General Biology: Resource Acquisition Nutrition And Transport In Vascular Plants

AI-Generated Study Guide

(Based on lectures delivered by Dr. Ty C.M. Hoffman)

I. Resource Acquisition and Metabolism
A. Essential Resources
Plants require material resources and one non-material resource.
1. **Non-Material Input:** Light is necessary for photosynthesis and provides energy in the form of electromagnetic energy. In a typical plant, leaves are specially adapted for collecting light.
2. **Material Inputs:** Carbon dioxide (CO_2) and water (H_2O) are essential chemicals. Water entering the roots is a solution containing dissolved minerals (solutes).
B. Photosynthesis and Fuel Oxidation
Photosynthesis is a complex set of reactions summarized by the following inputs and outputs:
Energy (Light)+$6CO_2$+$6H_2O$→$C_6H_{12}O_6$ (Sugars)+$6O_2$ Photosynthesis uses light energy and spends ATP to create sugars.
The **complete oxidation of fuel** (glycolysis and cellular respiration) is the reverse process, breaking down sugar ($C_6H_{12}O_6$) and O_2 to produce CO_2 and H_2O, releasing energy and producing ATP.
The main function of photosynthesis is **carbon fixation**, the process of incorporating inorganic carbon (CO_2) into organic compounds (sugars).
C. Gas Exchange
• **Leaves (Photosynthetic tissue):** Take in CO_2 (source of carbon) and release O_2 (waste product of photosynthesis). Since photosynthesis usually outpaces cellular respiration in leaves, there is a net income of CO_2.
• **Roots (Non-photosynthetic tissue):** Roots perform cellular respiration to stay alive. They take in O_2 and release CO_2 as waste.

II. Transport Systems and Compartments
A. Xylem (Water and Minerals)
Water and dissolved minerals enter through the root system. This is a **one-way flow** through the **xylem** vessels, moving up the plant body and exiting as water vapor through the leaves in a process called **transpiration**.
B. Phloem (Sugar)
Sugars (primarily sucrose) are the main fuels transported.
• **Sugar Source:** Where sugar is produced (e.g., leaves).
• **Sugar Sink:** Places that need sugar but cannot produce it (e.g., roots).

• Sugar is transported through the **phloem** tubes. The flow is **bidirectional** depending on the needs of the plant, moving from source to sink.

C. Cellular Compartments

Plant cells are connected by tunnels called **plasmodesmata**, effectively creating a shared internal environment.

• **Symplast:** The combined intracellular compartment, consisting of the cytoplasm of all connected cells.

• **Apoplast:** The entire extracellular compartment, including the cell walls.

Particles traveling within the plant can take three routes:

1. **Symplastic Route:** Travel entirely through the cytoplasm, moving cell-to-cell via plasmodesmata.
2. **Apoplastic Route:** Travel entirely outside the cells, within the cell walls (extracellular space).
3. **Transmembrane Route:** A combination route that requires the particle to cross the plasma membrane at least once.

III. Membrane Transport

Transmembrane transport moves particles across the plasma membrane.

A. Passive Transport (Diffusion)

Passive transport moves particles **down** a concentration or electrochemical **gradient** (high concentration to low). It requires energy, but this energy is stored potential energy within the gradient itself, requiring no additional outside energy expenditure.

• **Direct Diffusion:** Requires particles to be **small enough** and **non-polar enough** to pass directly through the phospholipid bilayer. Charged or highly polar molecules are usually blocked.

• **Facilitated Diffusion:** Passive movement aided by membrane-bound proteins.

◦ **Channel Proteins:** Form open tunnels; they are always passive.

◦ **Carrier Proteins:** Temporarily bind the particle (ligand), change shape, and drop the particle off on the other side. Can be passive if moving down the gradient.

B. Active Transport

Active transport moves particles **against** their gradient (low concentration to high). This process requires the expenditure of additional external energy, often ATP. Only carrier proteins, typically called **pumps**, can perform active transport.

• **Primary Active Transport:** Uses energy (e.g., ATP) directly to move a particle against its gradient, often establishing an electrochemical gradient (e.g., Proton pumps pumping H+ out of the cell).

• **Secondary Active Transport:** Utilizes the potential energy stored in an existing gradient (created by primary transport) to move a second particle against its own gradient. For example, the diffusion of H+ back into the cell down its gradient provides the energy to pump sucrose into the cell using a **symporter**.

Transport Terminology

• **Uniport:** Moves one type of particle.

• **Cotransport:** Moves two different kinds of particles simultaneously.

◦ **Symport:** Both particles move in the same direction.

◦ **Antiport:** Particles move in opposite directions.

IV. Osmosis and Water Relations

Osmosis is the diffusion of water (the solvent in biology) across a selectively permeable membrane down its own concentration gradient (from where it is more watery to where it is less watery).

Tenicity describes the environment surrounding a cell relative to the cell's solute concentration.

Environment	Solute Concentration (vs. cell)	Water Movement	Plant Cell State
Hypotonic	Lower outside; more watery outside	Water moves into cell	**Turgid (swollen, ideal)**; cell wall prevents lysis. High turgor pressure causes erection/rigidity.
Isotonic	Equal outside; equally watery	Water moves in and out equally	Flaccid (limp); surviving but not ideal.
Hypertonic	Higher outside; less watery outside	Water moves out of cell	**Plasmolysis** (plasma membrane shrinks from cell wall); potentially lethal.

V. Plant Nutrition and Soil Acquisition

A. Essential Elements

Essential elements are determined using **hydroponics**, where plants are grown in controlled watery solutions without soil.

• **Macronutrients:** Needed in large amounts (e.g., Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus). Nitrogen is crucial for proteins and nucleic acids; Phosphorus is vital for nucleic acids and ATP.

• **Micronutrients:** Needed in trace amounts, often metal ions that serve as **cofactors** to activate enzymes.

B. Cation Exchange

Soil particles are typically negatively charged, attracting essential positively charged ions (**cations**) such as K^+, Ca^{2+}, and Mg^{2+}.

• Plants acquire these nutrients via **cation exchange** by trading hydrogen ions (H^+) for the desired cations.

• H^+ ions are produced by:

1. Root respiration releases CO_2, which mixes with water to form carbonic acid (H_2CO_3), which then dissociates into H^+ and bicarbonate (HCO_3^-).
2. Roots actively pump H^+ out using proton pumps.

C. Nitrogen Cycle

Atmospheric nitrogen (N_2) is unusable because the triple covalent bond is too strong.

• **Nitrogen-fixing bacteria** convert N_2 into ammonia (NH_3).

• Ammonia is protonated in the soil solution to form the **ammonium ion** (NH_4^+).
• **Nitrifying bacteria** convert ammonium into nitrite, and then into **nitrate** (NO_3^-).
• Plants can take up both ammonium and nitrate, but nitrate is the preferred form for entry into the root system.
• **Dinitrifying bacteria** convert nitrate back into N_2, completing the cycle.

VI. Specialized Structures and Adaptations
A. Root Control and Xylem Loading
• **Casparian Strip:** A waxy, waterproof ring surrounding the vascular tissue in the root. This strip acts as a barrier, specifically blocking the **apoplastic route**.
• To reach the xylem vessels, water and solutes must be filtered by crossing the plasma membrane and entering the **symplast** (intracellular compartment) to bypass the Casparian strip.
B. Leaf Structure and Stomata
• **Phyllotaxy:** The specific, highly ordered arrangement of leaves on a stem, usually in a spiral pattern, which maximizes light capture by ensuring leaves do not shade each other.
• **Stomata:** Pores on the leaf surface required for gas exchange (CO_2 in, O_2 and H_2O vapor out). The opening is surrounded by two **guard cells**.
• **Stomata Opening:** Opening occurs when guard cells swell (become turgid). Swelling is caused by the active transport (pumping) of potassium ions (K^+) into the guard cells, which draws water in by osmosis.
C. Special Plant Lifestyles and Adaptations
• **Root Nodules:** Found on legumes (e.g., peanuts), these structures house nitrogen-fixing bacteria in a mutualistic endosymbiosis, making nitrogen acquisition highly efficient.
• **Mycorrhizae (Fungus Root):** Mutualistic symbiosis between fungi and plant roots that increases the root's surface area for absorption.
  ◦ **Ectomycorrhizae:** Fungi form a thick mat on the outside of the root.
  ◦ **Arbuscular Mycorrhizae:** Fungi penetrate between root cells in tree-like arrangements.
• **Epiphytes:** Plants that grow on other plants for physical support only, not stealing resources.
• **Parasitic Plants:** Plants that tap into the host's vascular system (xylem or phloem) to steal water or nutrients. Some (like mistletoe) still photosynthesize; others have lost this ability.
• **Carnivorous Plants:** Supplement their photosynthetic nutrition by trapping and digesting small animals, usually insects.
D. Desert Adaptations (Water Conservation)
• **Ocotillo:** Sheds leaves most of the year and becomes dormant, limiting water loss through transpiration.
• **Oleander:** Stomata are located within deep **crypts** (cave-like structures) to prevent water vapor from being rapidly swept away by wind.
• **Old Man Cactus:** Covered in white, hair-like spines (modified leaves) that reflect sunlight, minimizing heat gain and reducing evaporative water loss.

VII. Mechanisms of Flow
A. Transpiration Pull (Xylem Flow)

Water movement up the plant is a **pull** from the leaves, not a push from the roots. This pull is driven by the evaporation of water from the leaf surface.

1. **Evaporation:** Water molecules evaporate from the leaf surface, creating surface tension and a curvature on the liquid water surface.
2. **Tension:** The surface tension pulls on the entire water column below it.
3. **Cohesion:** Water molecules are attracted to each other (due to polarity/hydrogen bonds), so when one is pulled, it drags the entire column with it.
4. **Adhesion:** Water molecules are also attracted to the polar walls of the xylem, which aids the upward movement.

B. Pressure Flow (Phloem Flow)

Phloem flow is driven by hydrostatic pressure differences between the sugar source and the sugar sink.

1. **Source Loading:** Sucrose is actively loaded into the phloem sieve tubes at the source.
2. **Source Pressure:** The high solute concentration in the phloem draws water from the adjacent xylem by osmosis, increasing the hydrostatic pressure at the source end.
3. **Sink Unloading:** Sucrose is continuously removed and used by sink cells.
4. **Sink Pressure:** Water leaves the phloem and re-enters the xylem by osmosis, reducing the hydrostatic pressure at the sink end.
5. This established pressure gradient drives the syrupy phloem sap flow from high pressure (source) to low pressure (sink).