air spaces between the leaf cells
  - These factors make them **vulnerable to water loss**
- Plants that live in conditions where **fresh water is limited** often have very different leaf structure to that described above; they have evolved **effective adaptations to conserve water** e.g.
  - Very few stomata
  - Sunken stomata
  - Hairs surrounding stomata
  - Needle-shaped or small leaves
  - Thickened waxy cuticle
- Plants with adaptations to conserve water are described as **xerophytic**, or known as **xerophytes**.

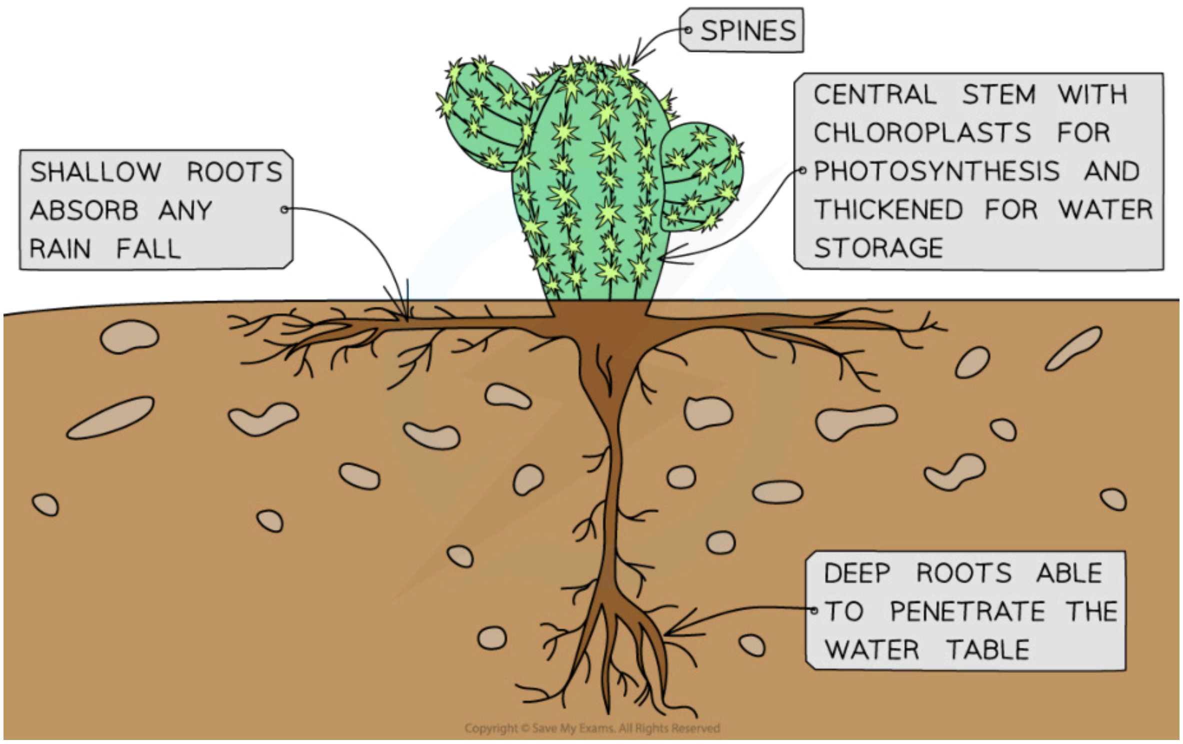


Xerophytes have features such as sunken stomata and a thickened waxy cuticle

Cacti

- Cacti are well-studied **xerophytes** usually found in the deserts of the USA
- They have several **xerophytic adaptations**

- Their **leaves are reduced to spines** that can no longer photosynthesise
  - This **reduces their leaf surface area** and so **reduces water loss**
  - Photosynthesis occurs in the green stem which possesses chloroplasts
- Stomata are located on the stem and they are **more sparsely distributed than they would be on a regular leaf**
- The stem has a **thick cuticle** and is very **large in diameter** which allows it to **store water**
  - The **stem can expand** to take on water, enabling water storage when it is available
- Cacti carry out a **specialised form of photosynthesis** known as CAM photosynthesis that enables them to **keep their stomata closed** during the day
  - This **reduces water loss by evaporation** in the heat of the day
- There are both shallow and deep penetrating roots which allow access to all available water

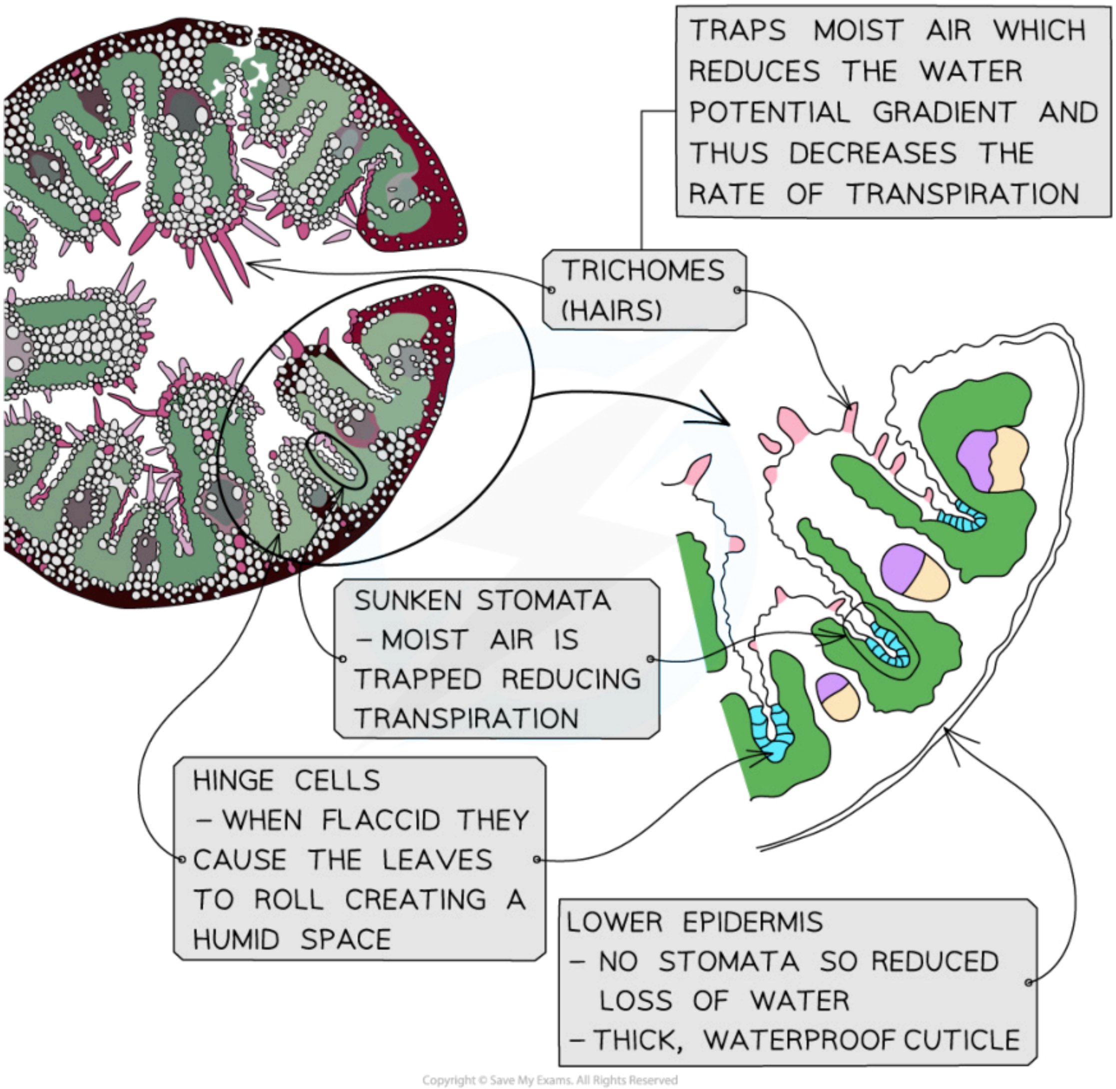


Cacti have several xerophytic features to reduce water loss

Marram Grass

- **Marram grass** is commonly found on sand dunes, another example of a **dry environment** where plants have evolved to survive
- Marram grass leaves are well adapted to **minimise water loss**
  - Leaves are **rolled up** to reduce the exposure of surfaces to the wind and so **reduce water loss by evaporation**
  - The **stomata are sunken** in pits to **reduce water loss by evaporation**

- The inner surface of the leaf possesses a large number of **hairs** which **shield the stomata**, again **reducing water loss**
- The exposed surface has a **thick waxy cuticle** to **reduce evaporation**



Marram grass has several features to reduce water loss by evaporation. Note that the term 'water potential gradient' refers here to the difference in water vapour concentration between the inside and outside of a leaf, while the term flaccid refers to cells that have lost water by osmosis.

Your notes

Xerophytic adaptations table

Xerophytic adaptation of leaves	Effect of adaptation	Example
Fleshy succulent leaves	Water stores for times of low availability	Fleshy leaves: Bryophyllum
'Hinge cells' shrink when flaccid	Causes leaves to roll exposing the thick, waterproof cuticle to the air and creates a humid space in the middle of the rolled leaf	Ammophila arenaria (Marram grass)
Leaves reduced to scales, spines or needles Leaves curled or rolled or folded when flaccid	Reduced transpiration due to reduced surface area available	Modified leaves: Opuntia (cactus) Rolled leaf: Ammophila arenaria (Marram grass)
Stomata closed during light Stomata open in the dark	CAM metabolism to minimise photorespiration; CO_2 fixed at night, day time water loss is minimised	CAM plants: Pineapple, American aloe, Yucca
Sunken stomata /presence of stomatal crypts Leaf surface covered in fine hairs	Water loss is minimised by trapping moist air close to the area of water loss reducing the diffusion gradient	Pinus sp, Phlomis italica, Nerium sp

Your notes

Reduced numbers of stomata	Less water loss due to fewer pores	Opuntia, Nerium sp
Stomata only found in the upper epidermis	Open into the humid space created by the hairs and rolled shape	Ammophila arenaria (Marram grass)
Thick waxy cuticle on leaves	Water loss reduced via the cuticle	Pinus sp, Opuntia

Adaptations of Halophytes

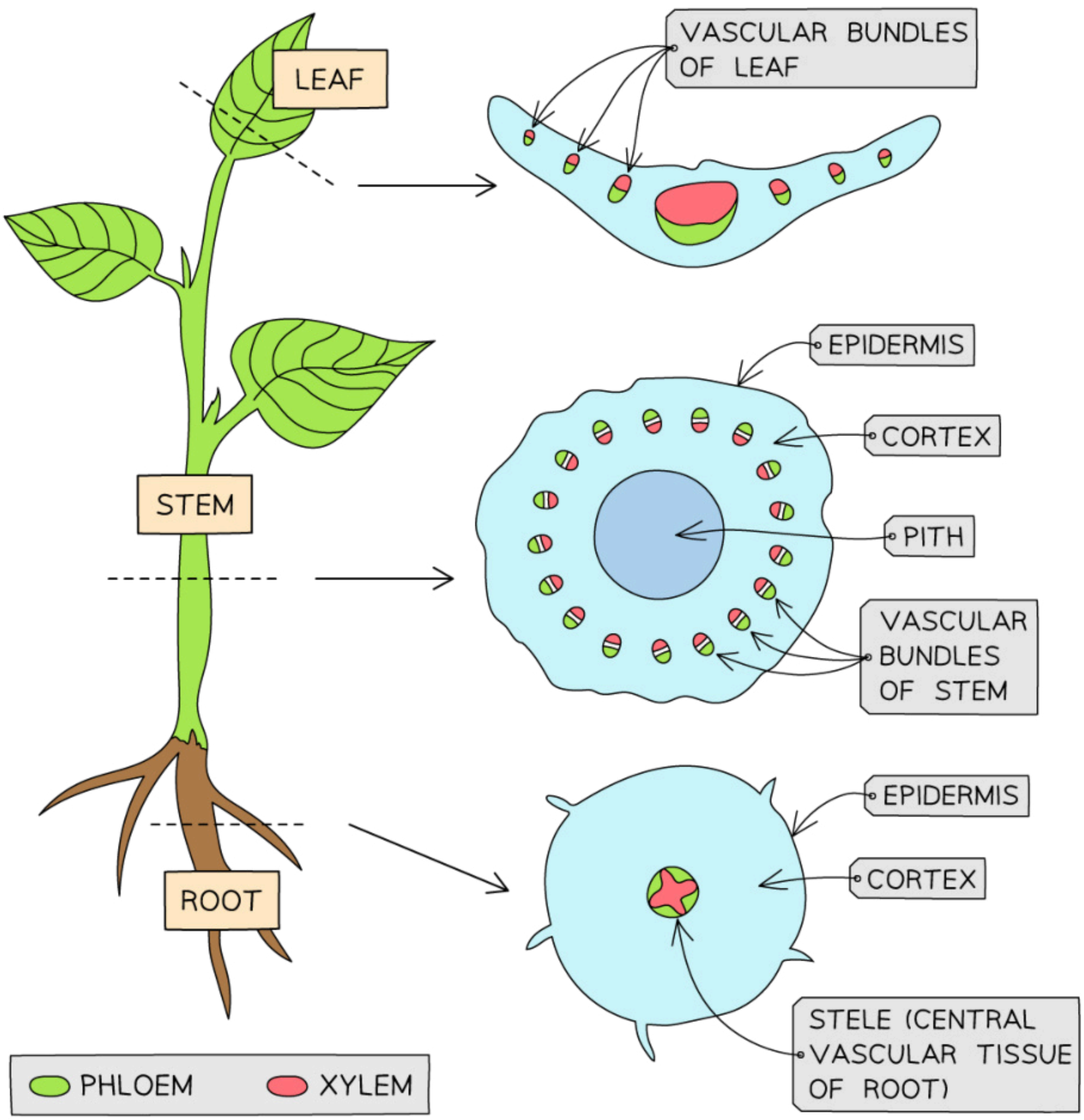
- **Halophytes** are plants that are adapted to **saline, or salty, conditions**
  - Halo = salt
- Saline soils are soils that contain **high concentration of salts**, such as coastal salt marshes and land where the tide comes in and out
- Halophytes have physiological and structural adaptations to survive in these conditions, including
  - Halophytes have the ability to **sequester, or store away, salts** within their cell wall or vacuoles
  - Some halophytes can **concentrate the salts they absorb in certain leaves**, which then fall off the plant
  - Halophytes can **shed their leaves** to reduce water loss
    - In such conditions the stem is able to take over the role of photosynthesis
  - Water loss reducing adaptations such as **reduced leaf surface area** and **sunken stomata** can be found in some halophytes
  - Some halophytes have **salt glands that actively excrete salt** to stop it from building up
  - Halophytes have **deep roots to reach fresh water** underground

9.1.5 Skills: Drawing Xylem Vessels

Your notes

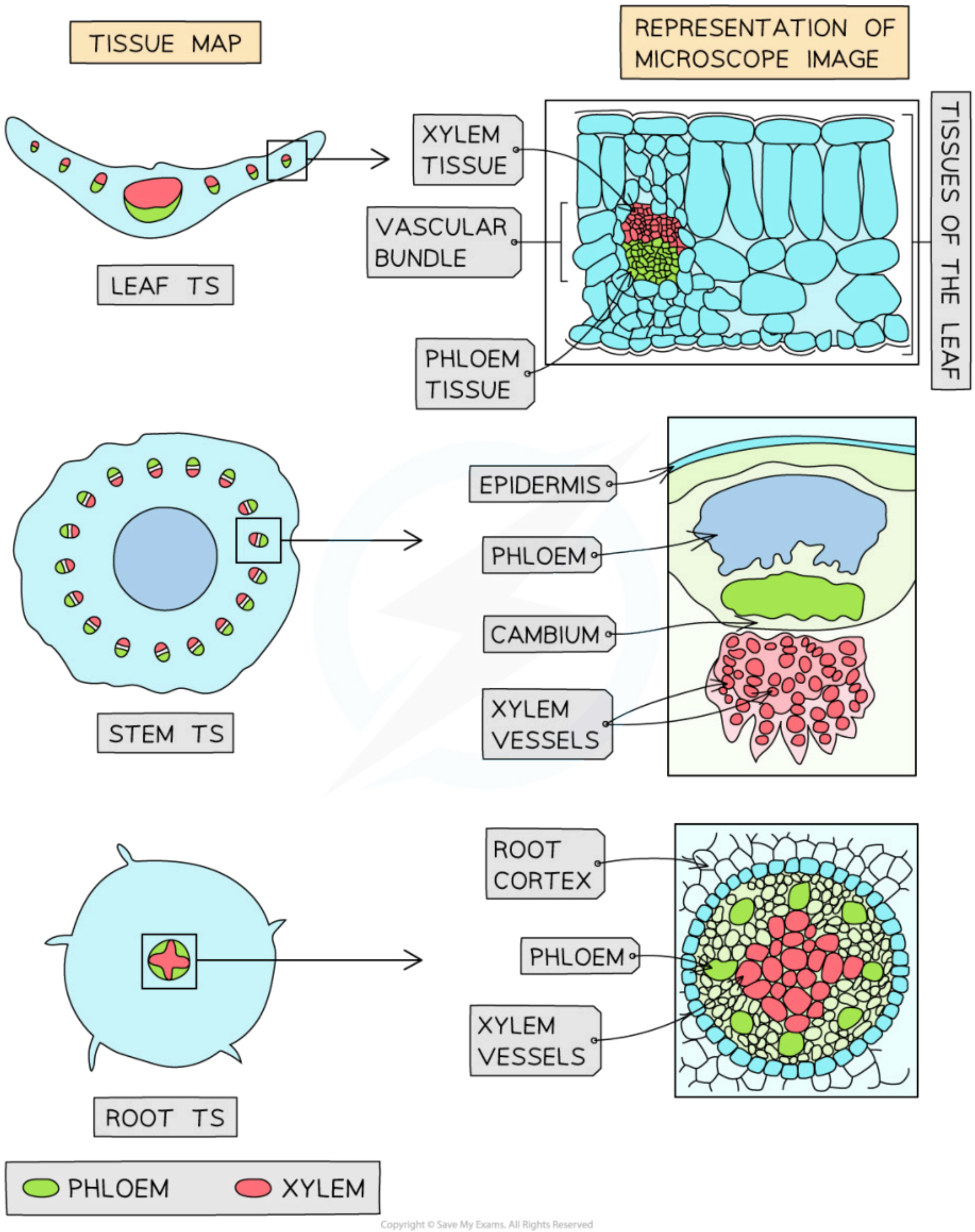
Drawing Xylem Vessels

- The internal structure of plants can be examined by taking transverse sections of different parts of a plant, including the leaves, stem and roots
  - Note that cross sections can be either **transverse** (TS), across the root or stem, or **longitudinal** (LS), along the length of the root or stem.
- From these transverse sections, tissue maps can be drawn
- These tissue maps show the **relative positions of structures within the different parts of a plant** but are not detailed enough to see individual cells
- Tissue maps can be used to show the **distribution of tissues types in plant leaves, stems, and roots**



Tissue maps can be used to show the distribution of tissues in the leaf, stem and root

Your notes



The arrangement of vascular tissue in the vascular bundles can also be seen using a tissue map

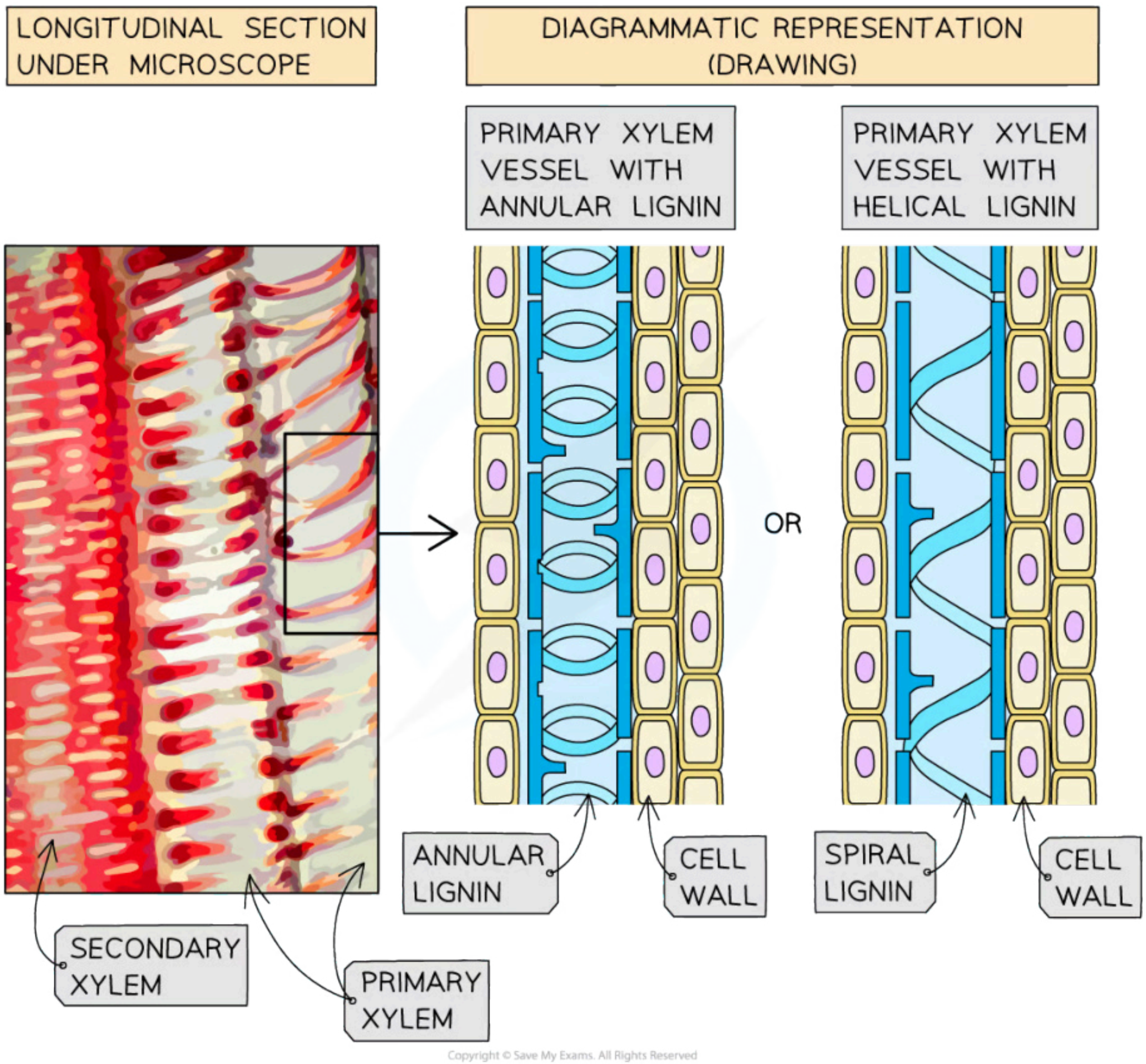
Your notes

Primary xylem vessels

- The lengthening growth of a plant is known as **primary growth** and takes place in certain plant meristems
- The **primary xylem vessels** form from meristem tissue called **cambium**
  - The xylem vessels form on the **inside of the cambium tissue**, towards the centre of plant stems and roots
- The detailed structure of xylem vessels can be seen when sections of plant stem are viewed under a microscope
- If stain is added to the plant tissue on a prepared slide, the cell walls that have been **strengthened with lignin** stand out clearly
  - The lignin in primary xylem forms **rings or spirals** in the xylem walls
    - The ring structure is known as annular, while the spiral structure is helical
  - The structure of the lignin in primary xylem allow the vessels to **continue to grow in length** as the plant grows taller; the **xylem rings or spirals can stretch** apart from each other as the xylem vessels grow
- **Primary xylem vessels have thinner walls than the secondary xylem tissue** that forms later in plant growth
  - Once the stem has **stopped growing longer** there is less need for the lignin to stretch, so the **lignin strengthening becomes much thicker**
  - Secondary xylem vessels are therefore **stronger** than primary xylem but **less flexible**

Your notes

Your notes



When viewed in longitudinal section the annular and helical structure of lignin in primary xylem vessels can be seen

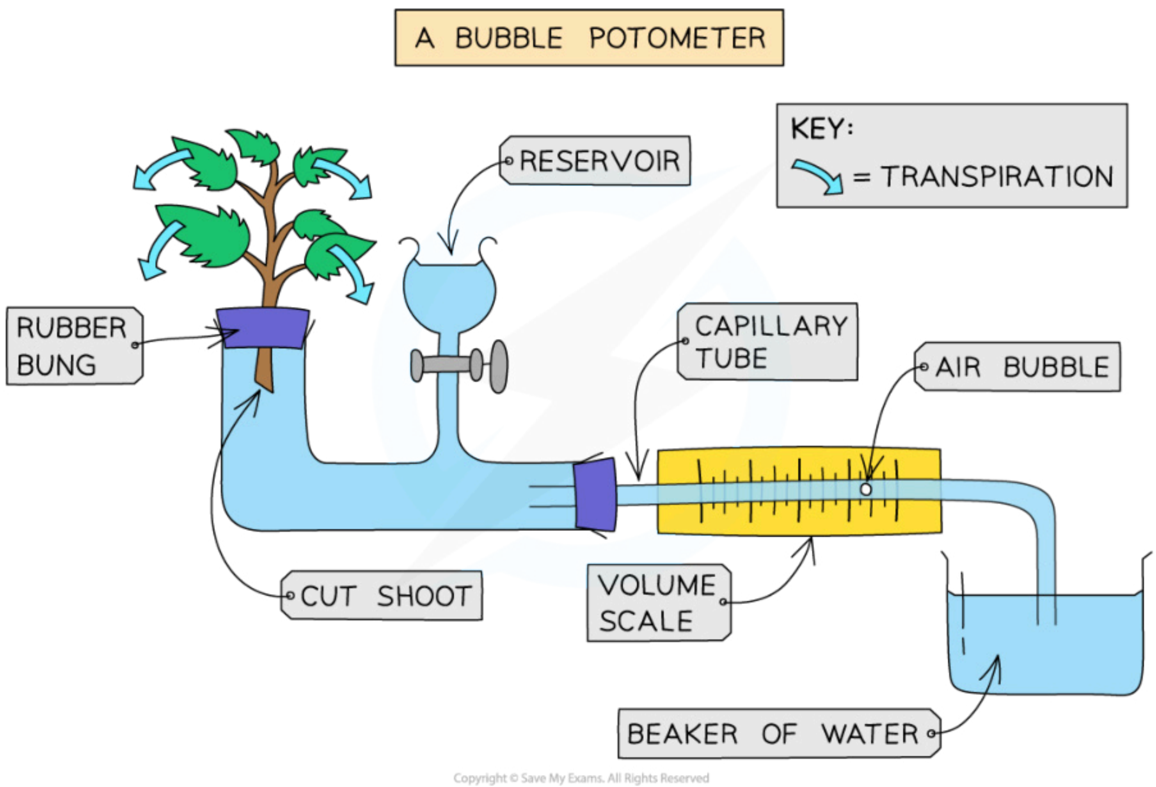
9.1.6 Skills: Experiments Investigating the Rate of Transpiration

Your notes

Practical 7: Potometers & the Rate of Transpiration

- The **effect of environmental factors on the rate of transpiration** in plants can be measured using a piece of equipment called a **potometer**
  - Note that while potometers are used to measure transpiration rates, they **technically measure the rate of water uptake** rather than the rate of transpiration, as a small amount of the water taken up by a plant **will be used in photosynthesis**
    - Because the amount of water used in photosynthesis is so small in relation to the total amount of water that passes through a plant, the **rate of water uptake can reasonably be used to represent the rate of transpiration**
- Different types of potometer exist
  - **Bubble potometers** measure the **movement of an air bubble along a water-filled tube** connected to a plant shoot as water is drawn up by the shoot
    - The position of the air bubble is **recorded at the start of an experiment**, and then a researcher can either measure **how far the bubble moves in a set amount of time**, or **time how long it takes for the bubble to move a certain distance**
  - **Mass potometers** measure the **change in mass of a water-filled test tube** connected to a plant shoot as it loses water over a set amount of time
- The effect of **various environmental factors** on transpiration can be measured by placing the potometer in different conditions e.g.
  - Wind speed
  - Humidity
  - Light intensity
  - Temperature

Your notes



A bubble potometer uses the movement of an air bubble to measure the rate at which water is drawn up by a plant shoot. In this image the air bubble will move to the left along the tube as the plant transpires.

Investigating the effect of light intensity on the rate of transpiration

Apparatus

- Plant shoot
- Cutting board
- Scalpel/scissors
- Paper towels
- Potometer
- Volume scale
- Beaker
- Capillary tube
- Stopwatch
- Vaseline

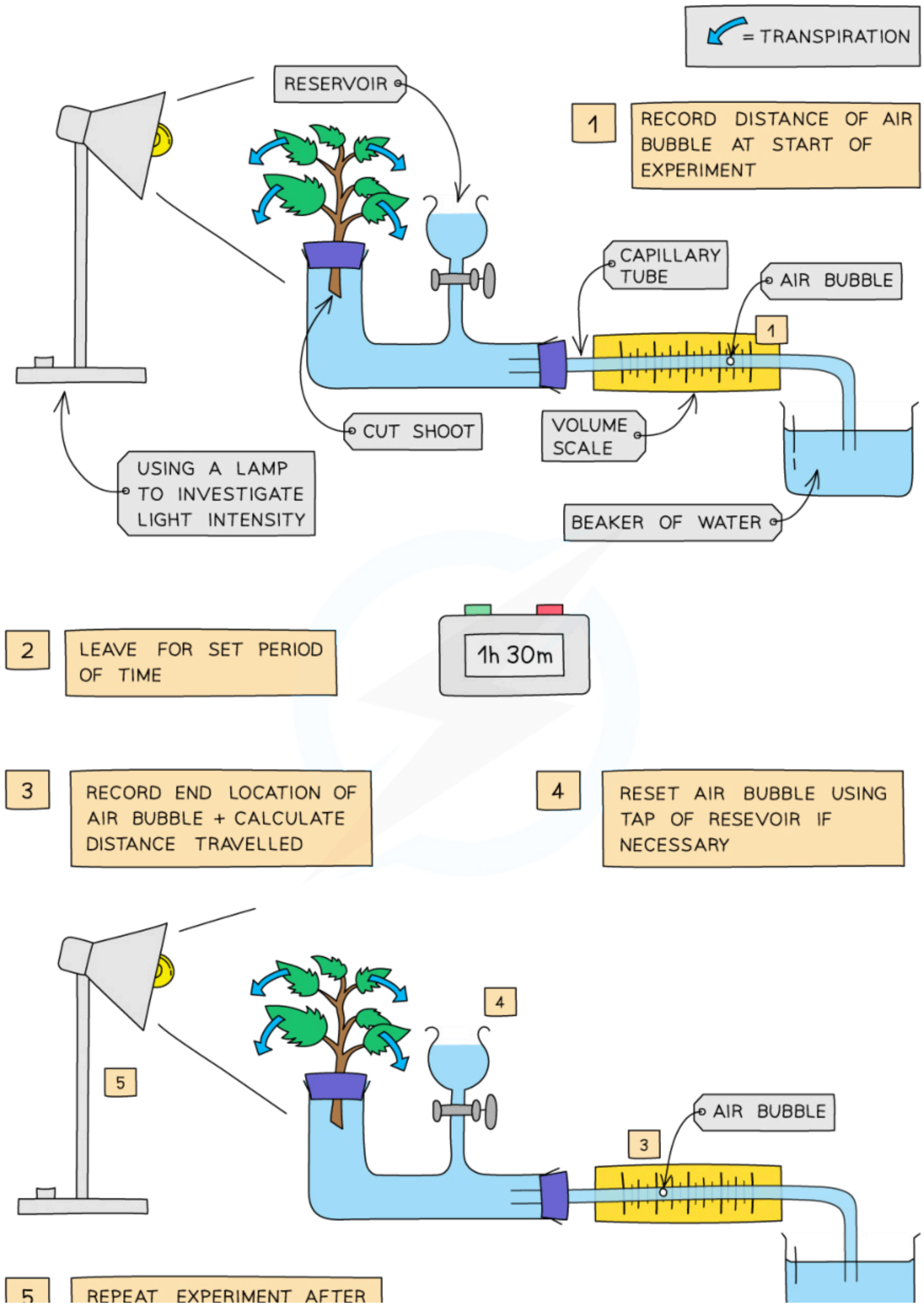
Method

- Cut a shoot **underwater**
  - This is done to **prevent air from entering the xylem**; this could block the movement of water through the plant

- Set up the apparatus **as shown in the diagram**, ensuring that it is **airtight**, and using vaseline to seal any possible gaps
- **Dry the leaves** of the shoot
  - Any water present on the leaves might affect the rate of transpiration as it **could block the stomata**
- Remove the capillary tube from the beaker of water to **allow a single air bubble to form** and then place the tube back into the water
- **Set up a light source** from which the **light intensity can be varied**
  - This could be achieved by varying the light bulbs used or by varying the distance between the light source and the plant shoot
- Allow the plant to adapt to the new environment for 5 minutes
- **Record the starting location** of the air bubble, leave for a **set period of time**, and then **record the end location** of the air bubble
- **Change the light intensity** by a measurable amount e.g. moving the lamp 10cm further away from the plant shoot
- **Reset the bubble** by opening the tap below the reservoir
- **Repeat** the experiment at the new light intensity, and again at a **range of different intensities**

Your notes

Your notes


= TRANSPIRATION
RESERVOIR
1
RECORD DISTANCE OF AIR BUBBLE AT START OF EXPERIMENT
CAPILLARY TUBE
AIR BUBBLE
1
CUT SHOOT
VOLUME SCALE
USING A LAMP TO INVESTIGATE LIGHT INTENSITY
BEAKER OF WATER
2
LEAVE FOR SET PERIOD OF TIME
1h 30m
3
RECORD END LOCATION OF AIR BUBBLE + CALCULATE DISTANCE TRAVELLED
4
RESET AIR BUBBLE USING TAP OF RESEVOIR IF NECESSARY
4
5
AIR BUBBLE
3
5
REPEAT EXPERIMENT AFTER

The effect of light intensity on rate of transpiration can be measured using a potometer

The Effect of Temperature & Humidity on Transpiration Rates

Your notes

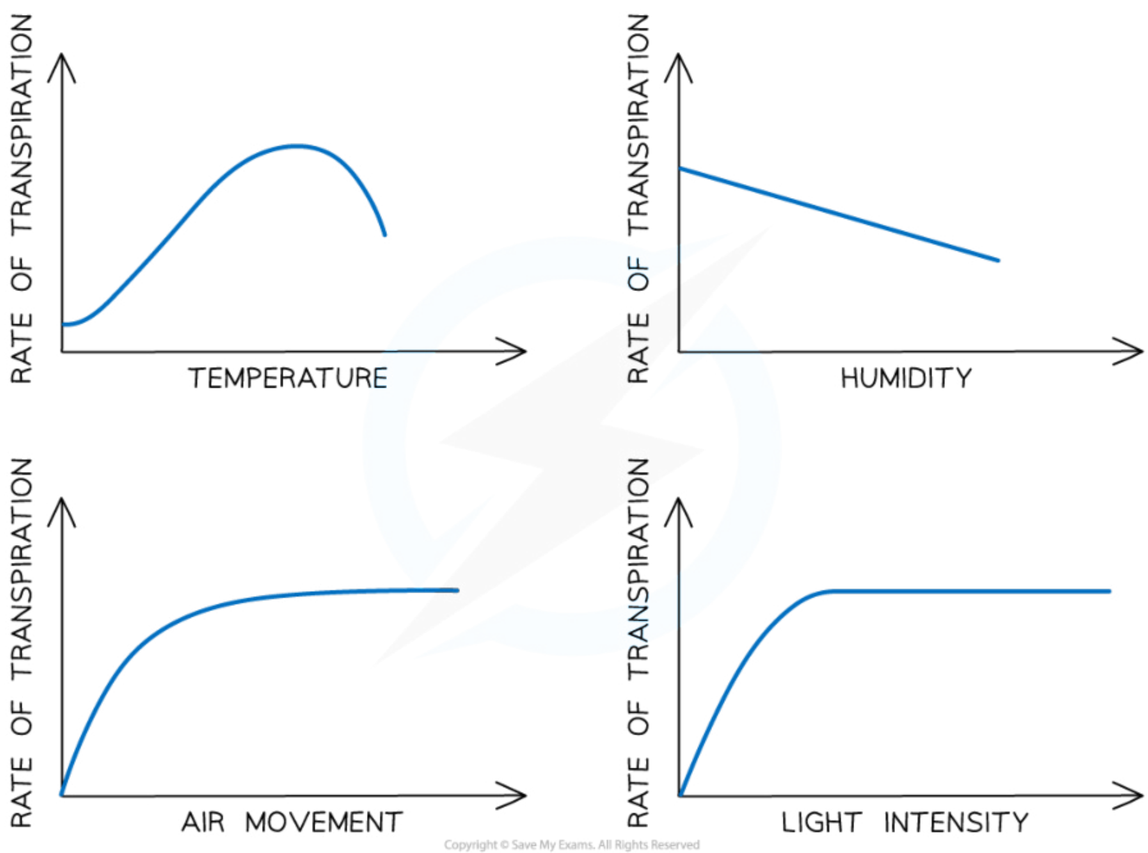
- A potometer can be used to **test hypotheses about the effect of various environmental factors**, including temperature or humidity, on **transpiration rates**
- Environmental factors can be investigated in the following ways
  - Air movement
    - A **fan on different settings** could be used to vary the flow of air around a plant shoot
  - Humidity
    - Enclosing the plant shoot in a **plastic bag** can increase the humidity
    - A **humidifier or dehumidifier** could be used to give a measurable variation in humidiy
  - Light intensity
    - A **lamp at different distances** or with **different types of light bulb** can be used to vary light intensity
  - Temperature
    - A **thermometer or temperature probe** can be used to find surroundings with different air temperatures
    - A **heater or air conditioner** can be used to give a measurable variation in temperature
- A researcher would need to be aware of the importance of **controlling any variables other than the variable of interest** to ensure that any results were valid e.g. placing a plant shoot in different rooms could be a way of varying temperature, but might bring the risk of also varying light levels and humidity; these variables would need to be controlled

Factors affecting the rate of transpiration

- Air movement
  - **More air movement leads to increased rates of transpiration**
    - The air outside a leaf usually contains a **lower concentration of water vapour** than the air spaces inside a leaf, causing water vapour to **diffuse out of the leaf**
    - When the air is relatively still, **water molecules can accumulate** just outside the stomata, creating a **local area of high humidity**
    - **Less water vapour will diffuse out** into the air due to the **reduced concentration gradient**
    - Air currents, or wind, can **carry water molecules away from the leaf surface**, increasing the **concentration gradient** and causing more water vapour to diffuse out
- Temperature
  - **Higher temperatures lead to higher rates of transpiration**, up to a point at which **transpiration rates will slow**
    - An increase in temperature results in an **increase in the kinetic energy** of molecules
    - This increases the rate of transpiration as **water molecules evaporate out of the leaf at a faster rate**
    - If the temperature gets too high the **stomata close to prevent excess water loss**
    - This dramatically **reduces the rate of transpiration**
- Light intensity
  - **Higher light intensities will increase the rate of transpiration** up to a point at which **transpiration rates will level off**
    - **Stomata close in the dark** and their closure greatly reduces the rate of transpiration

Your notes

        - **Stomata open when it is light** to enable gas exchange for photosynthesis; this increases the rate of transpiration
        - Once the stomata are all open any increase in light intensity has no effect on the rate of transpiration
- Humidity
    - **Higher humidity levels reduce the rate of transpiration**
        - If the humidity is high that means the **air surrounding the leaf surface is saturated with water vapour**
        - This causes the rate of transpiration to decrease as there is **no concentration gradient** between the inside of the leaf and the outside
            - At a certain level of humidity, an **equilibrium** is reached; water vapour levels inside and outside the leaf are the same, so there is no net loss of water vapour from the leaves



Several environmental factors affect the rate of transpiration in plants

Examiner Tip

Remember when designing an investigation that you must keep all factors the same other than the one you are investigating. This ensures that you measure the variable that you set out to measure and not the impact of any other variable.