Chapter 9 – Transport in Plants

Subject content

Content

- Water and Ion Uptake
- Transpiration and Translocation

Learning outcomes

(a) identify the positions and explain the functions of xylem vessels, phloem (sieve tube elements and companion cells) in sections of a herbaceous dicotyledonous leaf and stem, using the light microscope

(b) relate the structure and functions of root hairs to their surface area, and to water and ion uptake

(c) explain the movement of water between plant cells, and between them and the environment in terms of water potential (calculations on water potential are not required)

(d) outline the pathway by which water is transported from the roots to the leaves through the xylem vessels

(e) define the term transpiration and explain that transpiration is a consequence of gaseous exchange in plants

(f) describe and explain
- the effects of variation of air movement, temperature, humidity and light intensity on transpiration rate
- how wilting occurs

(g) define the term translocation as the transport of food in the phloem tissue and illustrate the process through translocation studies

Use the knowledge gained in this section in new situations or to solve related problems.

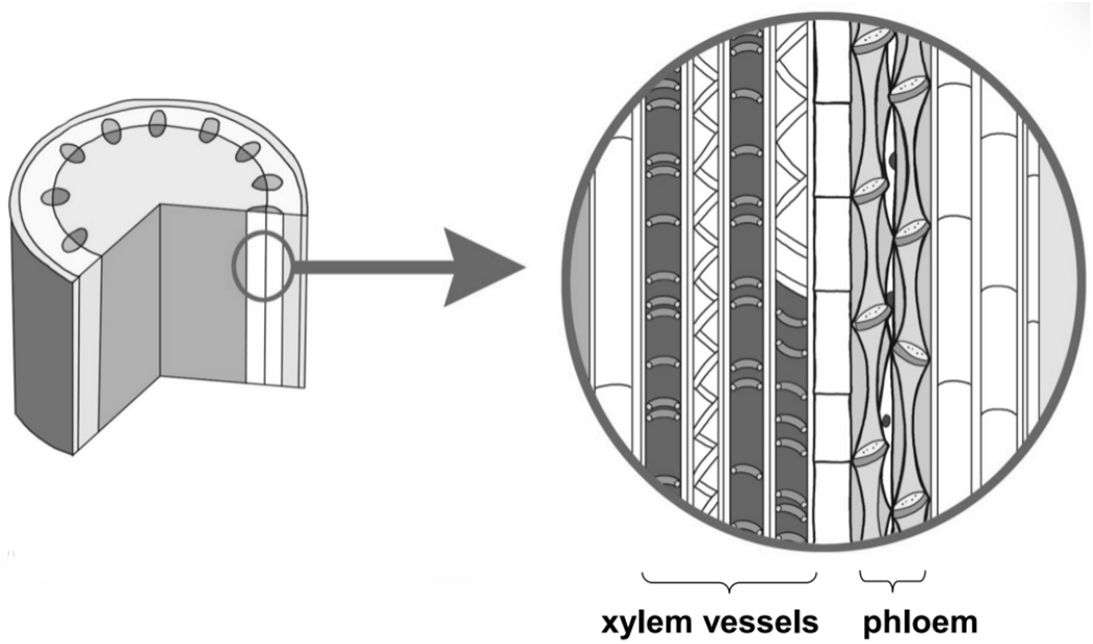
Definition

Phrase	Definition
Translocation	Transport of manufactured food substances (sucrose, amino acids) from leaves to other parts of plant along phloem
Transpiration	Loss of water vapour from aerial parts of plant, mainly through stomata of leaves

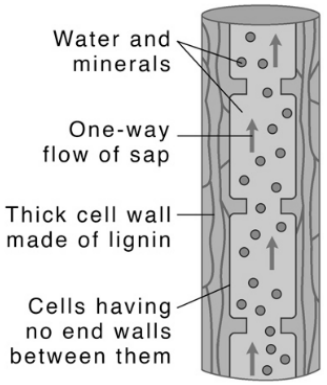
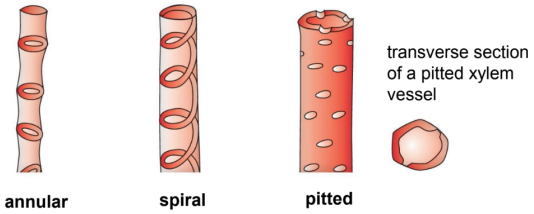
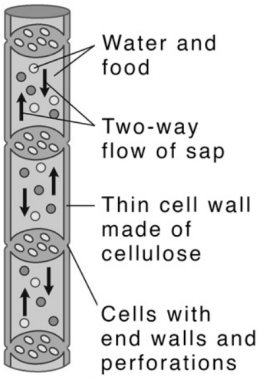
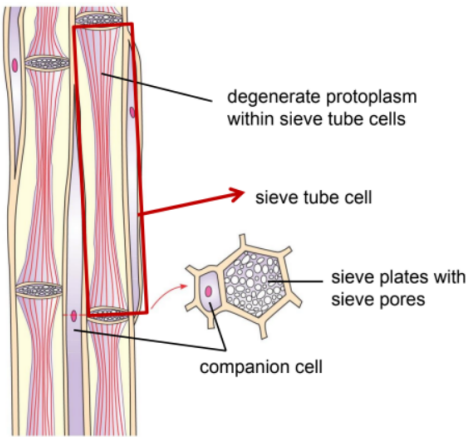
9.1 Transport Structures – Xylem and Phloem

Vascular tissues

- made up of
  1. **Xylem tissues**
  2. **Phloem tissues**
- combine → hollow connected cells (carry fluids throughout plant)



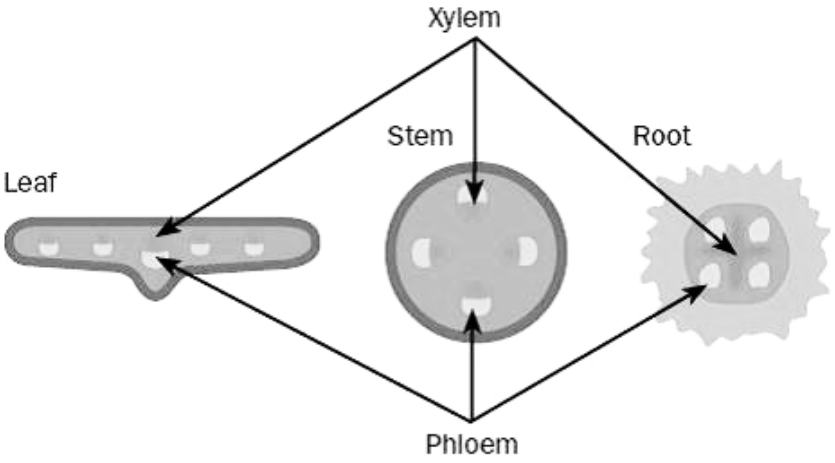
Vascular tissue	Xylem	Phloem
Description	**Xylem vessels** ● made up of: dead tube-like cells joined end to end ● inner walls strengthened by lignin ○ rings ○ spirals ○ pitted walls	**Sieve tube** ● made up of: **sieve tube elements** (living tube-like cells) joined end to end ● **Sieve plates** (cross-walls) ○ end walls of sieve tube elements ○ minute pores: contain thin strands of cytoplasm → allow translocation (flow of manufactured food substances) **Companion cell** ● narrow, thin-walled cell with cytoplasm + nucleus + numerous mitochondria ● support sieve tube elements metabolically → <u>phloem loading</u> (move sugars + amino acids into sieve tube elements via active transport)

Made up of	1. Xylem vessel	1. Sieve tube ● sieve tube elements ● sieve plates 2. Companion cell
Adaptation	Xylem vessel 1. Hollow, continuous lumen without protoplasm or cross-walls ● allow unobstructed passage ● reduce resistance to flow of water + dissolved mineral salts 2. Lignified cell walls ● provide mechanical support ● prevent collapse of vessel	Sieve tube element 1. Minute pores on sieve plates ● allow rapid transport of manufactured food substances 2. Continuous column with very little protoplasm and ● allow unobstructed passage ● reduce resistance to flow of sucrose + amino acids Companion cell 1. Numerous mitochondria ● release large amt of energy ● load sucrose from mesophyll cells into sieve tubes by active transport
Figure	 	 

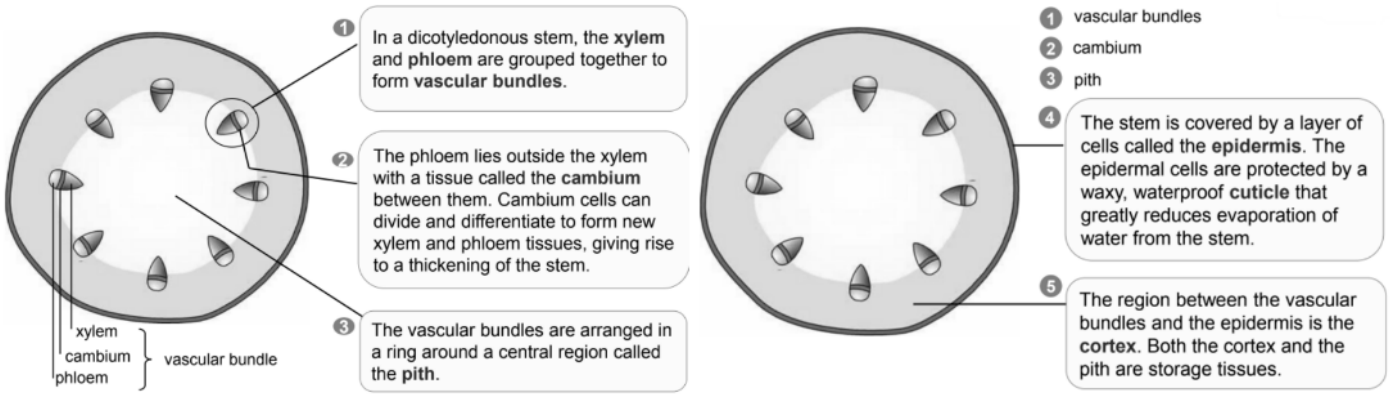
Structural comparison

Aspect	Xylem	Phloem
Type of cells	xylem cells	sieve tube elements and companion cells
Protoplasm	no (hollow)	little (in sieve tube)
Mitochondria	absent	abundant (in companion cell)
Lignified cell walls	✔	✘
Cross walls	no	sieve plates b/w sieve tube elements

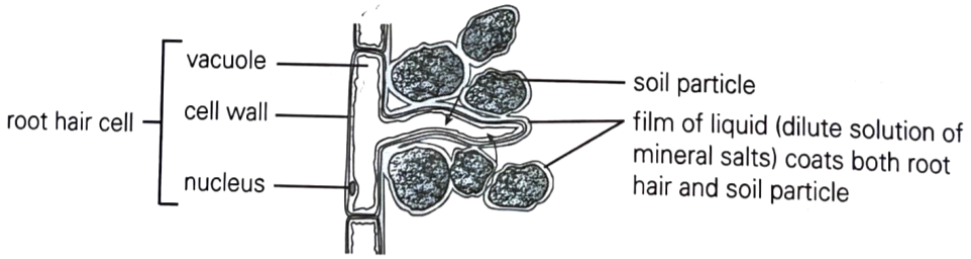
<u>Vascular tissues</u> (dicotyledonous)



Stem:

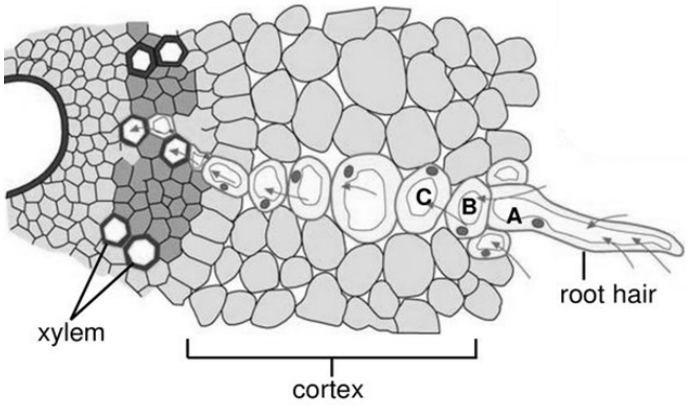


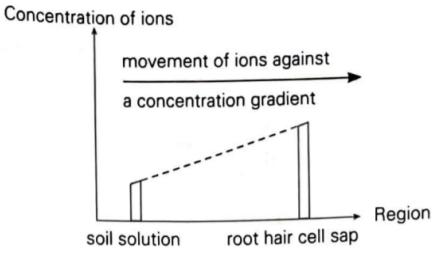
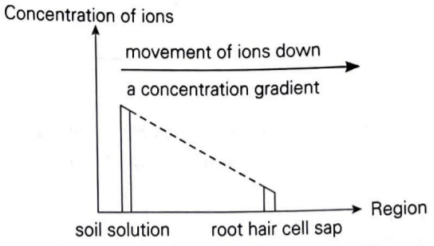
9.2 Movement of Substances into a Plant (Roots)



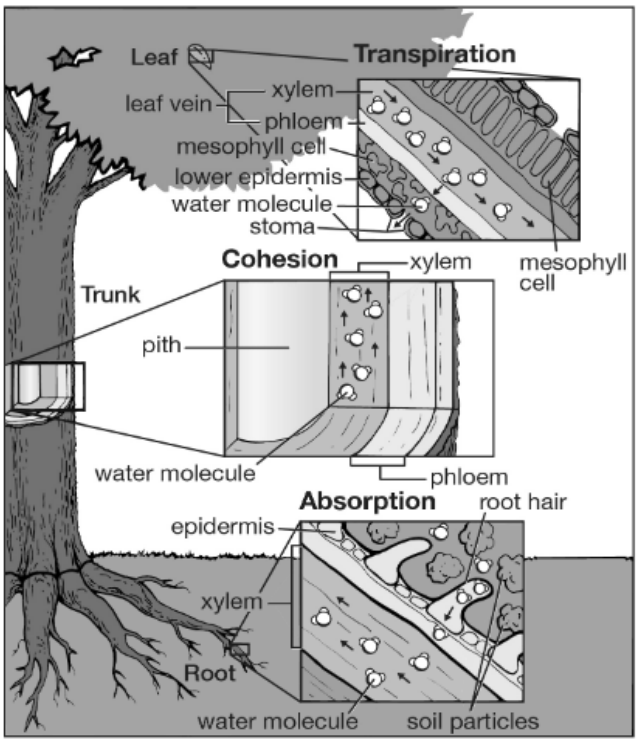
Adaptations of root hair cell

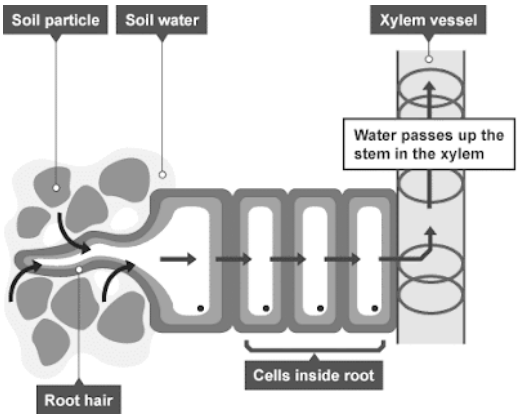
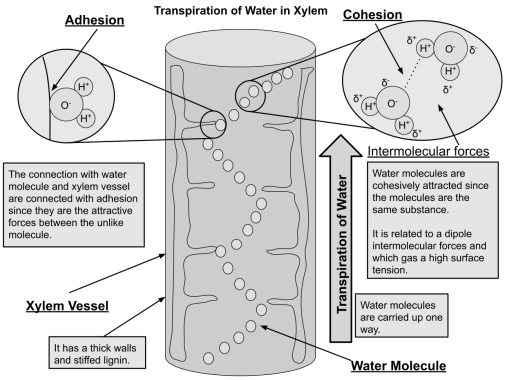
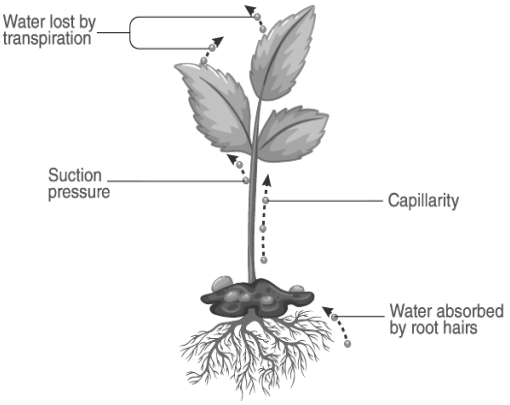
Adaptation	Explanation
1. **Long narrow outgrowth**	● increase SA:V ● increase rate of absorption of water + dissolved mineral salts
2. **Numerous mitochondria**	● release large amt of energy ● increase rate of active transport of water + dissolved mineral salts
3. **Presence of cell membrane**	● prevent leakage of cell sap ● allow water mol enter cell by osmosis down water potential gradient
4. **Cell sap contain sugar, amino acids and mineral salts**	● water potential lower than soil solution ● water molecules enter by osmosis



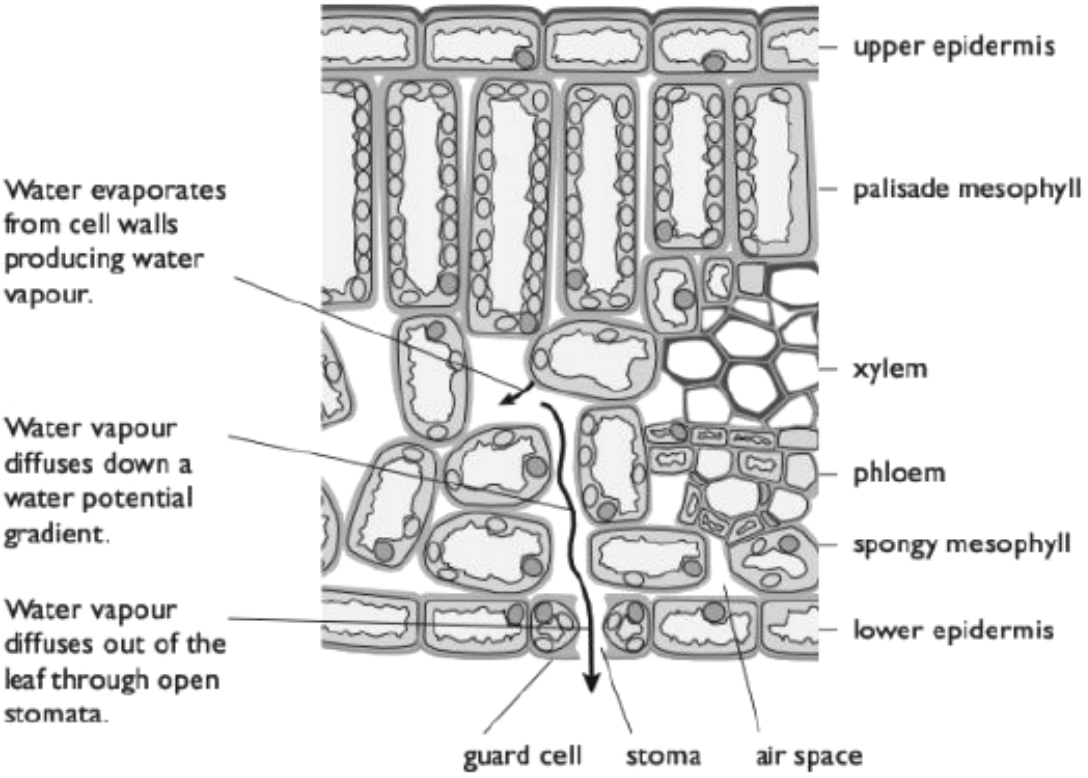
① Water	② Ions + mineral salts	
osmosis	**active transport**	**diffusion**
Wp: soil sol > RHC sap ● enter RHC ● dilute RHC sap Wp: RHC sap > neighbouring cell ● enter neighbouring cell ● cell-to-cell movement in cortex → xylem	Conc of ions: soil sol < RHC sap ● against conc gradient ● cellular respiration in root hair cell → release energy 	Conc of ions: soil sol > RHC sap ● down conc gradient 

9.3 Movement of Water Up Plant (Stem)



Mechanism	Process	Figure
1. **Root pressure**	1) Cells continuously pump ions → xylem vessels [active transport] 2) Wp: xylem vessel < surrounding cells 3) Water mol: cell → xylem vessel [osmosis] → flow upwards Max height: 20 m	
2. **Capillary action**	Spontaneous movement of water along narrow tubes 1) **cohesion**: force of attraction b/w water mol 2) **adhesion**: force of attraction b/w water mol & inner surface of capillary tube Max height: 3 m	
3. **Transpiration pull** (main)	Transpiration stream: continuous column of water moving up xylem due to transpiration pull 1) Water mol evaporate from stomata 2) Transpiration lower wp of mesophyll cells → water move from xylem vessel into mesophyll cell 3) Water removed from xylem vessel → **<u>suction force</u>** → pull water up xylem 4) Water move up: ● cohesion: water column X break apart ● adhesion: water column X slip back down	

9.4 Transpiration



Process of transpiration

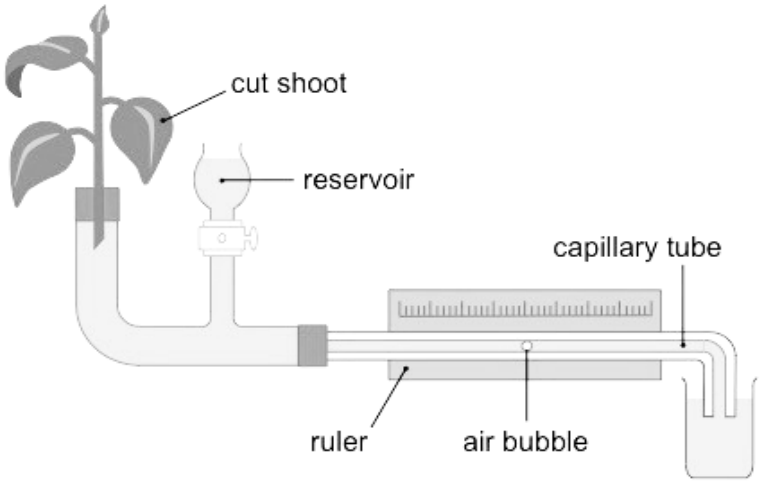
1. Water mol <u>move out</u> of mesophyll cells + form <u>thin film of moisture</u> over cell surface
2. Water from thin film of moisture <u>evaporate</u> → water vapour in intercellular air spaces
3. Water vapour <u>accumulate</u> in air spaces near stomata
4. Water vapour <u>diffuse out</u> of stomata → atmospheric air

5. Water <u>move out</u> of mesophyll cells to replace thin film of moisture that has evaporated → decreases wp of cell sap → <u>mesophyll cells absorb water</u> from cells deeper in leaf [osmosis]
6. In turn, these <u>cells absorb water</u> from xylem vessels
7. Result: **<u>suction force</u>** produced → pull water column up xylem vessels

Importance

1. Transpiration pull: major suction force to <u>draw water + dissolved mineral salts</u> up xylem
2. <u>Water</u> transported to leaves:
   1) raw material for photosynthesis
   2) replace water lost by cells
   3) maintain turgidity → keep leaves spread out widely to absorb sunlight for photosynthesis
3. Evaporation of water: remove latent heat of vapourisation → <u>cool</u> plant, X scorched by hot sun

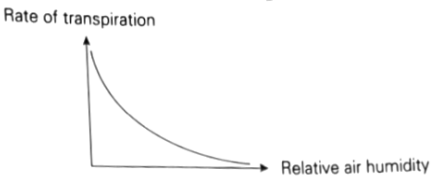
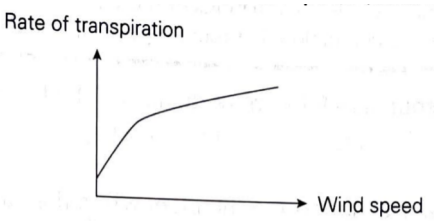
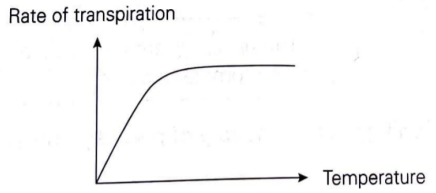
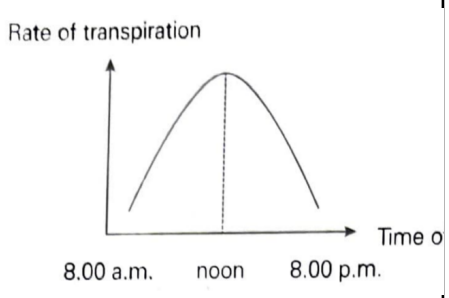
Potometer: measure rate of transpiration



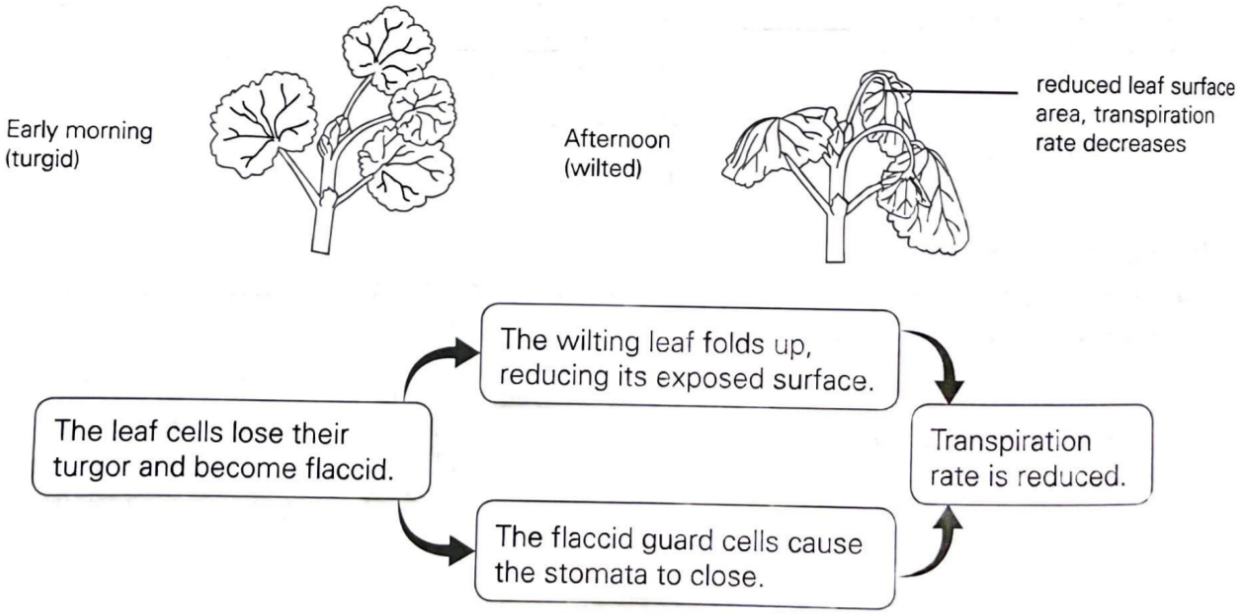
Procedure	1. Prepare shoot: cut leafy shoot under water 2. Insert shoot through hole in cork 3. Smear vaseline / petroleum around region of shoot that passes through cork → make apparatus airtight 4. Open tap of reservoir + fill graduated capillary tube with water 5. Close tap when tube is full 6. Note reading of water column at B + record time taken for water column to move from A to B
Observation	Water column in capillary tube moves towards shoot
Explanation	● Shoot transpire → absorb water from potometer to replace that which is lost during transpiration ● Rate of movement of water column = rate of water absorption ● Assume rate of water absorption is proportional to rate of transpiration

Factors affecting rate of transpiration

Factors

Factor	Explanation	Graph
1. **Air humidity**	● Atmospheric humidity increase ● Water vapour conc gradient decrease	
2. **Wind / air movement**	● Water vapour diffuse out of leaf, accumulate in layer around leaf → increase air humidity around leaf → rate decrease ● Wind blow away layer of water vapour around leaf → water vapour conc gradient increase	
3. **Air temperature**	● High temp → rate increase until reach max ● Relative air humidity surrounding leaf decrease → water vapour conc gradient increase	
4. **Light**	Light stimulates stomata to open ● light → stomata open → rate increases ● darkness → stomata close → rate decreases	

Wilting

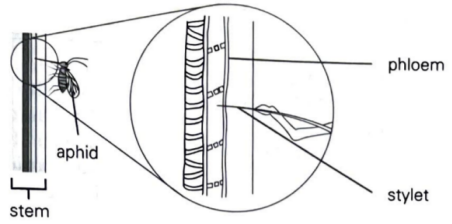
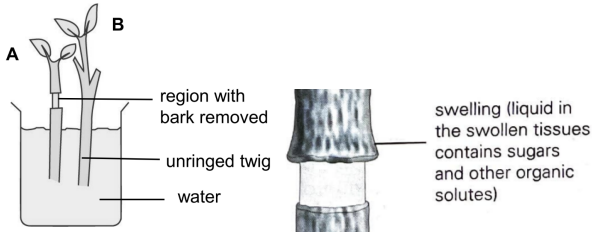
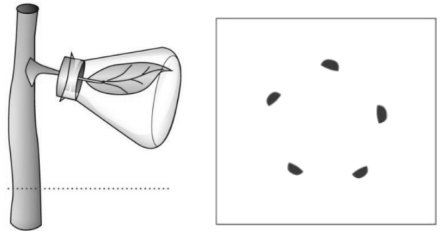


Process

- Strong sunlight: rate of transpiration > absorption
- Cells lose turgor
- Excessive loss of water from plant cells → lose turgor → becomes flaccid, shrink, curl up

Advantages	Disadvantages
Reduce rate of transpiration	Reduce rate of photosynthesis
1. Leaf fold & droop → SA exposed to sunlight reduced → reduce rate of transpiration 2. Guard cells flaccid → stomata close → prevent excessive water loss	1. Leaf fold & droop → SA exposed to sunlight reduced → reduce rate of photosynthesis 2. Guard cells flaccid → stomata close → decrease intake of CO_2 → reduce rate of photosynthesis

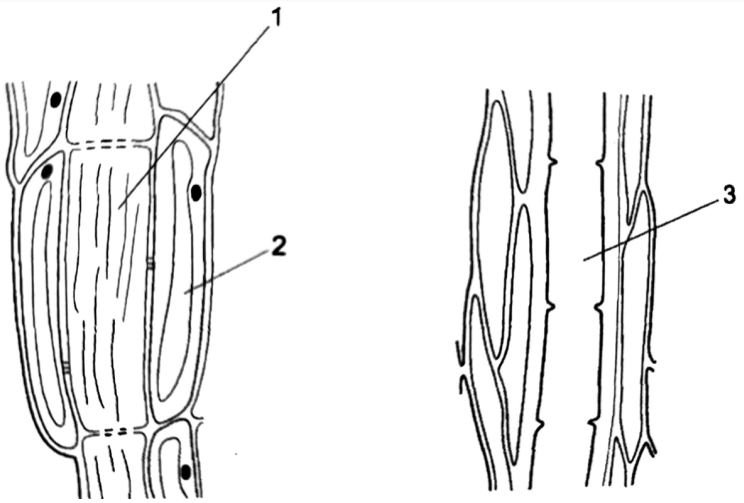
7.5 Translocation Studies

Experiment	Procedure	Explanation	Figure
1. **Alpha feeding**	1) Anaesthetise aphid with CO_2 while feeding on stem (enable the body of the aphid to be cut off while the aphid is feeding. This ensures that the proboscis remains in phloem sieve tube) 2) Cut off body + proboscis remain in tissue 3) Analyse liquid that exudes from cut end of proboscis (3 food tests) → contain sucrose + amino acids 4) Section portion of stem that contains proboscis + examine under microscope (determine which tissue the proboscis was inserted into)	• Aphid pierce into stem with stylet → feed on sap within phloem sieve tubes	
2. **Ringing experiment**	1) Cut off complete ring of bark from stem of woody twig A (ring is above water level) 2) Set up <u>control</u> using unringed twig B 3) Ensure that bottom end of both twigs are in contact with water 4) Observe the twigs daily	• Remove phloem: prevent translocation of sugars • Accumulation of sugars lower wp of cells → water mol enter → swelling	
3. **Carbon-14 radioactive testing**	1) Supply radioactive carbon-14 (^{14}C) to intact leaf enclosed in sealed chamber 2) Allow photosynthesis to take place 3) Cut section of stem + expose onto X-ray photographic film	• Radioactivity detected in phloem • Sugars formed contain radioactive carbon	

Typical questions

Multiple choice questions

1 The diagrams represent some plant cells seen in a section of a stem.



Which cells have the functions shown? (N2011/P1/Q11)

	1	2	3
A	support of young stems	transport of water	transport of sucrose
B	transport of amino acids	supply of energy to surrounding cells	transport of minerals
C	transport of sucrose	transport of water	transport of amino acids
D	transport of water	supply of energy to surrounding cells	support of young stem

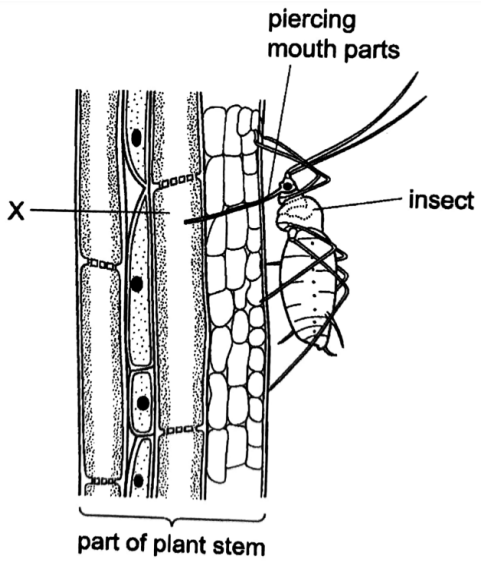
2 Which process contributes **most** to the rise of water in the xylem? (N2011/P1/Q13)

A capillary
B osmosis
C root pressure
D transpiration

3 Where does most transpiration in a plant take place? (N2012/P1/Q11)

A cuticle
B mesophyll cells
C stomata
D xylem vessels

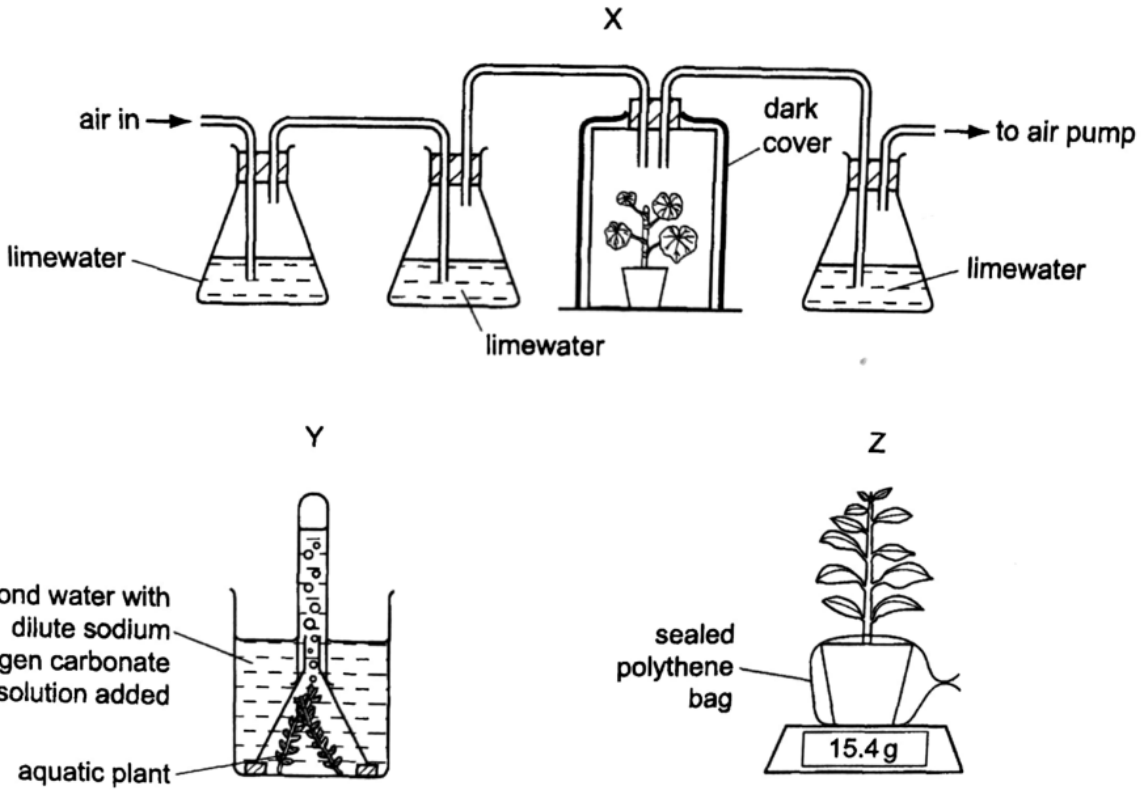
4 Some insects use piercing mouthparts to obtain sugars from plants.
The diagram shows an insect feeding on a plant stem.



What is structure X? (N2012/P1/Q12)

A companion cell
B mesophyll cell
C sieve tube element
D xylem vessel

5 The diagrams show simple experiments used to demonstrate the processes of photosynthesis, respiration and transpiration in plants. All were carried out in the light.



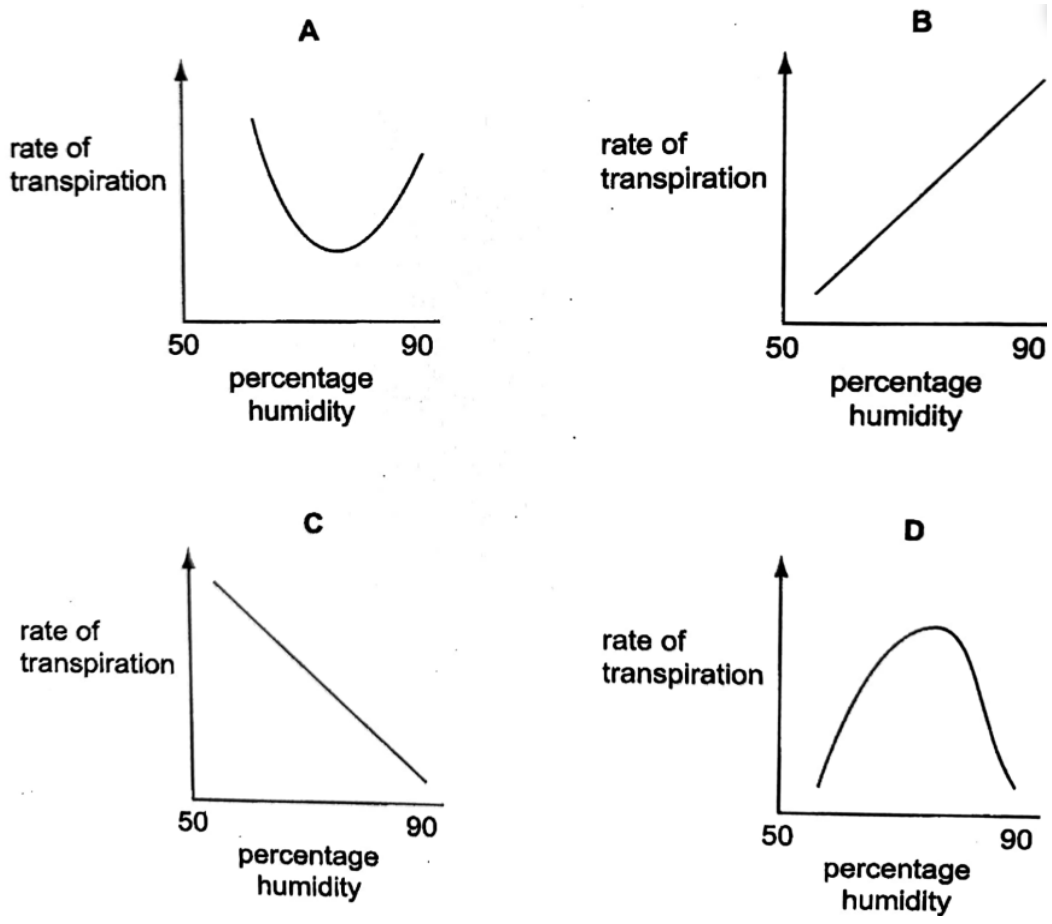
Which experiment is used to demonstrate each process? (N2012/P1/Q13)

	photosynthesis	respiration	transpiration
A	X	Z	Y
B	Y	X	Z
C	Y	Z	X
D	Z	Y	X

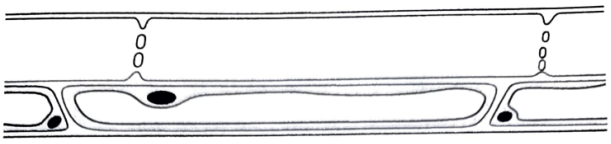
6 When young leaves are being formed on a plant, large quantities of mineral ions are needed. Where and when is the movement of mineral ions in the plant the greatest?
(N2013/P1/Q12 / N2014/P1/Q11)

A companion cells on a hot sunny day
B root hair cells on a cool cloudy day
C sieve tube elements during a warm night
D xylem vessels on a warm sunny day

7 Which graph shows the effect humidity on the rate of transpiration of a well-watered plant?
(N2014/P1/Q12)

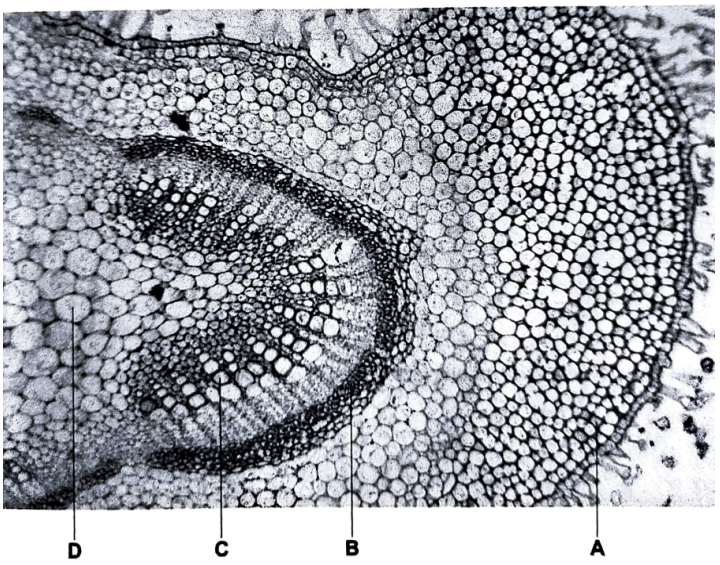


8 The diagram below shows some components of a plant stem in longitudinal section.



The diagram below shows a photomicrograph of part of a plant stem in transverse section.
Which part of the diagram contains the components shown in the diagram above?

(N2015/P1/Q11)



9 Transpiration enables water to reach the top of trees.
Which of these statements correctly describes part of this process? (N2015/P1/Q13)

1. Water evaporates into the air spaces between the palisade cells.
2. Water molecules are pulled upwards in the xylem.
3. Water molecules are pulled upwards in the phloem.
4. Water vapour diffuses through the spongy mesophyll cells.

A 1 and 2
B 2 and 3
C 2 only
D 3 and 4

10 Mature xylem vessels have no cell contents and no cross walls.
Which function do these features allow? (N2019/P1/Q1)

A absorb water from the soil
B conduct water from root to leaf
C support the stem and the leaves
D transport sugars around a plant

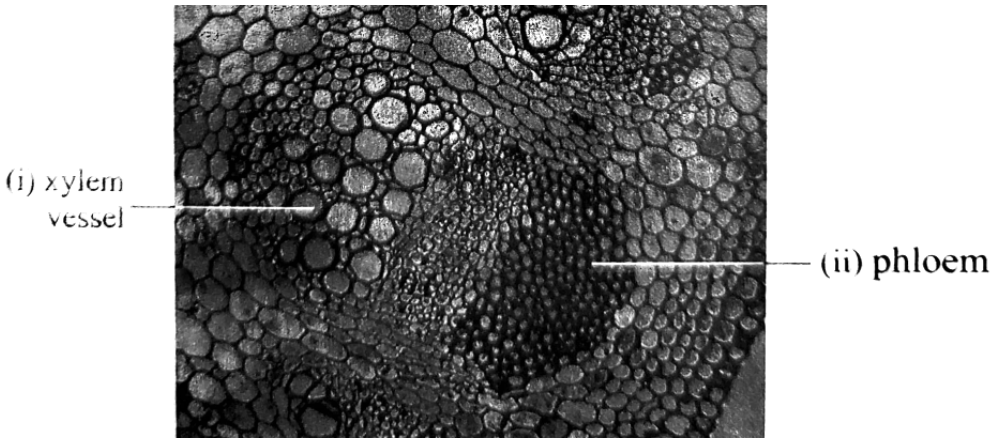
Structured questions

1 (N2013/P2/A2)

(a) Define the term translocation. [2]

Transport of food substances, such as sugars and amino acids synthesised by plants, in the phloem of plants.

(b) The figure below shows a transverse section of part of the stem of *Helianthus annuus*.



Use label lines and labels to identify the position on the figure above of:

(i) a xylem vessel [1]

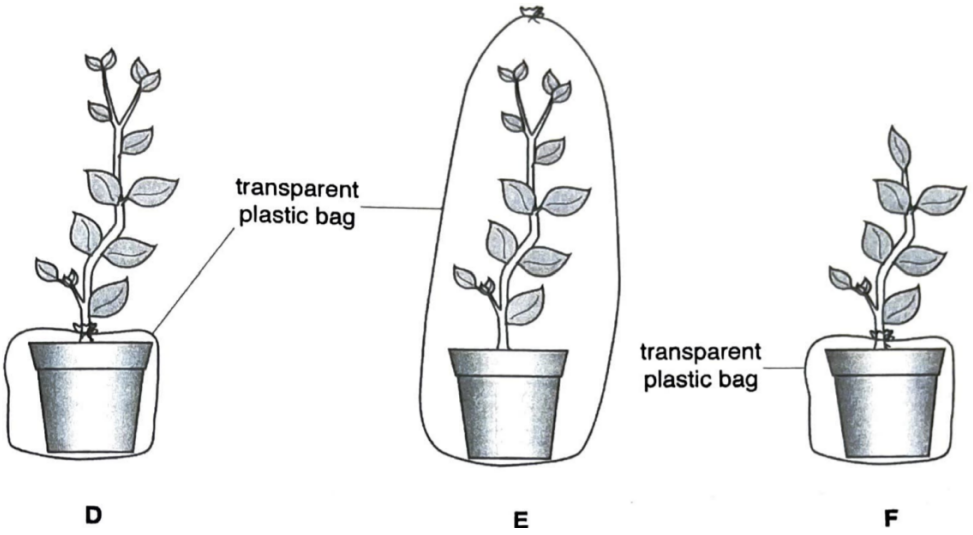
(ii) the phloem [1]

(c) Some weedkillers stop the plant from photosynthesising. These are applied to the soil where the weeds are growing. Explain how the weedkiller reaches its site of action in the leaves. [4]

- The weedkiller dissolves in the water found in the soil.
- The root hair cells of the plant absorb water and the dissolved weedkiller by osmosis and diffusion respectively.
- The water and dissolved weedkiller move down the concentration gradient into neighbouring cells and finally into the xylem vessel in the roots.
- The xylem vessel conducts the water and dissolved weedkiller up the stem of the plant to the leaves.
- The dissolved weedkiller moves out of the xylem vessel and enters the leaf cells.
- In the leaf cells, it exerts its effects and stops the plant from photosynthesising.

2 The figure below shows three plants, **D**, **E** and **F**, growing in pots. Each plant was treated in the following way:

- an equal volume of water was given to each plant
- plastic bags were placed around the pots of plants **D** and **F**
- the whole of plant **E** was enclosed within a plastic bag
- each plant was placed in a sunny position by a window.



The loss in mass of each plant was calculated each day for a period of 10 days.

(N2017/P2/A4)

(a) Describe the procedure that should be followed to enable the loss of mass each day to be calculated. [2]

- At the start of the experiment, measure the mass of each pot of plant.
- At the end of each day, measure the mass of each pot of plant again.
- To calculate the loss of mass each day, find the difference in the mass of each pot of plant from the previous day.

(b) Name the process responsible for any loss of mass by the plants. [1]

Transpiration

(c) Suggest which plant would lose the most mass over the 10-day period. Give a reason for your answer. [2]

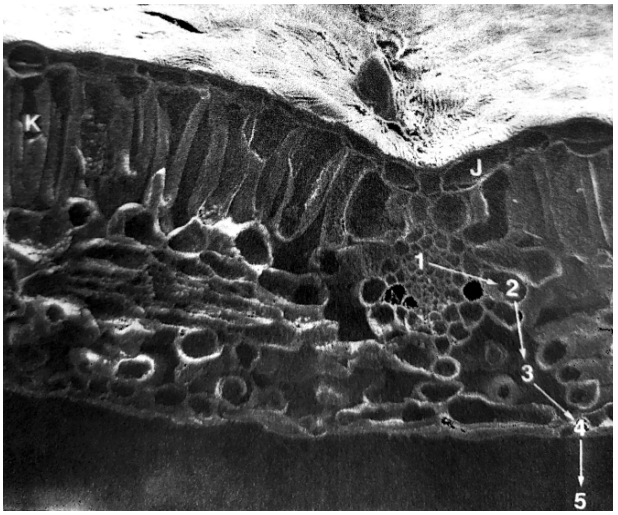
Plant D loses the most mass.

- Plant D has more leaves than plant F, so plant D loses more water through the stomata found on its leaves than plant F.
- Plant E is enclosed within a plastic bag. Plant D loses more water than plant D because the air surrounding plant D is less humid.

(d) Suggest why the pots of plants **D** and **F** were enclosed in plastic bags. [1]

This prevents water in the soil solution from evaporating into the atmosphere, ensuring that the loss of mass in the plants is only due to transpiration and not due to evaporation of water from the soil into the atmosphere.

3 The figure below is a photomicrograph showing a cross-section of part of a dicotyledonous leaf.



Explain how water moves in the leaf from 1 to 5 in the figure above. [5]
(N2019/P2/A3a)

- The water potential in the xylem vessel is higher than the mesophyll cell adjacent to the xylem vessel. Water molecules move from the xylem vessel into the adjacent mesophyll cell via osmosis, through the partially permeable cell surface membrane.
- Water molecules then move into adjacent spongy mesophyll cells down a water potential gradient via osmosis (1 to 2).
- Some of the water moves out of the spongy mesophyll cells to form a thin film of moisture over the cell surface. The water evaporates from this thin film of moisture to form water vapour and moves into the intercellular air spaces near the stomata (2 to 3).
- Water vapour then diffuses out of the intercellular air space via the stomata to the surroundings (3 to 5).

4 Describe the process of transpiration. [4]

(N2013/P2/B10 OR)

- In the mesophyll layer of the leaf, water from the mesophyll cells forms a thin film of moisture over the cell surfaces. Water evaporates from this film of moisture into the intercellular air spaces.
- Water vapour accumulates in the air spaces near stomata. The humidity of the air outside the lead is lower than that inside the leaf. This creates a steep water vapour concentration gradient between the leaf and the atmosphere. Therefore, water vapour diffuses from the air spaces through the stomata to the air outside the leaf.
- As water vapour moves out of the leaf, this decreases water potential in the cell sap of mesophyll cells of the leaf. Mesophyll cells absorb water from neighbouring cells again via oxmosis. Water constantly moves from xylem vessels into mesophyll cells, then evaporates and diffuses out of the leaf.
- More water evaporates to replace the loss of water vapour in the leaf. This creates a suction force known as transpirational pull which draws water up the xylem vessels in the stems and roots.

5 (N2015/P2/B10 EITHER)

(a) Describe the similarities and differences in the function of xylem tissue and phloem tissue. [6]

<table>
<tr><th>Xylem tissue</th><th>Phloem tissue</th></tr>
<tr><td colspan="2">● Consist of tubes that run through the whole plant.
● Part of the plant transport system
● Transport useful substances to all parts of the plant.</td></tr>
<tr><td>● Transport water and dissolved mineral salts from roots to other parts of plant
● Transpiration of water occurs
● Cells are dead when matured, form a continuous, hollow tube that conducts water and mineral salts
● Cells have thick lignified cell walls that prevent cells from collapsing, prodvide strength and support the plant</td><td>● Transport manufactured food products (sugars, amino acids) from leaves to other parts of plant
● Translocation of food substances occurs
● Consist of sieve tube cells and companion cells.
○ Sieve tube cells transport amino acids and sucrose; companion cells supply energy to surrounding sieve tube cells.</td></tr>
</table>

	○ Companion cells load sugars into sieve tubes by active transport. Active transport requires energy which is provided by aerobic respiration in companion cells. Companion cells have many mitochondria that carry out respiration.

(b) Explain how environmental factors affect transpiration. [4]

Factor	Explanation
1. **Air humidity**	● When environment is less humid, there is little water vapour in the air. Water vapour concentration gradient between stomata and atmosphere becomes steeper. ● Water vapour diffuses out of leaves through stomata at a faster rate. ● Therefore, transpiration rate increases.
2. **Air movement**	● When it is windy, water vapour near surface of leaves is blown away, air becomes drier. ● Water vapour diffuses out of leaves through stomata at a faster rate. ● Therefore, transpiration rate increases.
3. **Air temperature**	● When temperature of surrounding air increases, higher temperature causes water in cells to have more energy and evaporate faster. ● Water vapour diffuses out of leaves through stomata at a faster rate. ● Therefore, transpiration rate increases.
4. **Light intensity**	● When light intensity is high, stomata open wider. ● More water vapour diffuses out of leaves through stomata at a faster rate. ● Therefore, transpiration rate increases.