Unit 2 · Water Relations

STUDY NOTES

WHAT NEB'S GRADE 12 EXAM ASKS

- **CDC's grid (2078):** Plant Physiology (Units 2–6 together): 11 of 75 marks; 3 MCQs (knowledge, application, higher ability) and 1 long question (8 marks: knowledge 1, understanding 3, application 2, higher ability 2); no short question by the plan
- **The paper:** Botany 37 + Zoology 38; each part: MCQs × 1 (5 Botany, 6 Zoology) · 4 short × 4 · 2 long × 8; one OR in each short and long group; 3 hours; 1 mark per expected point
- **CDC's model paper:** MCQ: what fills the space between wall and protoplast in a plasmolyzed cell (the hypertonic solution)
- **MCQ (1 mark)**
  - cause and medium of diffusion; its direction
  - a semipermeable membrane; when endosmosis happens
  - exosmosis → flaccid; pickles and jam (plasmolysis)
  - imbibition: wood, swelling
  - tracheary elements; main cause of ascent of sap
  - stomatal transpiration; guttation: *Colocasia*, hydathode
- **Short and long (in parts)**
  - a dye spreading: name the process, its cause, the medium, warmer water
  - osmosis: definition, conditions, significance; non-living things
  - endosmosis and its effect; plasmolysis steps from a figure; significance
  - ascent of sap: definition, three points; the eosin balsam twig
  - transpiration: types, role of stomata, diffusion and osmosis in it
  - light and temperature; advantages and disadvantages; all factors (1 + 7)
  - transpiration vs guttation

Key terms

Plant physiology: how plants work: growth, reproduction, metabolism, defense; **Stephen Hales**, father of plant physiology.

Diffusion: net movement of particles from **higher to lower concentration**, by their own kinetic energy, until even.

Diffusant: the diffusion **medium**; **diffusate**: the diffusing particles (biology's usage).

Diffusion pressure (DP): the tendency of particles to diffuse; $\propto$ their concentration.

Osmosis: movement of **water** through a **semipermeable membrane** from a dilute to a concentrated solution.

Semipermeable membrane: lets water through, not larger solutes; cell membranes are **selectively permeable**.

Hypotonic: more water (less solute); **hypertonic**: less water; **isotonic**: equal.

Osmotic pressure (OP): pressure needed on a solution to **stop** water entering it through a semipermeable membrane.

Turgor pressure (TP): outward push of the protoplast on the wall; **wall pressure (WP)**: equal, inward; TP = WP.

DPD (suction pressure): DPD = OP − TP; **Renner** (1915) suction pressure; **Meyer** (1938) DPD.

Imbibition: hydrophilic solids take in water and **swell**, no solution formed; **imbibant** (solid), **imbibate** (liquid).

Plasmolysis: protoplast shrinks from the wall by exosmosis; **deplasmolysis**: recovers in water.

Ascent of sap: upward movement of water and minerals from roots to leaves, against gravity, in xylem.

Transpiration: loss of water as **vapor** from aerial parts of a living plant.

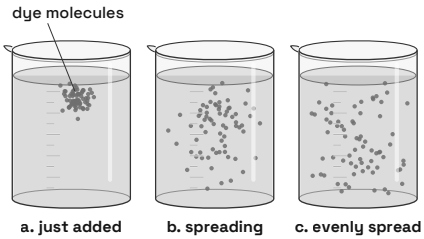
Guttation: loss of **liquid** water drops through **hydathodes**, pushed by root pressure.

Diffusion

- passive: no ATP; energy = particles' kinetic energy
- faster when warmer; fastest in gases, slowest in solids
- light particles faster: H_2 3–4 × faster than O_2 in air
- net movement down the **concentration gradient**; steeper gradient → faster

Significance

- ions spread through protoplasm
- some minerals absorbed passively
- scent of flowers → insects, cross-pollination
- water vapor out, CO_2 in, O_2 out through stomata
- short-distance movement in all cells; translocation of solutes
- osmosis is a special kind of diffusion



A dye spreading in water: diffusion.

Osmosis

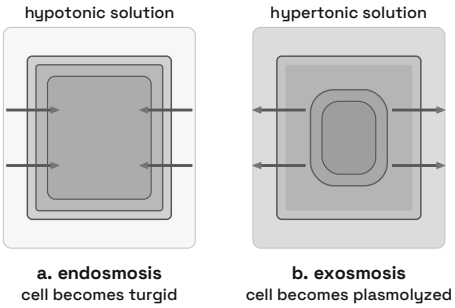
- **conditions**: two solutions of **different concentration**; separated by a **semipermeable membrane**
- dead cell: membranes not selective → **no osmosis** (boiled potato)
- plant cell: wall (fully permeable), cytoplasm with plasma membrane, vacuole with **tonoplast**; the two membranes act as one
- OP ∝ concentration; pure water OP = 0; cell sap 5–20 atm; units atm, bar, MPa (1 MPa = 10 bar)
- osmotic egg: shell dissolved in vinegar; in water swells (endosmosis), in sugar shrinks (exosmosis)

$DPD = OP - TP$	DPD (suction pressure), OP osmotic, TP turgor pressure (atm) **Use:** water moves from **lower DPD to higher DPD**
$DPD = OP - WP$	WP wall pressure = TP **Use:** the same
$TP = OP \Rightarrow DPD = 0$	fully turgid **Use:** takes in no more water
$TP = 0 \Rightarrow DPD = OP$	plasmolyzed (from incipient plasmolysis) **Use:** loses water until its OP = the solution's OP

- cell A: OP 12, TP 4 → DPD 8; cell B: OP 10, TP 7 → DPD 3 ∴ water B → A
- cell DPD 8 atm in solution OP 10 atm (a free solution's DPD = its OP) → cell loses water

Endosmosis: cell in **hypotonic** solution (water) → water in → **turgid**; OP falls a little, TP rises until TP = OP, DPD = 0

Exosmosis: cell in **hypertonic** solution → water out → **flaccid** → plasmolyzed



Endosmosis and exosmosis.

Significance

- roots absorb water (root-hair sap more concentrated)
- water passes cell to cell, towards higher DPD
- turgidity keeps soft parts firm; loss → **wilting**
- stomata open and close
- dehiscence of anthers, sporangia, fruits; touch-me-not's leaves droop
- radicle and plumule push out
- salt and sugar preserve food

Potato osmometer (Practical 3)

- raw potato cup with sugar solution, in water → level rises
- boiled potato (control) → no change: osmosis needs **living** membranes

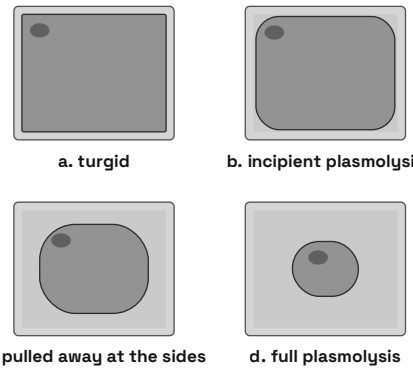
Imbibition

- needs **attraction** between imbibant and liquid: wood, seeds take water, not petrol; rubber takes petrol
- imbibant **swells**; volume a little less than the sum
- **exothermic**: heat of wetting
- **imbibition pressure**: seeds burst a tin; wet wooden wedges split rock
- in **dead** materials too; first step of germination
- e.g. door swelling in the monsoon; soaked chana; raisins
- % water taken in = (final − dry mass) ÷ dry mass × 100%

Plasmolysis

- exosmosis → **flaccid** → protoplast leaves the wall at corners (**incipient plasmolysis**) → round mass in the middle
- the **outside (hypertonic) solution** fills the space between wall and protoplast
- long plasmolysis → cell dies; **deplasmolysis** in water if soon enough
- OP rises, TP falls; from incipient plasmolysis TP = 0, DPD = OP; stops when cell's OP = solution's OP

- *Rhoeo* leaf peel or red onion skin (Practical 4): salt → plasmolysis; water → deplasmolysis



Plasmolysis step by step.

Significance

- tells **living from dead** cells
- demonstrates exosmosis; OP of cell sap (solution causing incipient plasmolysis)
- **food preservation**: salt (pickles, meat, fish), sugar (jam, jelly)
- **killing weeds** with salt; too much fertilizer burns crops
- shows the cell wall is fully permeable

Ascent of sap

- path: root hair (epiblema) → cortex → endodermis → pericycle → protoxylem → metaxylem → xylem of stem, branch, petiole, midrib, veins → mesophyll
- in **tracheary elements**: vessels and tracheids (gymnosperms: tracheids only)

Cohesion–tension theory (transpiration pull; **Dixon and Joly**, 1894)

1. **unbroken column** of water in thin vessels and tracheids
2. **cohesion** (H-bonds between water molecules) + **adhesion** (to walls) → column bears great **tension**
3. **transpiration pull**: water evaporates from mesophyll walls → cells draw from neighbors, then from veins → tension passed down to roots

- energy from the **Sun**; the plant spends none
- not enough alone: **root pressure** (small, often absent); **capillarity** (< 1 m)
- pump lifts water only 10.3 m (air's push); a tree **pulls** (Hyperion ~116 m)
- leafy twig on a water-filled tube → colored water rises (Practical 8d)

Eosin balsam twig (Activity 2.2)

- white flowers and leaf veins turn red
- T.S.: only **xylem** red → water rises in xylem, pulled by transpiration

Significance

- water for photosynthesis
- water and minerals to every part, through vessels and tracheids
- water for every living cell
- replaces water lost in transpiration
- keeps roots absorbing (linked with absorption)

Transpiration

- 97–99.5% of absorbed water lost from aerial parts
- **stomatal**: 80–90%; **cuticular**: 3–10% (more in thin-cuticle shade herbs; main way when stomata shut); **lenticular**: well under 1%, woody plants

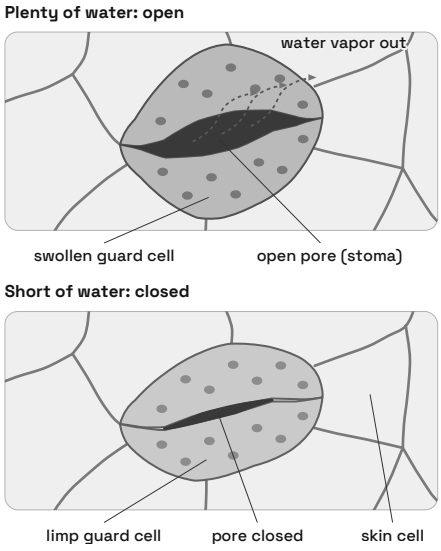
Stomatal transpiration: two steps

1. **evaporation** from wet mesophyll walls into air spaces and the **sub-stomatal cavity**; vapor pressure high
2. **diffusion** of vapor out through the open stoma (higher vapor pressure inside)

- osmosis moves water into mesophyll cells and into guard cells

Stomata

- dicot guard cells **kidney-shaped**: thick inner wall, thin outer wall
- water in (turgid) → outer walls bulge → pore **opens**; flaccid → **closes**
- monocots (grasses): **dumbbell-shaped**; swollen ends push the middles apart
- open by day, shut at night (CAM plants the reverse)
- dicots: more on lower surface; maize: both equally; water lily: upper only
- counting: nail-varnish prints; cobalt chloride paper (blue → pink), lower surface first



Stoma open and closed.

Advantages

- transpiration pull: water and minerals up
- steady flow of water; absorption balanced with loss
- minerals concentrated where used
- keeps cells turgid
- **cools** leaves (~2,400 J per gram evaporated)
- moderate transpiration → healthy growth

Disadvantages

- **wilting** when roots can't keep up; stomata close; death
- far more water moved than used (maize ~370 g, wheat ~510 g per g dry matter)
- closed stomata shut out CO_2 → less food
- a **necessary evil**: stomata must open for CO_2

External factors

- **humidity** ↑ → transpiration ↓
- **temperature** ↑ → transpiration ↑ (midday closure in very hot hours)
- **light**: stomata open → more by day; blue and red open them, not green (CDC: nor UV, infrared)
- **wind**: faster; ~20–30 km/h favorable, 40–50 km/h stomata close
- **CO_2**: low inside leaf → open; high → close
- **atmospheric pressure** ↓ → transpiration ↑ (mountains)
- **soil water**: dry soil → stomata close

Internal factors

- **leaf area**: more area, more loss; xerophytes: small leaves, early fall, **spines** (cacti)
- **leaf structure**: thick cuticle, fewer stomata, lower surface only; **sunken stomata** (*Pinus*, *Nerium*); *Nerium*: stomatal crypts with hairs
- **modifications**: **phylloclade** (*Opuntia*), **cladode** (*Asparagus*), **phyllode** (*Acacia*)

Guttation

- humid nights and mornings: little transpiration, roots still absorb → **root pressure** pushes sap out of **hydathodes**
- grasses (young rice, wheat), tomato, balsam, *Colocasia* (taro), strawberry, nasturtium; rare in tall trees
- **hydathode**: pore at a vein's end, always open; **epithem** (loose thin-walled cells) under it
- fluid carries sugars, salts, amino acids → white crust

	Transpiration	Guttation
through	stomata, cuticle, lenticels	hydathodes
lost as	vapor	liquid drops
when	mostly day	night, early morning
air	dry favors	humid favors
process	evaporation, diffusion	root pressure
control	stomata open, close	none: always open
root pressure	not needed	needed
water	pure	with sugars, salts
cooling	cools	doesn't cool

COMMON MISTAKES

✗ Osmosis: from higher to lower concentration
✓ water moves from **dilute to concentrated** solution.

✗ Osmosis needs no membrane
✓ needs a **semipermeable membrane**; dead cells don't show it.

✗ Water moves from the higher DPD cell
✓ moves **to** the higher DPD.

✗ Plasmolyzed cell: TP = OP
✓ **TP = 0, DPD = OP**; fully turgid: TP = OP, DPD = 0.

✗ Pure water fills a plasmolyzed cell's gap
✓ the **outside (hypertonic) solution**.

✗ Imbibition only in living cells
✓ dead wood and seeds imbibe too.

✗ Energy is released in transpiration
✓ evaporation takes up heat; that is why it cools.

✗ Guttation is dew
✓ water pushed out of the plant by root pressure.

✗ Root pressure lifts sap up tall trees
✓ **transpiration pull** with cohesion does.