NCERT Exemplar Solutions of Class 11 Biology – Chapter 11: Transport in plants

LONG ANSWER TYPE QUESTIONS

1. Minerals are present in the soil in sufficient amounts. Do plants need to adjust the types of solutes that reach the xylem? Which molecules help to adjust this? How do plants regulate the type and quantity of solutes that reach xylem?

Solution: Yes, plants must carefully regulate mineral uptake and transport to xylem.

Why regulation is necessary:

1. **Variable soil composition**: Mineral availability changes with location and season
2. **Selective requirements**: Different tissues need different mineral ratios
3. **Toxic prevention**: Must exclude harmful elements while accumulating nutrients
4. **Metabolic demands**: Growing tissues have higher mineral requirements
5. **Seasonal changes**: Mineral needs vary with growth phase and environmental conditions

Regulatory molecules:

Transport proteins:

- **Specific ion channels**: Selective for particular ions (K^+, Ca^{2+}, Cl^-)
- **Carrier proteins**: High specificity for transport substrates
- **ATPases**: Energy-dependent pumps for active accumulation
- **Antiporters/Symporters**: Coupled transport systems

Regulatory compounds:

- **Hormones**: Control transporter gene expression
- **Signaling molecules**: Ca^{2+}, IP_3, cAMP regulate transport
- **Transcription factors**: Control transporter protein synthesis
- **MicroRNAs**: Fine-tune transporter expression

Regulation mechanisms:

1. Root uptake control:

- **Selective absorption**: Root hair and cortical cells control initial uptake
- **Concentration sensing**: Feedback mechanisms adjust uptake rates
- **Transporter regulation**: Expression levels respond to mineral status

2. Endodermal screening:

- **Casparian strips**: Force all transport through living endodermal cells
- **Active selection**: Endodermis actively transports selected minerals
- **Barrier function**: Prevents passive leakage of minerals

3. Xylem loading control:

- **Pericycle function**: Controls final entry into xylem vessels
- **Active transport**: Energy-dependent loading of minerals
- **Concentration adjustment**: Maintains optimal mineral ratios

4. Remobilization systems:

- **Phloem redistribution**: Mobile minerals move through phloem
- **Source-sink dynamics**: Minerals relocate from old to young tissues

- **Storage and release**: Vacuoles buffer mineral concentrations

Specific examples:

Phosphorus regulation:

- **Low-P conditions**: Increased phosphate transporter expression
- **Root morphology**: Enhanced root hair development
- **Mycorrhizal associations**: Symbiotic enhancement of P uptake

Iron regulation:

- **Strategy I plants**: Acidification and reduction at root surface
- **Strategy II plants**: Chelation and specific uptake systems
- **Cellular control**: Tight regulation due to toxicity risk

Potassium regulation:

- **High-affinity transporters**: For low-K conditions
- **Low-affinity channels**: For adequate K supply
- **Tissue distribution**: Preferential allocation to growing regions

Enhanced Explanation: Plants have evolved sophisticated regulatory networks that integrate environmental sensing, metabolic demands, and transport mechanisms to ensure optimal mineral nutrition while avoiding toxicity. This regulation occurs at multiple levels from root uptake to tissue distribution.

2. Plants show temporary and permanent wilting. Differentiate between the two. Do any of them indicate the water status of the soil?

Solution:

Aspect	Temporary Wilting	Permanent Wilting
Duration	Recovers without watering (hours)	Does not recover without watering
Timing	Usually midday, hot conditions	Any time of day
Recovery	Recovers naturally at night/cool conditions	Requires water addition
Soil water	Water still available in soil	Soil water below wilting point
Plant response	Protective mechanism	Stress response
Cellular state	Temporary turgor loss	Severe dehydration
Metabolic impact	Minimal long-term effects	Serious metabolic disruption

Temporary wilting mechanisms:

Causes:

1. **High transpiration rate**: Exceeds water absorption capacity
2. **Environmental stress**: High temperature, low humidity, wind
3. **Diurnal patterns**: Natural daily water balance fluctuations

4. **Root-shoot imbalance**: Insufficient root system for shoot demands

Recovery process:

- **Reduced transpiration**: Evening cooling reduces water loss
- **Continued absorption**: Roots continue water uptake
- **Turgor restoration**: Cells regain internal pressure
- **Normal function**: Metabolic processes resume

Permanent wilting mechanisms:

Causes:

1. **Soil water depletion**: Water content below permanent wilting point (~-1.5 MPa)
2. **Root damage**: Impaired water absorption capacity
3. **Vascular damage**: Blocked water transport pathways
4. **Severe stress**: Extended drought conditions

Consequences:

- **Cellular damage**: Protein denaturation, membrane damage
- **Metabolic shutdown**: Photosynthesis and respiration impaired
- **Growth cessation**: All developmental processes stop
- **Eventual death**: If conditions don't improve

Water status indication:

Temporary wilting:

- **Indicates**: Soil water still available but absorption rate limited
- **Soil condition**: Above permanent wilting point but high demand
- **Management**: May need irrigation scheduling adjustment

Permanent wilting:

- **Indicates**: Soil water below critical threshold (~15% for most soils)
- **Soil condition**: Available water capacity exhausted
- **Management**: Immediate irrigation required

Permanent Wilting Point (PWP):

- **Definition**: Soil water content at which plants cannot recover turgor
- **Measurement**: Typically -1.5 MPa water potential
- **Soil type dependence**: Varies with clay content and soil structure
- **Agricultural importance**: Critical parameter for irrigation scheduling

Field applications:

Agricultural management:

- **Irrigation timing**: Schedule based on approaching PWP
- **Crop selection**: Choose varieties suited to local water availability
- **Soil improvement**: Enhance water holding capacity
- **Mulching**: Reduce evaporation losses

Physiological indicators:

- **Leaf temperature**: Wilted leaves often warmer than turgid ones
- **Stomatal closure**: Reduced gas exchange rates

- **Growth rates**: Decreased cell expansion and elongation
- **Hormone levels**: Increased ABA, decreased cytokinins

Enhanced Explanation: Understanding the distinction between temporary and permanent wilting is crucial for plant water management, as it determines whether intervention is necessary and helps assess soil water availability for plant growth.

3. Why are natural membranes selectively permeable. Give examples.

Solution: Selective permeability is essential for cellular function and survival.

Why selective permeability evolved:

Functional necessities:

1. **Concentration gradients**: Maintain different ion concentrations inside vs outside
2. **Metabolic control**: Keep enzymes and substrates in appropriate compartments
3. **pH regulation**: Control hydrogen ion distribution
4. **Osmotic balance**: Prevent excessive water influx or efflux
5. **Signal transduction**: Control movement of signaling molecules
6. **Energy conservation**: Prevent dissipation of energy-rich gradients

Structural basis of selectivity:

Lipid bilayer properties:

- **Hydrophobic core**: Blocks polar and charged molecules
- **Fluid mosaic structure**: Allows insertion of specific transport proteins
- **Cholesterol content**: Modulates membrane fluidity and permeability
- **Lipid composition**: Different lipids confer different properties

Protein components:

1. **Channel proteins**:
    - **Ion selectivity**: Size and charge filters
    - **Gating mechanisms**: Voltage, ligand, or mechanically gated
    - **Specificity examples**: Na^+ channels vs K^+ channels
2. **Carrier proteins**:
    - **Conformational changes**: Alternating access mechanisms
    - **Substrate binding**: Specific recognition sites
    - **Transport coupling**: Link movement of different substances

Examples of selective permeability:

Cell membrane examples:

High permeability:

- **Water**: Passes through lipid bilayer and aquaporins
- **Oxygen and CO_2**: Small, nonpolar gases diffuse freely
- **Ethanol**: Small, relatively nonpolar molecule
- **Urea**: Small, uncharged but polar (limited permeability)

Low permeability:

- **Ions**: Na^+, K^+, Ca^{2+}, Cl^- require specific channels
- **Glucose**: Requires glucose transporters (GLUT proteins)

- **Amino acids**: Need specific carrier proteins
- **Large proteins**: Generally cannot cross intact membranes

Specialized membrane examples:

1. Mitochondrial inner membrane:

- **Impermeable to**: Most ions and metabolites
- **Selective transport**:
  - ATP/ADP antiporter
  - Phosphate carrier
  - Pyruvate carrier
- **Function**: Maintains proton gradient for ATP synthesis

2. Chloroplast thylakoid membrane:

- **Impermeable to**: Protons (maintains pH gradient)
- **Selective transport**:
  - Light-driven proton pumping
  - ATP synthase complex
- **Function**: Photosynthetic energy conversion

3. Nuclear envelope:

- **Nuclear pores**: Size-selective (molecules <40 kDa pass freely)
- **Active transport**: Large proteins need nuclear localization signals
- **RNA export**: mRNA, tRNA, rRNA specific export mechanisms

4. Vacuolar membrane (tonoplast):

- **Ion selectivity**: Maintains different ion concentrations
- **pH regulation**: H^+-ATPase maintains acidic vacuolar pH
- **Secondary transport**: Uses H^+ gradient to drive other transport

Physiological examples:

Root cell membranes:

- **Mineral uptake**: Specific transporters for each nutrient
- **Water absorption**: Aquaporins facilitate rapid water movement
- **Ion exclusion**: Prevents uptake of toxic elements

Leaf mesophyll cells:

- **CO_2 permeability**: Allows photosynthetic gas exchange
- **Water retention**: Controls transpiration through stomatal regulation
- **Sugar export**: Facilitates phloem loading

Pathological conditions:

- **Membrane damage**: Loss of selectivity leads to cell death
- **Ion imbalance**: Disrupted gradients affect cellular function
- **Water imbalance**: Osmotic stress from selectivity loss

Enhanced Explanation: Selective permeability is not just a property but a fundamental requirement for life, allowing cells to maintain the controlled internal environment necessary for biochemical processes while interacting with their external environment. The evolution of increasingly sophisticated transport mechanisms has enabled the complexity of modern cellular life.

4. Halophytes may show cell pressure very much higher than atmospheric pressure. Explain how this can happen?

Solution: Halophytes (salt-tolerant plants) develop extremely high cell pressures as an adaptation to saline environments.

Environmental challenge:

- **High soil salinity**: Salt concentrations that would kill normal plants
- **Low soil water potential**: High salt content reduces available water
- **Osmotic stress**: Tendency for water to leave plant cells
- **Ion toxicity**: High Na^+ and Cl^- concentrations can damage cellular processes

Mechanisms for generating high cell pressure:

1. Compatible solute accumulation:

- **Organic solutes**: Proline, betaine, trehalose, mannitol
- **Function**: Lower cellular water potential without disrupting metabolism
- **Advantage**: Non-toxic even at high concentrations
- **Energy cost**: Significant metabolic investment in solute synthesis

2. Ion compartmentalization:

- **Vacuolar sequestration**: Na^+ and Cl^- stored in vacuoles
- **Cytoplasmic protection**: Essential enzymes protected from salt damage
- **Selective transport**: Active pumping maintains compartment differences
- **Osmotic contribution**: Vacuolar ions contribute to overall osmotic pressure

3. Active water uptake mechanisms:

- **Enhanced root surface**: Extensive root systems
- **Specialized root structures**: Salt-secreting roots
- **Hydraulic conductivity**: Increased aquaporin expression
- **Root pressure**: Active ion transport creates positive pressure

Pressure generation process:

Step 1: Osmotic adjustment

- **Solute accumulation**: Compatible solutes + sequestered ions
- **Water potential reduction**: ψs becomes very negative (-2 to -8 MPa)
- **Gradient establishment**: Cellular water potential < soil water potential

Step 2: Water influx

- **Osmotic driving force**: Water moves into cells down potential gradient
- **Cell wall constraint**: Rigid cell walls resist expansion
- **Pressure development**: Turgor pressure increases dramatically

Step 3: Pressure regulation

- **Balance achievement**: Turgor pressure + osmotic pressure = soil water potential
- **Homeostatic control**: Maintains pressure within functional limits
- **Growth regulation**: Controls cell expansion under high pressure

Physiological adaptations supporting high pressure:

Structural modifications:

1. **Reinforced cell walls**:
    - Increased cellulose and lignin content
    - Enhanced tensile strength
    - Resistance to bursting under high pressure
2. **Specialized tissues**:
    - **Succulent structures**: Store water and accommodate high pressures
    - **Aerenchyma**: Air spaces reduce density and provide flexibility
3. **Membrane adaptations**:
    - **Modified lipid composition**: Maintain integrity under osmotic stress
    - **Enhanced transport proteins**: Efficient ion and water movement

Metabolic adaptations:

1. **Enzyme modifications**:
    - **Salt tolerance**: Enzymes function at high ionic strength
    - **Osmolyte compatibility**: Function with high solute concentrations
2. **Antioxidant systems**:
    - **ROS scavenging**: Combat oxidative stress from high salinity
    - **Protective compounds**: Maintain cellular integrity

Salt secretion mechanisms:

1. **Salt glands**:
    - **Specialized structures**: Actively excrete excess salt
    - **Energy-dependent**: Use ATP to pump salt against gradients
    - **Pressure relief**: Reduce internal osmotic pressure
2. **Bladder cells**:
    - **Salt storage**: Isolate excess salt from metabolic tissues
    - **Sacrifice strategy**: Cells eventually burst, removing salt

Examples of high-pressure halophytes:

Salicornia (glasswort):

- **Turgor pressures**: Up to 4-6 MPa
- **Succulence**: Stores water in specialized tissues
- **Salt accumulation**: Extremely high tissue salt content

Atriplex (saltbush):

- **Bladder hairs**: Salt-accumulating structures on leaf surface
- **High turgor**: Maintains growth in saline conditions
- **Ion regulation**: Sophisticated Na^+/K^+ discrimination

Mangroves:

- **Root adaptations**: Specialized for saltwater uptake
- **Salt exclusion**: Filter salt at root level
- **Pressure gradients**: Transport water against osmotic gradients

Evolutionary significance:

- **Niche exploitation**: Allows growth where other plants cannot survive
- **Competitive advantage**: Reduced competition in saline environments
- **Agricultural potential**: Models for developing salt-tolerant crops

Enhanced Explanation: The ability of halophytes to generate and withstand extremely high cell pressures represents a remarkable evolutionary adaptation that involves coordinated changes in cell structure, membrane transport, metabolism, and whole-plant physiology. This adaptation allows them to thrive in environments that would be lethal to most plants.

5. The radiolabelled carbon in carbon dioxide supplied to potato plants in an experiment was seen in the tuber eventually. Trace the movement of the labelled carbon dioxide.

Solution: Experimental tracking of $^{14}CO_2$ movement in potato plants:

Initial conditions:

- **Radioactive CO_2**: $^{14}CO_2$ supplied to potato leaves
- **Detection method**: Autoradiography tracks radioactive carbon
- **Time course**: Movement traced over hours to days
- **Tissue analysis**: Different plant parts examined for radioactivity

Step-by-step carbon movement:

Phase 1: Photosynthetic fixation (minutes)

1. **CO_2 uptake**: $^{14}CO_2$ enters leaves through stomata
2. **Calvin cycle entry**: $^{14}CO_2$ fixed by RuBisCO enzyme
3. **^{14}C-labeled intermediates**: 3-phosphoglycerate → glyceraldehyde-3-phosphate
4. **Sugar synthesis**: Formation of ^{14}C-glucose and other sugars

Chemical pathway:

$^{14}CO_2$ → ^{14}C-3-PGA → ^{14}C-G3P → ^{14}C-glucose → ^{14}C-sucrose

Phase 2: Sugar processing and loading (30-60 minutes)

1. **Sucrose formation**: ^{14}C-glucose converted to ^{14}C-sucrose
2. **Phloem loading**: Active transport of ^{14}C-sucrose into sieve tubes
3. **Companion cell activity**: Energy-dependent loading mechanisms
4. **Osmotic adjustment**: Water follows sucrose into phloem

Phase 3: Long-distance transport (hours)

1. **Mass flow initiation**: High pressure in leaf phloem drives flow
2. **Phloem transport**: ^{14}C-sucrose moves through sieve elements
3. **Pathway direction**: From photosynthetic leaves toward developing tubers
4. **Transport rate**: Can reach speeds of 50-100 cm/hour

Phase 4: Sink tissue arrival (hours to days)

1. **Phloem unloading**: ^{14}C-sucrose removed from sieve tubes in tubers
2. **Metabolic conversion**: Sucrose → glucose → starch in tuber cells
3. **Storage accumulation**: ^{14}C incorporated into starch granules
4. **Cellular distribution**: Radioactivity concentrated in storage parenchyma

Detailed tuber processes:

Arrival and unloading:

- **Phloem termination**: Sieve tubes end in tuber vascular bundles
- **Active unloading**: Energy-dependent sucrose export from phloem
- **Apoplastic route**: Movement through cell walls and intercellular spaces
- **Cellular uptake**: Transport across plasma membranes into storage cells

Metabolic conversion:

^{14}C-sucrose → ^{14}C-glucose + ^{14}C-fructose → ^{14}C-glucose-6-phosphate → ^{14}C-starch

Storage formation:

1. **Starch synthesis**: ^{14}C incorporated into amylose and amylopectin
2. **Granule formation**: Starch deposited in specialized plastids (amyloplasts)
3. **Long-term storage**: Carbon retained for future sprouting and growth

Experimental evidence:

Autoradiography results:

- **Time 0**: Radioactivity only in treated leaves
- **30 minutes**: Signal appears in leaf veins (phloem)
- **2-4 hours**: Radioactivity detected in stems and stolons
- **6-12 hours**: Signal reaches developing tubers
- **24-48 hours**: Maximum accumulation in tuber starch

Quantitative analysis:

- **Leaf decline**: Gradual decrease in leaf radioactivity
- **Tuber increase**: Progressive accumulation in storage tissue
- **Transport efficiency**: 60-80% of fixed carbon reaches tubers
- **Storage stability**: ^{14}C remains in tuber starch long-term

Physiological controls:

Source regulation:

- **Photosynthetic rate**: Determines initial $^{14}CO_2$ fixation
- **Export capacity**: Phloem loading limits transport rate
- **Diurnal patterns**: More transport during active photosynthesis

Sink regulation:

- **Tuber development**: Growing tubers are strong carbon sinks
- **Starch synthesis rate**: Determines storage capacity
- **Hormonal control**: Growth regulators influence sink strength

Environmental factors:

- **Light intensity**: Affects photosynthesis and $^{14}CO_2$ fixation
- **Temperature**: Influences both photosynthesis and transport rates
- **Water status**: Affects phloem transport efficiency

Agricultural implications:

Crop management:

- **Leaf health**: Maximize photosynthetic carbon fixation
- **Tuber development**: Optimize conditions for storage organ growth

- **Harvest timing**: Understanding carbon accumulation patterns

Breeding applications:

- **Transport efficiency**: Select for improved phloem transport
- **Storage capacity**: Enhance tuber starch accumulation
- **Source-sink balance**: Optimize carbon allocation

Enhanced Explanation: This experiment elegantly demonstrates the complete pathway from atmospheric CO_2 to stored starch, showing how plants integrate photosynthesis, transport, and storage processes. The ability to trace radioactive carbon provides direct evidence for the source-to-sink transport system that enables plants to store energy for future use, which is fundamental to both plant biology and agricultural productivity.

6. Water molecule is very polar. Polar end of molecule attracts opposite charges on another water molecule (acts like a magnet). How will you explain this property of water with reference to the upward movement of water? Comment on the upward movement of water given the intermolecular hydrogen bonding in water.

Solution: Water's polar nature and hydrogen bonding are fundamental to upward water transport in plants.

Molecular basis of water polarity:

Water molecule structure:

- **Bent geometry**: 104.5° angle between O-H bonds
- **Electronegativity difference**: Oxygen more electronegative than hydrogen
- **Partial charges**: δ^- on oxygen, δ^+ on hydrogens
- **Dipole moment**: Net separation of charge creates molecular dipole

Hydrogen bond formation:

δ^+H-O-H...δ^-O-H_2 (hydrogen bond shown as ...)

- **Strength**: 20-25 kJ/mol (weaker than covalent bonds but significant)
- **Directionality**: Specific geometric requirements
- **Number**: Each water molecule can form up to 4 hydrogen bonds
- **Cooperativity**: Multiple bonds reinforce each other

Properties relevant to water transport:

1. Cohesion: **Definition**: Attraction between water molecules via hydrogen bonding

Mechanisms:

- **Intermolecular forces**: H-bonds link water molecules in continuous chains
- **Tensile strength**: Water columns can withstand tension up to -30 MPa
- **Bulk properties**: Cohesion creates strong intermolecular attraction
- **Temperature dependence**: Stronger cohesion at lower temperatures

Role in transport:

- **Continuous water column**: Unbroken chain from roots to leaves
- **Tension resistance**: Column doesn't break under negative pressure
- **Mass flow**: Entire column moves as integrated unit
- **Cavitation prevention**: Maintains column integrity under stress

2. Adhesion: **Definition**: Attraction between water molecules and other surfaces

Mechanisms:

- **Hydrogen bonding to surfaces**: Water bonds to polar groups on xylem walls
- **Electrostatic interactions**: Attraction to charged surfaces
- **van der Waals forces**: Weak attractions to non-polar surfaces
- **Wetting properties**: Water spreads on hydrophilic surfaces

Role in transport:

- **Wall attachment**: Prevents water column from detaching from xylem walls
- **Capillary action**: Assists initial water rise in narrow vessels
- **Column stability**: Anchors water column against gravitational pull
- **Surface tension effects**: Creates upward forces in small-diameter vessels

Cohesion-tension theory explanation:

Driving force generation:

1. **Transpiration**: Water evaporation from leaf mesophyll creates water deficit
2. **Meniscus formation**: Curved water surfaces in leaf cell walls
3. **Surface tension**: Cohesion creates tension at air-water interfaces
4. **Negative pressure**: Tension transmitted throughout water column

Force transmission:

1. **Cohesive links**: H-bonds transmit tension from leaf to root
2. **Unbroken column**: Continuous water pathway essential
3. **Pressure gradient**: Negative pressure decreases from leaf to root
4. **Bulk flow**: Entire column moves upward together

Quantitative aspects:

Cohesive strength:

- **Theoretical maximum**: Pure water can withstand -140 MPa tension
- **Practical limits**: Natural conditions allow -3 to -30 MPa
- **Safety factors**: Plants operate well within these limits
- **Cavitation threshold**: Air bubbles form when cohesion fails

Transport efficiency:

- **Flow rates**: Can transport water at rates of several meters per hour
- **Height limitations**: Cohesion allows transport to 100+ meter heights
- **Energy efficiency**: Passive process requiring no metabolic energy
- **Pressure gradients**: Typically 0.01-0.1 MPa per meter of height

Supporting evidence:

Direct measurements:

- **Xylem pressure**: Demonstrated negative pressures in transpiring plants
- **Cavitation detection**: Acoustic sensors detect bubble formation
- **Flow rates**: Measured transport velocities match theoretical predictions
- **Column integrity**: Dye experiments show continuous pathways

Experimental manipulations:

- **Pressure chamber**: Applied pressure can reverse xylem flow
- **Cavitation induction**: Vibration can break water columns
- **Adhesion disruption**: Chemical treatments affect wall-water interactions
- **Column sectioning**: Breaking xylem stops transport

Anatomical adaptations supporting cohesion-tension:

Xylem vessel structure:

- **Narrow diameter**: Increases relative surface area for adhesion
- **Smooth walls**: Minimize turbulence and cavitation sites
- **Reinforcement**: Secondary wall thickening resists collapse under tension
- **Pit membranes**: Allow lateral water movement while preventing air spread

Safety mechanisms:

- **Redundancy**: Multiple parallel pathways
- **Embolism repair**: Mechanisms to restore flow in cavitated vessels
- **Vessel segmentation**: Isolate air bubbles to prevent spread
- **Seasonal replacement**: New xylem formation replaces damaged tissue

Environmental factors affecting cohesion-tension:

Temperature effects:

- **Cohesion strength**: Decreases with increasing temperature
- **Viscosity changes**: Affects flow resistance
- **Cavitation risk**: Higher temperatures increase bubble formation risk

Water availability:

- **Soil water potential**: Determines maximum sustainable tension
- **Humidity effects**: Influences transpiration rate and driving force
- **Seasonal variation**: Transport capacity changes with water status

Evolutionary significance:

Adaptive advantages:

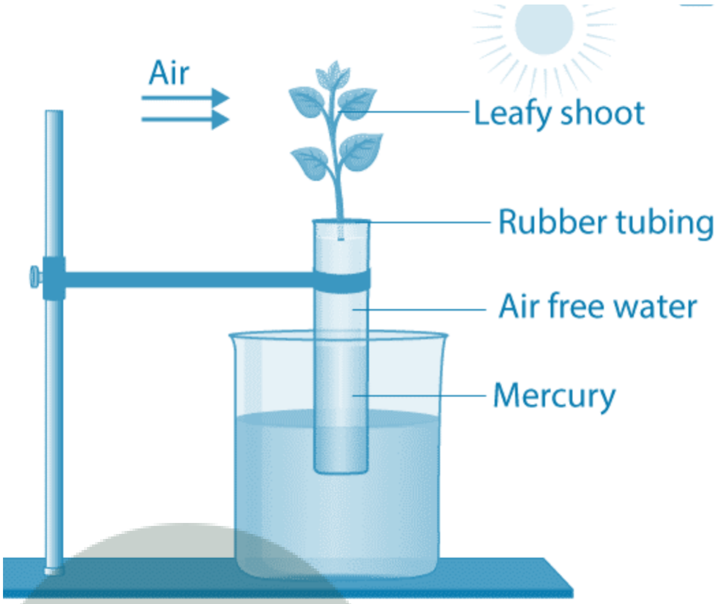
- **Height achievement**: Enables evolution of tall plants and trees
- **Competitive advantage**: Access to light resources above shorter plants
- **Efficiency**: Passive transport system with minimal energy cost
- **Reliability**: Robust mechanism operating across diverse environments

Constraints and limitations:

- **Cavitation vulnerability**: Risk increases with plant height and drought
- **Freezing sensitivity**: Ice formation breaks cohesive bonds
- **Chemical sensitivity**: Some substances can disrupt surface tension

Enhanced Explanation: The polar nature of water and resulting hydrogen bonding create a unique transport medium that enables plants to move water efficiently over long distances without direct energy input. This system represents one of nature's most elegant solutions to the challenge of long-distance transport, allowing the evolution of large terrestrial plants and forest ecosystems. The cohesion-tension mechanism demonstrates how molecular properties can scale up to enable complex biological functions, illustrating the fundamental importance of water's chemical properties to life on Earth.

7. Comment on the experimental setup. What does the setup demonstrate? b. What will happen to the level of water if a blower is placed close to setup? c. Will the mercury level fluctuate (go up/down) if phenylmercuric acetate is sprayed on leaves?



[Figure shows experimental apparatus with leafy shoot in rubber tubing connected to mercury column]

Solution:

a. What the setup demonstrates:

Experimental design:

- **Leafy shoot**: Connected to water column via rubber tubing
- **Mercury manometer**: Measures pressure changes in the system
- **Closed system**: Demonstrates transpiration-driven water movement
- **Air-free water**: Prevents cavitation and maintains column integrity

Demonstrated principles:

1. **Transpiration pull**:
    - **Negative pressure creation**: Water evaporation from leaves creates suction
    - **Pressure transmission**: Tension transmitted through water column
    - **Driving force**: Demonstrates mechanism of water transport in plants
2. **Cohesion-tension theory**:
    - **Water column integrity**: Shows water can be pulled under tension
    - **Pressure gradients**: Mercury column indicates negative pressure
    - **Mass flow**: Entire water system responds as integrated unit
3. **Plant water relations**:
    - **Transpiration measurement**: Mercury movement indicates transpiration rate
    - **Pressure dynamics**: Real-time monitoring of plant water status

  - **Environmental responses**: System responds to external conditions

b. Effect of blower placement:

Expected changes:

- **Mercury level rise**: Increased upward movement indicating stronger suction
- **Enhanced transpiration**: Wind increases water loss from leaf surfaces
- **Greater negative pressure**: Stronger tension in the water column

Physiological mechanisms:

1. **Increased transpiration rate**:
   - **Boundary layer disruption**: Wind removes humid air from leaf surface
   - **Vapor pressure gradient**: Steeper gradient between leaf and air
   - **Enhanced evaporation**: Faster water loss from stomatal cavities
2. **Feedback effects**:
   - **Stomatal response**: Initially may open wider due to increased demand
   - **Water stress development**: Prolonged exposure may trigger closure
   - **Pressure amplification**: System demonstrates increased water demand

Quantitative expectations:

- **Mercury rise**: Proportional to increased transpiration rate
- **Response time**: Near-immediate response to wind exposure
- **Saturation effects**: Maximum response limited by stomatal capacity

c. Effect of phenylmercuric acetate spray:

Expected result: **Mercury levels will stabilize (reduce fluctuation)**

Chemical properties of phenylmercuric acetate:

- **Anti-transpirant**: Reduces water loss from plant surfaces
- **Stomatal closure**: Induces closure of stomatal pores
- **Film formation**: Creates barrier reducing water vapor diffusion

Physiological effects:

1. **Immediate responses**:
   - **Stomatal closure**: Direct effect on guard cell function
   - **Reduced transpiration**: Decreased water loss from leaves
   - **Pressure stabilization**: Less negative pressure in system
2. **System-level changes**:
   - **Mercury stability**: Reduced fluctuations indicate steady state
   - **Lower baseline**: Overall reduction in transpiration-driven suction
   - **Homeostasis**: System reaches new equilibrium with reduced transport

Mechanism of action:

- **Membrane effects**: Alters guard cell membrane permeability
- **Metabolic interference**: Disrupts normal stomatal regulation
- **Physical barrier**: Reduces vapor diffusion from leaf surface

Time course:

- **Rapid onset**: Effects visible within minutes of application

- **Duration**: Effects persist for hours to days depending on concentration
- **Recovery**: Natural recovery as chemical degrades or is diluted

Experimental significance:

Teaching value:

- **Cause and effect**: Clear demonstration of transpiration-transport linkage
- **Environmental factors**: Shows how external conditions affect plant function
- **Control mechanisms**: Illustrates plant responses to water stress

Research applications:

- **Transpiration measurement**: Quantitative assessment of water loss
- **Chemical screening**: Testing effects of various compounds
- **Environmental studies**: Monitoring plant responses to conditions

Limitations and considerations:

- **Artificial system**: May not perfectly reflect natural plant behavior
- **Mercury toxicity**: Safety considerations for handling mercury