وزارة التعليم
Ministry of Education

موهبة
Mawhiba

نسمو
NSMO

National Science and Mathematics Olympiad

Learning Materials for the Biology Track

National Teams Competition 2026

Biology

Dear Student,

The King Abdulaziz and His Companions Foundation for Giftedness and Creativity (Mawhiba) is a distinguished non-profit civilizational institution, established in 1419H / 1999 by the Custodian of the Two Holy Mosques, the late King Abdullah bin Abdulaziz Al Saud (may Allah rest his soul). The Foundation endeavors to provide a stimulating environment for talent and creativity, to strengthen passion for science and knowledge, and to contribute to the preparation of future leaders. This is achieved through a well-defined methodology that is aligned with the most advanced scientific approaches and global best practices in the education of the gifted and creative, thereby enabling the optimal investment of their potential as a fundamental resource for the prosperity of humanity.

Mawhiba seeks to advance a long-term national vision for the nurturing and sponsorship of creativity and giftedness in the Kingdom, fully consistent with the aspirations and objectives of Saudi Vision 2030 to develop outstanding human capital. The Foundation is committed to preparing a new generation that embodies achievement and represents the hope of the future. It firmly believes that investing in the education of gifted individuals is neither a luxury nor an elitist pursuit, but an imperative for raising quality standards, enhancing capabilities, and enabling such individuals to contribute effectively to the building of society as the leaders of tomorrow.

With its accumulated expertise, Mawhiba has implemented a wide range of programs for gifted and creative students, assuming a central role within the institutional framework that supports gifted education in the Kingdom. The Foundation complements the national education system through comprehensive programs for the identification, nurturing, and integrated development of gifted students. It also actively exchanges expertise with stakeholders—including the Ministry of Education and leading international academic institutions—regarding the planning and execution of advanced programs and initiatives in gifted education.

It is noteworthy that scientific competitions are no longer regarded as an optional luxury, but rather as an objective measure of excellence and advancement in scientific domains. Given the intensifying competition for international recognition, any aspirant to the podium of honor must adopt all possible approaches that will secure not only access to these platforms, but also a sustained and distinguished presence upon them.

The Foundational Training Pack you now hold has been designed to provide an initial introduction to the nature of competition topics and questions, as well as to the fundamental principles required for mastery. This foundational stage constitutes the essential first step toward proficiency, positioning you at the outset of the pathway to competition and the honor of representing the nation in international scientific arenas.

In preparing this pack, we have sought to present the scientific material in a manner that is clear, engaging, and conducive to nurturing curiosity, thereby inspiring you to pursue new horizons of challenge and to derive fulfillment from the process of learning. It is also appropriate, at this juncture, to recall the journey that you commenced with us through the Mawhoub Competition, which, God willing, shall continue until your aspirations are realized and your ambitions fulfilled.

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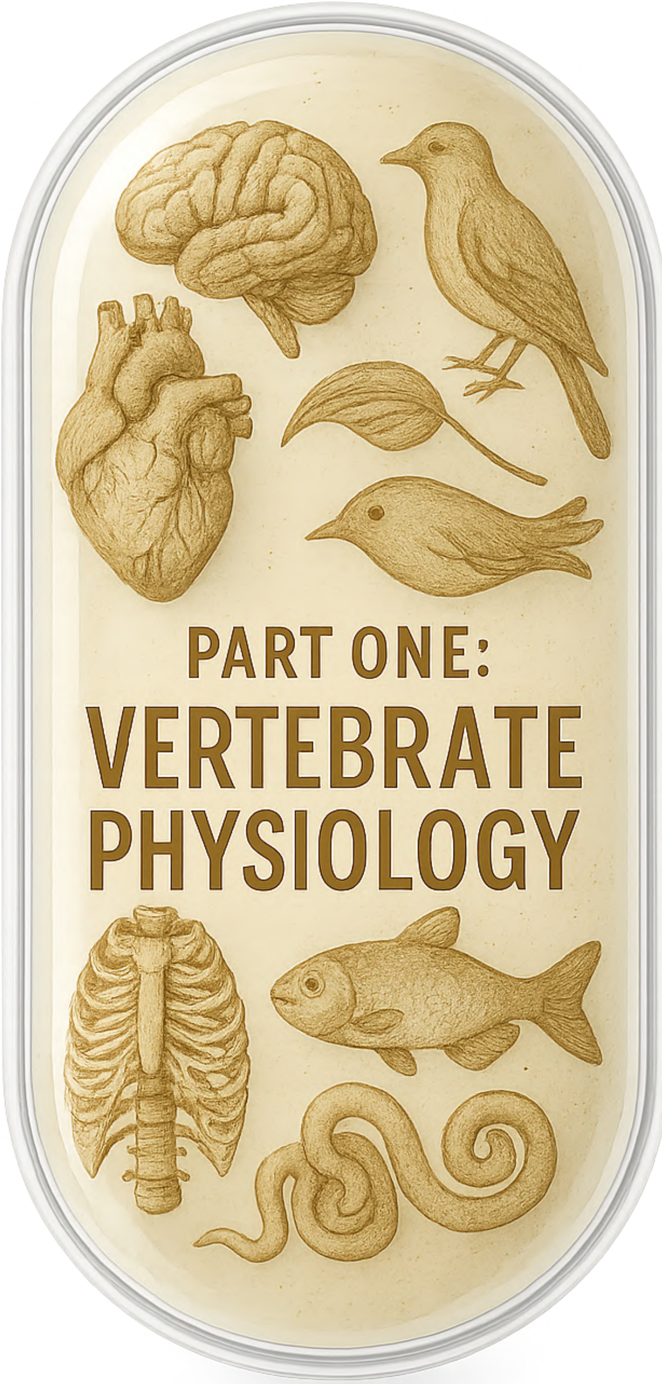

PART ONE:
VERTEBRATE
PHYSIOLOGY

Introduction to Vertebrate Physiology

Vertebrate physiology is one of the fundamental branches of biology, concerned with the study of the vital functions of the systems and organs of vertebrate organisms such as humans and animals. The importance of this science lies in its explanation of how different organs work together to maintain homeostasis and ensure the continuation of life.

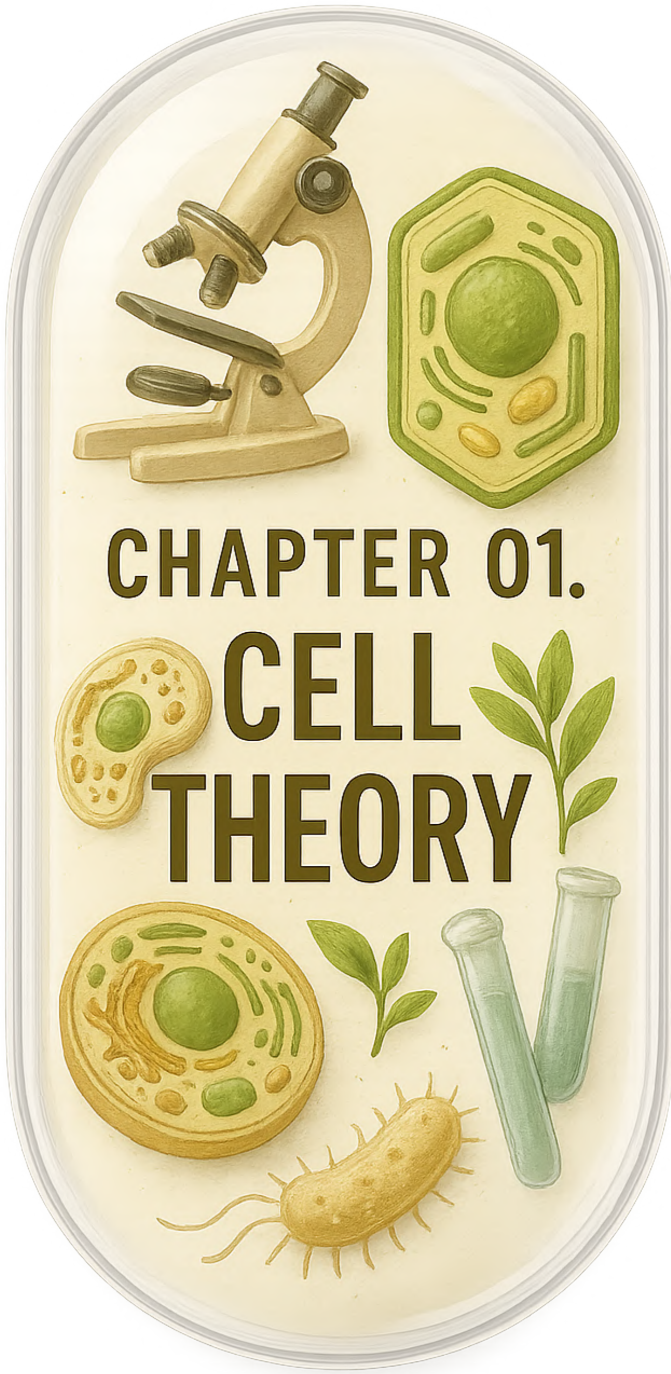
Understanding the mechanisms of the vertebrate body—such as respiration, circulation, excretion, digestion, and the nervous and muscular systems—helps explain biological phenomena, develop medical and veterinary applications, improve animal production, and enhance basic scientific knowledge about the nature of life.

General objectives:

1. To identify the functional basis of vertebrate organs and systems.
2. To understand the mechanisms of regulation and integration between vital systems in the body of a living organism.
3. To apply physiological concepts in medical, veterinary, and research fields.
4. Develop the ability to analyze various physiological phenomena in vertebrates.

Specific objectives:

1. Study the functions of body systems such as the nervous, digestive, circulatory, respiratory, excretory, and reproductive systems.
2. Identify physiological differences between vertebrate species (fish, amphibians, reptiles, birds, and mammals.
3. Explain the relationship between the anatomical structure and physiological function of each system.
4. Train students to conduct physiological experiments and analyze their results scientifically.
5. Relate physiological concepts to everyday life and practical applications in the fields of health, agriculture, and the environment.


CHAPTER 01.
CELL
THEORY

The Cell Theory

The cell theory is considered the cornerstone of modern biology, as it states the fundamental principles that describe the structure and function of living organisms. Historically, cells could not be observed until the invention of the microscope in the 17th century. Robert Hooke was the first to describe them in 1665, followed by Anton van Leeuwenhoek, who was the first to observe living cells. In the 19th century, the work of Schleiden and Schwann formally established the theory.

A. Principles of the Cell Theory

The modern form of the theory is based on three fundamental principles:

1. Unity of structure and function: All living organisms are composed of one or more cells, and within these cells all essential life processes such as metabolism and heredity occur.
2. The basic unit of life: The cell is the smallest living unit and represents the fundamental building block of all organisms.
3. Origin of cells: All cells arise only from the division of pre-existing cells, confirming the continuity of life from a common ancestor.

B. Limitations of Cell Size

The small size of most cells is a nearly universal feature, primarily due to physical limitations imposed by diffusion and material exchange with the surrounding environment. The efficiency of a cell is determined by the **surface area–to–volume ratio**.

As a cell grows, its volume (proportional to r^3) increases much faster than its surface area (proportional to r^2). This means that as the cell becomes larger, its surface area becomes insufficient to meet its increasing metabolic demands, leading to slower nutrient transport and waste removal. To overcome this limitation, some large cells have evolved specialized adaptations:

- **Nerve cells** are long and thin, keeping most of the cytoplasm close to the membrane.
- **Skeletal muscle cells** contain multiple nuclei to efficiently manage their large cellular functions.

C. Microscopes and Resolving Power

Because the diameter of most cells is less than 50 micrometers, they are too small to be seen with the naked eye. This limitation arises from the **resolving power** of the human eye—the minimum distance at which two points can be distinguished as separate—which is about 100 micrometers. To study smaller objects, microscopes are required.

Types of Microscopes:

1. Light Microscopes

Light microscopes, particularly compound microscopes, increase resolving power using multiple glass lenses to magnify the image in stages.

- **Principle:** Use visible light and multiple lenses to magnify specimens.
- **Limitations:** Their resolving power is about 200 nanometers. They cannot distinguish structures smaller than this (like the 5 nm-thick cell membrane) because of light wave interference and the wavelength limits of visible light.

2. Electron Microscopes

To overcome these limits, electron microscopes use a beam of electrons instead of light. Because electrons have a much shorter wavelength, they provide much higher resolution.

- **Transmission Electron Microscope (TEM):** Electrons pass through the specimen, providing highly detailed images of internal structures with a resolution up to 0.2 nanometers (about the size of two hydrogen atoms).
- **Scanning Electron Microscope (SEM):** Electrons scan the specimen's surface, producing stunning three-dimensional (3D) images of surface details.

D. Staining Techniques for Enhanced Contrast

To improve visibility of cellular structures and increase contrast, chemical stains are used. One of the most advanced techniques is **Immunohistochemistry (IHC)**, which is based on:

1. Producing specific antibodies that bind to particular proteins within the cell. Linking these antibodies to colored dyes or enzymes.
2. When applied to cells, these antibodies attach only to their target proteins, making them visible under the microscope and allowing precise analysis of cell structure and function.

Common Structural Features of Cells

Despite the great diversity in cell forms and functions, all cells share four essential components that enable basic life processes:

1. Genetic Material (DNA)

Every cell contains genetic material (DNA) carrying genes responsible for protein synthesis.

- In **prokaryotes**, DNA is located in a central region not enclosed by a membrane called the **nucleoid**.
- In **eukaryotes**, DNA is enclosed within the **nucleus**, a double-membrane organelle separating it from the cytoplasm.

2. Cytoplasm

A semi-fluid, gel-like substance filling the cell, composed of sugars, amino acids, proteins, and ions. In eukaryotic cells, it is divided into:

- **Cytosol:** The liquid portion where organic molecules dissolve.
- **Organelles:** Specialized membrane-bound structures suspended within the cytosol.

3. Ribosomes

Structures responsible for synthesizing proteins according to genetic instructions encoded in DNA.

4. Plasma Membrane

A thin boundary (5–10 nanometers thick) surrounding the cell, separating its interior from the external environment. It is primarily composed of a **phospholipid bilayer** interspersed with proteins, regulating the movement of substances into and out of the cell.

CHAPTER 02

VERTEBRATE BODY ORGANIZATION

Levels of Organization in the Vertebrate Body

The organization of the vertebrate body follows a hierarchical structure, progressing from simple units to complex systems. It consists of **four main levels:**

1. Cells and Tissues

- **Cells:** The basic unit of life. The body of a vertebrate animal consists of hundreds of specialized cell types (about **210 types in humans**).
- **Tissues:** Groups of cells similar in structure and function. All tissues develop during embryonic growth from **three primary germ layers**:

1. **Ectoderm (outer layer)**
2. **Mesoderm (middle layer)**
3. **Endoderm (inner layer)**

In adult animals, there are **four main types of tissues:** epithelial, connective, muscular, and nervous.

2. Organs and Organ Systems

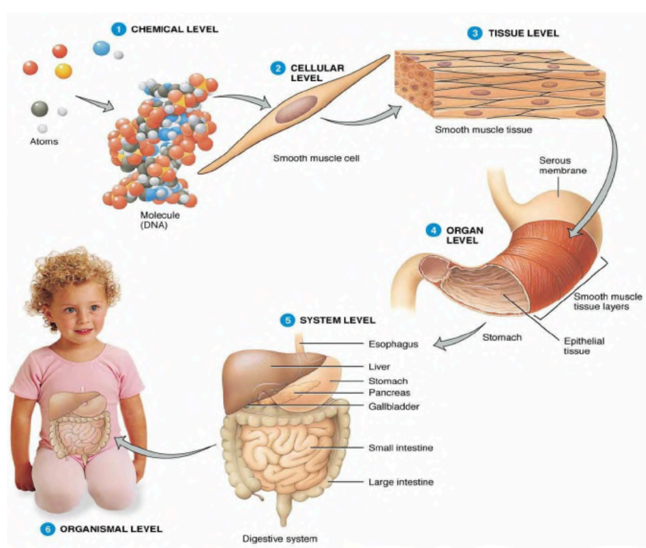


Figure 1: Levels of Organization in the Vertebrate Body

- **Organs:** Structural and functional units composed of different tissue types working together. Example: The **heart** is made up of muscular, connective, epithelial, and nervous tissues.
- **Organ Systems:** Groups of organs that work together to perform major vital functions. Example: The **circulatory system**, which includes the heart and blood vessels. The vertebrate body has **11 major organ systems**.

3. General Body Plan and Cavities

Vertebrates are characterized by a specific and well-defined general body plan and structural organization:

- **Tube-within-a-tube body plan:** The body consists of an outer main tube supported by an internal skeleton, enclosing an inner tube — the digestive tract.
- **Body cavities:** The vertebrate body is divided into two main cavities:
  - **Dorsal cavity:** Includes the skull and vertebral column.
  - **Ventral cavity:** In mammals, this is divided by the diaphragm muscle into two parts:
    - The **thoracic cavity**, which contains the heart and lungs.
    - The **abdominopelvic cavity**, which contains the organs of digestion and excretion.

These cavities are remnants of the **coelom**, an embryonic cavity derived from the **mesoderm** layer. In adult vertebrates, the coelom becomes partitioned into specialized membranes surrounding internal organs—such as the **peritoneal cavity** around abdominal organs, the **pericardial cavity** around the heart, and the **pleural cavities** around the lungs.

Epithelial Tissue

Epithelial tissue is defined as the tissue that covers all external body surfaces and lines internal cavities and organs. It arises from all three germ layers (ectoderm, mesoderm, and endoderm) and also forms the functional units of glands.

Main Characteristics and Functions:

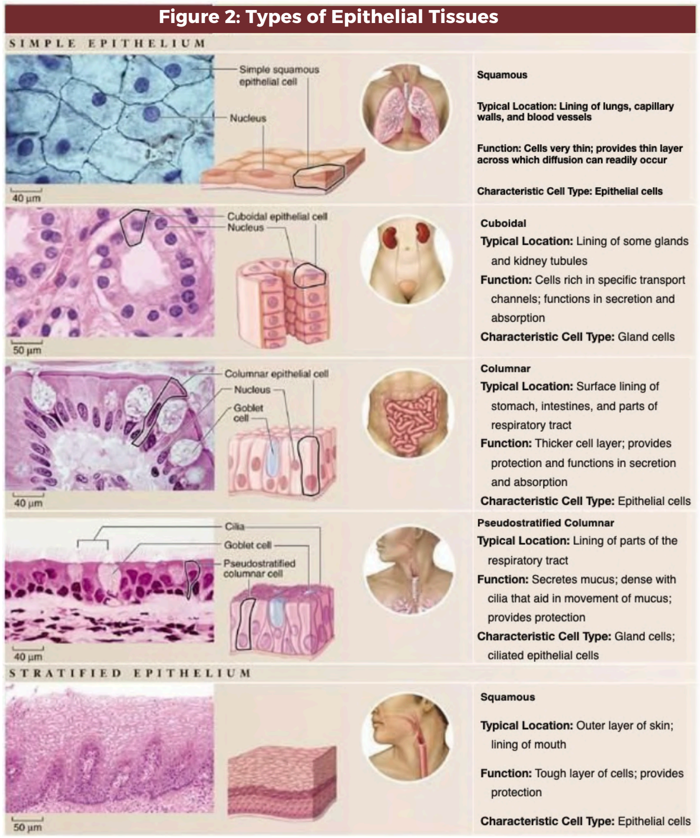
1. **Barrier Function:** Acts as a selective barrier that regulates the movement of substances between the external environment and internal organs. It protects against dehydration and pathogens (as in the skin), allows selective nutrient absorption (as in the intestines), and permits rapid gas exchange (as in the lungs).

2. **Cellular Cohesion:** Epithelial cells are tightly bound together, minimizing intercellular spaces and reinforcing their barrier role.
3. **Polarity:** Epithelial cells have distinct surfaces:
   - The **apical surface**, which faces the cavity or external environment.
   - The **basal surface**, which rests on a specialized fibrous layer called the **basement membrane**, anchoring the epithelium to the underlying connective tissue.
4. **Regenerative Capacity:** Epithelial tissue has a remarkable ability to divide and regenerate continuously—essential for surfaces exposed to wear or damage. For example, the skin renews approximately every two weeks, while the stomach lining regenerates every 2–3 days.

Classification of Epithelial Tissues

Epithelial tissue is classified based on the number of cell layers and the shape of the cells in the surface layer.

Figure 2: Types of Epithelial Tissues



Glands

Specialized structures of epithelial tissue whose function is secretion.

- **Exocrine Glands:** Retain their connection to the epithelial surface through ducts and release their products (such as sweat and saliva) onto the body surface or into its cavities.
- **Endocrine Glands:** Lose their connection to the surface and secrete their products (hormones) directly into the bloodstream.

Connective Tissues

Connective tissues are derived from the embryonic mesoderm layer and are distinguished from other tissues by the presence of an abundant **extracellular matrix** that separates their widely spaced cells. This matrix consists of **protein fibers** and a **ground substance**, whose consistency varies from fluid (as in blood) to solid (as in bone), giving each tissue its unique characteristics. Connective tissues are broadly classified into two main groups:

1. Connective Tissue Proper

In this type, **fibroblasts** (fiber-producing cells) generate the extracellular matrix. It is further divided into subtypes depending on fiber arrangement and density.

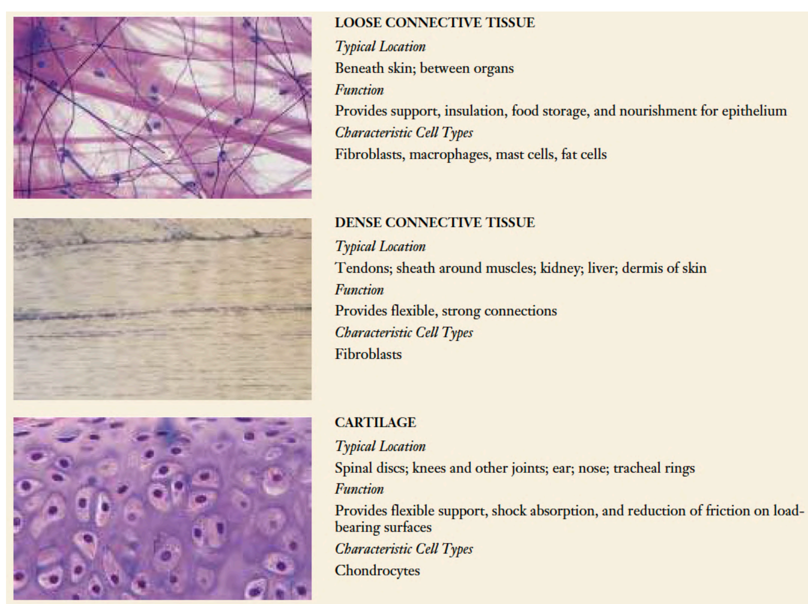


Figure 3: Types of Connective Tissue Proper

2. Specialized Connective Tissue

Despite their tremendous diversity in form and function, all connective tissues share a common embryonic origin (**the mesoderm**) and a fundamental structure composed of **scattered cells embedded within an extracellular matrix**.

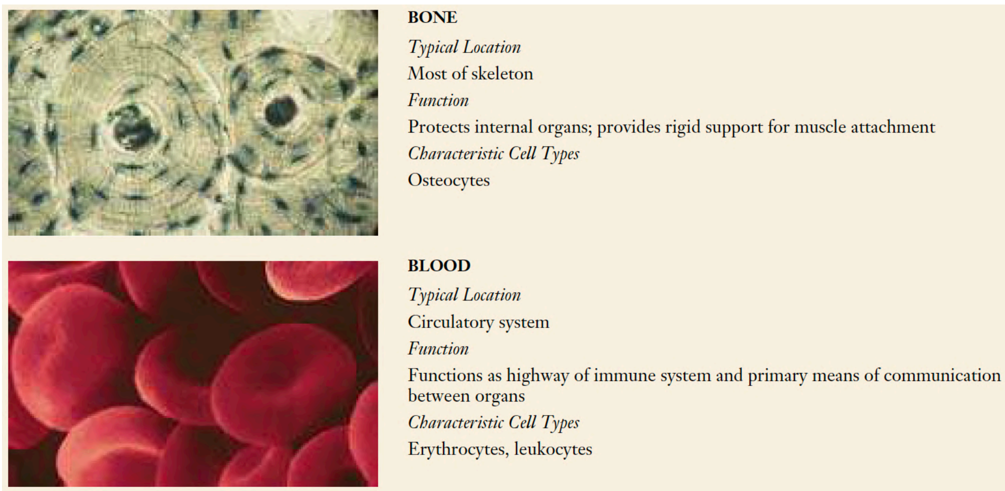


Figure 4: Types of Specialized Connective Tissues

Muscle Tissue

Muscle tissue is responsible for movement in the bodies of vertebrates. Its cells are characterized by an abundance and precise organization of the protein filaments **actin** and **myosin**, which give them a specialized ability to contract. Vertebrates possess three main types of muscles. These three types perform distinct vital functions: **smooth muscles** carry out the functions of internal organs, **skeletal muscles** move the body, and **cardiac muscles** form the muscular pump of the heart.

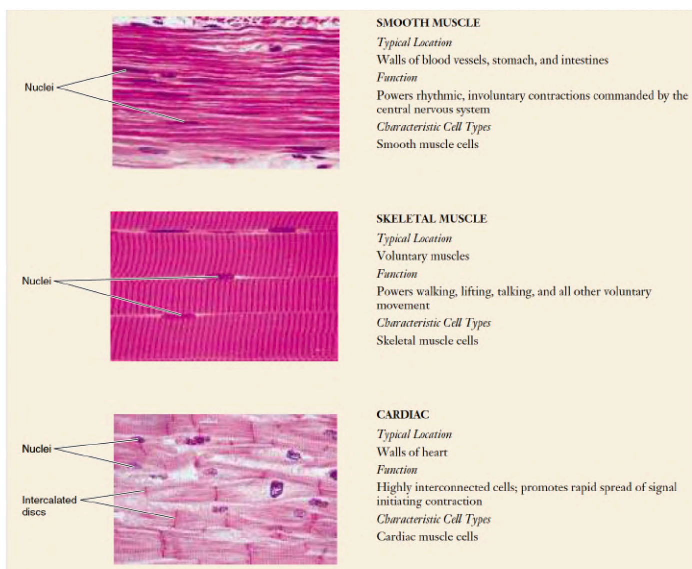


Figure 5: Types of Muscle Tissues

Nervous Tissue

Nervous tissue constitutes the fourth main type of tissue in vertebrates and is responsible for coordination and communication within the body. This tissue consists of two main types of cells: **neurons**, which are the basic functional units, and **neuroglia**, which provide support and protection.

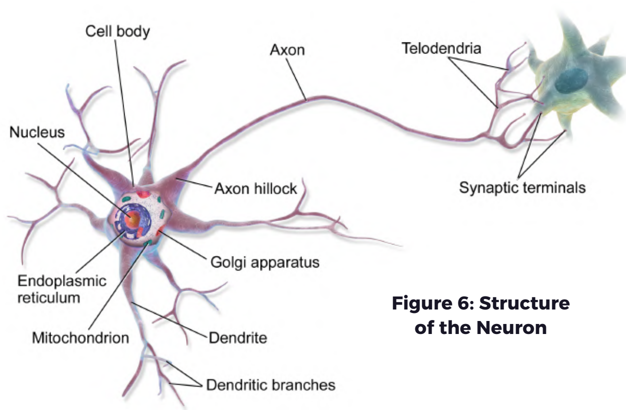


Figure 6: Structure of the Neuron

1. Organization of the Nervous System

The nervous system is divided into two main parts:

- **Central Nervous System (CNS):** Consists of the brain and spinal cord. Its function is to process and integrate information received from the body and issue commands.
- **Peripheral Nervous System (PNS):** Consists of nerves (bundles of axons) and ganglia (clusters of neuron cell bodies). Its function is to transmit signals between the central nervous system and the rest of the body, such as muscles and gland

Functional Classification of Organ Systems in Vertebrates

The relationship between the structure and function of organ systems in vertebrates can be understood by classifying them into **five main functional groups**, each performing vital and integrated tasks.

1. Communication and Integration

This group is responsible for detecting stimuli and coordinating the body's responses.

- **Nervous System:** Consists of the brain, spinal cord, and nerves; it collects information from the internal and external environment, processes it, and generates appropriate responses.
- **Sensory System:** Considered part of the nervous system, it includes specialized organs that detect sensory stimuli such as vision, hearing, and smell.
- **Endocrine System:** Releases chemical signals (hormones) that regulate metabolic processes and vital functions across different body systems.

2. Support and Movement

These systems enable the animal to maintain its shape and perform various movements.

- **Skeletal System:** Provides a rigid internal framework that supports the body and serves as an attachment point for muscles.
- **Muscular System:** Responsible for generating the force required for movement through contraction and pulling against the skeletal system.

3. Regulation and Maintenance

This group maintains the stability of the body's internal environment (**homeostasis**).

- **Digestive System:** Responsible for ingesting, digesting, and absorbing food, and eliminating solid waste.
- **Circulatory System:** Pumps blood to distribute oxygen, nutrients, and hormones throughout the body.
- **Respiratory System:** Supplies the body with oxygen and removes carbon dioxide.

- **Urinary System:** Regulates the balance of fluids and salts in the body (**osmoregulation**) and eliminates liquid metabolic wastes.

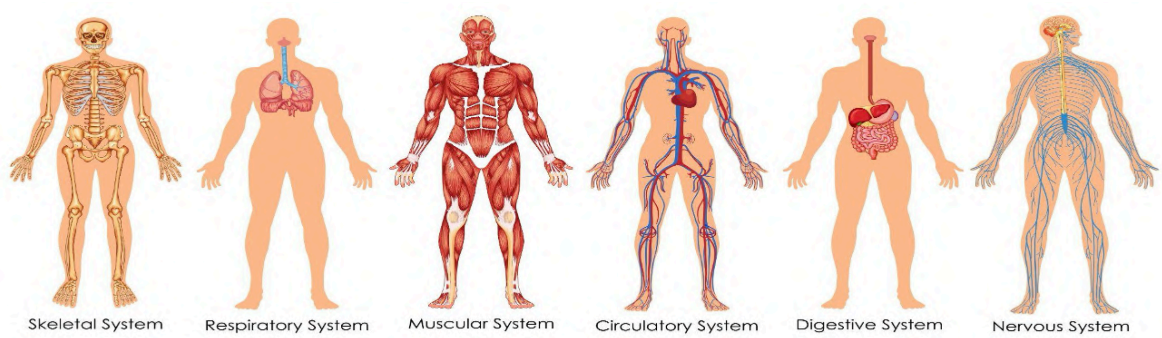


Figure 7: Body Organ Systems

4. Defense

These systems protect the body from pathogens and external damage.

- **Integumentary System:** The skin forms the first line of defense against microbes and harmful environmental factors.
- **Immune System:** Provides the second line of defense by attacking foreign bodies that penetrate the first barrier through specialized cells and antibodies.

5. Reproduction and Development

This group ensures the continuity of the species.

- **Reproductive System:** Produces gametes and provides the mechanisms necessary for fertilization. In females, it often provides an environment for nurturing the developing embryo.
- **Development:** The process by which the zygote (fertilized egg) undergoes cell divisions and differentiation to form a multicellular adult organism.

CHAPTER 03

Skeletal System

Types of Skeletal Structures

To perform movement, muscles require a framework to work against. Animals possess **three main types of skeletal systems:**

A. Hydrostatic Skeleton

This type relies on the pressure of a fluid contained within the body cavity. It is found in soft-bodied invertebrates such as **earthworms**, **jellyfish**, and **squid**.

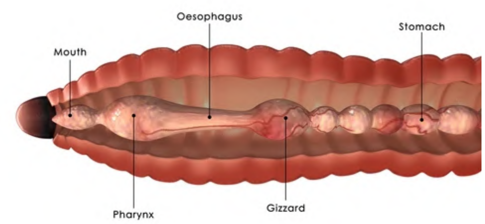
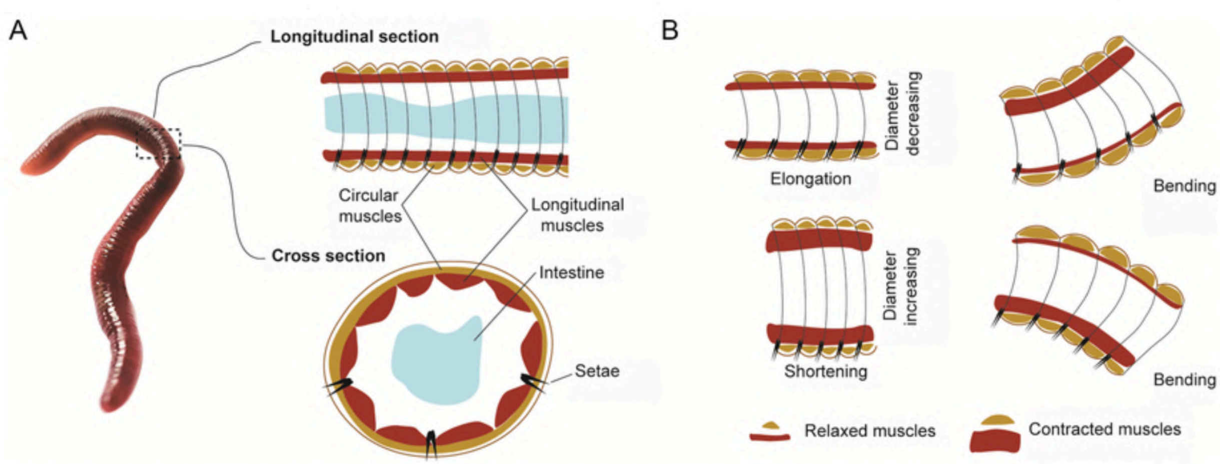


Figure 8: Muscular Structure in the Earthworm Body

- **Mechanism of Movement (Earthworm):**

Movement occurs through alternating contractions of the **circular muscles** (which make the body long and thin) and the **longitudinal muscles** (which make it short and thick). These contractions pressurize the internal fluid, while **setae** (small bristles) anchor parts of the body to the ground, resulting in a forward, wave-like motion.



Earthworm muscles and motion. A) Schematic diagram of the longitudinal section and cross-section of earthworm segments. B) Schematic diagram of the motion patterns and the muscle states within segments.

Figure 9: Mechanism of Earthworm Movement Through Contraction and Relaxation of Longitudinal and Circular Muscles

- **Jet Propulsion (Aquatic Animals):** Organisms such as **jellyfish** and **squid** use the surrounding water as a medium for movement. The squid fills its **mantle cavity** with water and then forcefully expels it through the **siphon**, propelling itself rapidly backward. This mechanism is highly efficient for **quick escape and maneuvering**.

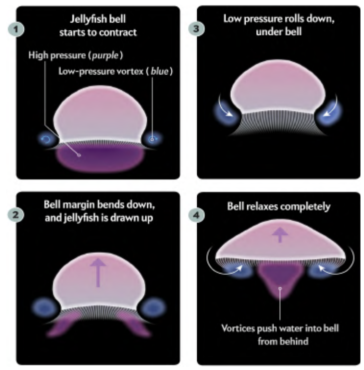


Figure 10: Mechanism of Jellyfish Movement in Water

B. Exoskeleton

A hard external covering that surrounds the body, as seen in **arthropods** (insects and crustaceans).

- **Structure and Function:**

Composed of **chitin**, it provides protection, support, and attachment points for internal muscles.

- **Disadvantages:**

It must be shed periodically (**molting**) to allow growth, during which the animal becomes vulnerable. Additionally, it limits the animal's maximum size due to its weight and the constraints of the respiratory system.

C. Endoskeleton:

An internal rigid framework found in **vertebrates** and **echinoderms**.

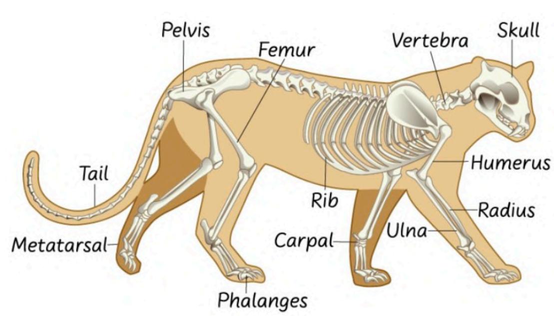


Figure 11: Components of the Endoskeleton

- **Structure:** In vertebrates, it is composed of **bone and cartilage**, while in echinoderms it is made of **calcium carbonate (calcite)**. Bone is harder and less flexible than cartilage, which serves as a cushion in joints.

- **Divisions in Vertebrates:**
  - o **Axial Skeleton:** Includes the skull, vertebral column, ribs, and sternum.
  - o **Appendicular Skeleton:** Includes the bones of the limbs and the pectoral and pelvic girdles.

Overview of Bone in Vertebrates

Bone is a **living, dynamic connective tissue** that undergoes continuous processes of formation, growth, and remodeling.

A. Ossification:

- **Intramembranous Ossification:** In this process, bones (such as flat skull bones) form **directly within layers of connective tissue**. **Osteoblasts** (bone-forming cells) secrete **hydroxyapatite crystals** (calcium phosphate) onto collagen fibers.
- **Endochondral Ossification:** Most bones (such as long limb bones) develop by **replacing a pre-existing cartilage model** with living bone tissue.

B. Structure of Bone:

- **Cells:** Bone tissue consists of **osteoblasts** (bone-forming cells), **osteocytes** (mature bone cells embedded within the solid matrix), and **osteoclasts** (bone-resorbing cells responsible for remodeling).

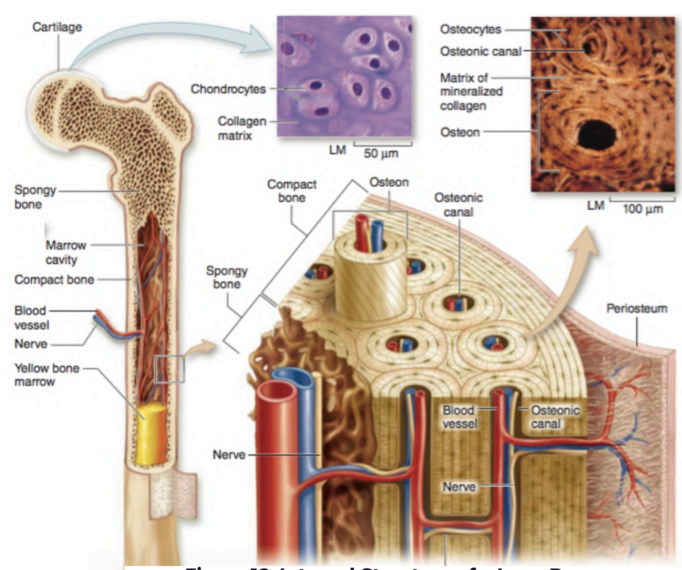


Figure 12: Internal Structure of a Long Bone

- **Types:** Classified into **compact (dense) bone** on the exterior and **spongy bone** on the interior.
- **Haversian System:** In compact bone, cells are arranged in **concentric rings** around **Haversian canals**, which contain blood vessels and nerves, keeping the tissue alive.

C. Bone Remodeling

Bone responds to **mechanical stress**. Repeated forces (such as physical exercise) generate a **piezoelectric effect** in the hydroxyapatite crystals, stimulating **osteoblasts** to increase bone density and strength.

Joints and the Mechanism of Movement

Movement occurs at **joints**, which are the points where bones meet.

- **Types of Joints:**

Joints are classified into:

- **Immovable joints** (such as the sutures of the skull)
- **Slightly movable joints** (between the vertebrae)
- **Freely movable joints** (**synovial joints**) such as the knee and hip

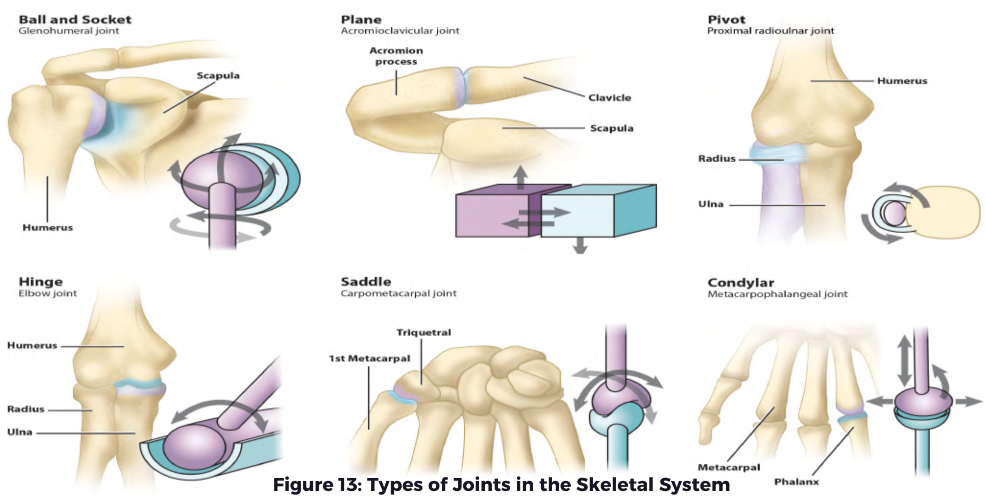


Figure 13: Types of Joints in the Skeletal System

Muscle Action: Muscles attach to bones through **tendons**. Each muscle has **an origin** (the fixed attachment point) and **an insertion** (the movable attachment point).

Muscles work in **antagonistic pairs**:

- The **agonist** (prime mover) produces the movement.
- The **antagonist** opposes or reverses that movement.

Mechanism of Skeletal Muscle Contraction

Muscle contraction occurs at the molecular level according to the **Sliding Filament Theory**.

A. Microscopic Structure

A muscle fiber is composed of **myofibrils**, which in turn consist of repeating units called **sarcomeres**. Each sarcomere contains two types of filaments:

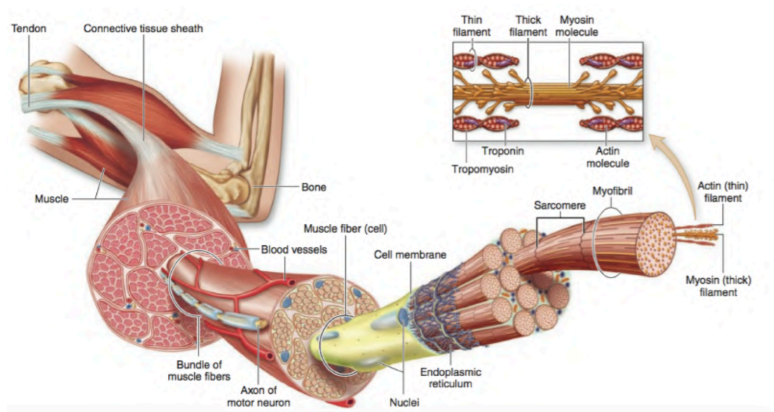


Figure 14: Microscopic Structure of Skeletal Muscle

- **Thick filaments:** Made of the protein **myosin**, which has movable heads.
- **Thin filaments:** Composed mainly of the protein **actin**.

B. Cross-Bridge Cycle

1. **Attachment:** The myosin head (activated by ATP) binds to an active site on the actin filament, forming a **cross-bridge**.
2. **Power Stroke:** The myosin head pivots, pulling the actin filament toward the center of the sarcomere, shortening it and producing contraction.
3. **Detachment:** A new ATP molecule binds to the myosin head, causing it to detach from actin.

4. **Reactivation:** The ATP is hydrolyzed, re-cocking the myosin head and preparing it for another cycle.The cycle **repeats continuously** as long as the muscle is stimulated.

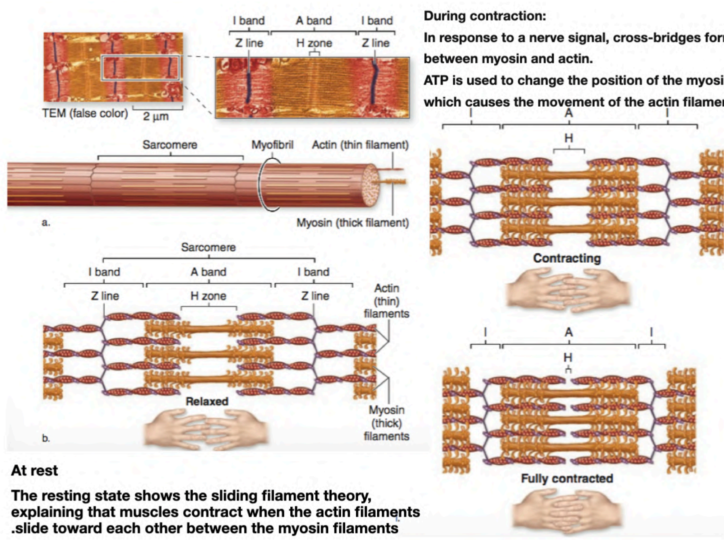


Figure 15: Mechanism of Myofibril Contraction (Sliding Filament

C. Role of Calcium in Regulation

- In the resting state, the proteins **tropomyosin** and **troponin** located on the actin filament block the myosin binding sites.
- When a **nerve impulse** arrives, **calcium ions (Ca^{2+})** are released from the **sarcoplasmic reticulum**.
- Calcium binds to the **troponin** protein, causing a change in its shape that moves **tropomyosin** away, exposing the **myosin-binding sites**.

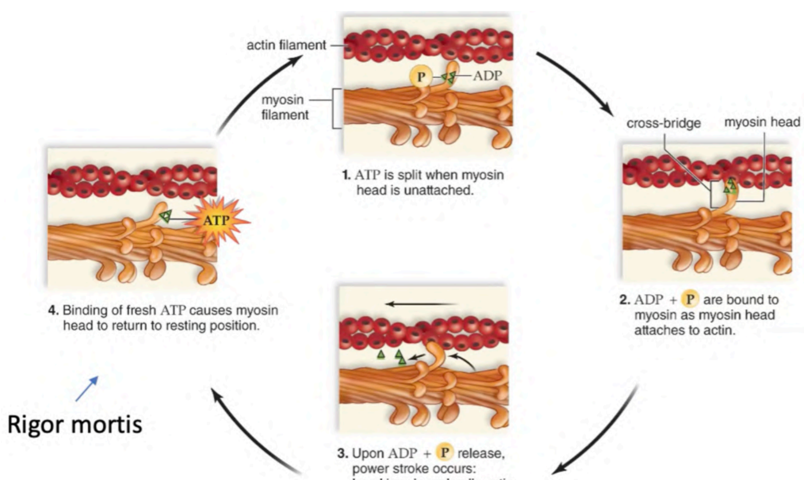


Figure 16: Cross-Bridge Cycle in Muscle Contraction

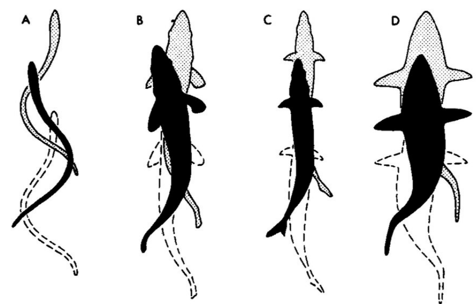
This allows the **cross-bridge cycle** to begin, leading to **muscle contraction**.

D. Types of Muscle Fibers

- **Slow-Twitch Fibers (Red):** Rich in **mitochondria** and **myoglobin**, rely on **aerobic respiration**, and are characterized by **high endurance** and **fatigue resistance**.
- **Fast-Twitch Fibers (White):** Depend on **anaerobic respiration** and **glycogen** reserves, contract **rapidly and powerfully**, but **fatigue quickly**.

Patterns of Animal Movement

Figure 17: Propulsion and Locomotion Mechanism in Fish

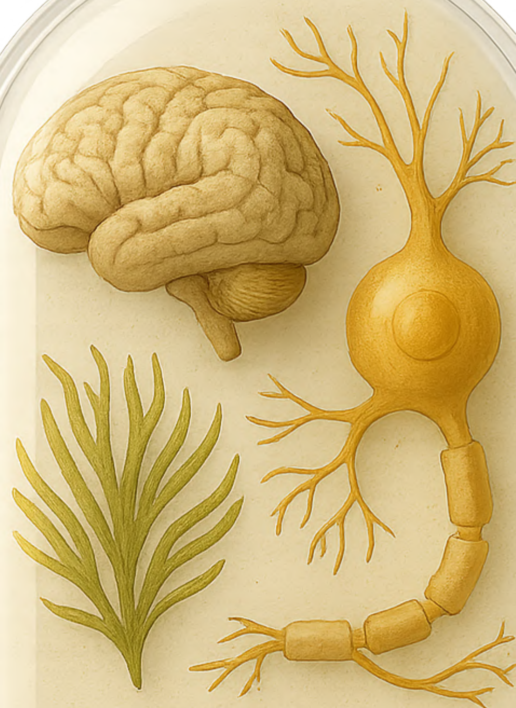


Gradation of swimming modes from (A) anguilliform, through (B) subcarangiform, and (C) carangiform, to (D) thunniform.

Modes of movement vary depending on the environment, but the **physical principles** governing them remain the same.

- **Movement in Water:** The main challenge is **drag (friction)**. Animals overcome it through **jet propulsion** (as in squid), **undulating body movements** (as in fish), or by using limbs like **paddles** (as in ducks and turtles).

- **Movement on Land:** The primary challenge is **gravity**. Limbs evolved for **support and propulsion**. Increasing the number of legs (as in arthropods) enhances **stability** but may reduce **speed**, while **four limbs** (in vertebrates) allow for **fast movements** such as running and jumping.
- **Flight:** Evolved independently **four times** (in insects, pterosaurs, birds, and bats). Flight depends on generating **lift** by pushing air downward with the wings and utilizing the **pressure difference** between the upper and lower wing surfaces



CHAPTER 04
Nervous System

Basic Organization of the Nervous System

The nervous system functions as a rapid communication and control network. It gathers information, processes it, and issues commands to maintain homeostasis and respond to stimuli. It consists of specific structural and functional units.

A. Types of Neurons:

1. **Sensory Neurons (Afferent):** Transmit information from sensory receptors (such as the skin and eyes) to the central nervous system.
2. **Motor Neurons (Efferent):** Carry commands from the central nervous system to effector organs (muscles and glands).
3. **Interneurons (Associative):** Found within the central nervous system; they process information and connect sensory and motor neurons. They form the basis of complex functions such as learning and memory.

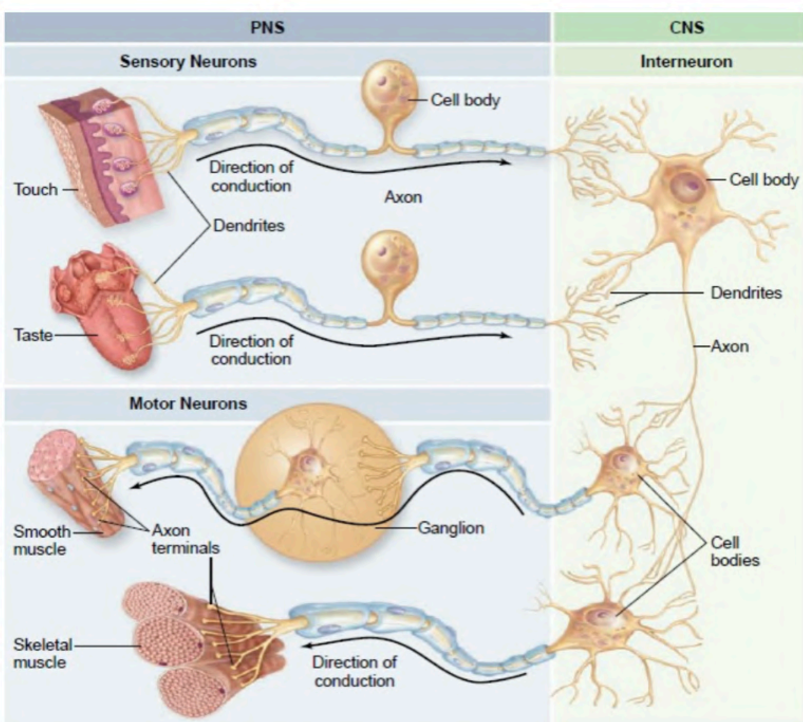


Figure 18: Types of Neurons in the Central and Peripheral Nervous Systems

B. Divisions of the Nervous System

- **Central Nervous System (CNS):** The control center of the body, consisting of the brain and the spinal cord.
- **Peripheral Nervous System (PNS):** Composed of nerves and ganglia located outside the central nervous system. It functions as a communication network linking the CNS with the rest of the body.

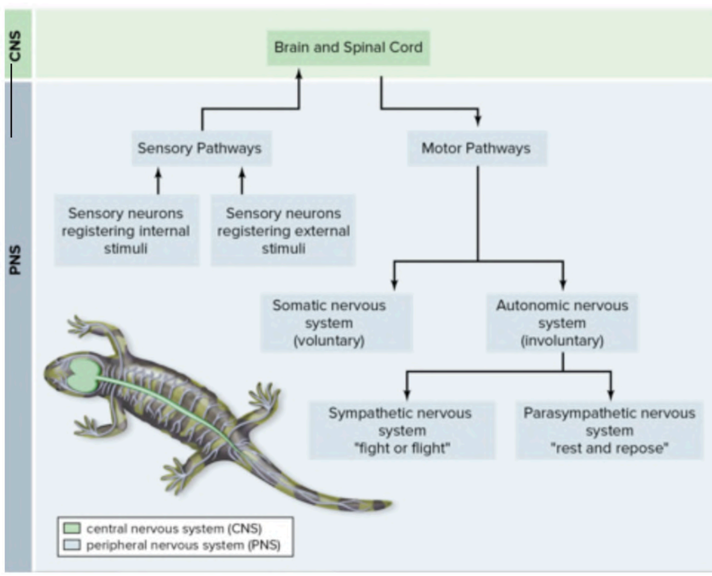


Figure 19: Diagram Showing the Divisions and Functions of the Central and Peripheral Nervous Systems

The Neuron (Nerve Cell):

It is the structural and functional unit of the nervous system, characterized by a unique structure that supports its function.

A. Structure of the Neuron

- **Cell Body:** Contains the nucleus.
- **Dendrites:** Branched extensions that receive signals from other neurons.
- **Axon:** A single long projection that transmits nerve impulses away from the cell body.

B. Supporting Cells (Neuroglia or Glial Cells)

These are non-neuronal cells that outnumber neurons and provide essential support.

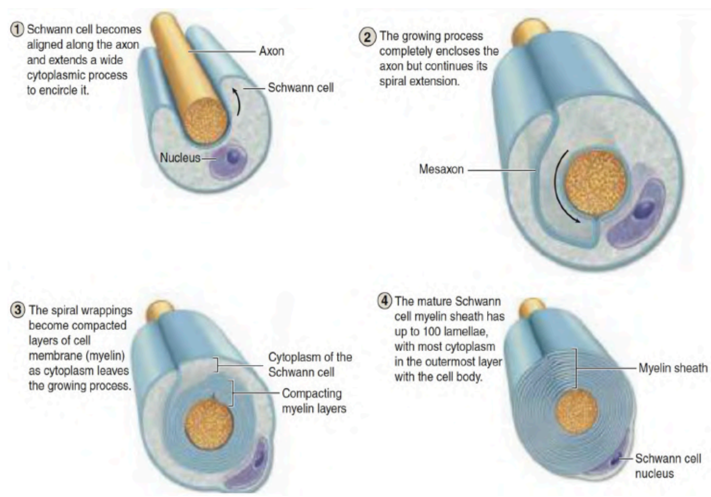


Figure 20: Formation of the Myelin Sheath Around the Axon

- **Function:** Supply nutrients, remove waste products, and provide structural support to neurons.
- **Myelin Sheath:** A fatty insulating layer that wraps around axons. It is produced by **Schwann cells** in the peripheral nervous system and **oligodendrocytes** in the central nervous system. This sheath greatly increases the speed of nerve impulse transmission.
- **Nodes of Ranvier:** Unmyelinated gaps along the myelinated axon where the nerve impulse "jumps" from one node to another in a process known as **saltatory conduction**.

The Nerve Impulse: The Language of the Nervous System

Neurons communicate through electrical signals generated by the movement of ions across their plasma membrane.

A. Resting Potential

When a neuron is not stimulated, it maintains an electrical potential difference across its membrane of about **–70 millivolts (mV)**, with the inside of the cell being negative relative to the outside. This potential arises due to:

1. **Sodium–Potassium Pump:** Actively transports **three sodium ions (Na^+)** out of the cell for every **two potassium ions (K^+)** pumped in.

2. **Leak Channels:** A large number of potassium leak channels remain open, allowing positive charges to leave the cell continuously.

B. Action Potential

An action potential is a rapid and temporary change in membrane potential that constitutes the nerve impulse. It is an **"all-or-none"** event.

1. **Depolarization (Rising Phase):** When a sufficient stimulus reaches the **threshold potential (around –55 mV)**, voltage-gated sodium channels open, and Na^+ rushes into the cell, reversing the charge inside to positive.
2. **Repolarization (Falling Phase):** Sodium channels close, and voltage-gated potassium channels open, allowing K^+ to flow out of the cell, restoring the negative internal charge.
3. The action potential propagates as a self-renewing wave of excitation along the axon to its terminal.

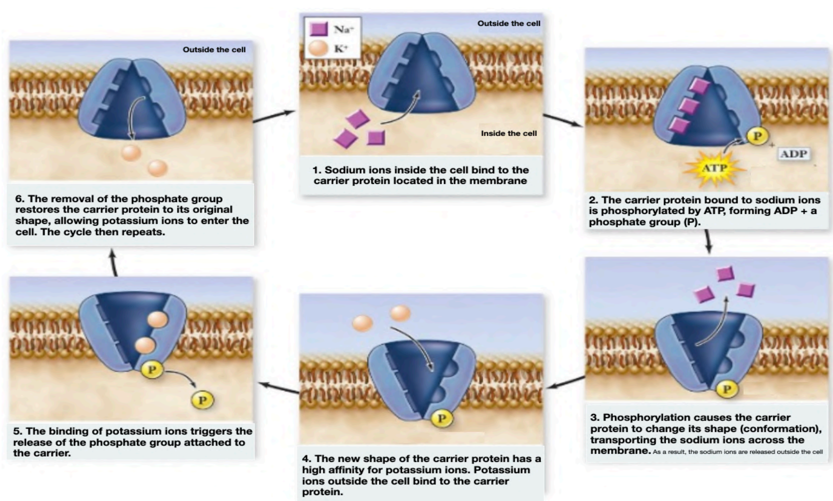


Figure 21: Mechanism of the Sodium-Potassium Pump in the Cell Membrane

The Synapse: The Point of Connection

A synapse is the junction between one neuron and another, or between a neuron and an effector cell (muscle or gland).

- **Electrical Synapse:** Rare in vertebrates; the signal is transmitted directly through gap junctions.
- **Chemical Synapse:** The most common type, where the electrical signal is converted into a chemical signal.

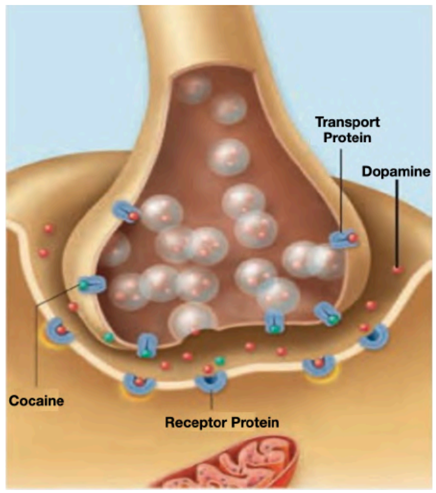


Figure 22: Structure of the Synaptic Junction

Mechanism of Chemical Synaptic Transmission:

1. The action potential reaches the end of the axon terminal.
2. Voltage-gated **calcium channels (Ca^{2+})** open, allowing calcium ions to enter.
3. Calcium triggers **synaptic vesicles** to fuse with the membrane and release **neurotransmitters** into the synaptic cleft.
4. The neurotransmitters bind to **receptors** on the postsynaptic membrane, causing a response — either **excitatory** or **inhibitory**.

Synaptic Integration:

A single neuron receives thousands of excitatory and inhibitory signals simultaneously. It integrates these signals (**spatial and temporal summation**), and if the combined input reaches the **threshold potential**, the neuron generates an action potential.

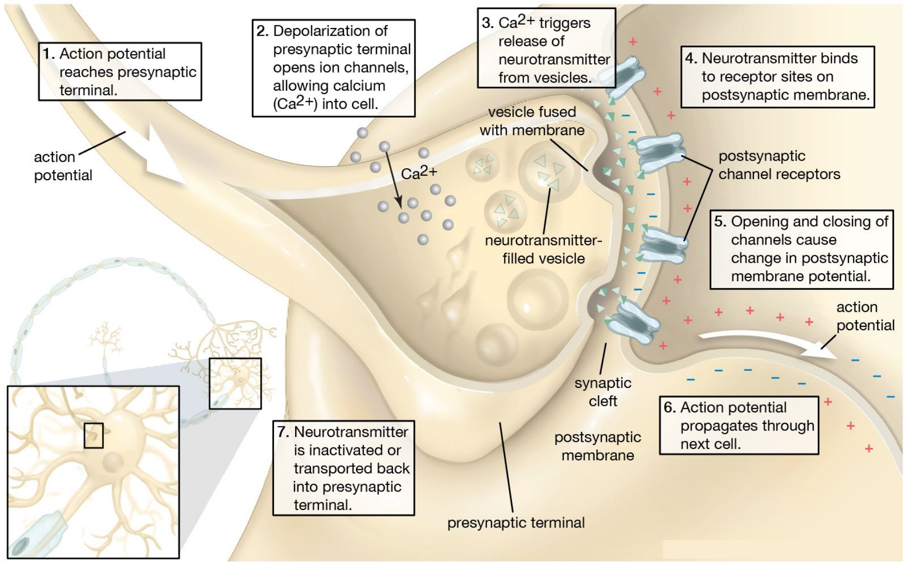


Figure 23: Mechanism of Nerve Impulse Transmission Across the Synapse

The Central Nervous System (Brain and Spinal Cord)

A. The Brain

The brain is the center for information processing and higher control. It has evolved greatly in vertebrates, especially the **forebrain**, which has become dominant.

- **Cerebrum:** The largest part of the human brain, responsible for higher functions. Its outer surface, the **cerebral cortex**, is the site of consciousness, thought, language, and memory.
- **Cerebellum:** Coordinates voluntary movements and maintains balance.
- **Brainstem:** Regulates vital functions such as breathing and heart rate.

B. The Spinal Cord

Extends from the brain through the vertebral column.

- **Function:** Acts as a main communication pathway between the brain and the body, and serves as a control center for **reflexes**, which are fast and involuntary actions.

The Peripheral Nervous System (PNS)

Consists of nerves that connect the central nervous system to the rest of the body.

A. Somatic Nervous System

- **Function:** Controls voluntary movements of skeletal muscles.

B. Autonomic Nervous System

- **Function:** Regulates involuntary functions of internal organs (such as the heart, blood vessels, and glands).
- **Sympathetic Division:** Prepares the body for emergencies — the **"fight or flight"** response.
- **Parasympathetic Division:** Dominates during rest — the **"rest and digest"** response. The two divisions work in **opposite yet complementary** ways.

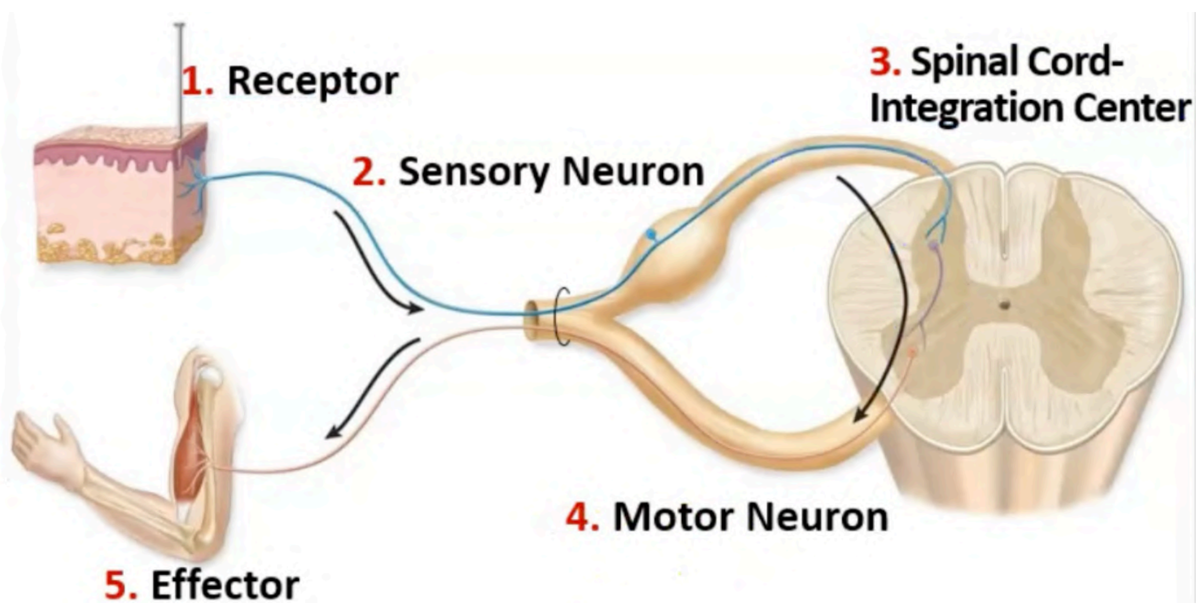
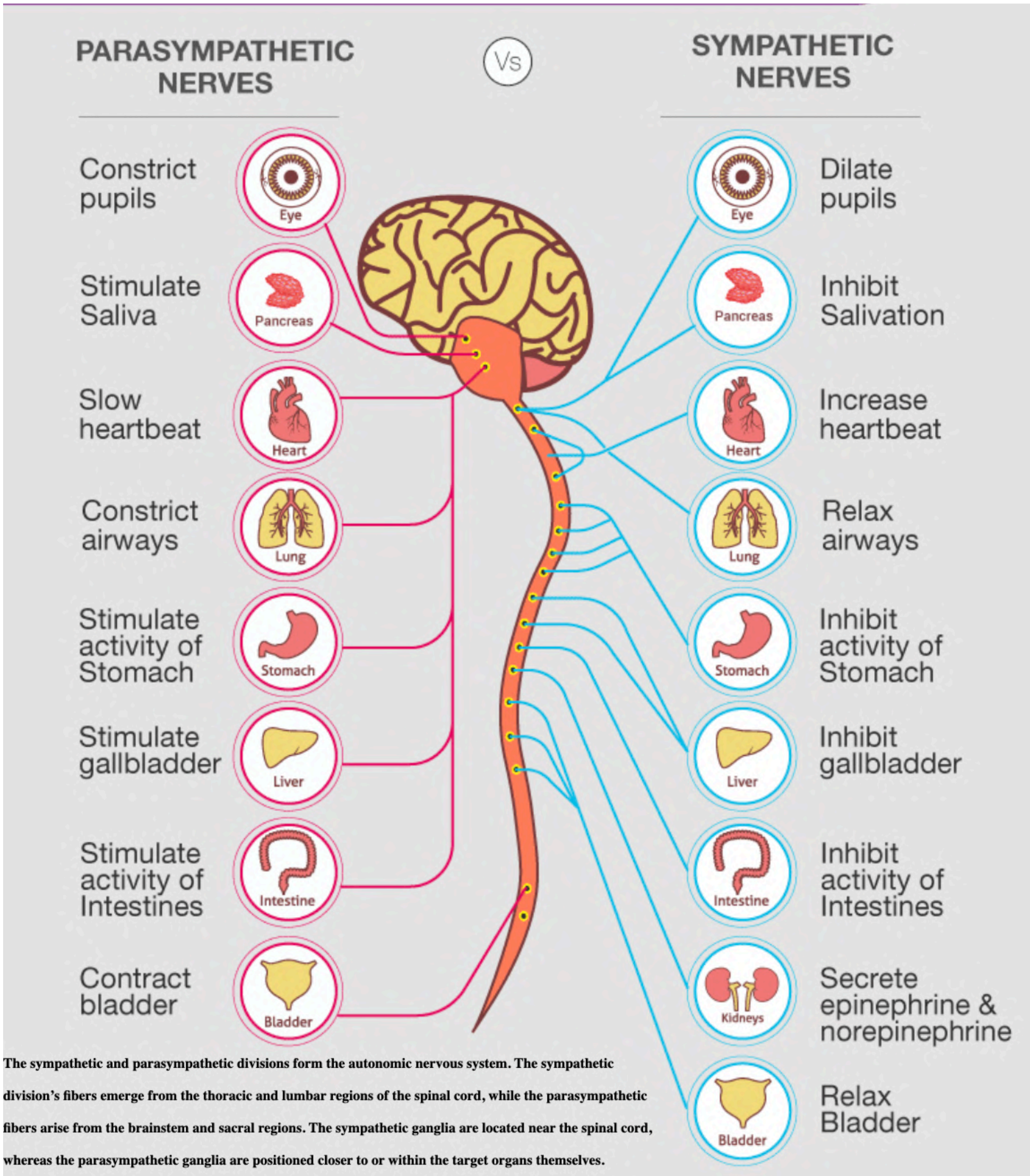


Figure 24: Structure of the Spinal Cord and the Pathway of Nerve Impulses Between the Skin and Muscles



The sympathetic and parasympathetic divisions form the autonomic nervous system. The sympathetic division's fibers emerge from the thoracic and lumbar regions of the spinal cord, while the parasympathetic fibers arise from the brainstem and sacral regions. The sympathetic ganglia are located near the spinal cord, whereas the parasympathetic ganglia are positioned closer to or within the target organs themselves.

Figure 25: Effects of the Sympathetic and Parasympathetic Nervous Systems on Body Organs

CHAPTER 05. / INTEGUMENTARY SYSTEM

Overview of the Integumentary System:

The integumentary system is defined as the outer covering that encloses the body of an organism and separates it from its environment. It mainly consists of the **skin** and its **accessory structures** (hair, nails, and glands), as well as **mucous membranes** that line internal passages.

Its primary function is to act as the **first line of immune defense**, forming a **physical and chemical barrier** that prevents the entry of disease-causing microbes. The skin is also home to a community of **normal flora** — beneficial microorganisms that help protect against harmful pathogens.

The Skin: Structure and Functions

The skin is the **largest organ** of the body in both weight and surface area. It is composed of three main layers:

- **Epidermis:** The thin, outermost layer that is continuously renewed. Its basal cells divide and migrate upward, producing the protein **keratin**, which provides strength and water resistance. These cells eventually die and slough off from the **stratum corneum** (the outer keratinized layer).
- **Dermis:** A thick layer of **connective tissue** beneath the epidermis that provides structural support. It contains **blood vessels**, **nerves**, **hair follicles**, and **glands**.

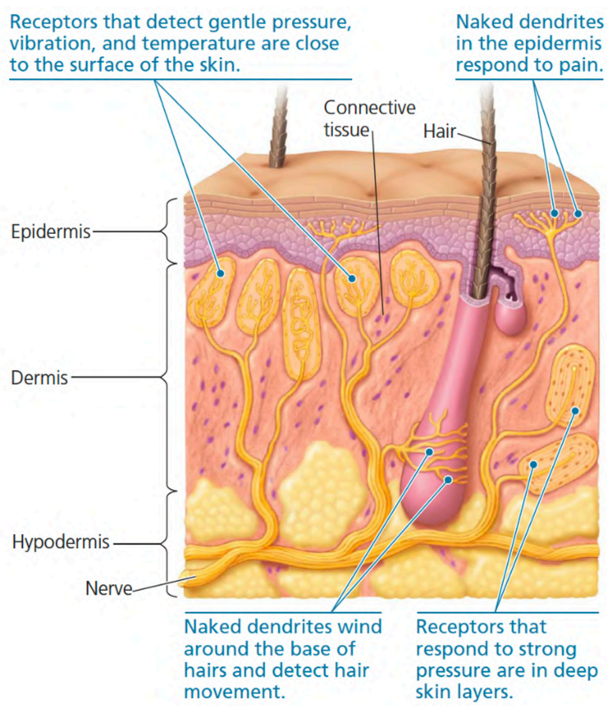


Figure 26: Anatomical Structure of the Skin Layers and Their Components

- **Hypodermis (Subcutaneous Layer):** The deepest layer, composed mainly of **fat tissue**, which serves as a **thermal insulator** and **shock absorber**.

Major Functions of Human Skin:

- **Protection:** Shields the body from physical, chemical, and ultraviolet (UV) damage.
- **Prevention of Water Loss:** Maintains body hydration and prevents dryness.
- **Thermoregulation:** Controls body temperature through **sweat secretion** and **blood vessel dilation or constriction**.
- **Sensation:** Contains nerve endings that detect **touch**, **pressure**, **temperature**, and **pain**.
- **Excretion:** Removes some waste products through sweat.
- **Vitamin D Synthesis:** Produces vitamin D upon **exposure to sunlight**.
- **Immune Role:** Contains specialized **immune cells** that contribute to body defense.

Skin Appendages:

These are specialized structures derived from the epidermis that perform additional functions.

A. Hair Hair consists of tough keratinized strands composed of a **root**, embedded in a **follicle** within the dermis, and a **shaft** that extends above the skin surface. Each hair is associated with a tiny **arrector pili muscle** and a **sebaceous (oil) gland**.

B. Nails: Nails are hard keratinized plates that cover the tips of fingers and toes. They grow from the **nail root** and slide over the **nail bed**. In other animals, **claws and hooves** are modified and analogous structures to human nails.

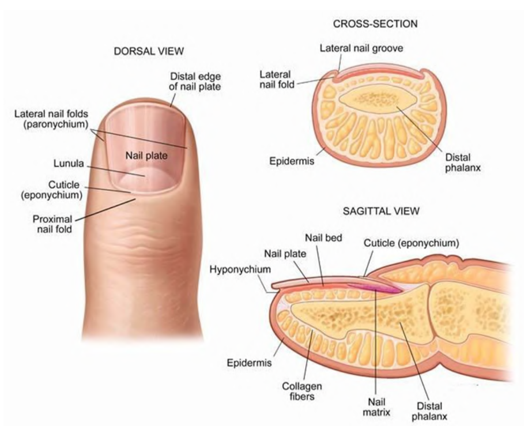


Figure 27: Anatomical Structure of the Nail and Its Components

C. Skin Glands

- **Sebaceous Glands:** Secrete an oily substance called **sebum** that lubricates the hair and skin. They are usually connected to hair follicles.
- **Eccrine Sweat Glands:** Distributed across most of the human body; they secrete **sweat**, which evaporates to cool the body, playing a vital role in **thermoregulation**.
- **Apocrine Sweat Glands:** Found in specific areas such as the **armpits**; they become active after puberty. The breakdown of their **organic-rich secretions** by bacteria causes **body odor**.

Diversity of the Integumentary Covering in Animals

The integumentary system shows great diversity and adaptations across the animal kingdom.

- **Vertebrates:** Fish possess **scales** and **mucous or venom glands**. Amphibians have **moist skin rich in glands**, which allows for **cutaneous respiration** (gas exchange through the skin).
- **Birds:** Their bodies are covered with **feathers**, which are **modified, lightweight scales** that provide **insulation** and enable **flight**.
- **Arthropods:** They have a **hard exoskeleton** that provides protection and support but requires **periodic molting** to allow for growth.

Skin Cancer

Skin cancer is the abnormal growth of skin cells, most often caused by **excessive exposure to ultraviolet (UV) radiation**.

A. Main Types:

1. **Basal Cell Carcinoma** and **Squamous Cell Carcinoma:** The most common and least dangerous forms. They originate in **non-pigmented epidermal cells**.
2. **Melanoma:** Arises from **melanocytes** (pigment-producing cells) and is the **most dangerous** and **aggressive** type, capable of spreading rapidly to other parts of the body.

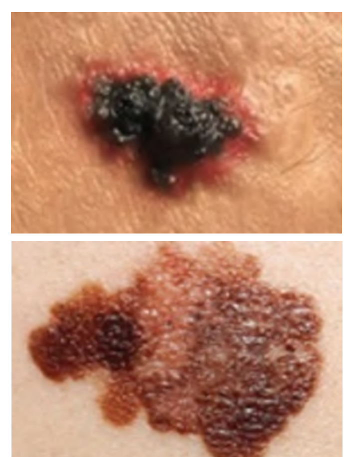


Figure 28: Skin Lesions with Irregular Borders and Uneven Pigmentation

B. Warning Signs (Distinguishing a Mole from Cancer):

- Any mole (nevus) that shows one or more of the following signs should be examined:
- **Asymmetry:** One half is different from the other.
- **Border:** Irregular, uneven, or blurred edges.
- **Color:** Uneven coloration with multiple shades.
- **Diameter:** Larger than 6 mm.
- **Evolving:** Changes in size, shape, or color over time.

Figure 29: A Raised Mole on the Skin Surface


CHAPTER 06
DIGESTIVE SYSTEM

Principles of Digestion and Feeding Types

Digestion is the process of breaking down large, complex food molecules into small, absorbable building units. Animals are classified according to their food sources into:

- **Herbivores:** Feed on plants.
- **Carnivores:** Feed on other animals.
- **Omnivores:** Feed on both plants and animals.

Digestion occurs either **intracellularly** (as in sponges) or **extracellularly** within a **digestive cavity**, which is the predominant method in most animals. The digestive system takes two main structural forms:

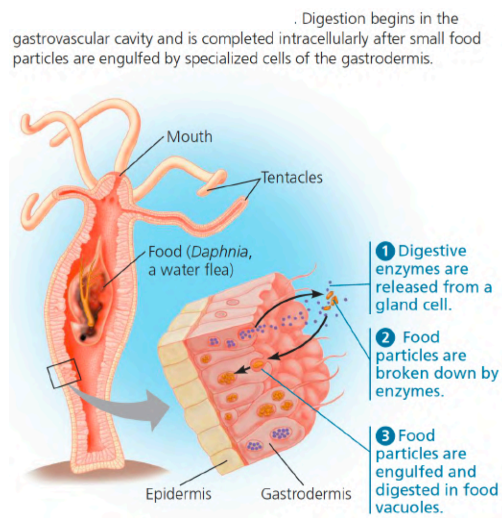


Figure 30: Anatomical Structure of Hydra and Its Feeding Mechanism

1. **Gastrovascular Cavity:** A simple digestive system with a single opening that functions as both mouth and anus (e.g., cnidarians).
2. **Digestive Tract (Alimentary Canal):** A specialized tube extending from the mouth to the anus, allowing each region to specialize in a particular function such as **digestion, absorption, or storage**.

The Journey of Food in the Vertebrate Digestive System

The vertebrate digestive system consists of a **tubular canal** and **accessory organs**, and the process of digestion proceeds through several sequential stages.

A. Mouth and Teeth

- **Function:** Digestion begins here with the **mechanical breakdown** of food by the teeth (chewing) and the **chemical digestion** of starch by **saliva**, which contains the enzyme **salivary amylase**.
- **Tooth Adaptations:** The shape of teeth reflects the animal's diet — **carnivores** have sharp canines for tearing, **herbivores** have flat molars for grinding, while **humans** possess a combination of both types.
- **Swallowing:** A coordinated process that begins voluntarily and then becomes involuntary. The **tongue** pushes food into the **pharynx**, while the **epiglottis** closes the airway to prevent food from entering the respiratory tract.

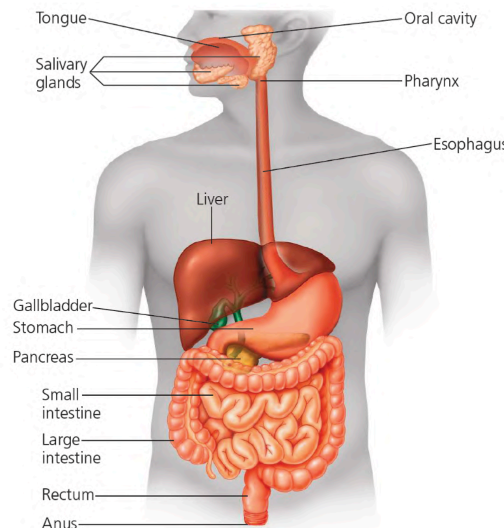


Figure 31: Anatomical Structure of the Human Digestive System

B. Esophagus and Stomach

- **Esophagus:** A muscular tube that transports food from the pharynx to the stomach through rhythmic contractions called **peristalsis**.
- **Stomach:** A muscular sac that stores, mixes, and begins the digestion of proteins.
  - **Gastric Juice:** Contains **hydrochloric acid (HCl)**, which kills microbes and denatures proteins, and **pepsinogen**, which is converted in the acidic environment to **pepsin**, the active enzyme that digests proteins.
  - **Chyme:** A semi-liquid mixture of partially digested food and gastric secretions.
  - **Gastric Ulcers:** Often associated with infection by the bacterium *Helicobacter pylori*.

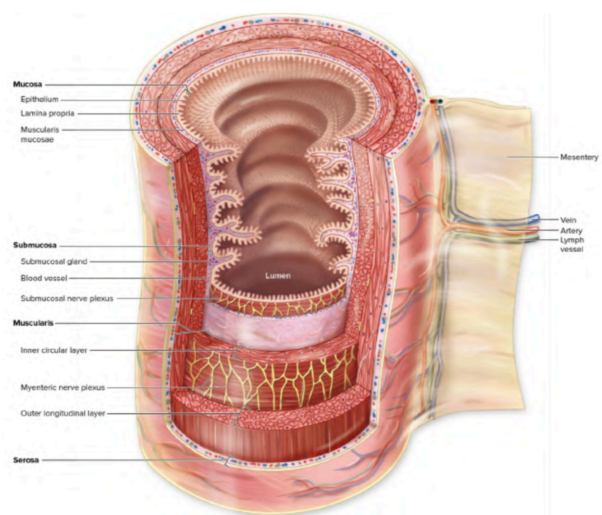


Figure 32: Anatomical Structure of the Gastrointestinal Tract Wall

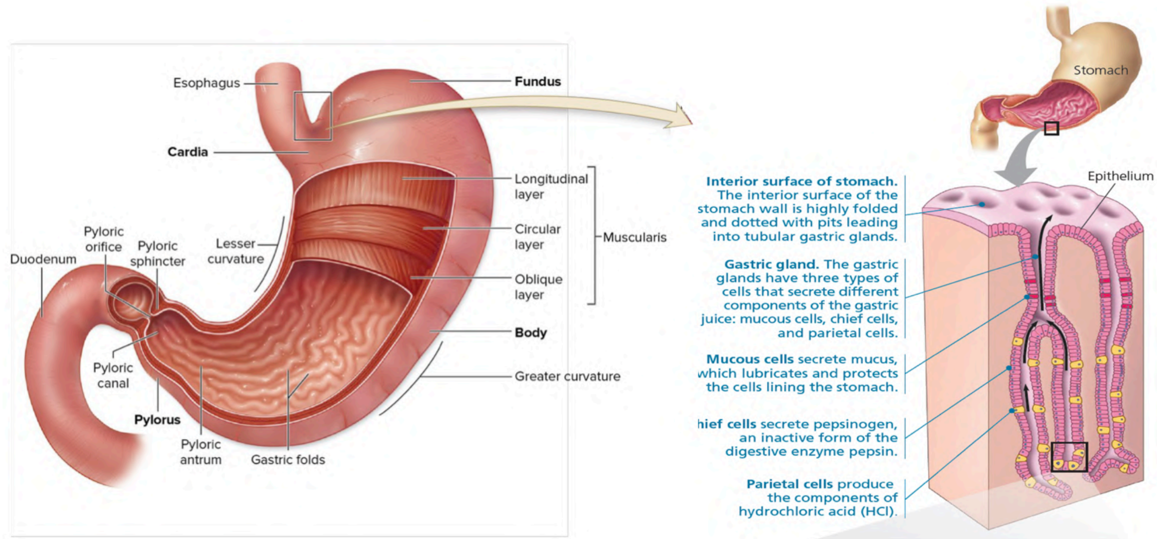


Figure 33: Internal Structure of the Stomach Wall and Gastric Glands

C. Small Intestine

The small intestine is the **main site for completing digestion** and **absorbing most nutrients**.

- **Structure:** It consists of three parts — the **duodenum**, **jejunum**, and **ileum**. Its inner wall contains folds covered with **finger-like projections** called **villi**, which are themselves lined with **microvilli**. These structures greatly increase the **surface area for absorption** — up to about **300 square meters** in humans.
- **Function:**
  1. **Completion of Digestion:** The small intestine receives **secretions from the pancreas and liver**, as well as **brush border enzymes** located on the microvilli, which complete the digestion of **carbohydrates, proteins, and fats**.
  2. **Absorption: Monosaccharides** and **amino acids** are absorbed into the bloodstream, while the products of fat digestion are assembled into **chylomicrons**, which enter the **lymphatic system** first.

D. Large Intestine / Colon

- **Function:** The large intestine is the **final section of the digestive tract**, responsible for **absorbing remaining water and salts**, and for **forming and storing feces** (waste material).
- **Colon Bacteria:** It hosts a vast number of **beneficial bacteria** that **ferment undigested fibers** and **produce essential vitamins** such as **vitamin K**.
- **Defecation:** Feces are expelled through the **rectum** and **anus**, which are controlled by two sphincters — an **internal (involuntary)** and an **external (voluntary)** sphincter.

Accessory Digestive Organs

These are organs located **outside the digestive tract** but essential for the digestion process through their secretions.

- **Pancreas:** Secretes **alkaline pancreatic juice** containing powerful digestive enzymes such as **trypsin** (for protein digestion), **amylase** (for starch digestion), and **lipase** (for fat digestion). It also produces the hormones **insulin** and **glucagon**, which regulate **blood sugar levels**.
- **Liver:** The **largest internal organ** in the body. It produces **bile**, which **emulsifies fats** - breaking them down into small droplets for easier digestion. The liver also performs vital **metabolic functions**, including **detoxification** and **synthesis of blood proteins**.
- **Gallbladder:** A small sac that **stores and concentrates bile** produced by the liver until it is released into the small intestine.

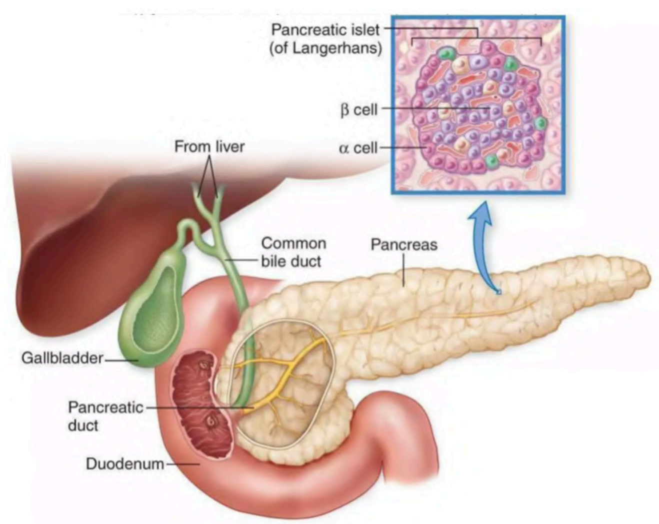


Figure 34: Anatomical Structure of the Pancreas

Specialized Digestive Adaptations in Vertebrates

Animals especially **herbivores**—have developed special adaptations for digesting **cellulose**, a major component of plant cell walls that most animals cannot digest on their own.

- **Ruminants:** Animals such as **cows** possess a **complex stomach with four chambers** (the largest being the **rumen**). Symbiotic **microorganisms in the rumen** ferment cellulose, breaking it down into simpler compounds. The animal then **regurgitates** the partially digested food (called **cud**) and **chews it again** to increase digestive efficiency.
- **Cecal Digesters:** Other animals, such as **rabbits and horses**, have an enlarged pouch called the **cecum** located at the junction of the small and large intestines. Microbes in the cecum **ferment cellulose**, aiding in digestion. Some of these animals (like rabbits) exhibit **coprophagy** — the behavior of **re-ingesting feces** to pass food through the digestive tract a second time and absorb fermentation products more effectively.

Regulation of Digestion

The process of digestion is precisely regulated by both the **nervous** and **hormonal** systems.

- **Nervous Regulation:** The sight, smell, or taste of food stimulates the secretion of **saliva** and **gastric juices** in preparation for digestion.
- **Hormonal Regulation:**
    - **Gastrin:** Secreted by the **stomach**; it stimulates the release of **hydrochloric acid (HCl)**.
    - **Secretin** and **Cholecystokinin (CCK):** Secreted by the **duodenum** when acidic or fatty chyme enters from the stomach. They **inhibit stomach activity** while **stimulating secretions from the pancreas and gallbladder**.

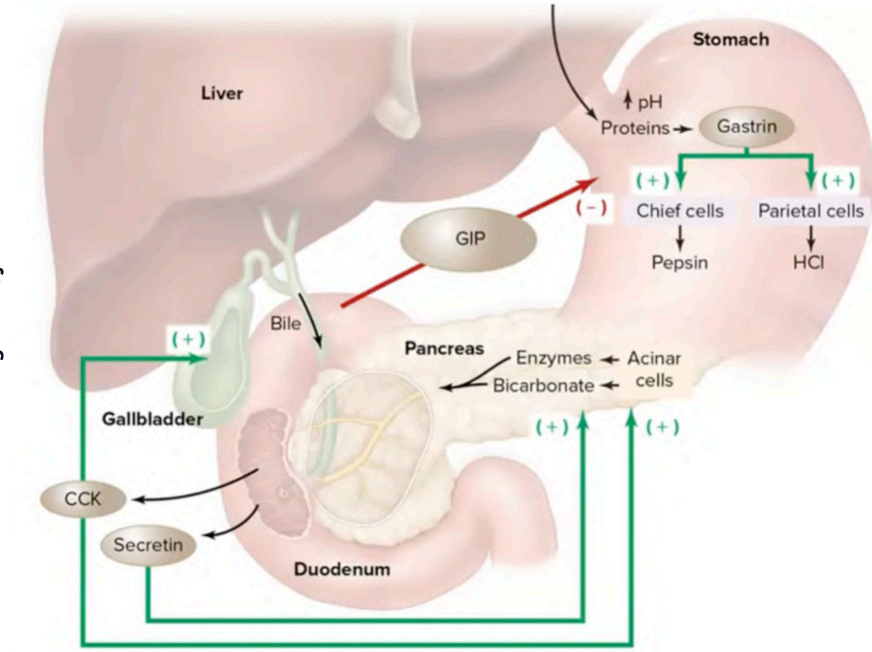
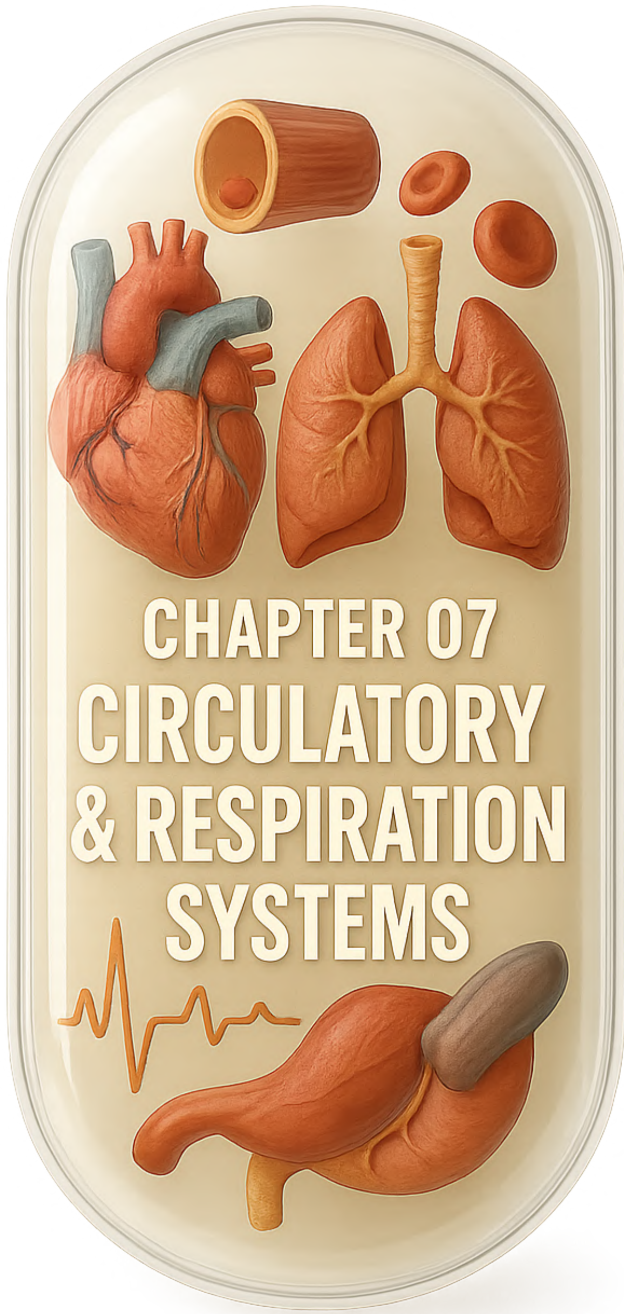


Figure 35: Hormonal Regulation of Digestive Secretions in the Digestive System

Nutrition and Energy

Food provides the body with both **energy** (measured in kilocalories) for vital activities and **essential nutrients** that the body cannot synthesize on its own.

- **Energy Balance:** When **energy intake exceeds energy expenditure**, the surplus is stored as **fat**, which may lead to **obesity**.
- **Appetite Regulation:** Controlled by a **center in the hypothalamus** of the brain and influenced by several hormonal signals, such as:
    - **Ghrelin:** Stimulates hunger.
    - **Leptin** and **Insulin:** Suppress appetite.
- **Essential Nutrients:** Include **essential amino acids**, **essential fatty acids**, **vitamins**, and **minerals** - all of which must be obtained through the **diet** to maintain proper body health.


CHAPTER 07
CIRCULATORY
& RESPIRATION
SYSTEMS

The Circulatory System: The Internal Transport Network

The circulatory system is the transport network responsible for distributing oxygen, nutrients, and hormones, as well as removing wastes from the body's cells. Its structural complexity ranges from simple organisms to highly developed vertebrates.

A. Circulatory Systems in Invertebrates

- **No true circulatory system:** Simple organisms (such as sponges and cnidarians) rely on the movement of water from the surrounding environment through body cavities to transport materials.
- **Open circulatory system:** Found in most arthropods and mollusks. In this system, a fluid called *hemolymph* is pumped from the heart into body cavities, where it directly bathes the tissues before returning to the heart.
- **Closed circulatory system:** Found in annelids and cephalopods. Here, blood is always confined within a network of blood vessels, allowing for faster and more efficient circulation.

B. Circulation in Vertebrates

- **Fish:** Possess a simple two-chambered heart (one atrium and one ventricle) and a single circulatory loop. The heart pumps blood to the gills, where it is oxygenated, and then to the rest of the body before returning to the heart. A disadvantage of this system is the drop in blood pressure after passing through the gills.

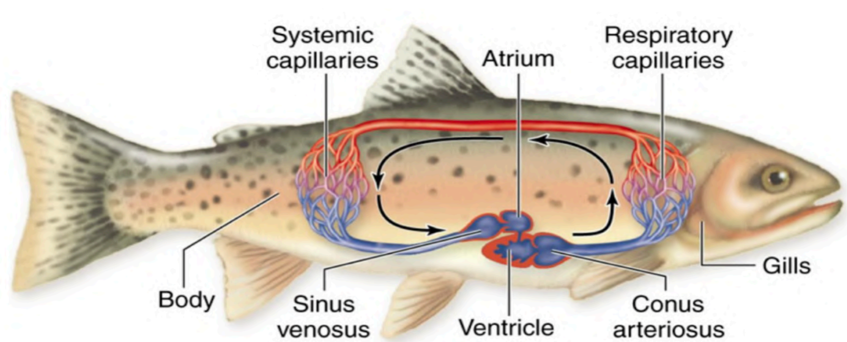


Figure 36: Circulatory System in Fish

- **Amphibians and reptiles:** Have a double circulatory system (pulmonary and systemic) and a three-chambered heart (two atria and one ventricle). This arrangement allows for partial separation of oxygenated and deoxygenated blood, providing higher pressure to blood flowing to the body.
- **Mammals, birds, and crocodiles:** Possess the most efficient system—a four-chambered heart (two atria and two completely separated ventricles). This complete separation prevents the mixing of oxygenated and deoxygenated blood, supporting the high metabolic rates required to maintain body temperature.

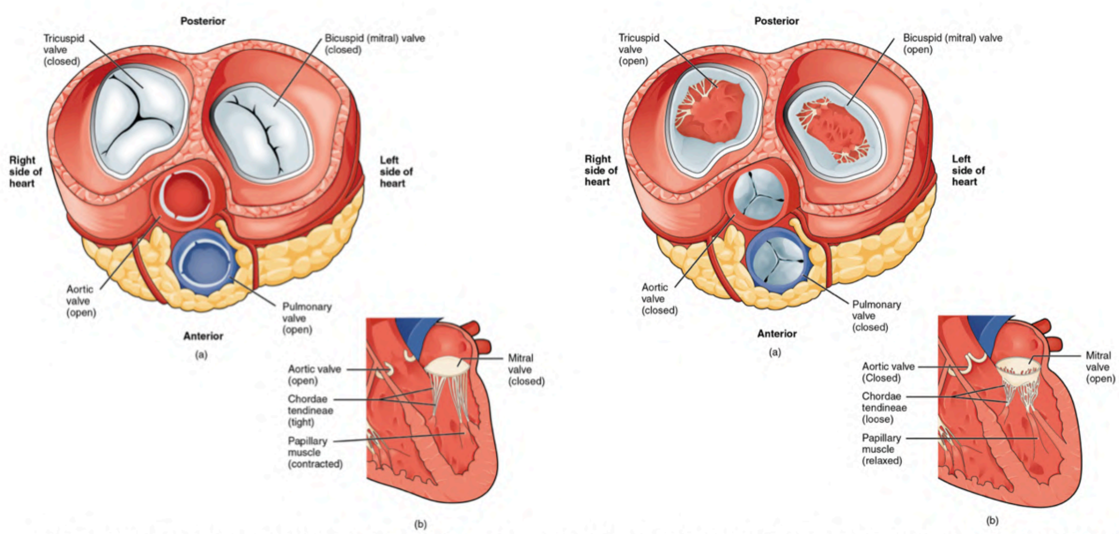
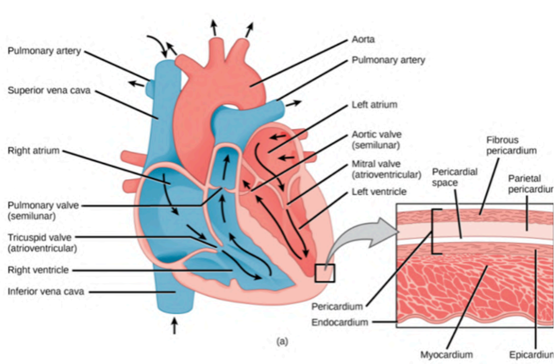


Figure 37: Cardiac Valves in Open and Closed Positions

(a) shows the atrioventricular valves closed while the two semilunar valves are open. This occurs when the ventricles contract to eject blood into the pulmonary trunk and aorta. Closure of the two atrioventricular valves prevents blood from being forced back into the atria. This stage can be seen from a frontal view in Figure (b). Blood Flow from the Left Ventricle into the Great Vessels (a) A transverse section through the heart illustrates the four heart valves during ventricular contraction. The two atrioventricular valves are closed, but the two semilunar valves are open. The atria and vessels have been removed. (b) A frontal view shows the closed mitral (bicuspid) valve that prevents back flow of blood into the left atrium. The aortic semilunar valve is open to allow blood to be ejected into the aorta.



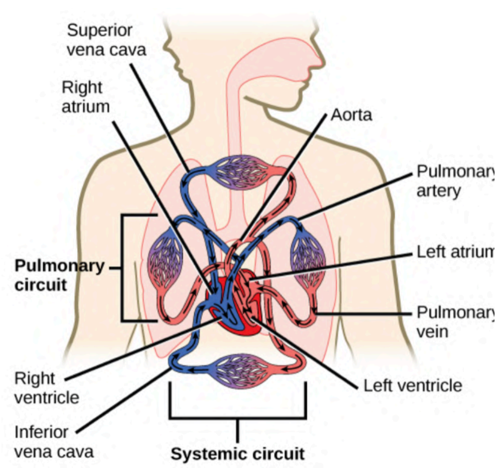


Figure 38: Diagram of Human Circulation and the Mechanism of Blood Flow Through the Heart

C. The Heart and Blood Vessels in Mammals

- **Cardiac Cycle:** The cardiac cycle is the sequence of **contraction (systole)** and **relaxation (diastole)** of the heart chambers, which together constitute a heartbeat. The characteristic **"lub-dub"** sounds of the heart are produced by the **closure of the heart valves**, which ensure that blood flows in only one direction.

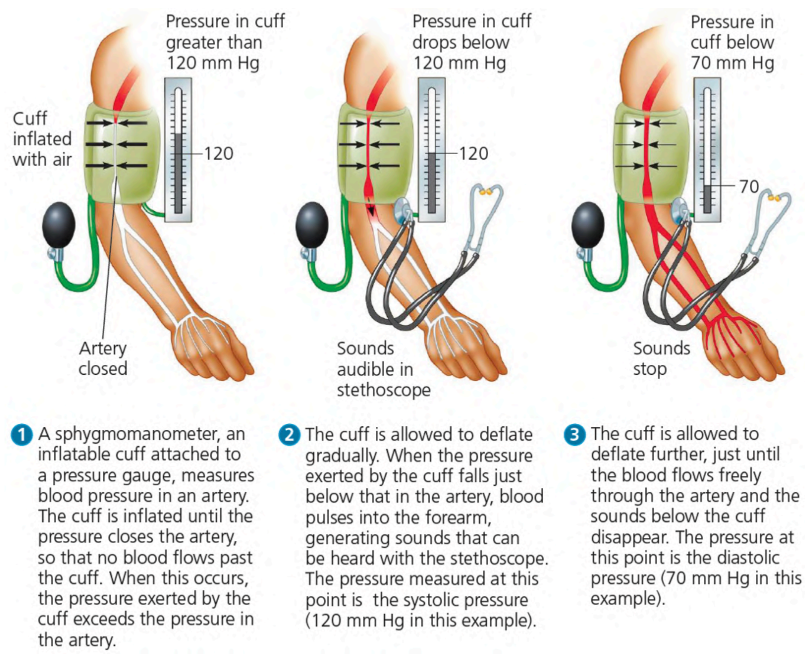


Figure 39: Steps for Measuring Blood Pressure Using a Sphygmomanometer and Stethoscope

Blood Vessels:

- Arteries: Carry blood away from the heart. They have thick, elastic walls to withstand high pressure.
- Veins: Return blood to the heart and contain valves that prevent the backflow of blood.
- Capillaries: A vast network of microscopic, thin-walled vessels that form the site of exchange of materials between the blood and body tissues.

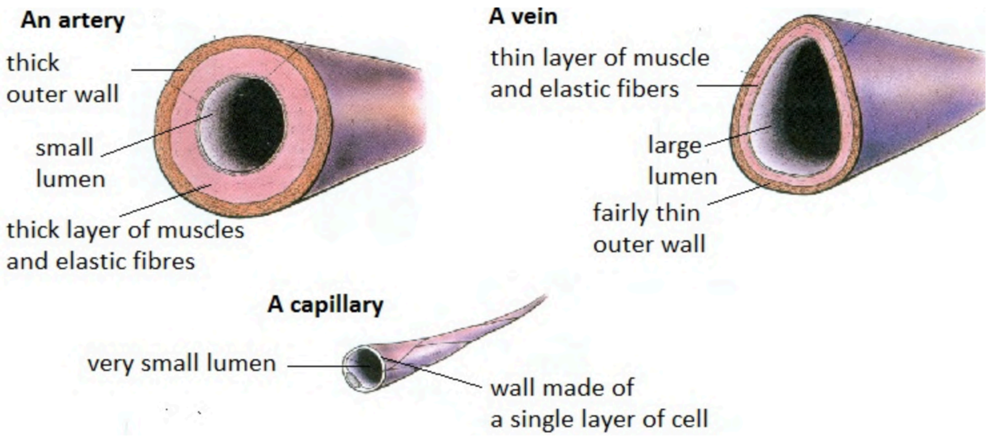


Figure 40: Structure of Blood Vessels – Arteries, Veins, and Capillaries

Regulation of Heartbeat and Blood Pressure:

- The heartbeat is initiated spontaneously by specialized cells in the sinoatrial (SA) node, which acts as the natural pacemaker of the heart.
- The autonomic nervous system adjusts the rate and strength of heart contractions.
- Blood pressure is maintained through a negative feedback mechanism known as the baroreceptor reflex, along with hormones that regulate blood volume.

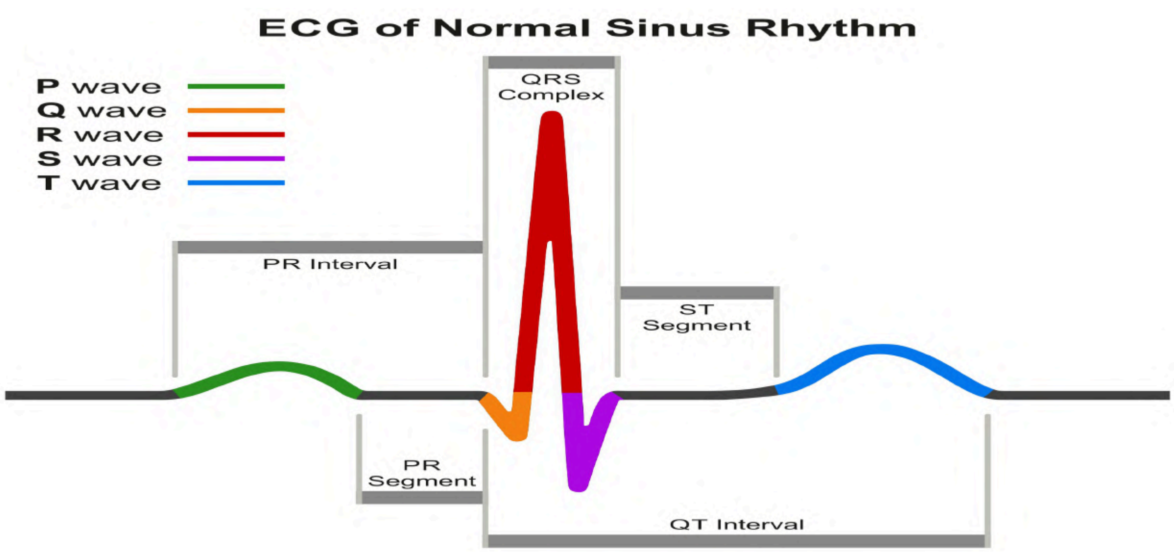


Figure 41. A normal sinus rhythm on an electrocardiogram (ECG) is a regular heart rhythm originating from the sinoatrial (SA) node, typically showing a consistent rate of 60-100 beats per minute with properly formed P waves before each QRS complex.

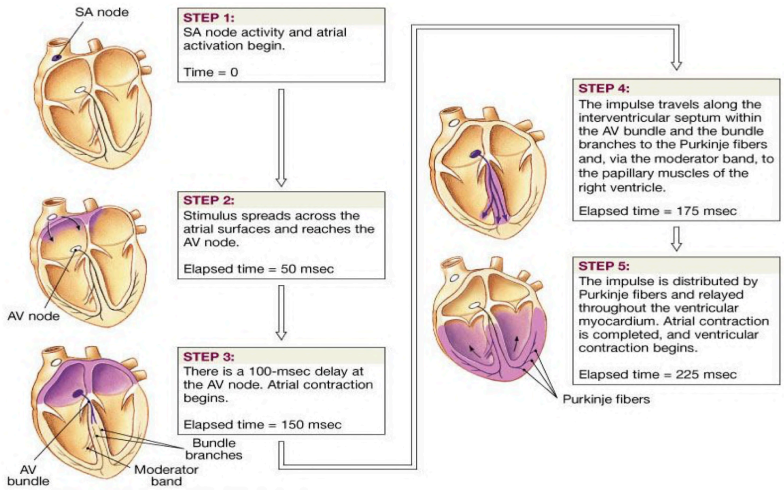


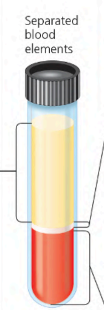
Figure 42. Impulse Conduction through the Heart

D. Components of the Blood and the Lymphatic System:

Blood: A fluid connective tissue composed of:

- **Plasma:** The liquid medium in which other components are suspended.
- **Red blood cells (erythrocytes):** Contain **hemoglobin**, which transports oxygen.
- **White blood cells (leukocytes):** Function as part of the **immune system**.
- **Platelets (thrombocytes):** Cell fragments essential for **blood clotting**.
- **Lymphatic System:** An **open network of vessels** that returns excess fluid and proteins from tissues back to the bloodstream, and plays a **vital role in immunity**.

Plasma 55%	
Constituent	**Major functions**
Water	Solvent
Ions (blood electrolytes) Sodium Potassium Calcium Magnesium Chloride Bicarbonate	Osmotic balance, pH buffering, and regulation of membrane permeability
Plasma proteins	
Albumin	Osmotic balance, pH buffering
Immunoglobulins (antibodies)	Defence
Apolipoproteins	Lipid transport
Fibrinogen	Clotting
Substances transported by blood Nutrients (such as glucose, fatty acids, vitamins), waste products of metabolism, respiratory gases (O_2 and CO_2), and hormones	



Cellular elements 45%		
Cell type	**Number** per μL (mm^3) of blood	**Functions**
Leukocytes (white blood cells) Basophils Lymphocytes Eosinophils Neutrophils Monocytes	5000–10 000	Defence and immunity
Platelets	250 000–400 000	Blood clotting
Erythrocytes (red blood cells)	5 000 000–6 000 000	Transport of O_2 and some CO_2

Figure 43: Components of Blood

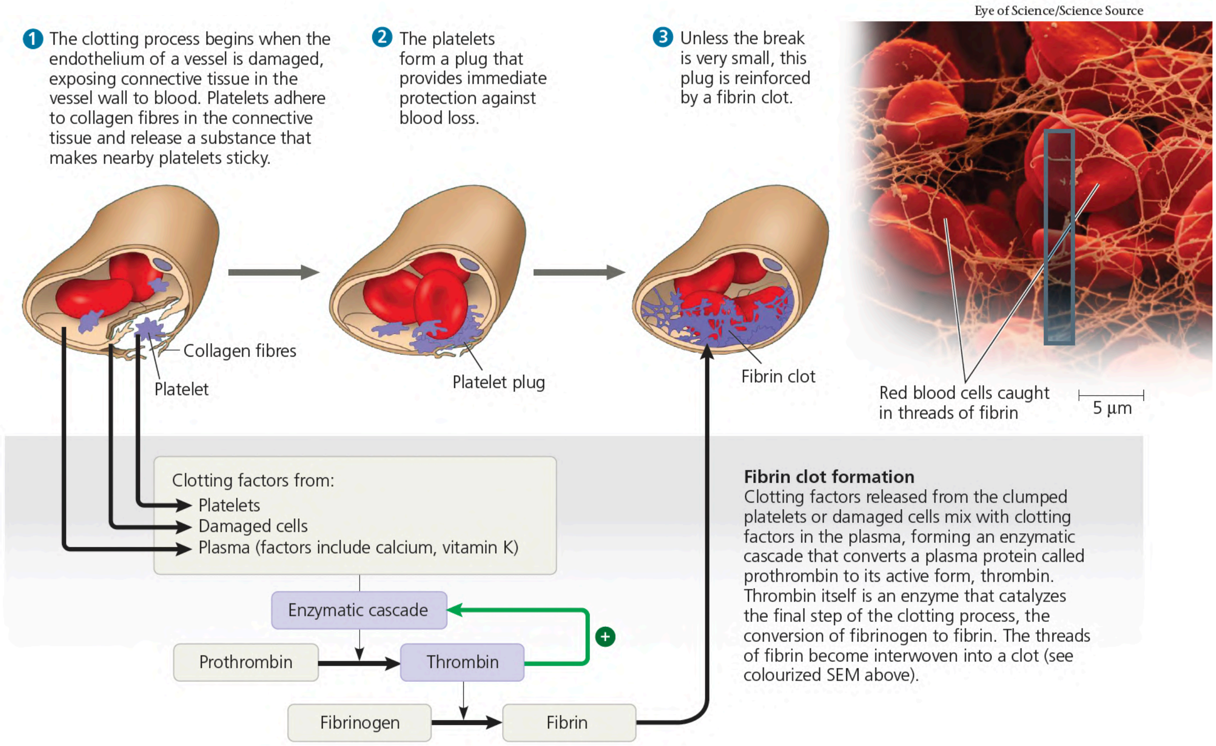


Figure 44: Stages of Blood Clotting and Formation of a Thrombus to Stop Bleeding

The Respiratory System: Gas Exchange Network

The respiratory system works in coordination with the circulatory system to **supply the body with oxygen** and **remove carbon dioxide**.

A. Principles of Gas Exchange

Gas exchange occurs by **diffusion** across **moist respiratory surfaces**. According to **Fick's Law**, the efficiency of diffusion increases with:

1. An **increase in the surface area** of the respiratory membrane.
2. A **decrease in the diffusion distance**.
3. A **greater difference in the partial pressure** of gases across the surface.

B. Diversity of Respiratory Organs

- **Gills:** Specialized structures for breathing in water. Fish gills are extremely efficient due to the **countercurrent flow mechanism**, where **blood flows in the opposite direction to water**, maximizing oxygen uptake.
- **Tracheal System:** A network of branched tubes found in insects that **delivers air directly to body cells**.
- **Lungs:** Internal sacs adapted for breathing air - a feature that **reduces water loss**.

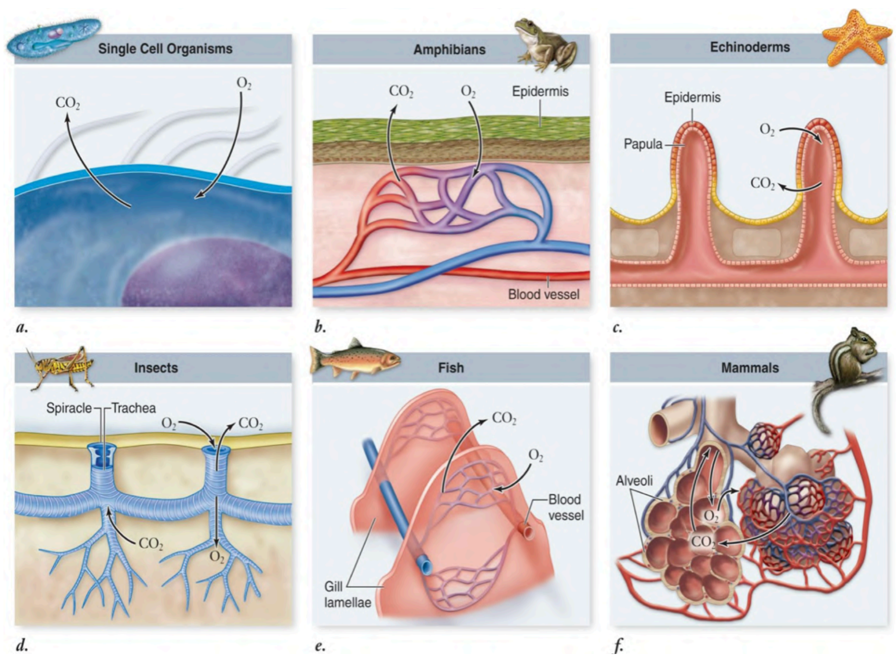


Figure 45: Mechanisms of Gas Exchange in Different Organisms

C. The Respiratory System in Mammals and Birds

- **Mammals:** The airway consists of the **trachea**, which branches into **bronchi** and further into **bronchioles**, ending in millions of tiny air sacs called **alveoli**, where **gas exchange** occurs with the blood. Breathing occurs through a **negative pressure mechanism** generated by the **contraction of the diaphragm** and **intercostal muscles**.
- **Birds:** Birds possess the **most efficient respiratory system** among terrestrial vertebrates. Their **unidirectional airflow system** through the lungs and air sacs prevents the mixing of **fresh air** with **stale air**, ensuring continuous oxygen exchange even during exhalation.

D. Gas Transport in the Blood

Blood acts as the **transport medium** linking the lungs to the body tissues.

- **Oxygen Transport:** About **98% of oxygen** is carried **bound to hemoglobin** within red blood cells.
- **Carbon Dioxide Transport:** Carbon dioxide is carried in **three forms**:
  - A small portion **dissolved in plasma**.
  - A portion **bound to hemoglobin**.
  - The majority (**about 70%**) is **converted inside red blood cells** into **bicarbonate ions ($-HCO_3$)**, which are then transported in the plasma.

Forced Breathing:

Forced breathing is a type of respiration in which **voluntary muscles** are used to assist in **inhaling or exhaling air** from the lungs. It typically occurs when the body requires a **greater amount of oxygen** or needs to **expel carbon dioxide more rapidly**, such as during **intense exercise** or certain **medical conditions**.

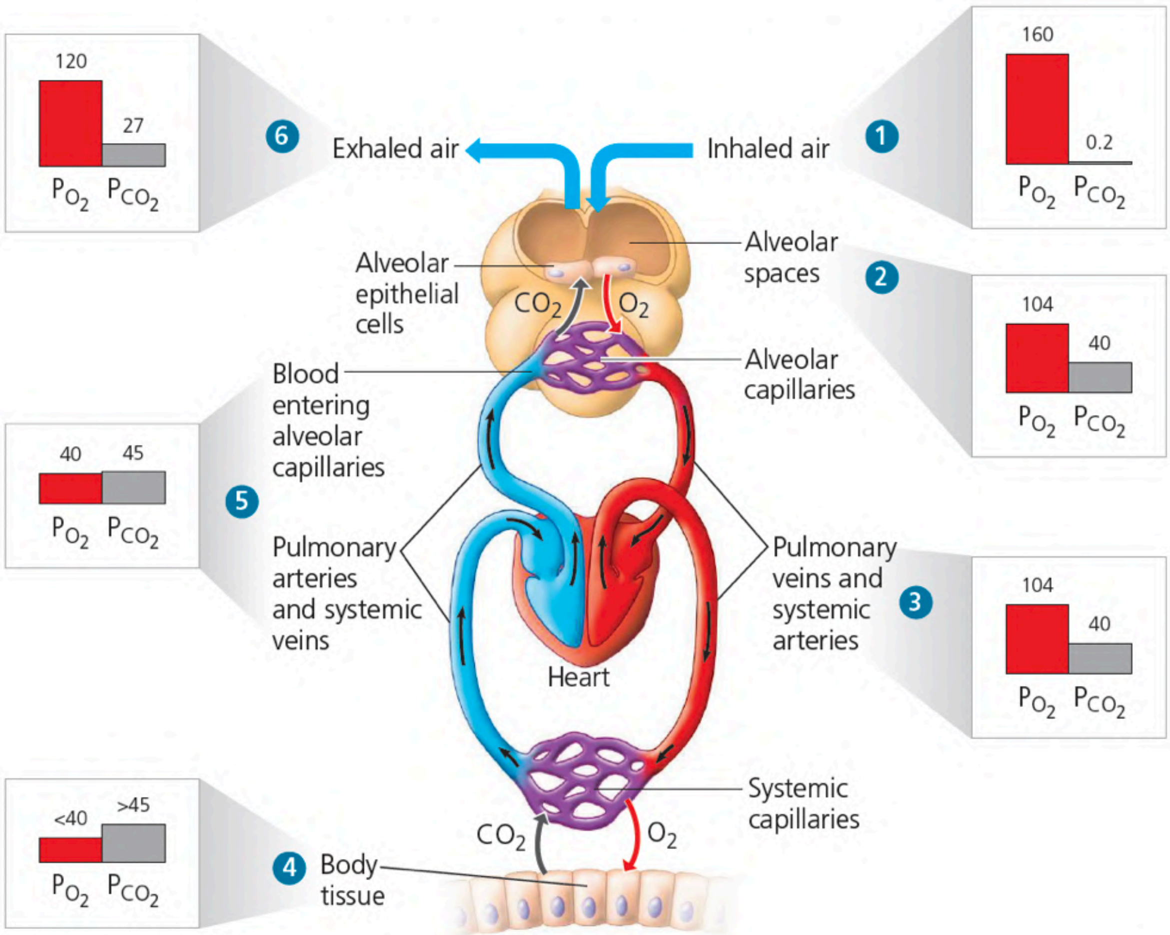
Types of Forced Breathing:

1. Forced Inspiration:

- Involves the use of **additional muscles**, such as the **neck muscles (sternocleidomastoid)** and **upper back muscles**, to **expand the chest cavity further**.
- Helps bring a **larger volume of air** into the lungs.

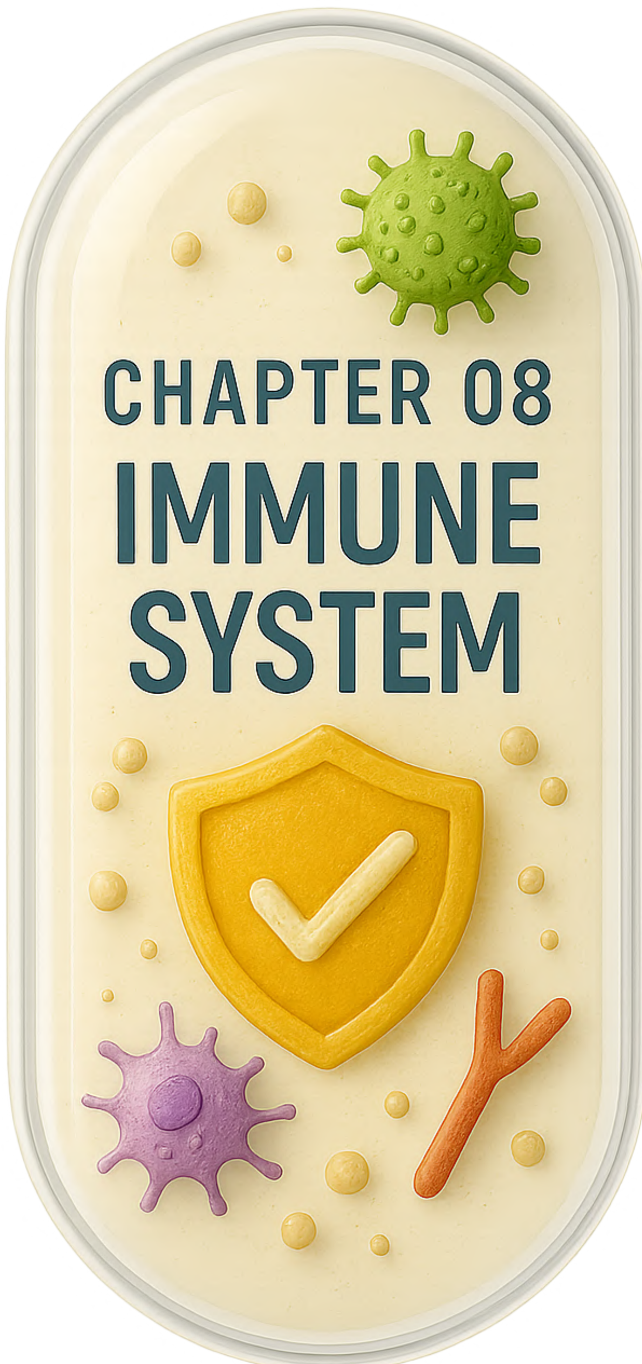
2. Forced Expiration:

- Utilizes the **abdominal muscles** and **internal intercostal muscles** to **forcefully expel air** from the lungs.
- Commonly occurs during **coughing**, **blowing**, or **intense physical exertion**.



Gas Exchange in Blood Capillaries of the Lungs and Systemic Circulation: As a result of gas exchange in the lungs**, the** pulmonary arteries **carry** deoxygenated blood **rich in** carbon dioxide **and low in** oxygen **concentration. After** oxygen diffusion **into the blood and** carbon dioxide removal**, the** oxygen content **of the blood in the** pulmonary veins **increases, while** carbon dioxide levels **decrease. During** systemic circulation**, the** arteries **carry** oxygen-rich blood **to the tissues, where** oxygen diffuses into the cells **and** carbon dioxide diffuses into the blood**. Consequently, the blood in the** systemic veins **becomes** low in oxygen **and** high in carbon dioxide**.**

Figure 46: Gas Exchange Between Alveoli and Body Tissues Through the Circulatory System


CHAPTER 08
IMMUNE
SYSTEM

Overview: The Three Lines of Defense

Vertebrates possess a multi-layered defense system to protect the body from pathogens. This system can be divided into three main lines of defense:

1. **First Line of Defense (Physical and Chemical Barriers):** Represented by the integumentary system (skin and mucous membranes), which prevents the entry of microbes in the first place.
2. **Second Line of Defense (Innate/Nonspecific Immunity):** A rapid, general response that begins once the first line is breached. It includes specialized cells and proteins that attack any foreign body.
3. **Third Line of Defense (Adaptive/Specific Immunity):** A highly specialized response that recognizes and eliminates a particular pathogen, characterized by the formation of long-term immune "memory."

The First Line of Defense: Physical and Chemical Barriers

This line serves as a protective shield preventing invaders from entering the body.

- **Skin:** The largest organ of the body, forming an impermeable physical barrier. It also secretes sweat and oils that make its surface acidic (pH 3–5), inhibiting the growth of many microbes. Sweat contains the enzyme *lysozyme*, which breaks down bacterial cell walls.
- **Mucous Membranes:** Line the digestive, respiratory, and urogenital tracts. These membranes secrete sticky mucus that traps microbes, which are then expelled or destroyed through various mechanisms:
  - **Respiratory system:** Cilia move mucus upward to be swallowed and digested in the stomach.
  - **Digestive system:** Strong stomach acid kills most microbes that reach it.
  - **Urogenital system:** Acidic secretions and the continuous flow of urine help prevent microbial growth.

The Second Line of Defense: Innate (Nonspecific) Immunity

When the first line is breached, an immediate, non-specific response begins.

A. Innate Immune Cells

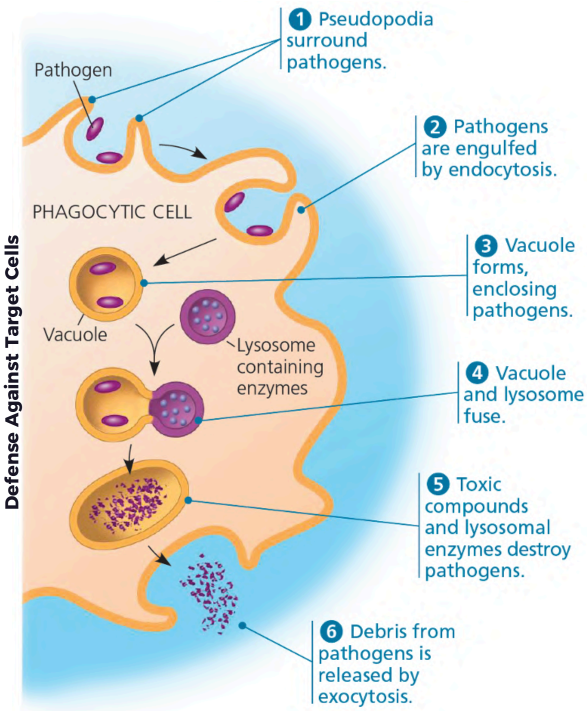


Figure 47: Mechanism of Natural Killer (NK) Cell Action in Immune Defense Against Target Cells

- **Macrophages:** Large phagocytic cells that roam tissues, engulfing and digesting any foreign particles they encounter - from bacteria and viruses to dead cell debris.
- **Neutrophils:** The most abundant white blood cells and the first to arrive at the infection site; they efficiently engulf pathogens.
- **Natural Killer (NK) Cells:** Do not attack microbes directly but specialize in identifying and destroying virus-infected or cancerous body cells by inducing programmed cell death (apoptosis).

B. The Inflammatory Response

It is a localized response to injury or infection, characterized by four main symptoms: redness, heat, swelling, and pain. This response occurs as a result of the release of chemical substances (such as histamine) from damaged cells, causing blood vessels to dilate and become more permeable, allowing immune cells to flow into the affected area.

C. Fever

Fever is a systemic (whole-body) response that raises the body's temperature. It is triggered by cytokines (such as interleukin-1) secreted by phagocytic cells and helps inhibit microbial growth while enhancing the activity of immune cells.

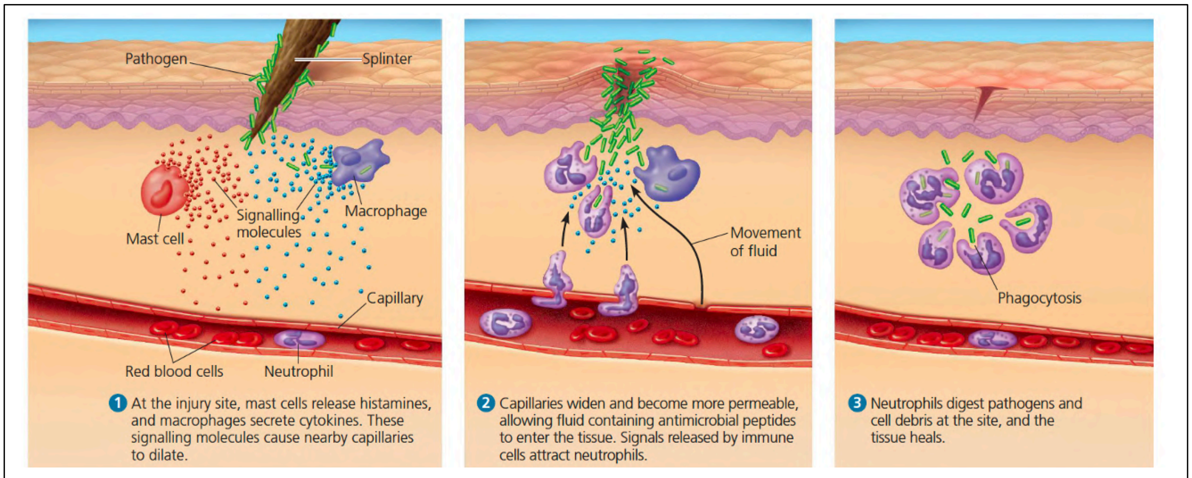


Figure 48: Innate Immune Response Following a Wound and Bacterial Entry

D. Antimicrobial Proteins

- **Complement System:** A group of about 30 proteins found in blood plasma. When activated, they can form pores in microbial membranes (leading to their death) or “tag” them to make phagocytosis easier.
- **Interferons:** Proteins secreted by virus-infected cells that act as warning signals to neighboring cells, stimulating their antiviral defenses and preventing viral replication.

The Third Line of Defense: Adaptive (Specific) Immunity

This is a highly advanced response characterized by four main features: **specificity**, **diversity**, **memory**, and the **ability to distinguish self from non-self**.

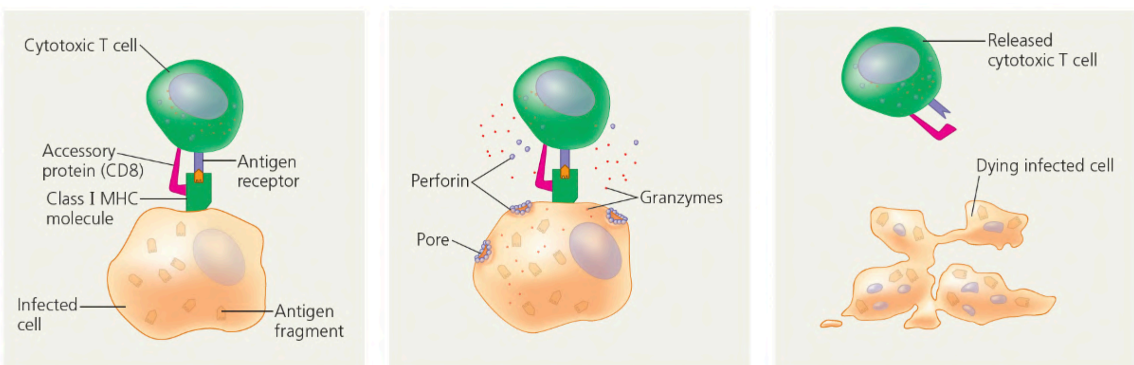
A. Basics of the Adaptive Response

- **Antigen:** Any molecule (usually a protein) capable of eliciting a specific immune response.
- **Lymphocytes:** The key cells of adaptive immunity, divided into two main types:
  - o **B Cells:** Responsible for humoral immunity.
  - o **T Cells:** Responsible for cell-mediated immunity.

B. Cell-Mediated Immunity (Role of T Cells)

This type of immunity targets infected body cells.

- **Major Histocompatibility Complex (MHC):** Proteins on the surface of body cells that "display" fragments of internal proteins (antigens) to T cells.
- **Helper T Cells (CD4):** The "commanders" of the immune system. They are activated when they recognize an antigen presented by an antigen-presenting cell (such as a macrophage). Once activated, they secrete cytokines that regulate and activate all other immune cells.
- **Cytotoxic T Cells (CD8):** The "soldiers." They recognize virus-infected or cancerous body cells displaying foreign antigens on their surfaces and kill them directly.



1. An activated cytotoxic T cell binds to a class I MHC–antigen fragment complex on an infected cell via its antigen receptor and an accessory protein (called CD8).
2. The T cell releases perforin molecules, which form pores in the infected cell membrane, and granzymes, enzymes that break down proteins. Granzymes enter the infected cell by endocytosis.
3. The granzymes initiate apoptosis within the infected cell, leading to fragmentation of the nucleus and cytoplasm and eventual cell death. The released cytotoxic T cell can attack other infected cells.

Figure 49: Mechanism of Cytotoxic T (CD8) Cell Action in the Cell-Mediated Immune Response

C. Humoral Immunity (Role of B Cells and Antibodies)

This type of immunity targets pathogens found in body fluids (blood and lymph).

- **Activation of B Cells:** Occurs when an antigen binds to a B cell receptor, and—along with helper T cell signals—the B cell becomes activated.

- **Plasma Cells and Memory Cells:** Activated B cells divide into plasma cells (factories that produce antibodies) and long-lived memory cells (the basis of immune memory).
- **Antibodies:** Y-shaped proteins secreted into body fluids. Antibodies do not kill microbes directly; rather, they neutralize or mark them for elimination by phagocytic cells or the complement system.

Organs of the Immune System

Immune cells develop and become active in specialized lymphoid organs.

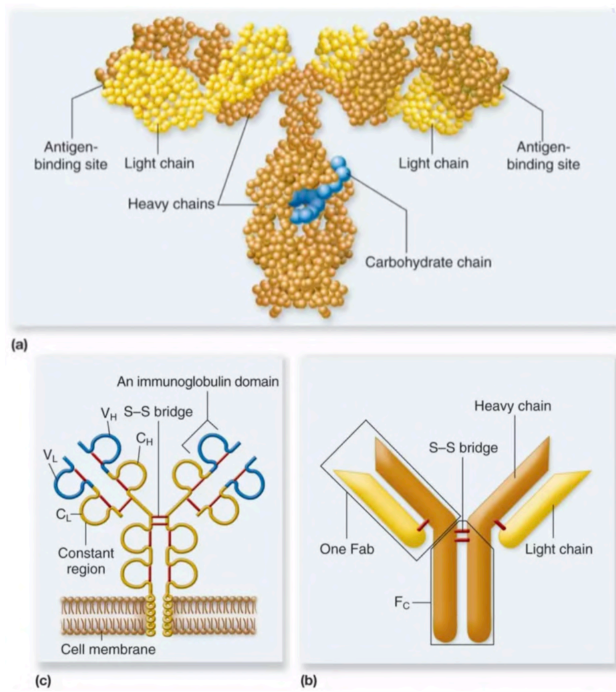


Figure 50: General Structure of Antibodies and Their Key Components

- **Primary Organs (Sites of Maturation):**
  - **Bone Marrow:** The source of all blood cells and the site where B cells mature.
  - **Thymus Gland:** The site where T cells mature.
- **Secondary Organs (Sites of Activation):**
  - **Lymph Nodes and Spleen:** Act as filters (for lymph and blood, respectively) and are the main locations where lymphocytes encounter antigens to activate the immune response.

Immune System Applications and Disorders

A. Blood Groups and Organ Rejection

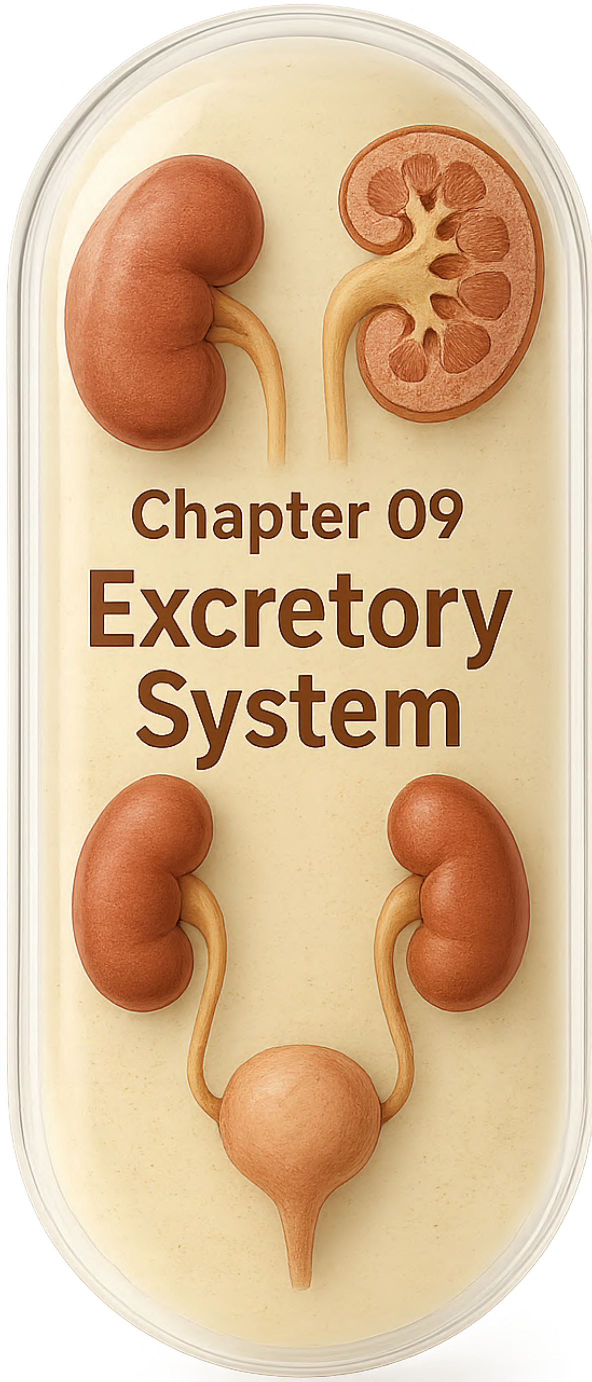
- **Blood Groups (ABO and Rh):** These are examples of antigens present on the surface of red blood cells. A mismatch during blood transfusion triggers a strong immune response.

- **Organ Transplant Rejection:** Occurs when the recipient's immune system recognizes the donor organ's MHC proteins as "foreign" and attacks them.

B. Pathogen Evasion Mechanisms

Many microbes have evolved strategies to escape the immune system, such as:

- **Antigenic Variation:** The influenza virus constantly changes its surface proteins, requiring new vaccines every year.
- **Direct Attack on the Immune System:** The Human Immunodeficiency Virus (HIV) attacks and destroys helper T cells (CD4), leading to the collapse of the immune system and the development of Acquired Immunodeficiency Syndrome (AIDS).



Chapter 09
Excretory System

Nitrogenous Wastes: Products of Protein and Nucleic Acid Metabolism

When animals break down amino acids and nucleic acids, they produce nitrogen-containing wastes that must be eliminated. The form in which these wastes are excreted depends on the animal's environment and its need to conserve water.

Forms of Nitrogenous Wastes

1. **Ammonia (NH_3):** The primary waste product. It is highly toxic and requires large amounts of water to be excreted safely. Therefore, it is the preferred form for most bony fish and aquatic animals, which can release it directly into the water through their gills.
2. **Urea:** A much less toxic and water-soluble compound. It is synthesized in the liver from ammonia and requires energy to produce, but it allows nitrogen to be excreted with less water loss. This is the main form of nitrogen waste in mammals and adult amphibians.
3. **Uric Acid:** A very low-toxicity compound with poor solubility in water, allowing it to be excreted as a semi-solid paste with minimal water loss. Its production requires the most energy, but it is a remarkable adaptation for water conservation—essential for animals living in arid environments or those that lay hard-shelled eggs, such as birds, reptiles, and insects.

The Urinary System in Mammals: The Kidney

The **kidney** is the primary organ responsible for filtering blood, removing metabolic wastes, and regulating the body's water and salt balance.

A. General Structure and Basic Functions

Blood flows into the kidneys through the renal artery, where it is filtered to produce urine. The urine then passes through the ureter to the bladder for temporary storage before being expelled from the body through the urethra. Internally, the kidney consists of an **outer cortex** and an **inner medulla**.

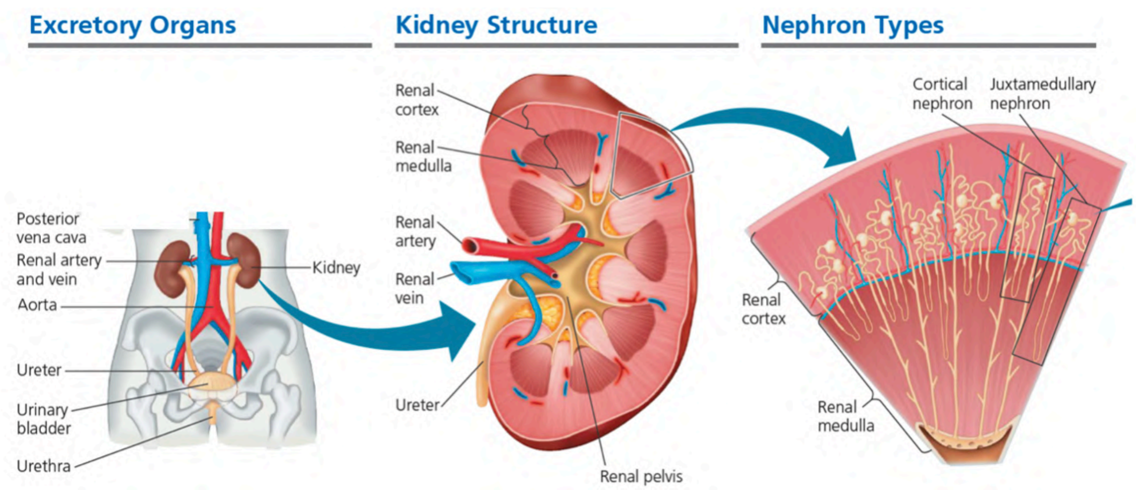


Figure 51: Anatomical Structure of the Urinary System, Kidneys, and the Nephron Unit

The Kidney Performs Three Main Processes:

1. **Filtration:** Blood plasma is forcefully pushed from the capillaries into the nephron, leaving behind blood cells and large proteins.
2. **Reabsorption:** Vital substances such as water, glucose, and salts are reabsorbed from the filtrate and returned to the bloodstream.
3. **Secretion:** Additional wastes, toxins, and excess ions are actively transported from the blood into the filtrate for elimina.

B. The Nephron: The Functional Unit of the Kidney

Each kidney contains about **one million microscopic filtering units** called **nephrons**. The nephron is responsible for **urine formation** through a series of specialized steps.

Main Parts of the Nephron:

- **Glomerulus:** A network of capillaries where filtration occurs.
- **Bowman's Capsule:** Surrounds the glomerulus and collects the filtrate.
- **Proximal Convoluted Tubule:** The site where most water and nutrients are reabsorbed.

- **Loop of Henle:** A U-shaped structure that plays a crucial role in concentrating urine.
- **Distal Convoluted Tubule:** Responsible for fine-tuning the balance of salts and water.
- **Collecting Duct:** Collects urine from multiple nephrons and transports it to the renal pelvis.

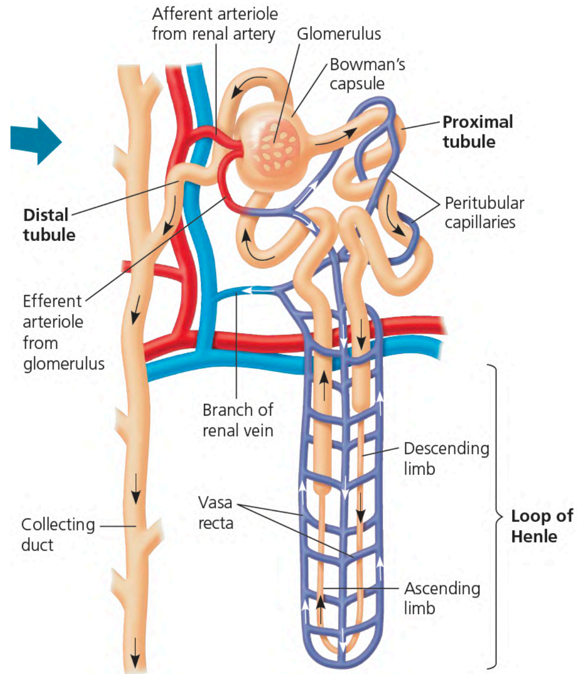
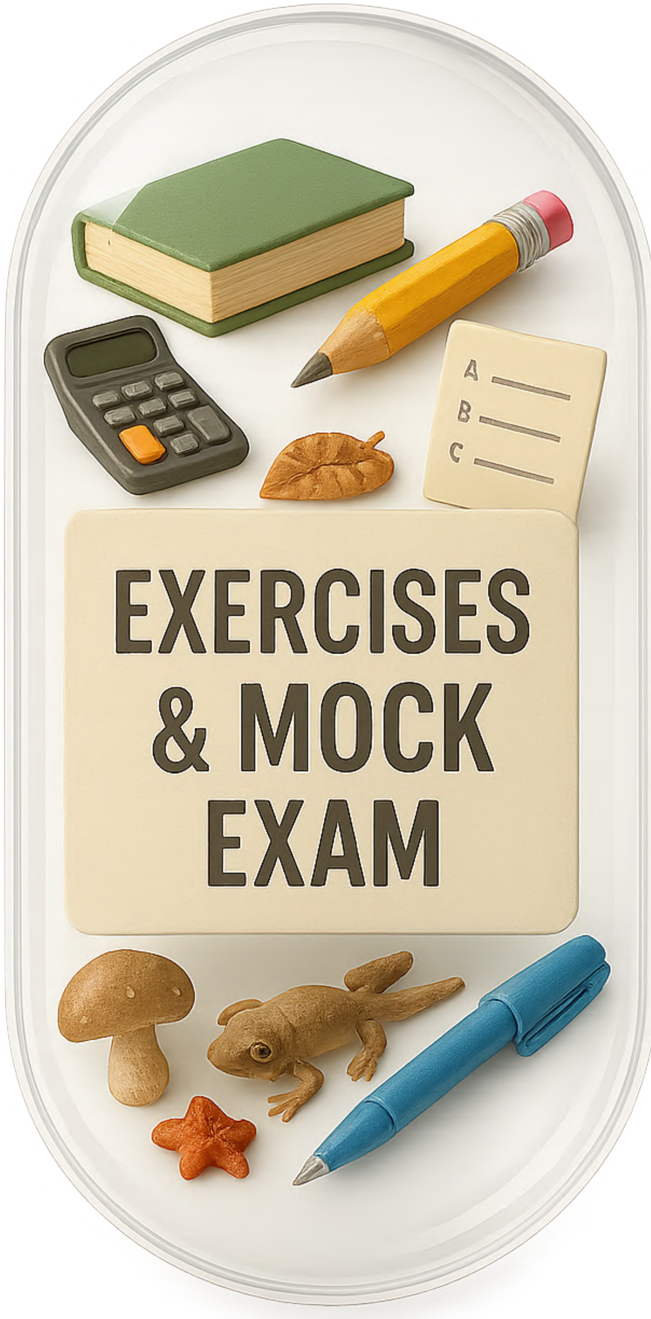


Figure 52: Detailed Structure of the Nephron and the Pathways of Blood and Filtrate Within the Kidney

C. Mechanism of Urine Formation and Concentration (Countercurrent Multiplier System)

The ability of mammals to produce concentrated urine (more concentrated than blood) depends on the structure and function of the Loop of Henle and the collecting duct — a mechanism known as the **countercurrent multiplier system**.

1. **Ascending Limb of the Loop of Henle:** Actively pumps out salts (NaCl) into the surrounding kidney medulla but is impermeable to water. This process makes the medullary region highly salty.
2. **Descending Limb of the Loop of Henle:** Permeable to water but not to salts. As the filtrate moves downward, water leaves the tubule by osmosis into the salty medulla, making the filtrate inside increasingly concentrated.
3. **Collecting Duct:** Also passes through the highly concentrated medullary region. Under the influence of **antidiuretic hormone (ADH)**, its walls become permeable to water, allowing more water to be reabsorbed into the bloodstream, producing **concentrated urine**.


EXERCISES
& MOCK
EXAM

Exercises

1	**Why is the size of the cell relatively small in most living organisms?**
A	To reduce the amount of genetic material
B	To make cell division easier
C	Because surface area grows more slowly than volume
D	Because large cells do not contain organelles
2	**What is the main reason that a light microscope cannot visualize the cell membrane?**
A	Because the membrane does not contain proteins
B	Because the membrane is completely transparent
C	Because the wavelength of light is greater than the thickness of the membrane
D	Because the membrane does not reflect light
3	**What is the main difference between the Transmission Electron Microscope (TEM) and the Scanning Electron Microscope (SEM)?**
A	TEM uses light, while SEM uses electrons
B	TEM produces surface images, while SEM produces internal images
C	TEM produces internal images, while SEM produces three-dimensional surface images
D	Both produce three-dimensional images
4	**Although connective tissues vary in structure and location, they share a common purpose, connecting and supporting other types of tissues. Although all the following tissues possess this characteristic, one of them is not a connective tissue:**
A	Blood
B	Muscles
C	Adipose tissue
D	Cartilage

5	**All body organs share the following characteristic:**
A	Contain the same types of cells
B	Are composed of several types of cells
C	Are derived from the ectoderm
D	Can be considered part of the circulatory system
6	**Epithelial tissues perform all of the following functions except:**
A	Forming barriers or boundaries
B	Absorbing nutrients in the digestive system
C	Transmitting information in the central nervous system
D	Allowing gas exchange in the lungs
7	**Endocrine and exocrine glands are formed from which type of tissue?**
A	Epithelial
B	Connective
C	Nervous
D	Muscular
8	**The exoskeleton and endoskeleton differ in the following way:**
A	The exoskeleton is rigid, while the endoskeleton is flexible.
B	Endoskeletons are found only in vertebrates.
C	Endoskeletons are found only in vertebrates.
D	Exoskeletons are located outside soft tissues, whereas endoskeletons are located inside the body.
9	**Worms and marine invertebrates use a hydrostatic skeleton for movement, in which:**
A	Their bones are filled with water that gives the skeleton its weight.
B	Changes in body shape result from muscle contractions that compress body fluids.
C	The muscles contain water-filled cavities that provide a rigid internal structure when filled.
D	The term hydrostatic refers to a moist environment, and movement occurs in a way like arthropods.

10	**You have X-ray images of two people: Rabea, a weightlifter and bodybuilder for 30 years, and Basheer, who has spent most of his life sitting. What difference would you expect between their X-ray images?**
A	No difference, both have thicker bones than younger people due to natural growth over time.
B	No difference, lifestyle does not affect bone density.
C	Rabea will have thicker bones due to remodeling caused by physical stress.
D	Basheer's bones will be thicker because bone accumulates like fat from sitting.
11	**The statement that best describes the sliding filament mechanism of muscle contraction is:**
A	The actin and myosin filaments do not shorten, but they slide past each other.
B	The actin and myosin filaments shorten and slide past each other.
C	When the filaments slide past each other, only the actin filaments shorten.
D	When the filaments slide past each other, only the myosin filaments shorten.
12	**Simple Nervous System:**
A	Must include chemical senses, mechanical senses, and vision
B	Information flows only toward an integration center
C	Information flows away from an integration center
D	Includes sensory input, an integration center, and a response
13	**Most neurons in the human brain:**
A	Sensory neurons
B	Motor neurons
C	Interneurons
D	Peripheral neurons

14	**This type of neuron can extend more than one meter in length:**
A	Glial cell in the brain
B	Sensory neurons
C	Interneurons
D	Neurons that control eye movements
15	**People with albinism have a defect in tyrosinase, an oxidase enzyme that helps regulate the production of skin pigments. In which layer of the epidermis is tyrosinase active?**
A	Stratum granulosum
B	Stratum lucidum
C	Stratum basale
D	Stratum spinosum
16	**Which of the following is not a characteristic of the granular layer (stratum granulosum)?**
A	The cells in this layer contain keratohyalin granules
B	There are 3–5 layers of cells in this layer
C	Keratin is produced in this layer
D	The cells of this layer secrete a waterproof lipid layer
17	**Which structures contain connective tissue, blood vessels, and nerves?**
A	Papillary dermis only
B	Papillary and reticular dermis
C	Epidermis, papillary dermis, and reticular dermis
D	Reticular dermis only
18	**In which part of the digestive system is most water reabsorbed?**
A	Kidneys
B	Stomach
C	Small intestine
D	Large intestine

19	**Why must most food materials be digested?**
A	Digestive enzymes require a variety of essential substances
B	To ensure the diet is balanced
C	Most food molecules are too large to be absorbed
D	To prevent intestinal disorders

20 **Enzyme**	**A**	**B**
A	Proteins	Amino acid
B	Fats	Proteins
C	Carbohydrates	Fats
D	Proteins	Fats

21	**Which of the following would be an advantage of breathing air rather than water?** I. Because air is less dense than water, less energy is required to move it across respiratory surfaces. II. Oxygen diffuses faster in air than in water. III. The oxygen content of air is greater than that of an equal volume of water.
A	Only I and II
B	Only I and III
C	Only II and III
D	I, II and III

22	**Which of the following conditions would occur if the lungs lost the elasticity of their alveoli?** I. Residual volume decreases. II. The pO_2 of inhaled air must increase in order to maintain hemoglobin saturation at the same level. III. Blood pH increases.
A	Only I
B	Only II
C	Only III
D	I and II
E	I and III
f	II and III
23	**Which of the following statements is true regarding gas exchange organs in animals?**
A	In a starfish, the gills play a role in gas exchange, but the tube feet do not participate in this process
B	In grasshoppers, the developed muscles surrounding the tracheal tubes control the movement of air in and out through an external opening
C	In fish, blood flows through the filamental capillaries in the same direction as the flow of water from the mouth and pharynx to the outside
D	In birds, during exhalation, the air sacs contract, pushing air outward while the lungs fill with air
E	In humans, a surfactant is required to increase surface tension in the thin fluid layer coating the inner surface of the bronchi; in the absence of surfactant, the alveoli collapse during exhalation, preventing air from entering during inhalation

24	**The systemic inflammatory response that is often life-threatening:**
A	Mild fever
B	Dull aches and pain
C	Septic shock
D	High blood pressure
25	**Both the eyes and the respiratory system are protected against infections by:**
A	The mucous membranes covering their surfaces
B	The secretion of complement proteins
C	The release of slightly alkaline secretions
D	The secretion of lysozyme on their surfaces
26	**Antihistamine treatment reduces:**
A	Vasodilation
B	Phagocytosis of antigens
C	MHC presentation by macrophages
D	Secondary immune response
27	**One of the main functions of the excretory system is to eliminate excess nitrogen produced by metabolism. Which of the following organisms is most efficient at packaging or processing nitrogen for excretion?**
A	Frog
B	Freshwater fish
C	Iguana
D	Camel
28	**The blood of sharks is isotonic with seawater because of the reabsorption of:**
A	Ammonia
B	Uric acid
C	Urea
D	Sodium chloride

29	**Functions of the kidney:**
A	Removing harmful substances from the body
B	Reabsorbing water for reuse
C	Regulating the level of salts in the blood
D	All the above

Mock Exam

1. A climber is training to participate in an expedition to the summit of Aconcagua. For this reason, he goes to an area of high altitude to acclimatize and avoid acute mountain sickness, caused by air pressure reduction and consequently a low partial oxygen pressure (PO2).
One of the acclimation mechanisms is:

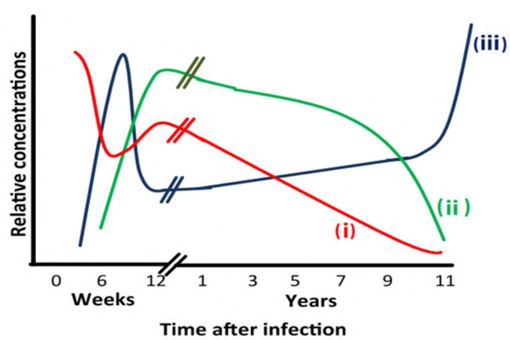
A. Pulmonary hyperventilation by venous chemoreceptors stimulation.

B. Increase in number of erythrocytes.

C. Decreased supply of oxygen to the muscles.

D. Decreased oxygen diffusion by increased capillary surface.

2. The Human Immunodeficiency Virus (HIV) can cause the disease AIDS. The HIV infects lymphocytes, the T-cells, that help in the production of antibodies. The following graph shows how the concentrations of HIV, T-cells, and antibodies against HIV develop in time in an untreated AIDS patient.



In the above graph, the lines marked (i), (ii) and (iii), respectively, represent:

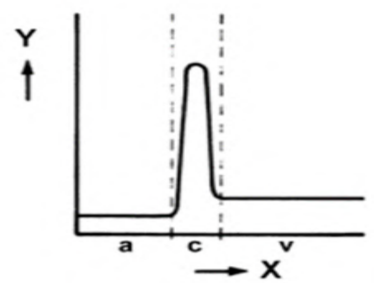
A) HIV, T-cells and antibodies.

B) T-cells, HIV and antibodies.

C) T-cells, antibodies and HIV.

D) Antibodies, T-cells and HIV.

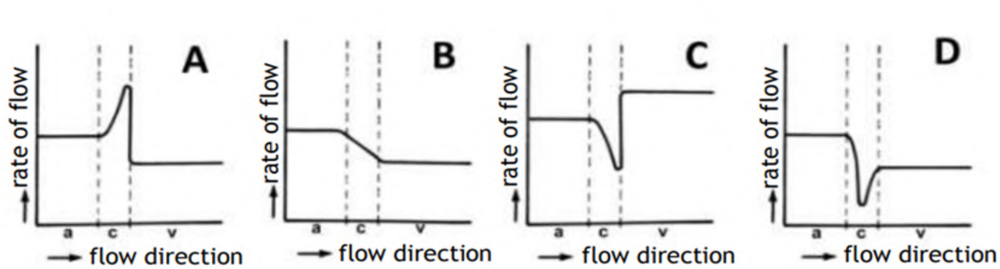
3. Rate of flow of blood in a muscle in the upper arm of a human, blood runs through arteries, capillary vessels and veins. The picture shows the total area of a cross section of one of these arteries (a), the subsequent capillary vessels (c) and the corresponding returning veins (v).



X = direction of the blood flow

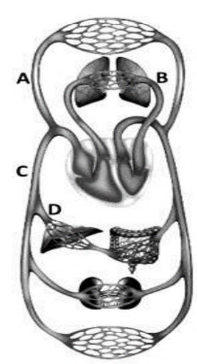
Y = total area of cross section

Which of the following pictures correctly shows the rate of flow (velocity) of the blood through an artery, a capillary vessel and a vein concerned?



4. Glucose concentration in blood the picture shows blood circulation in a mammal. Four locations are indicated by A, B, C and D. Which location has the lowest glucose concentration?

A	B	C	D
A	B	C	D



Theoretical Question

A 13-year-old teenager enjoys physical activity. For several months, she has been training for an athletic competition. Today she got up early and had breakfast, which consisted of a cup of milk, a slice of toast and a banana.

1. Carbohydrate digestion results in the catabolism of the large molecules into simpler molecules. The enzymes contained in the body catalyze this transformation.

a. Carbohydrate digestion results in the catabolism of the large molecules into simpler molecules. The enzymes contained in the body catalyze this transformation.

b. Then, use the corresponding number given to the enzyme shown on Table B, to match the Structure where this enzyme is produced.

Hint: the same enzyme may be produced by more than one structure.

Table A

STRUCTURE	SECRETORY STRUCTURE INVOLVED IN THE DIGESTION OF STARCH	ENZYME
Liver		
Stomach		
Salivary Glands		
Large intestine		
Pancreas		
Esophagus		
Small Intestine		

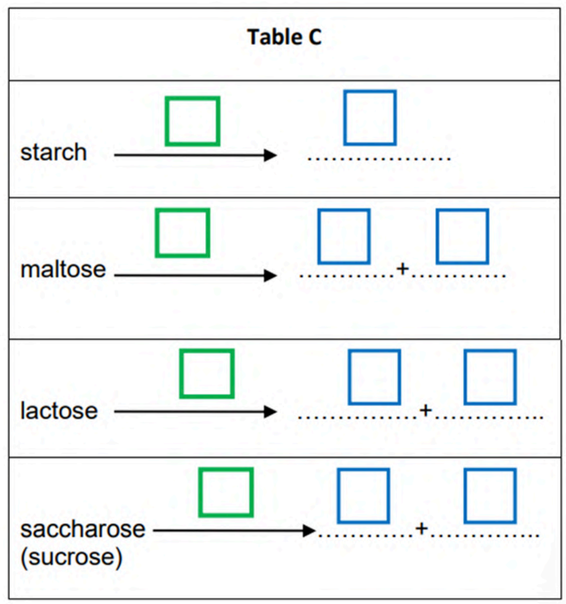
Table B

1	Phospholipase
2	Maltase
3	Amylase
4	Lipase
5	Glucosidase
6	Sucrase

2- At breakfast, she also incorporated carbohydrates from milk and fruit, which will be broken down during digestion into simpler sugars due to the activity of specific enzymes.

Fill in Table C (indicated on the Answer Sheet) which shows enzymatic reactions. Write the corresponding letter of the enzyme in the green box and the corresponding number for the products in the blue boxes (each number may be used more than once).

ENZYMES		PRODUCTS	
A	Creatin kinase	1	Maltose
B	Amylase	2	Glucose
C	Lactase	3	Fructose
D	Glucosidase	4	Lactose
E	Sucrase	5	Galactose
F	Maltase	6	Saccharose (sucrose)



3. After breakfast, the athlete goes to the sports field for her daily workout routine. If we study in detail the movement of the athlete and the processes involved in the musculature, we can say:

a. The muscular system together with the skeletal system forms the musculoskeletal system, which is responsible for human body movement. The mechanism of muscle contraction can be explained through an ordered sequence of events. Table (D) illustrates the processes of muscle contraction. Complete Table (E) by indicating the letter of each process in the order in which it occurs.

Table D: Processes of muscle contraction	
A	ATP is hydrolyzed to ADP + Pi (inorganic phosphorus) and the myosin head is separated from the active site
B	Acetylcholine acts on a local area of the sarcolemma to open multiple membrane protein channels. This allows the entry of large amounts of sodium ions into the sarcolemma, which initiates an action potential in the muscle fiber.
C	The action potential depolarizes the sarcolemma. The release of Ca++ ions from the sarcoplasmic reticulum occurs.
D	Ca++ ions are pumped back into the sarcoplasmic reticulum, where they remain until the arrival of a new action potential to the muscle.
E	An action potential reaches the neuromuscular junction (synapse) of a motor neuron and a muscle; acetylcholine is released from the axon terminal.
F	Ca++ ions initiate attractive forces between the actin and myosin. Filaments of myosin and actin are arranged next to each other within the sarcomere so that that they can interact in an organized fashion resulting in muscle contraction. During contraction, myosin heads bind actin and pull the filaments in towards the center.

Tabla E	
ORDER	CORRESPONDING LETTER
1	
2	
3	
4	
5	
6	

Answer Keys for Exercises and the Mock Exam

Exercises

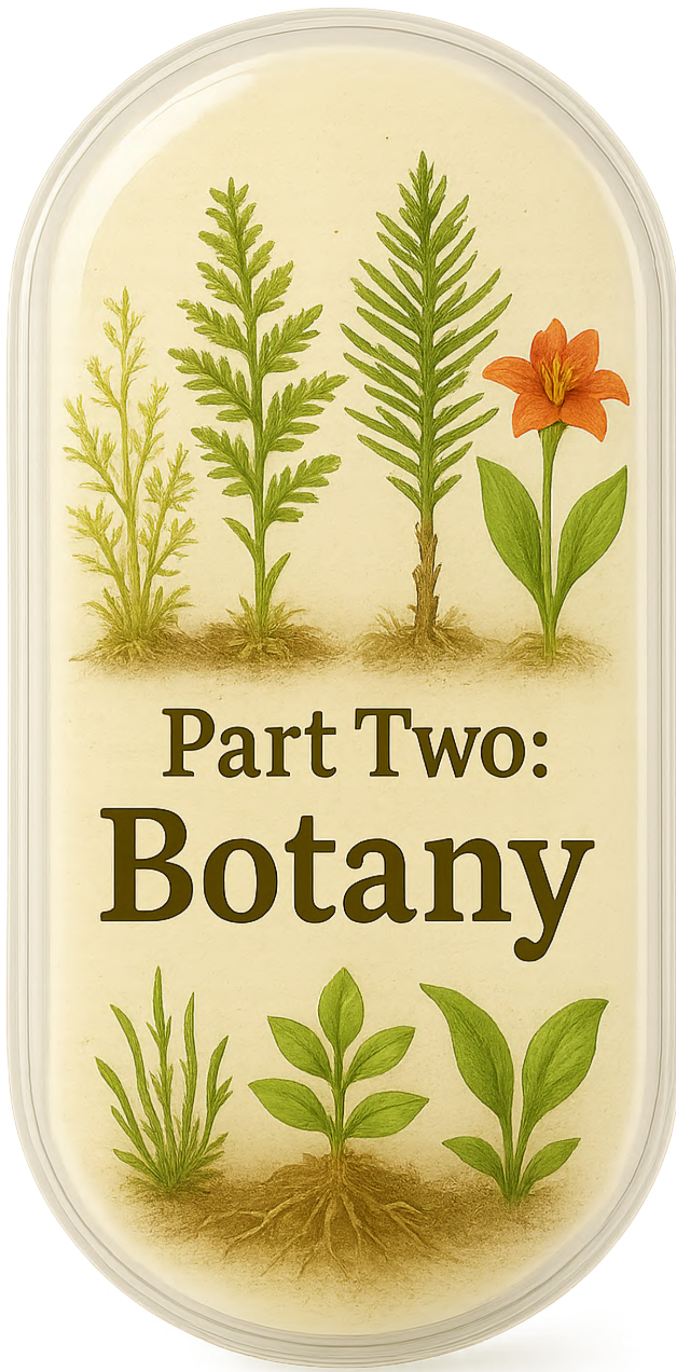
C	**25**	D	**13**	C	**1**
D	**26**	C	**14**	C	**2**
A	**27**	B	**15**		
D	**28**	C	**16**	C	**4**
C	**29**	C	**17**	B	**5**
D	**30**	B	**18**	B	**6**
		C	**19**	C	**7**
		C	**20**	A	**8**
		D	**21**	D	**9**
		A	**22**	B	**10**
		B	**23**	C	**11**
		D	**24**	A	**12**

Mock Exam

Answer	Question
B	**1**
C	**2**
D	**3**
A	**4**

Theoretical Question

TABLE (A)		
STRUCTURE	secretory structure involved in the digestion of starch	ENZYME
Salivary Glands	A	3 (B)
Pancreas	C	3 (D)
Small intestine	E	2 (F)
TABLE (C)		
B (A)	1 (B)	
F (C)	2 (D)	2 (E)
C (F)	2 (G)	5 (A)
E (I)	2 (J)	3 (K)
TABLE (E)		
1	E (A)	
2	B (B)	
3	C (C)	
4	F (D)	
5	A (E)	
6	D (F)	


Part Two:
Botany

Introduction to Botany:

Botany is one of the major branches of the biological sciences and is concerned with the study of plants in terms of their structure, functions, genetics, environment, and evolution. Plants constitute the primary producers in most terrestrial and marine ecosystems, as they convert solar energy into chemical energy through photosynthesis. This process provides the organic compounds and oxygen essential for the survival of most forms of life on Earth. Modern botany is not limited to describing or morphologically classifying plants; rather, it integrates molecular biology, biochemistry, genomics, and ecology to understand the mechanisms that regulate growth, development, and adaptation. At the cellular level, botanists study processes such as cell wall synthesis, plant hormone signaling, and metabolic pathways related to growth and responses to environmental stresses. On a broader scale, botany examines plant diversity, evolutionary relationships among species, and the ecological interactions that determine species distribution and success. The importance of these studies continues to grow considering rapid climate change, habitat loss, and the increasing global demand for food.

Objectives

1. To understand the hierarchical organization of plants, including the structure and function of organs, tissues, and cells.
2. To identify the different types of meristems and explain how each contributes to primary and secondary growth.
3. To describe the mechanisms and outcomes of primary growth, focusing on how it extends the length of roots and shoots.
4. To analyze the process of secondary growth and its role in increasing the thickness of stems and roots in woody plants.
5. To explain how growth, morphogenesis, and cell differentiation interact to form the complete plant body.
6. To relate meristem activity to overall plant form and developmental patterns.
7. To compare primary vs. secondary tissues and understand how each supports plant structure and function.

CHAPTER 01
VASCULAR PLANT STRUCTURE, GROWTH AND DEVELOPMENT

Plants have a hierarchical organization consisting of organs, tissues, and cells:

- Plants, like most animals, are composed of cells, tissues, and organs.
- As you learn about each level of plant organization, keep in mind how natural selection has produced plant forms suited to their functions at all levels of organization.

Basic Vascular Plant Organs: Roots, Stems, and Leaves:

The basic form of vascular plants reflects their evolutionary history as organisms that live on land (terrestrial). These organs form a root system and a shoot system, the latter consisting of stems and leaves (see figure). Vascular plants depend on both systems for survival

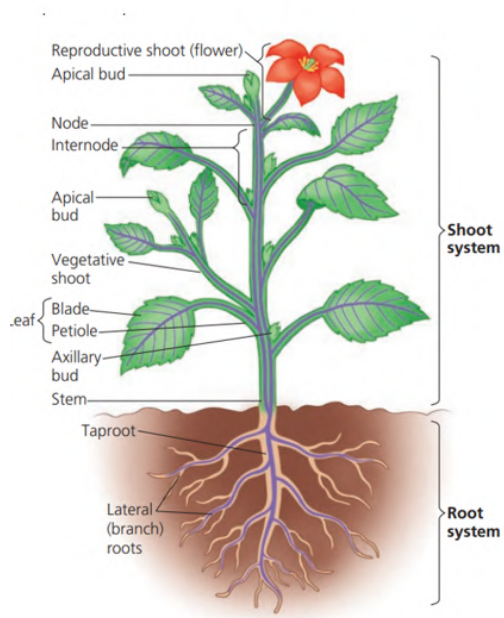


Figure 53 An overview of a flowering plant

Roots:

A root is the organ that anchors a vascular plant in the soil, absorbs minerals and water, and often stores carbohydrates and other reserves.

The primary root, which originates in the seed embryo, is the first organ to emerge from a germinating seed. It soon branches to form lateral roots (as shown in the figure).

Tall, erect plants with large shoot masses generally have a taproot system, consisting of one main vertical root, the taproot, which typically develops from the primary root.

Small vascular plants are particularly vulnerable to grazing animals that can uproot and kill them. Such plants are more securely anchored by a fibrous root system, a dense mat of thin roots spreading just below the soil surface.

Most root systems also form mycorrhizal associations, symbiotic interactions with soil fungi that enhance the plant's ability to absorb minerals.

The roots of many plants are adapted to perform specialized functions (see figure).

Most root systems also form mycorrhizal associations, which are symbiotic interactions with soil fungi that enhance the plant's ability to absorb minerals.

The roots of many plants are also adapted to perform specialized functions.

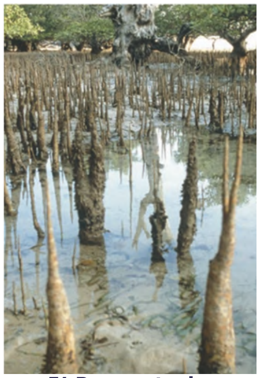


Figure 54 Pneumatophores

Figure 55 Prop roots

Figure 58 Storage roots

Figure 56 Buttress roots

Figure 57 Root hairs

Stems

A stem is a plant organ that bears leaves and buds. Its main function is to elongate and orient the shoot in a way that maximizes photosynthesis by the leaves. Another function of stems is to elevate reproductive structures, thereby facilitating the dispersal of pollen and fruit. Green stems may also carry out a limited amount of photosynthesis. Some plant stems perform alternative functions, such as food storage or asexual reproduction. Many of these modified stems are often mistaken for roots, including rhizomes, tubers, and stolons

.

Figure 59 modified stems

Leaves

In most vascular plants, the leaf is the main organ of photosynthesis. In addition to intercepting light, leaves exchange gases with the atmosphere, dissipate heat, and defend themselves from herbivores and pathogens. These functions may sometimes have conflicted physiological, anatomical, or morphological requirements. For example:

A dense covering of hairs may help deter herbivorous insects but can also trap air near the leaf surface, reducing gas exchange and thus photosynthesis. In general, a leaf consists of a flattened blade and a stalk, the petiole, which attaches the leaf to the stem at a node.

Monocots and eudicots differ in the arrangement of veins (the leaf's vascular tissues).

Almost all leaves are specialized for photosynthesis; however, some species have leaves with adaptations that enable them to perform additional functions, such as support, protection, storage, or reproduction.

Spines

Spines

Tendrils

Storage Leaves

Figure 60 adaptations of leaves

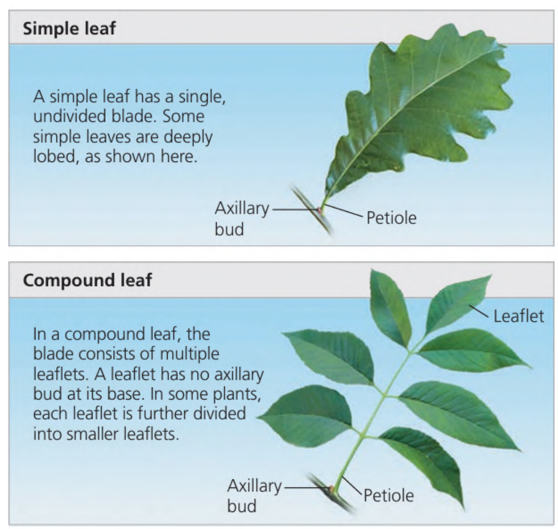


Figure 61 Simple versus compound leaves

Dermal, Vascular, and Ground Tissues

All three basic organs of vascular plants — roots, stems, and leaves — are composed of three fundamental tissue types: dermal tissue, vascular tissue, and ground tissue.

Each of these general types forms a continuous tissue system throughout the plant, connecting all organs. The arrangement and location of these tissues vary from one organ to another.

The three tissue systems

Dermal Tissue	Vascular Tissue	Ground Tissue
The dermal tissue system provides a protective cover for the entire body of a plant.	The vascular tissue system, which transports materials between the root and shoot systems	The ground tissue system, which is responsible for most of the metabolic functions, is located between the dermal tissue and the vascular tissue in each organ

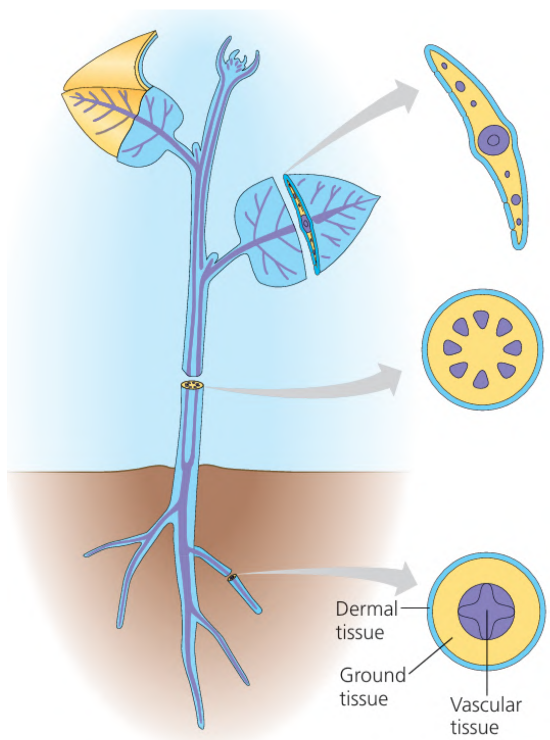


Figure 62. The three tissue systems in plants

Common Types of Plant Cells

Parenchyma Cells

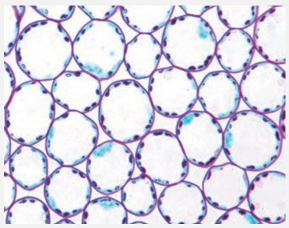


Figure 63. Parenchyma cells

Mature parenchyma cells have primary walls that are relatively thin and flexible, and most lack secondary walls. When mature, parenchyma cells generally have a large central vacuole. Parenchyma cells perform most of the metabolic functions of the plant, synthesizing and storing various organic products. For example, photosynthesis occurs within the chloroplasts of parenchyma cells in the leaf. Some parenchyma cells in stems and roots have colorless plastids that store starch. Most parenchyma cells retain the ability to divide and differentiate into other types of plant cells

Collenchyma Cells

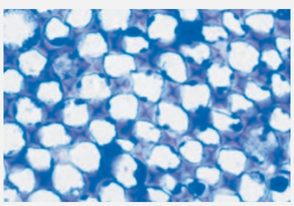


Figure 64. Collenchyma cells

Grouped in strands, collenchyma cells (seen here in cross section) help support young parts of the plant shoot. Collenchyma cells are generally elongated cells that have thicker primary walls than parenchyma cells, though the walls are unevenly thickened. Young stems and petioles often have strands of collenchyma cells just below their epidermis. Collenchyma cells provide flexible support without restraining growth. At maturity, these cells are living and flexible, elongating with the stems and leaves they support

Sclerenchyma Cells

Figure 65. Sclerenchyma cells

Sclerenchyma cells also function as supporting elements in the plant but are much more rigid than collenchyma cells. In sclerenchyma cells, the secondary cell wall is thick and contains large amounts of lignin a relatively indigestible strengthening polymer that occur in regions of the plant that have stopped growing in length. Sclerenchyma cells are so specialized for support that many are dead at functional maturity. There are Two types of sclerenchyma cells, known as sclereids and fibers. Sclereids impart the hardness to nutshells and seed coats, Fibers, which are usually grouped in strands, are long, slender, and tapered. Some are used commercially, such as hemp fibers for making rope and flax fibers for weaving into linen.

Water-Conducting Cells of the Xylem

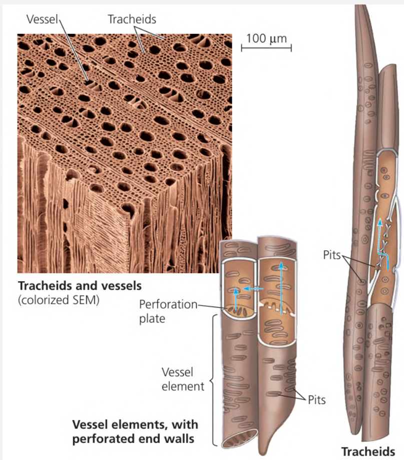


Figure 66. Cells of the Xylem

There are two types of water-conducting cells: tracheids and vessel elements. These are elongated, tubular, dead, and lignified cells at functional maturity. Tracheid's occur in all vascular plants, whereas in most angiosperms and some gymnosperms, vessel elements are present in addition to tracheids.

Tracheids and vessel elements form non-living channels through which water flows. The secondary walls of tracheids and vessel elements often intersect through pits, which are thin regions that allow water to move laterally. The secondary walls of tracheids and vessel elements are reinforced with lignin, which provides structural support and protects them from collapsing under the tension generated during water transport.

Sugar-Conducting Cells of the Phloem

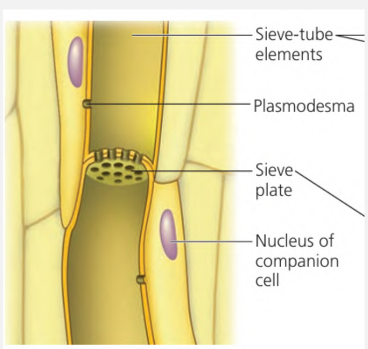


Figure 67. Cells of the Xylem

Phloem cells transport sugars and other nutrients through long, narrow cells called sieve tubes, which are composed of chains of cells known as sieve-tube elements. Although sieve-tube elements are living cells, they lack a nucleus, ribosomes, and a large central vacuole. This reduction in cellular contents allows nutrients to pass through more easily. The end walls between sieve-tube elements, known as sieve plates, contain pores that facilitate the flow of sap from one cell to the next. Adjacent to each sieve-tube element are non-conducting cells called companion cells, which assist in loading sugars into the sieve tube.

Different meristems generate new cells for primary and secondary growth

The main difference between plants and most animals is that plant growth is not limited to the embryonic period. Instead, growth occurs throughout the plant's lifetime, a process known as indeterminate growth. Plants can continue to grow because they possess undifferentiated tissues called meristems, which contain cells capable of division, producing new cells that elongate and become differentiated. There are two main types of meristems: apical meristems (located at the tips of roots and shoots) and lateral meristems (responsible for thickening growth). Primary growth allows roots to extend throughout the soil and shoots to grow upward, increasing their exposure to light.

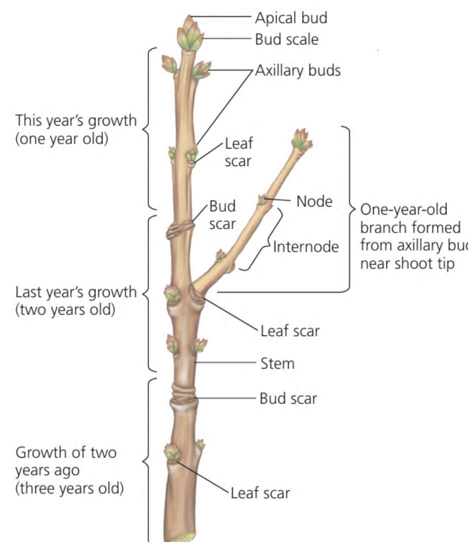


Figure 68. Three years' growth in a winter twig

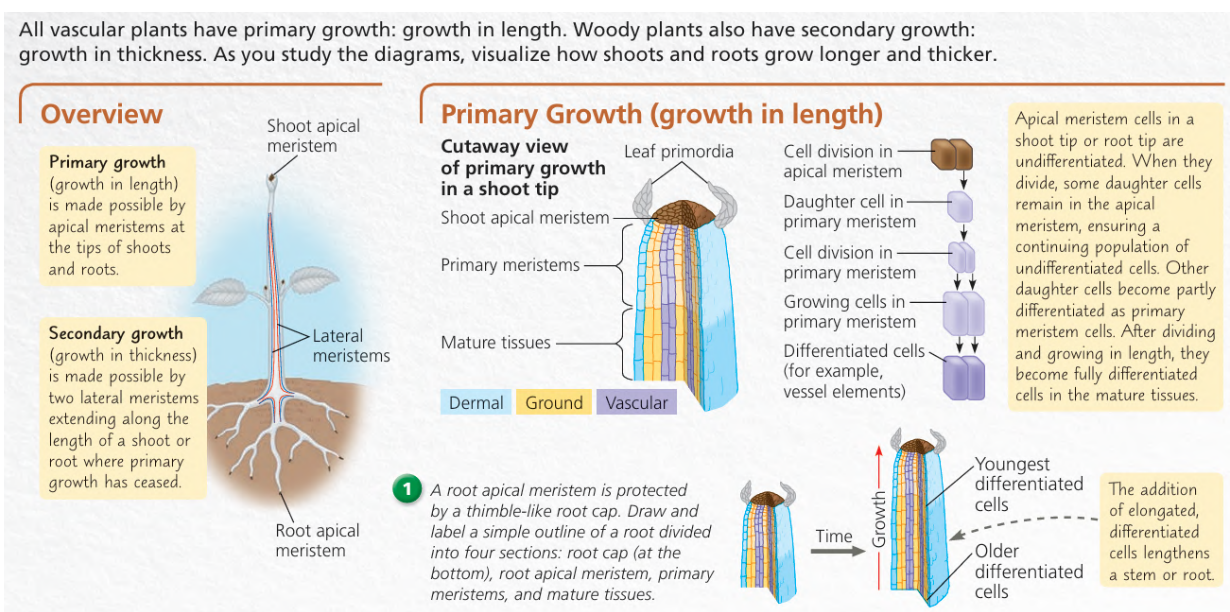


Figure 69. Visualizing Primary Growth in plant

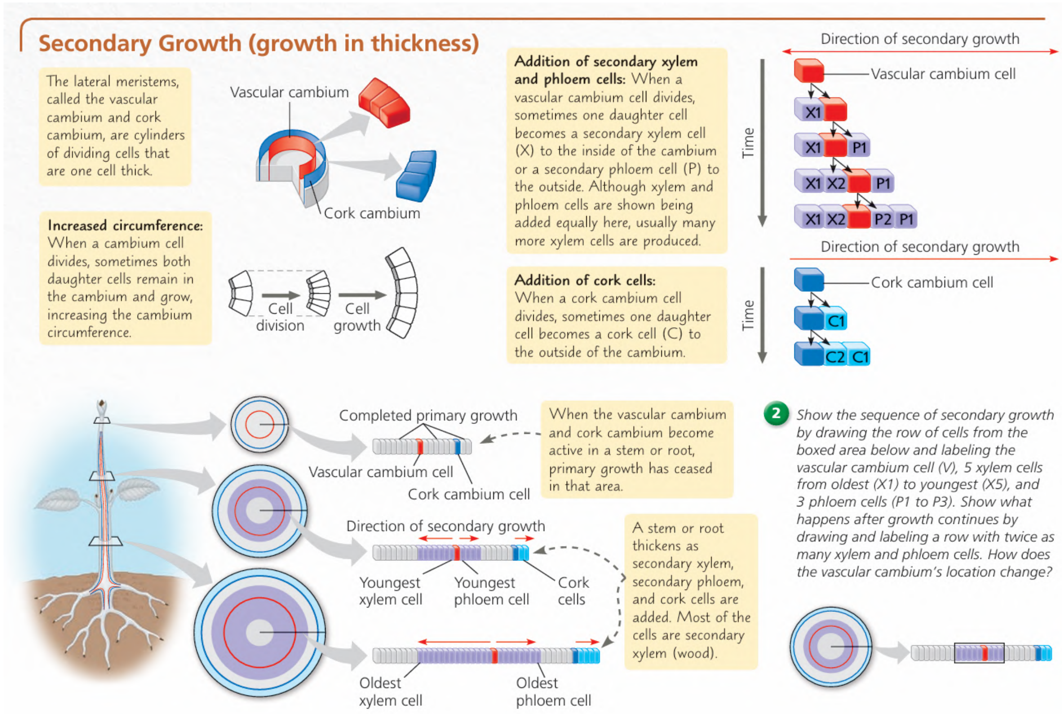


Figure 70. Visualizing secondary Growth in plant

Primary growth lengthens roots and shoots

Primary Growth of roots

The entire biomass of a primary root is derived from the root apical meristem. The root apical meristem also makes a thimble-like root cap, which protects the delicate apical meristem as the root pushes through the abrasive soil. Growth occurs just behind the tip in three overlapping zones of cells at successive stages of primary growth. These are:

- The zones of cell division
- The zone of elongation
- The zone of differentiation

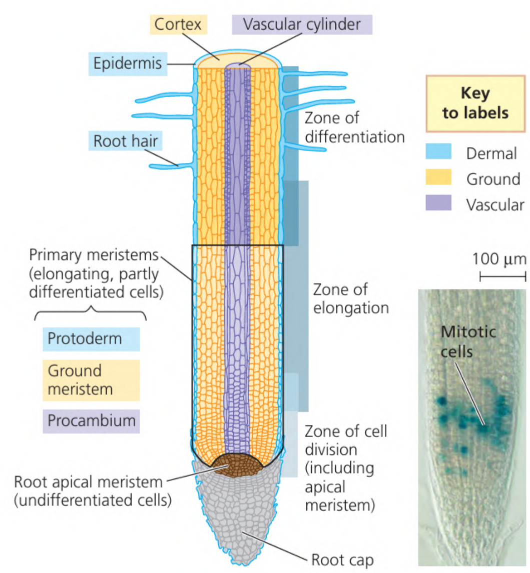


Figure 71. primary growth of a eudicot root

Stem Growth and Anatomy

- Root hairs are the most prominent feature of the root epidermis.
- The cortex is the region between the vascular tissues and the epidermis, and it is composed mainly of parenchyma cells.
- The endodermis acts as a selective barrier that regulates the passage of substances from the soil into the vascular cylinder.
- The procambium gives rise to the vascular cylinder, which consists of a solid core of xylem and phloem tissues surrounded by a single layer of cells called the pericycle. Lateral (branch) roots originate from the meristematic regions of the pericycle, which is the outermost cell layer of the vascular cylinder, located just inside and adjacent to the endodermis, The emerging lateral roots grow destructively through the outer tissues until they emerge from the established root.

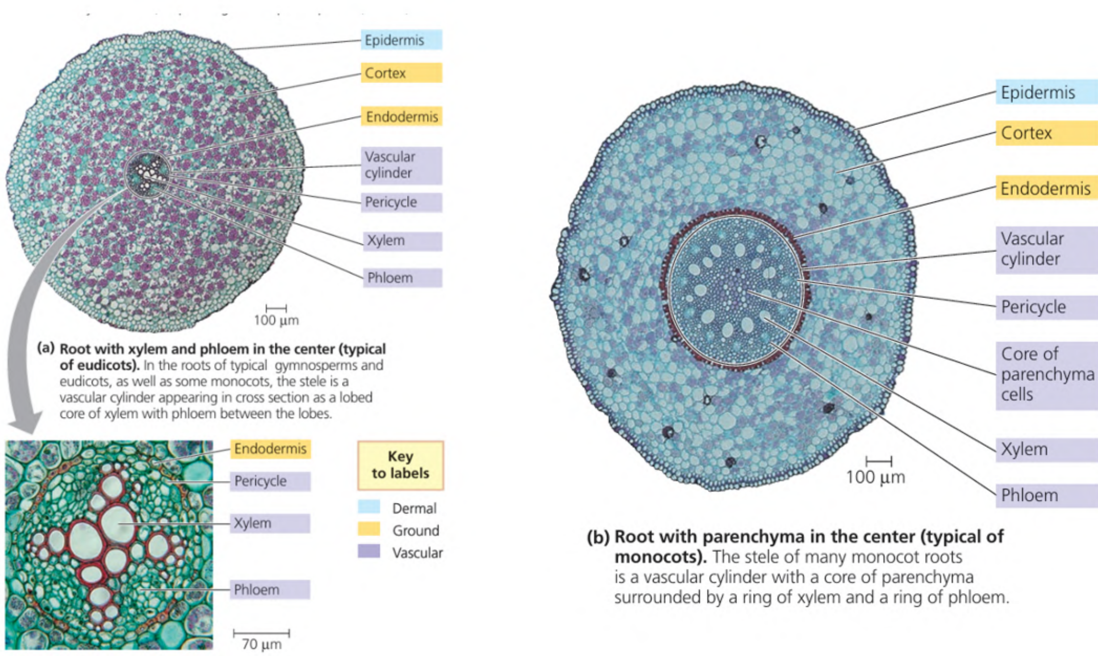


Figure 72. The internal structure of the root in monocots and dicots7

Primary Growth of Shoots:

The entire primary shoot biomass—including all its leaves and stems—is derived from the shoot apical meristem, a dome-shaped mass of dividing cells located at the tip of the stem (see figure). Branching of shoots, which is also part of primary growth, arises from the activation of axillary buds, each of which contains its own apical meristem. Due to chemical signaling through plant hormones, the closer an axillary bud is to an active apical bud, the more it is inhibited—a phenomenon known as apical dominance.

The shoot tip. Leaf primordia arise from the flanks of the dome of the apical meristem. This is a longitudinal section of the shoot tip of *Coleus* (LM).

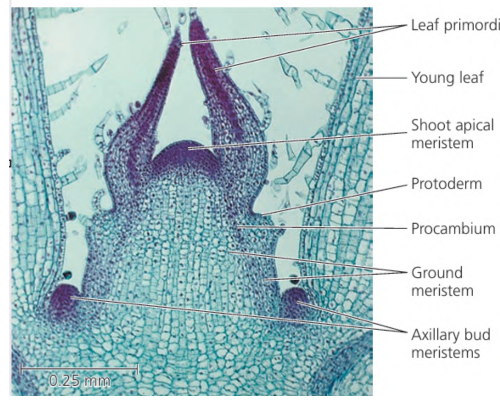


Figure 73. A longitudinal section of the shoot tip

Stem Growth and Anatomy

The stem is covered by an epidermis, usually one cell layer thick, and coated with a waxy cuticle that prevents water loss. Examples of specialized epidermal cells in the stem include protective cells and trichomes (glandular hairs or outgrowths found on the stems and leaves of many plants). The ground tissue of stems consists mainly of parenchyma cells. Collenchyma cells, located just beneath the epidermis, provide support for many stems during primary growth. Sclerenchyma cells, particularly fiber cells, also contribute to support in regions of the stem that are no longer elongating. The vascular tissues extend along the stem in distinct vascular bundles.

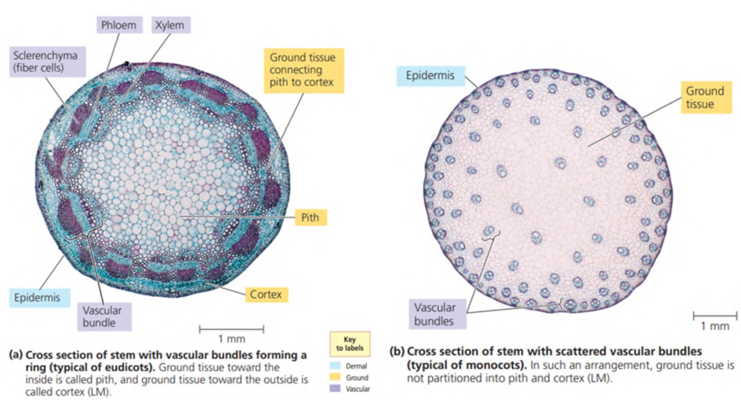


Figure 74. The stem structure in monocots and dicots

Leaf Growth and Anatomy

- The epidermis of a leaf is covered by a waxy cuticle, except in areas where stomata are present. These stomata allow the exchange of carbon dioxide (CO_2) and oxygen (O_2) between the surrounding air and the photosynthetic cells inside the leaf. In addition to regulating the uptake of carbon dioxide for photosynthesis, the stomata are also the primary pathways for water vapor loss (transpiration). And they surrounded by two specialized epidermal cells known as guard cells.
- The ground tissue of the leaf, called the mesophyll (literally "middle leaf"), is located between the upper and lower epidermal layers. And differentiated into two distinct layers:
  - o The palisade mesophyll consists of one or more layers of elongated parenchyma cells located in the upper part of the leaf.
  - o The spongy mesophyll lies beneath the palisade layer and is made up of loosely arranged parenchyma cells with intercellular air spaces through which CO_2 and O_2 circulate around the cells and up to the palisade region.
- The vascular tissues of each leaf are connected to those of the stem.
- The veins branch repeatedly and spread throughout the mesophyll, forming a network that brings the xylem and phloem into close contact with the photosynthetic tissue. Through this network, the xylem supplies water and minerals, while the phloem transports sugars and other organic products to other parts of the plant.

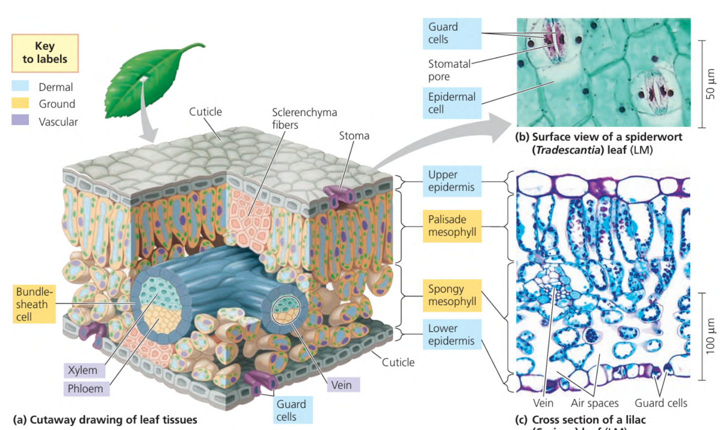


Figure 75. Leaf anatomy

Secondary growth increases the diameter of stems and roots in woody plants

All gymnosperms and many eudicot species undergo secondary growth, but it is uncommon in monocots. This type of growth occurs in the stems and roots of woody plants, but only rarely in leaves. Secondary growth consists of tissues produced by the vascular cambium and the cork cambium.

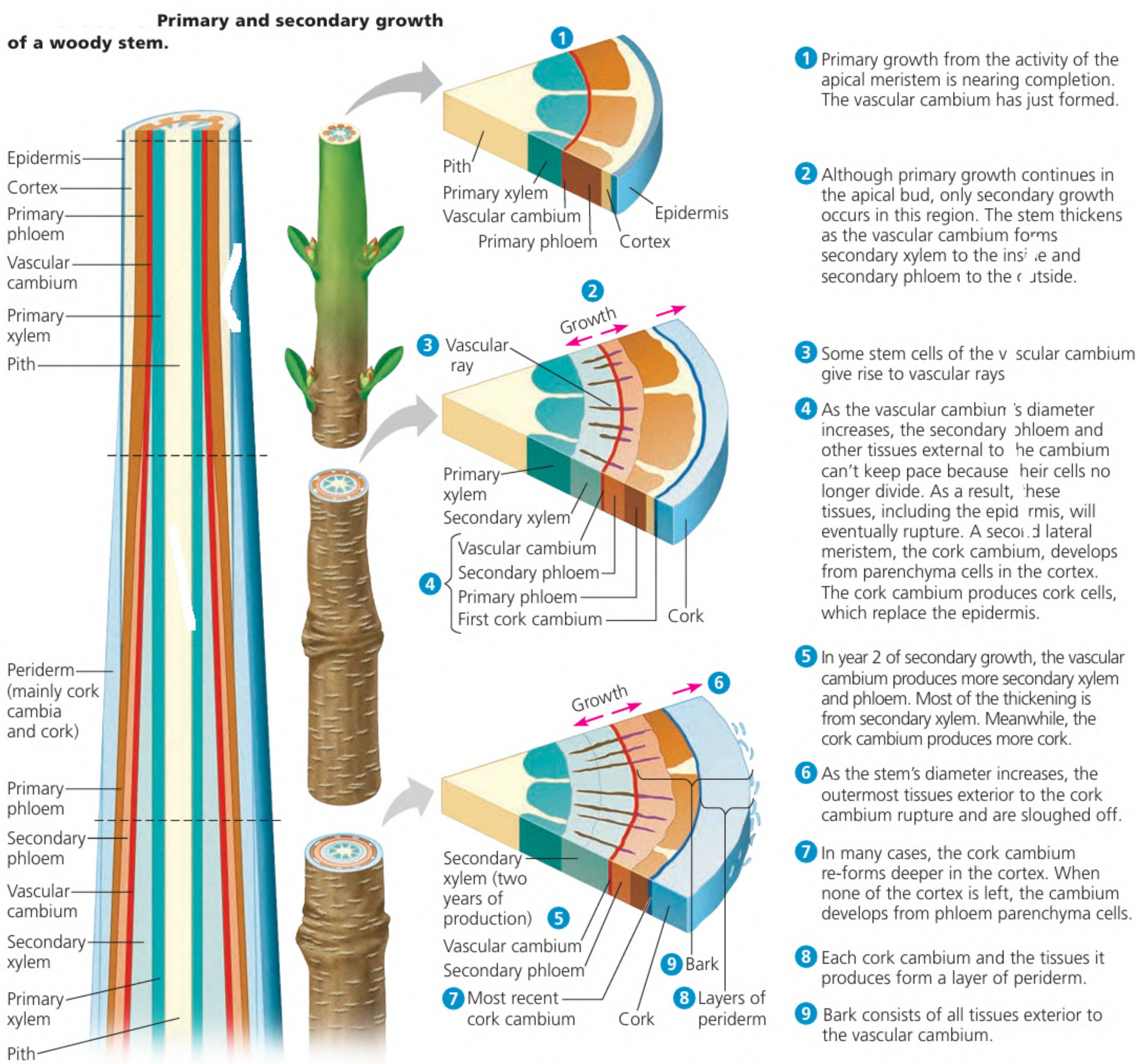


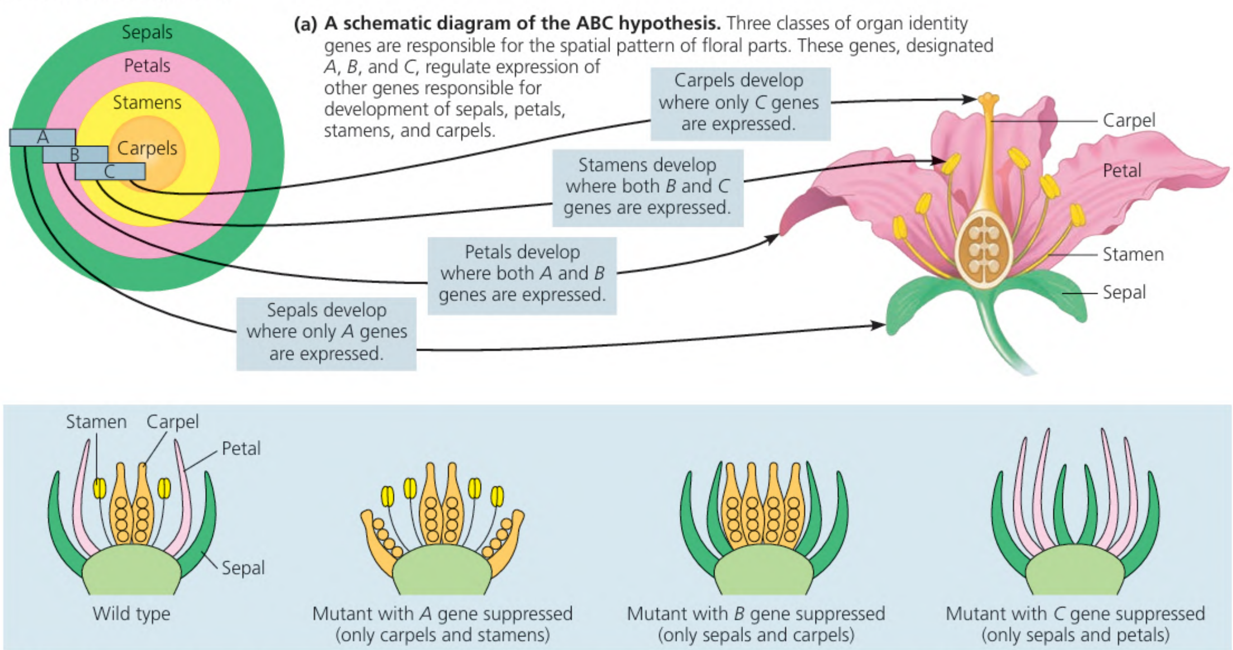
Figure 76. primary and secondary growth of a woody stem.

Genetic Control of Flowering:

Flower formation involves a phase change from vegetative growth to reproductive growth. This transformation is triggered by a combination of environmental signals, such as day length, and internal signals, such as hormones. The transition from vegetative growth to flowering is associated with the switching on of floral meristem identity genes. The protein products of these genes are transcription factors that regulate other genes required to transform indeterminate vegetative meristems into determinate floral meristems.

These floral organs are arranged in four concentric whorls, which can be described as roughly circular layers when viewed from above.

The ABC hypothesis for the functioning of organ identity genes in flower development.



(b) Side view of wild type flower and flowers with organ identity mutations. The phenotype of mutants lacking a functional *A*, *B*, or *C* organ identity gene can be explained by the model in part (a) and the observation that if either the *A* gene or *C* gene is suppressed, the other gene is expressed in that whorl. For example, if the *A* gene is suppressed in a mutant, the *C* gene is expressed where the *A* gene would normally be expressed. Therefore, carpels (*C* gene expressed) develop in the outermost whorl, and stamens (*B* and *C* genes expressed) develop in the next whorl.

Figure 77. The ABC hypothesis for the functioning of organ identity genes in flower development.

CHAPTER 02.

RESOURCE ACQUISITION AND TRANSPORT IN VASCULAR PLANT

Adaptations for acquiring resources were key steps in the evolution of vascular plants:

Most plants grow in soil and therefore live in two worlds: above ground, where the shoot system acquires sunlight and carbon dioxide (CO_2), and below ground, where the roots absorb water and minerals. The following figure provides an overview of resource acquisition and transport in an actively photosynthesizing plant

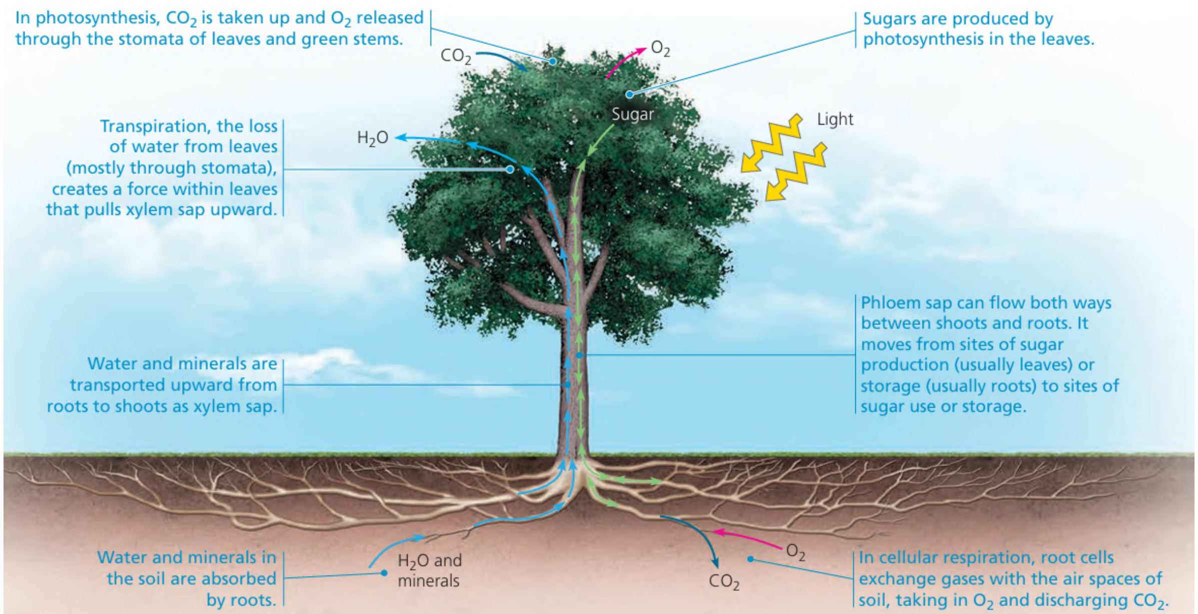


figure 78. An overview of resource acquisition and transport in a vascular plant

Adaptations of roots and leaves for resource acquisition

Root Architecture and Acquisition of Water and Minerals:	Shoot Architecture and Light Capture
1. Modification in root structure and composition. 2. Beneficial relationships with microorganisms	1. Variation in branching patterns 2. Diversity in leaf size and structure 3. Leaf arrangement on the stem

Different mechanisms transport substances over short or long distances:

Short-Distance transport of Water across Plasma membranes

Absorption or loss of water by a cell occurs through osmosis, the diffusion of free water—that is, water not bound to solutes or surfaces—across a membrane.

The physical property that predicts the direction of water movement is called water potential (Ψ). It is a quantity that combines the effects of solute concentration and physical pressure.

Free water moves from regions of higher water potential (higher Ψ) to regions of lower water potential (lower Ψ), provided there is no barrier to its flow.

Water potential is abbreviated by the Greek letter Ψ (psi). Plant biologists measure Ψ in a pressure unit called the megapascal (MPa).

By definition, the Ψ of pure water in an open container exposed to the atmosphere under standard conditions (at sea level and room temperature) is 0 MPa.

Let us now consider how water potential (Ψ) affects the absorption and loss of water by a living plant cell.

First, imagine a flaccid (limp) cell that has lost water. In this case, the cell's pressure potential (ΨP) is 0 MPa. Suppose this flaccid cell is immersed in a solution with a higher solute concentration than that inside the cell (Figure a).

Because the external solution has a lower (more negative) water potential, water diffuses out of the cell, and the protoplast of the cell undergoes plasmolysis—that is, it shrinks and pulls away from the cell wall.

If the same flaccid cell is placed in pure water (Ψ = 0 MPa) (Figure b), the cell, which contains solutes, has a lower water potential than pure water. As a result, water enters the cell by osmosis. The contents of the cell begin to swell, pressing the plasma membrane against the cell wall. The partially elastic wall exerts a turgor pressure (ΨP) that confines the swollen protoplast. When this turgor pressure is sufficient to balance the tendency of water to enter because of the solutes in the cell, then ΨP and ΨS are equal in magnitude but opposite in sign, making Ψ = 0.

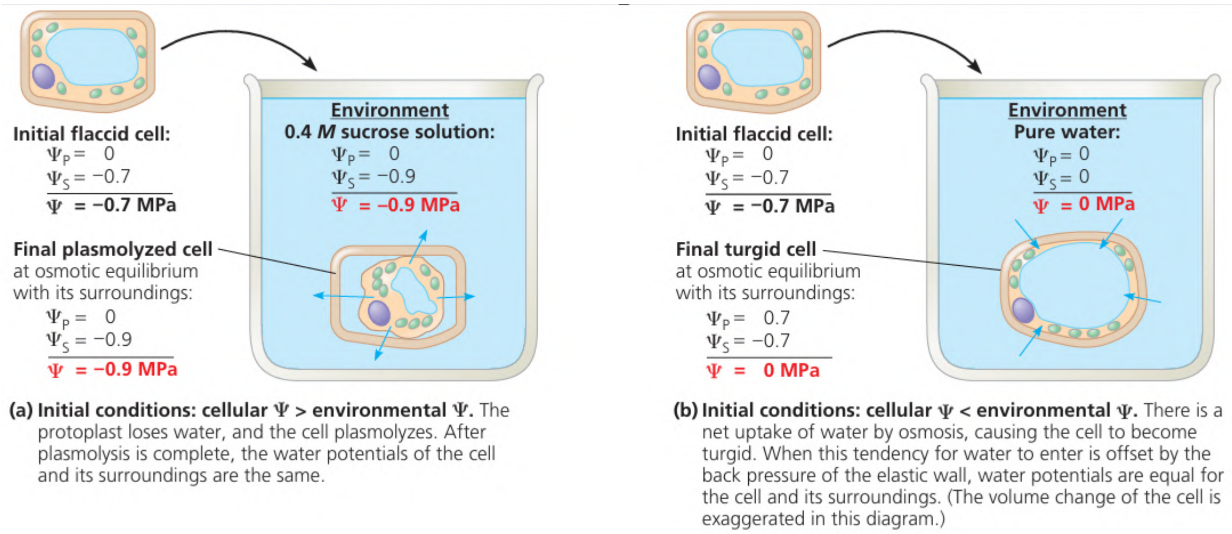


figure 79. The effect of water potential on the absorption and loss of water by a living plant cell

Aquaporins: Facilitating Diffusion of Water:

Differences in water potential (Ψ) determine the direction of water movement across membranes — but how do water molecules cross membranes?

Water molecules are small enough to diffuse through the phospholipid bilayer, even though the inner region of the bilayer is hydrophobic. However, their movement across biological membranes is too rapid to be explained by unaided diffusion alone. Transport proteins called aquaporins facilitate the movement of water molecules across the plasma membranes of plant cells. Aquaporin channels, which can open and close, regulate the rate of osmotic water movement across the membrane. This permeability decreases when there is an increase in cytosolic Ca^{2+} concentration or a decrease in cytosolic pH.

The apoplast and Symplast: transport Continuums:

Plasmodesmata	Symplast	Apoplast
the cytoplasmic channels that connect these cells to one another.	consists of the entire mass of cytosol of all the living cells in a plant,	consists of everything external to the plasma membranes of living cells, including the cell walls, extracellular spaces, and the interiors of dead cells, such as xylem vessel elements and tracheids.

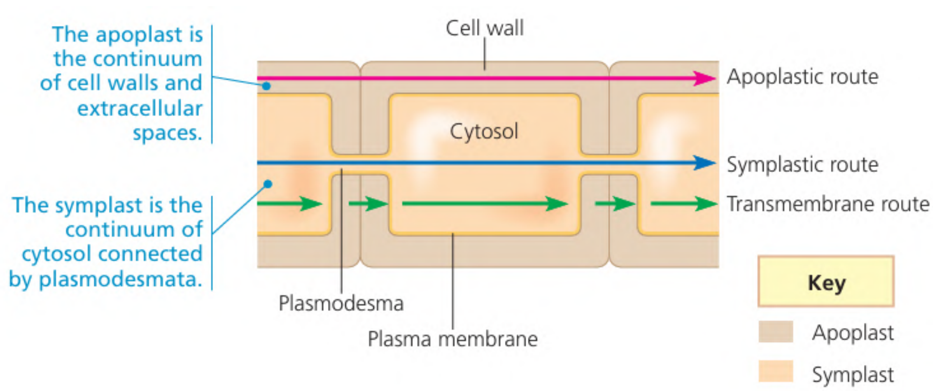


figure 80. Cell compartments and routes for short-distance transport

Long-Distance transport: the role of Bulk Flow:

Long-distance transport occurs through bulk flow, which is the movement of a fluid in response to a pressure gradient. Bulk flow of substances always occurs from regions of higher pressure to regions of lower pressure. Unlike osmosis, bulk flow is independent of solute concentration. Bulk flow over long distances take place within the specialized cells of the vascular tissues — the tracheid's and vessel elements of the xylem, and the sieve-tube elements of the phloem.

Transpiration drives the transport of water and minerals from roots to shoots via the xylem:

The absorption and transport of water and minerals through the xylem occur in three stages

Absorption of Water and minerals by root Cells	Transport of Water and minerals into the Xylem	Bulk Flow transport via the Xylem
1. Osmosis 2. Active Transport	1. Symplast. 2. Apoplast	1. Pushing Xylem Sap: Root Pressure 2. Pulling Xylem Sap: The Cohesion-Tension Hypothesis.

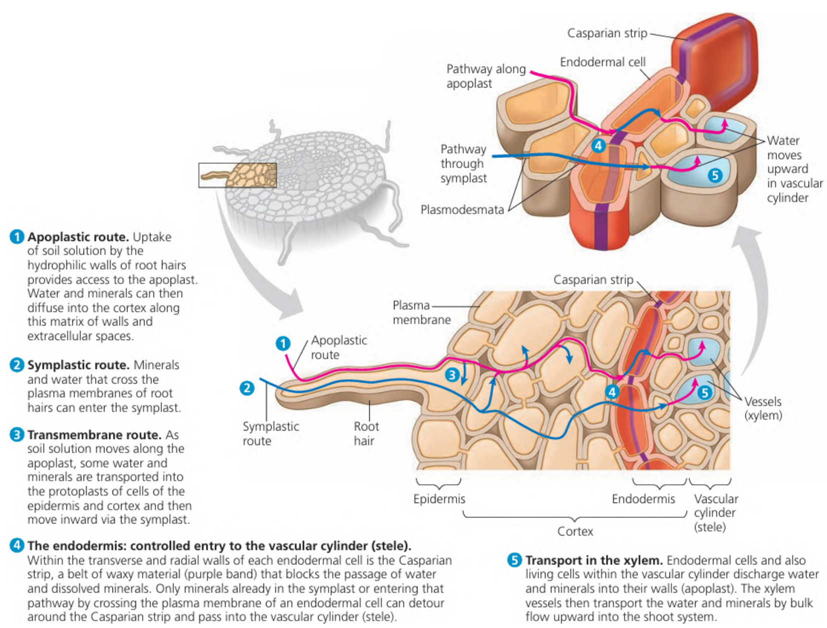


figure 81. Transport of water and minerals from root hairs to the xylem

Ascent of xylem sap

Ascent of xylem sap. Hydrogen bonding forms an unbroken chain of water molecules extending from leaves to the soil. The force driving the ascent of xylem sap is a gradient of water potential (Ψ). For bulk flow over long distance, the Ψ gradient is due mainly to a gradient of the pressure potential (ΨP). Transpiration results in the ΨP at the leaf end of the xylem being lower than the ΨP at the root end.

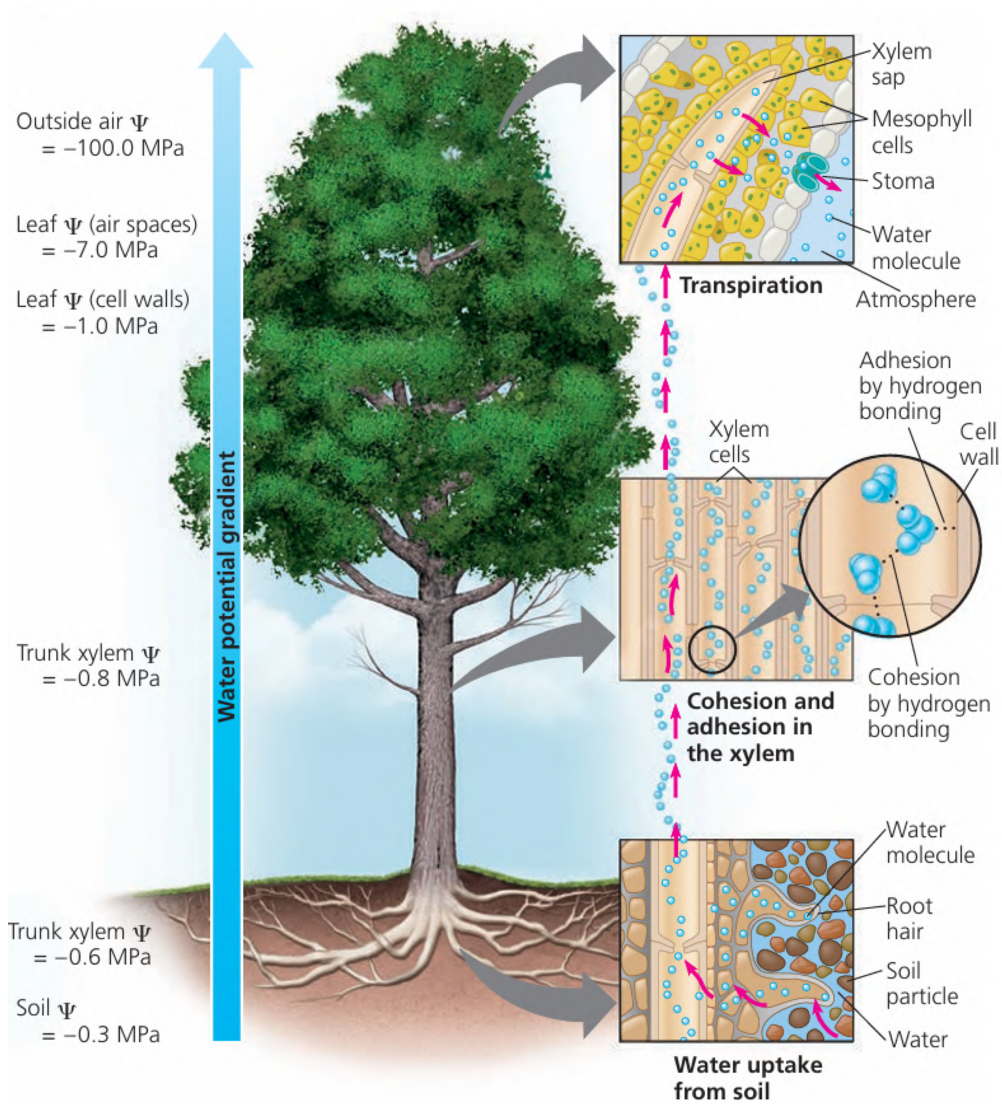
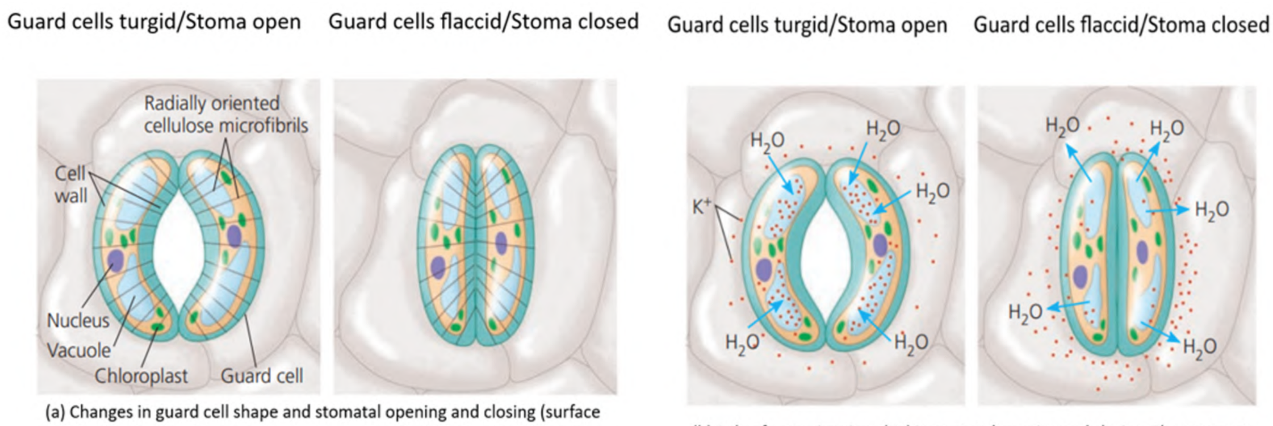


figure 82. Ascent of xylem sap

The rate of transpiration is regulated by stomata

- Stomata: major Pathways For Water Loss
- Mechanisms of Stomatal opening and Closing
- Stimuli For Stomatal opening and Closing



(a) Changes in guard cell shape and stomatal opening and closing (surface view). Guard cells of a typical angiosperm are illustrated in their turgid (stoma open) and accid (stoma closed) states. The radial orientation of cellulose micro-brils in the cell walls causes the guard cells to increase more in length than width when turgor increases. Since the two guard cells are tightly joined at their tips, they bow outward when turgid, causing the stomatal pore to open.

(b) Role of potassium ions (K+) in stomatal opening and closing. The transport of K+ (symbolized here as red dots) across the plasma membrane and vacuolar membrane causes the turgor changes of guard cells. The uptake of anions, such as malate and chloride ions (not shown), also contributes to guard cell swelling.

figure 83. Mechanisms of stomatal opening and closing

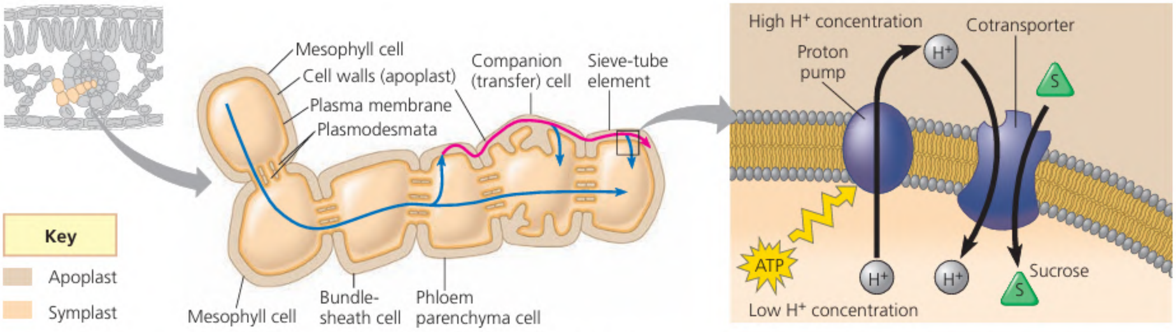
Adaptations that reduce Evaporative Water Loss:

Xerophytes have unusual physiological or morpho logical adaptations that enable them to withstand harsh desert conditions. The stems of many xerophytes are fleshy because they store water for use during long dry periods. Cacti have highly reduced leaves that resist excessive water loss; photo synthesis is carried out mainly in their stems. Another adaptation common in arid habitats is crassulacean acid metabolism (CAM), a specialized form of photosynthesis found in succulent's plants. Because the leaves of CAM plants take in CO2 at night, the stomata can remain closed during the day, when evaporative stresses are greatest.

Sugars are transported from sources to sinks via the phloem:

Sugar is transported through the phloem in two stages

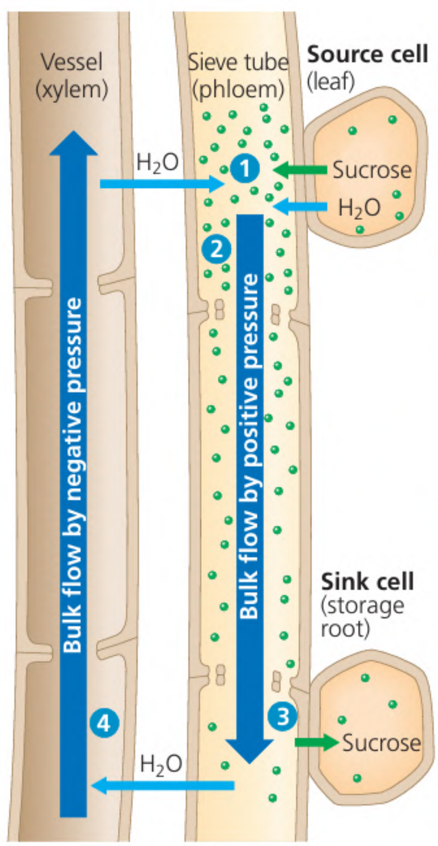
Movement from Sugar Sources to Sugar Sinks	Bulk Flow by Positive Pressure
1. Symplast 2. Apoplast 3. Active transport	The uptake of water from the xylem into the phloem generates a positive pressure within the phloem elements.



(a) Sucrose manufactured in mesophyll cells can travel via the symplast (blue arrows) to sieve-tube elements. In some species, sucrose exits the symplast near sieve tubes and travels through the apoplast (red arrow). It is then actively accumulated from the apoplast by sieve-tube elements and their companion cells.

(b) A chemiosmotic mechanism is responsible for the active transport of sucrose into companion cells and sieve-tube elements. Proton pumps generate an H^+ gradient, which drives sucrose accumulation with the help of a cotransport protein that couples sucrose transport to the diffusion of H^+ back into the cell.

figure 84. Loading of sucrose into phloem.



1. Loading of sugar (green dots) into the sieve tube at the source (in this example, a mesophyll cell in a leaf) reduces water potential inside the sieve-tube elements. This causes the tube to take up water by osmosis.

2. This uptake of water generates a positive pressure that forces the sap to flow along the tube.

3. The pressure is relieved by the unloading of sugar and the consequent loss of water at the sink.

4. In leaf-to-root translocation, xylem recycles water from sink to source.

figure 85. Bulk flow by positive pressure in a sieve tube.

CHAPTER 03.

Soil and Plant Nutrition

Soil contains a living, complex ecosystem

The upper layers of the soil, from which plants absorb nearly all the water and minerals they require, contain a wide range of living organisms that interact with each other and with the physical environment.

Essential elements:

The inorganic substances in plants contain more than 50 chemical elements. When studying the chemical composition of plants, it is important to distinguish between essential elements and those that are merely present in the plant. A chemical element is considered an essential element only if it is required for the plant to complete its life cycle and reproduce.

nutrients	CO_2	O_2	H_2O	NO_3^-,NH_4^+	K^+	Ca^{2+}	Mg^{2+}	H_2PO^{4-}	SO^{4-}
Symptom(s) of nutrient Deficiencies	Poor growth	Poor growth	Wilting, poor growth	Chlorosis at tips of older leaves	Mottling of older leaves weak stems; roots	Crinkling of young leaves; death of terminal buds	Chlorosis between veins	slow develop -ment; thin stems	chlorosis in young leaves

Plant nutrition often involves relationships with other organisms:

Up to this point, we have described plants as exploiters of soil resources, but the relationship between plants and soil is a two-way relationship. Dead plants provide much of the energy needed by bacteria and fungi living in the soil. Many of these organisms also benefit from the sugar-rich secretions produced by living roots. At the same time, plants benefit from their associations with soil bacteria and fungi.

The roles of soil bacteria in the nitrogen nutrition of plants:

Ammonium is made available to plants by two types of soil bacteria: those that fix atmospheric N2 (nitrogen-fixing bacteria) and those that decompose organic material (ammonifying bacteria). Although plants absorb some ammonium from the soil, they absorb mainly nitrate, which is produced from ammonium by nitrifying bacteria.

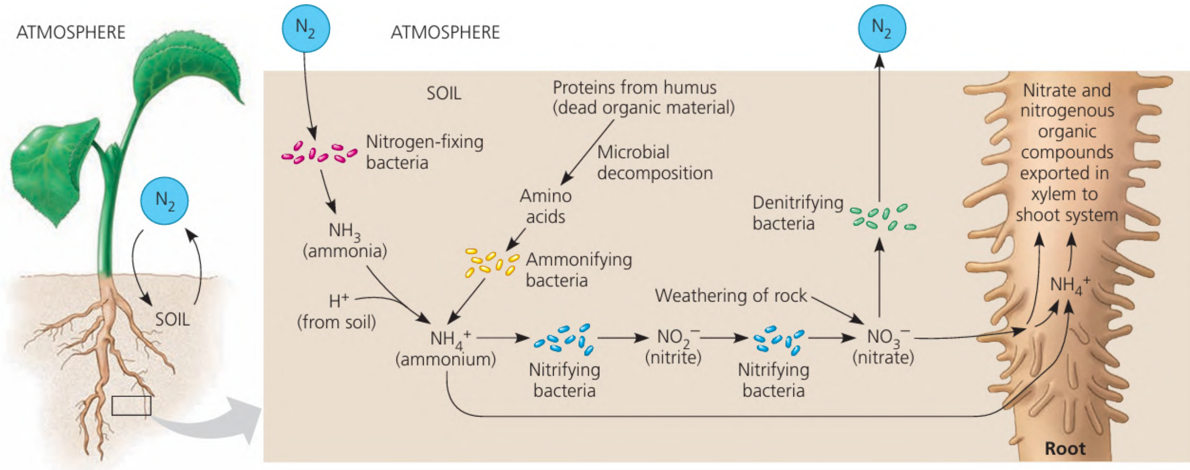


figure 86. The roles of soil bacteria in the nitrogen Fixation

Rhizobacteria

Development of a soybean root nodule:

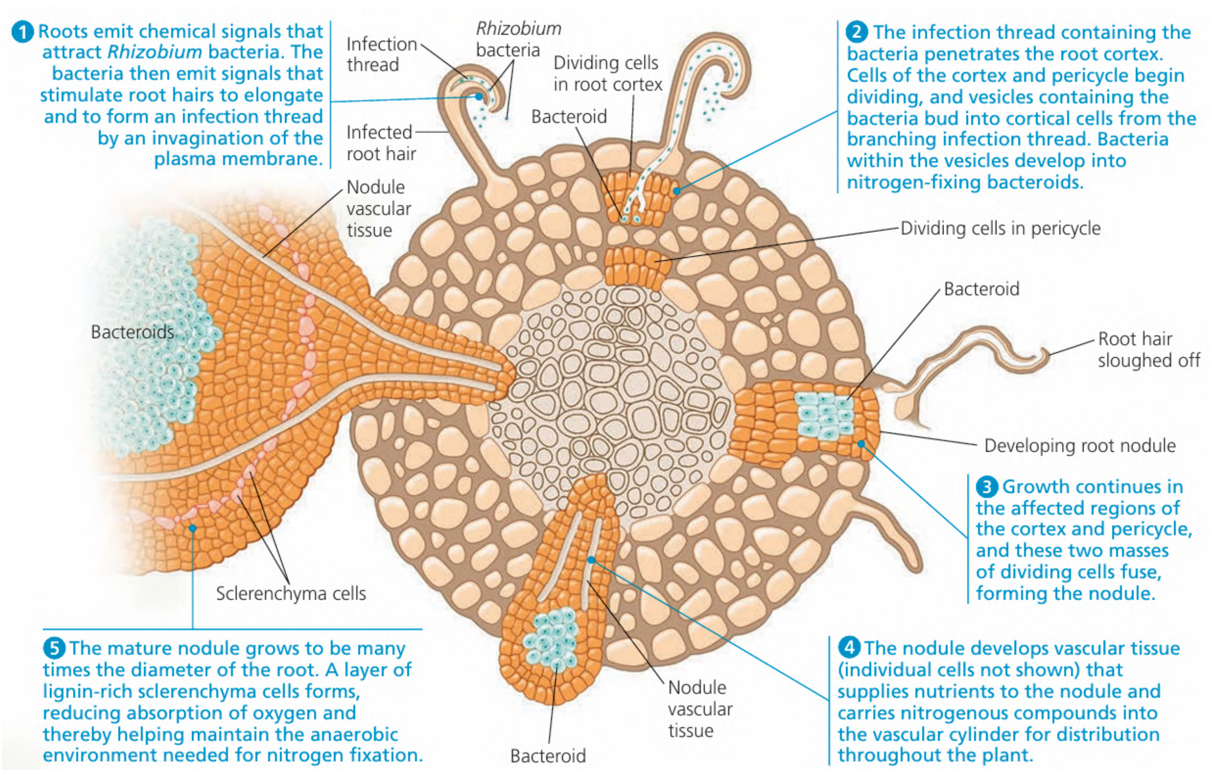


Figure 87. Development of a soybean root nodule

Fungi and Plant nutrition

Arbuscular mycorrhizae (Endomycorrhizae)	Ectomycorrhizae.
No mantle forms around the root, but microscopic fungal hyphae extend into the root. Within the root cortex, the fungus makes extensive contact with the plant through branching of hyphae that form arbuscules, providing an enormous surface area for nutrient swapping. The hyphae penetrate the cell walls, but not the plasma membranes, of cells within the cortex.	The mantle of the fungal mycelium ensheathes the root. Fungal hyphae extend from the mantle into the soil, absorbing water and minerals, especially phosphorus. Hyphae also extend into the extracellular spaces of the root cortex, providing extensive surface area for nutrient exchange between the fungus and its host plant.

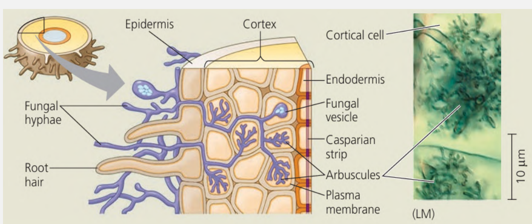


Figure 88. Endomycorrhizae

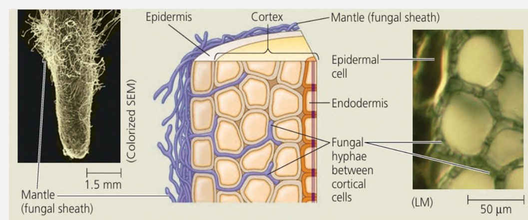
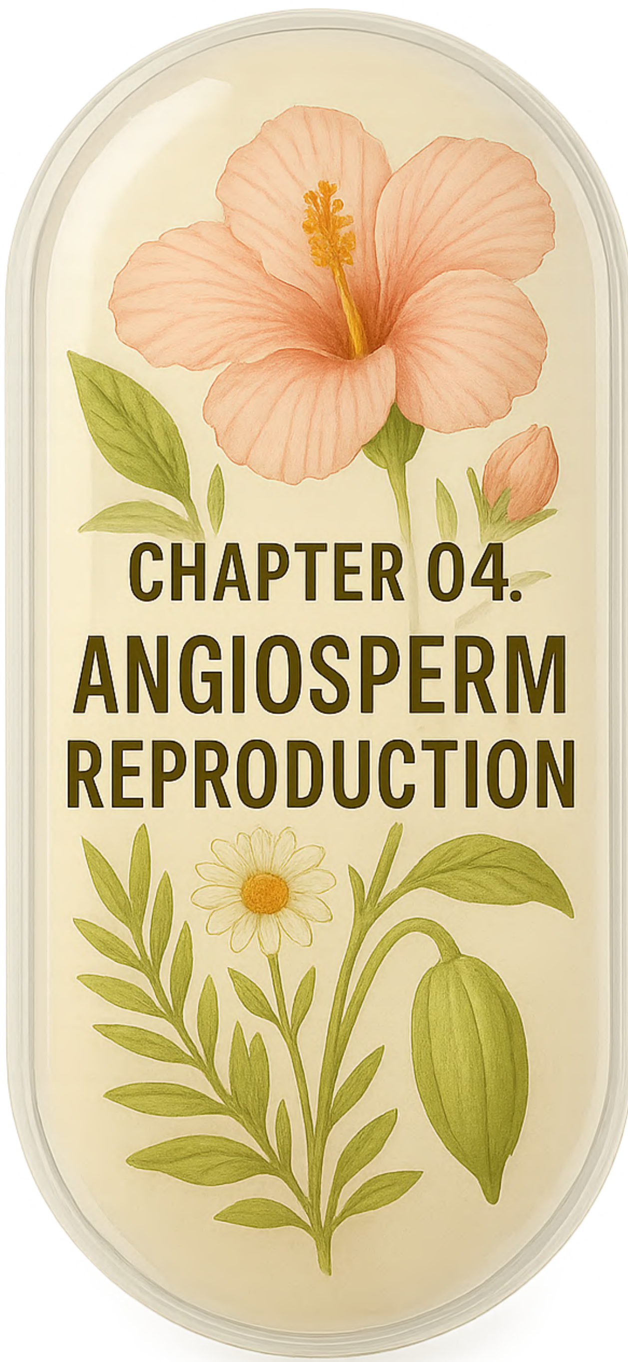


Figure 89. Ectomycorrhizae

Unusual nutritional adaptations in Plants

1. Epiphytes
2. Parasitic Plants
3. Carnivorous Plants

figure 90. From the left (Carnivorous, Parasitic and Epiphytes)



CHAPTER 04.
ANGIOSPERM REPRODUCTION

Flowers, double fertilization, and fruits are key features of the angiosperm life cycle

The life cycles of all plants are characterized by an alternation of generations, in which multicellular haploid (n) and multicellular diploid (2n) generations alternately produce each other. Fertilization, the fusion of gametes, results in a diploid zygote, which divides by mitosis and forms a new sporophyte. In angiosperms, the sporophyte is the dominant generation: It is larger, more conspicuous, and longer-lived than the gametophyte. The key traits of the angiosperm life cycle can be remembered as the "three Fs"—f lowers, double fertilization, and fruits.

Flower Structure and Function:

The flower, which is the sporophytic structure in angiosperms specialized for sexual reproduction, is typically composed of four types of floral organs: carpels, stamens, petals, and sepals (see figure). The carpel (also called a megasporophyll) contains an ovary at its base and a slender neck called the style. At the top of the style is a sticky structure known as the stigma, which functions to capture pollen grains. The stamen (also called a microsporophyll) consists of a stalk called the filament and a terminal structure called the anther. Inside the anther are chambers known as microsporangia or pollen sacs, which produce pollen grains.

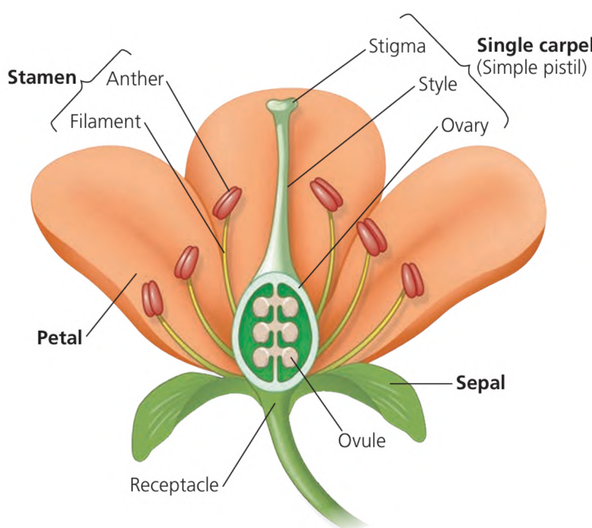


Figure 91. The structure of an idealized flower

Methods of Pollination

Pollination by Bees

The flowers have attractive colors and fragrances.

Pollination by Wind

floral structures can create eddy currents that aid in pollen capture

Pollination by Bats

Bat-pollinated flowers, and the flowers, are light colored and aromatic

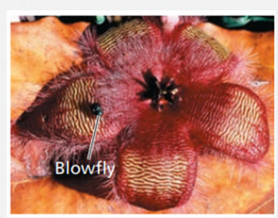
Pollination by Moths and Butterflies

the flowers they pollinate are often sweetly fragrant. And they are usually white or yellow,

Pollination by Birds

flowers, are usually large and bright. The petals of such flowers are often fused, forming a bent floral tube that fits the curved beak of the bird.

Pollination by Flies



flowers are reddish and fleshy, with an odor like rotten meat.

The life cycle of angiosperms:

Pollination is one step in the angiosperm life cycle. Figure below provides a complete overview of the life cycle, focusing on gametophyte development, sperm delivery by pollen tubes, double fertilization, and seed development. Over the course of seed plant evolution, gametophytes became reduced in size and wholly dependent on the sporophyte for nutrients (see Figure 30.2). The gametophytes of angiosperms are the most reduced of all plants, consisting of only a few cells: They are microscopic, and their development is obscured by protective tissues. For simplicity, a flower with a single carpel (simple pistil) is shown. Many species have multiple carpels, either separate or fused.

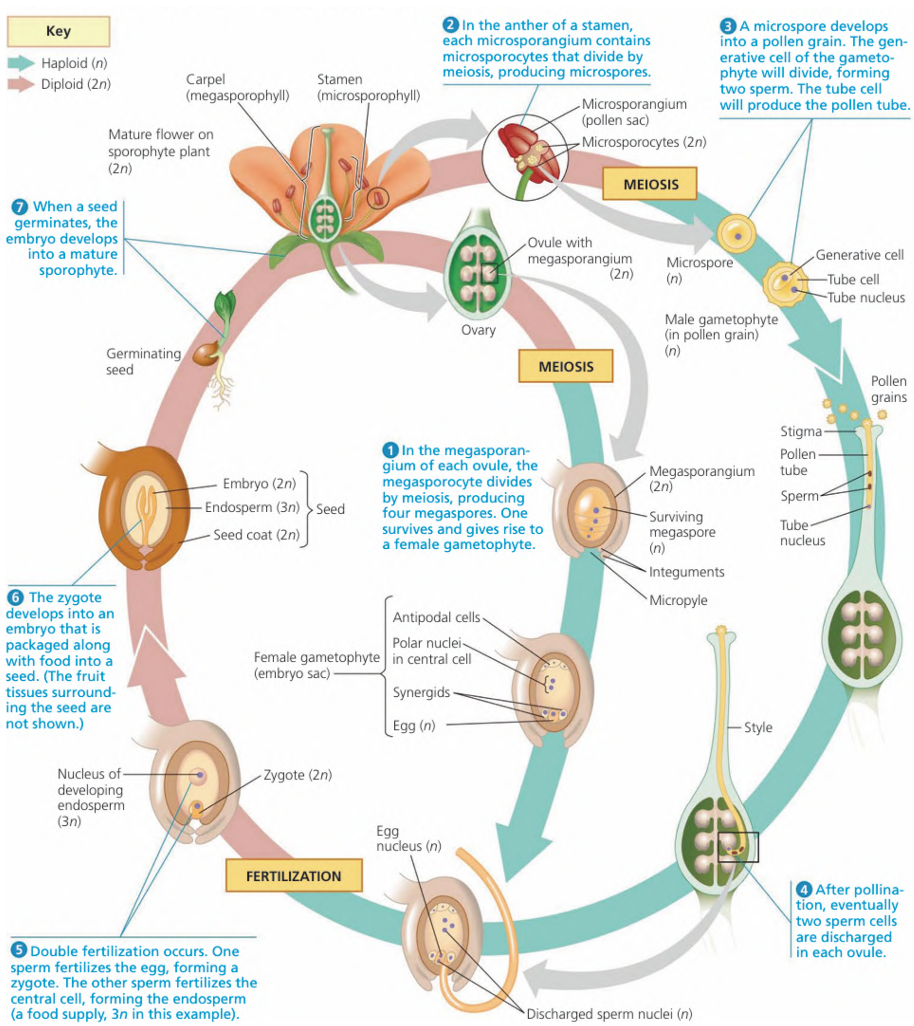


Figure 92. The life cycle of angiosperms

Seed Development and Structure:

Seed formation goes through three stages:

1. Endosperm Development:

Endosperm usually develops before the embryo does. After double fertilization, the triploid nucleus of the ovule's central cell divides, forming a multinucleate "supercell" that has a milky consistency. This liquid mass, the endosperm, becomes multicellular when cytokinesis partitions the cytoplasm by forming membranes between the nuclei. Eventually, these "naked" cells produce cell walls, and the endosperm becomes solid.

2. Embryo Development:

By the time the ovule becomes a mature seed, and the integuments harden and thicken into the seed coat, the zygote has given rise to an embryonic plant with rudimentary organs.

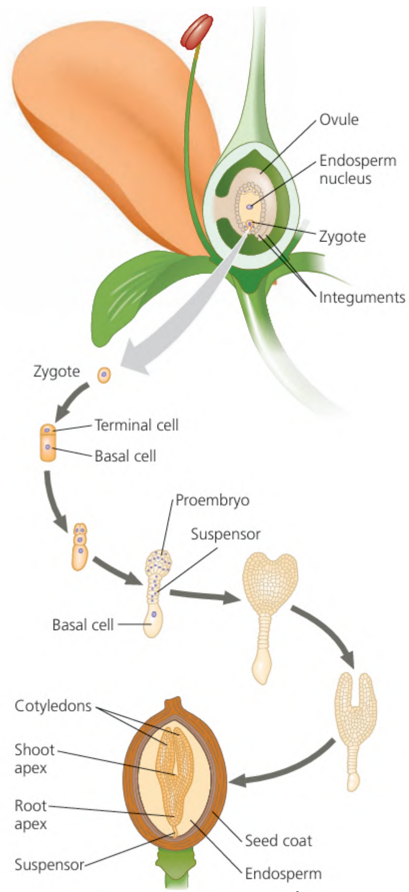


Figure 93. The development of a eudicot plant embryo

3. Mature Seed:

During the last stages of its maturation, the seed dehydrates until its water content is only about 5–15% of its weight. The embryo, which is surrounded by a food supply (cotyledons, endosperm, or both), enters dormancy; that is, it stops growing and its metabolism nearly ceases

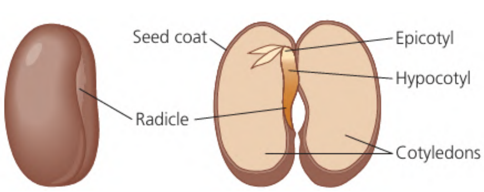


Figure 95. Seed structure in eudicot

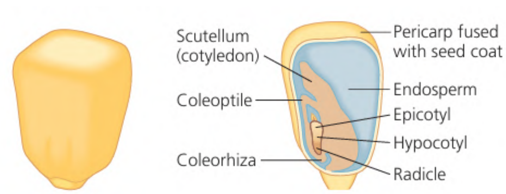


Figure 94. Seed structure in monocot

Seed Germination

When environmental conditions are favorable for growth, dormancy in the seeds is broken and germination continues. Germination is followed by the growth of stems, leaves, and roots, and eventually flowering.

Maize.	Common garden bean.
In maize and other grasses, the shoot grows straight up through the tube of the coleoptile.	In common garden beans, straightening of a hook in the hypocotyl pulls the cotyledons from the soil.

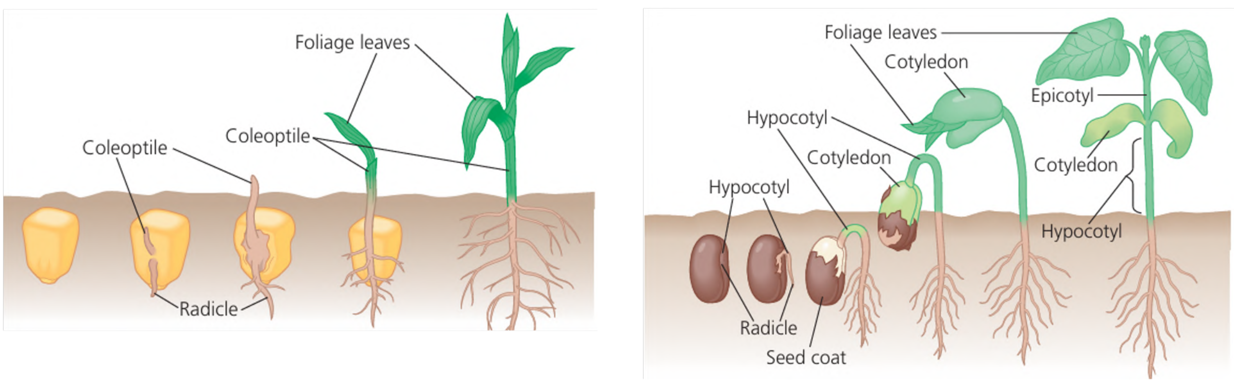
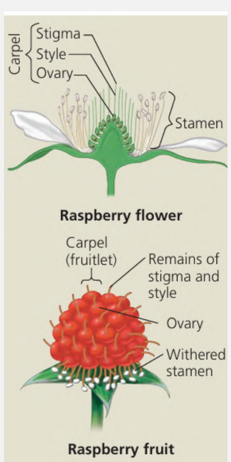
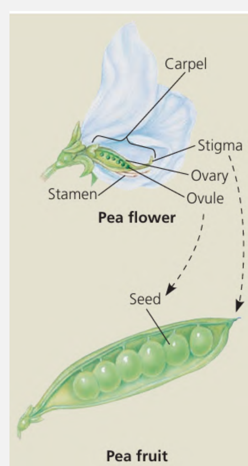


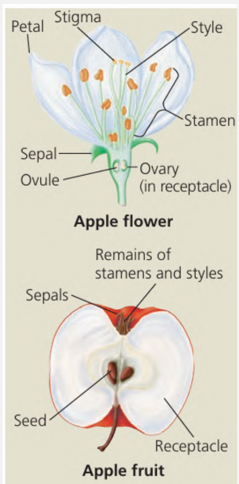
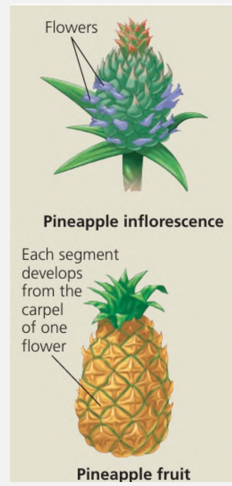
Figure 96. Stages of seed germination in monocots and dicots

Fruit Structure and Function:

Aggregate fruit	Simple fruit
develops from many separate carpels of one flower	develops from a single carpel (or several fused carpels) of one flower





Accessory fruit	Multiple fruit
develops largely from tissues other than the ovary	develops from many carpels of the many flowers that form an inflorescence
	

Fruit and Seed Dispersal

Dispersal by Wind

- With a wingspan of 12 cm, the giant seed of the tropical Asian climbing gourd *Alsomitra macrocarpa* glides through the air of the rain forest in wide circles when released
- Some seeds and fruits are attached to umbrella like" parachutes" that are made of intricately branched hairs.
- Tumbleweeds break off at the ground and tumble across the terrain, scattering them seeds.
- The winged fruit of a maple spins like a helicopter blade, slowing descent and increasing the chance of being carried farther by horizontal winds.

Dispersal by Water

- Some buoyant seeds and fruits can survive months or years at sea. In coconut, the seed embryo and fleshy white “meat” (endosperm) are within a hard layer (endocarp) surrounded by a thick and buoyant fibrous husk.

Dispersal by Animals

- The sharp, tack-like spines on the fruits of puncture vine (Tribulus terrestris) can pierce bicycle tires and injure animals, including humans. When these painful" tacks" are removed and discarded, the seeds are dispersed.
- Some animals, such as squirrels, hoard seeds or fruits in underground caches. If the animal dies or forgets the cache's location, the buried seeds are well positioned to germinate.

Figure 97. fruits of (Tribulus)

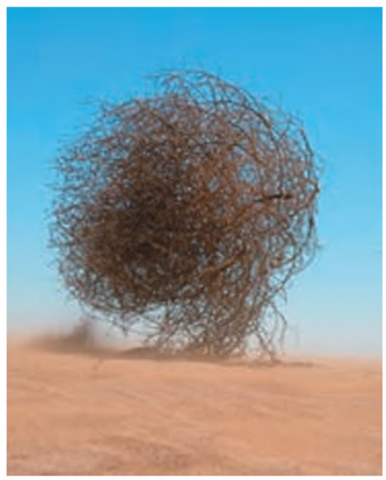
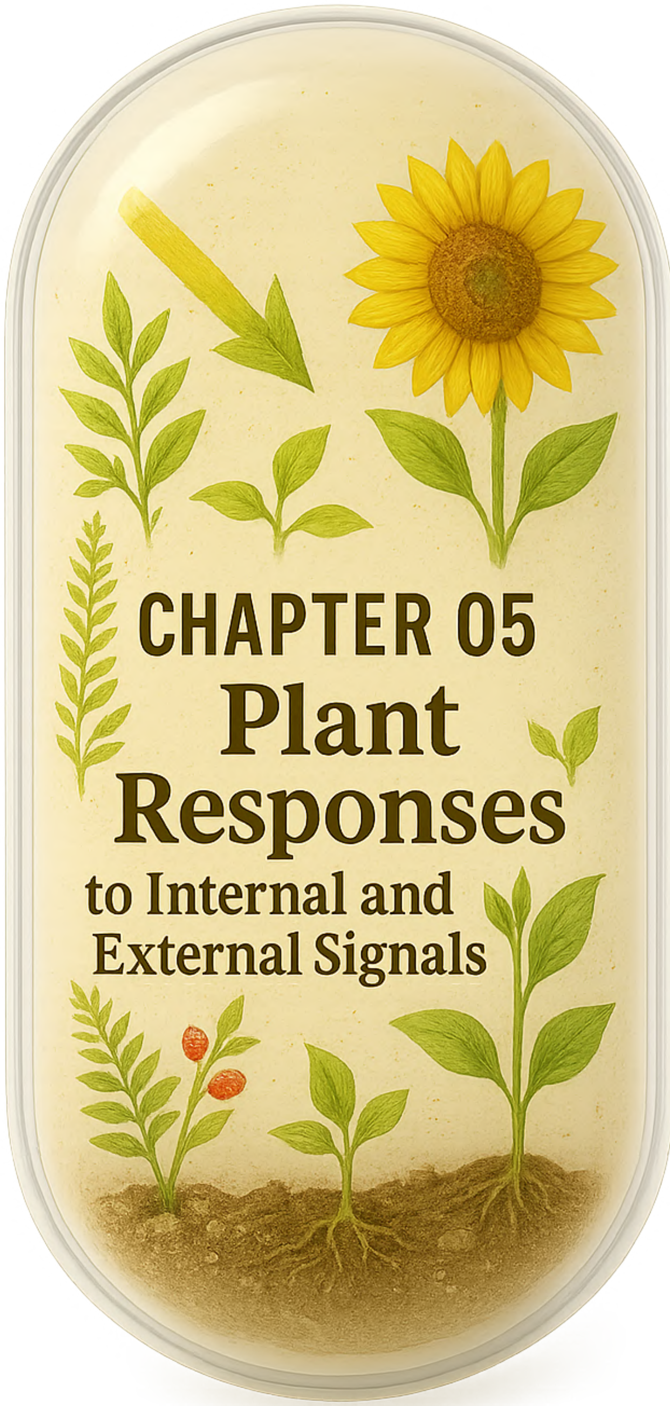


Figure 98. Desert grass plants

Figure 99. Seed of the tropical Asian climbing gourd

Figure 100. Fruit of a maple spins

Figure 101. Seeds and fruits are attached to umbrella


CHAPTER 05
Plant Responses
to Internal and
External Signals

Plant hormones help coordinate growth, development, and responses to stimuli

A hormone, in the original meaning of the term, is a signaling molecule that is produced in low concentrations by one part of an organism's body and transported to other parts, where it binds to a specific receptor and triggers responses in target cells and tissues.

Study of plant hormones:

The major plant hormones are auxins, cytokinins, gibberellins, abscisic acid, ethylene, brassinosteroids, jasmonates, and strigolactones.

Auxin:

1. Charles Darwin and his son Francis
2. The role of auxin in Cell elongation
3. Auxin's role in Plant Development

Cytokinins:

1. Control of Cell Division and Differentiation
2. Control of apical Dominance
3. Anti-aging effects

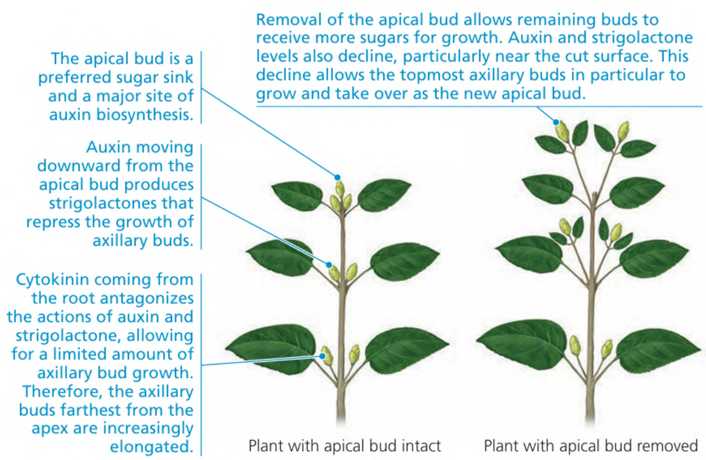


Figure 102. Effects on apical dominance of removing the apical bud.

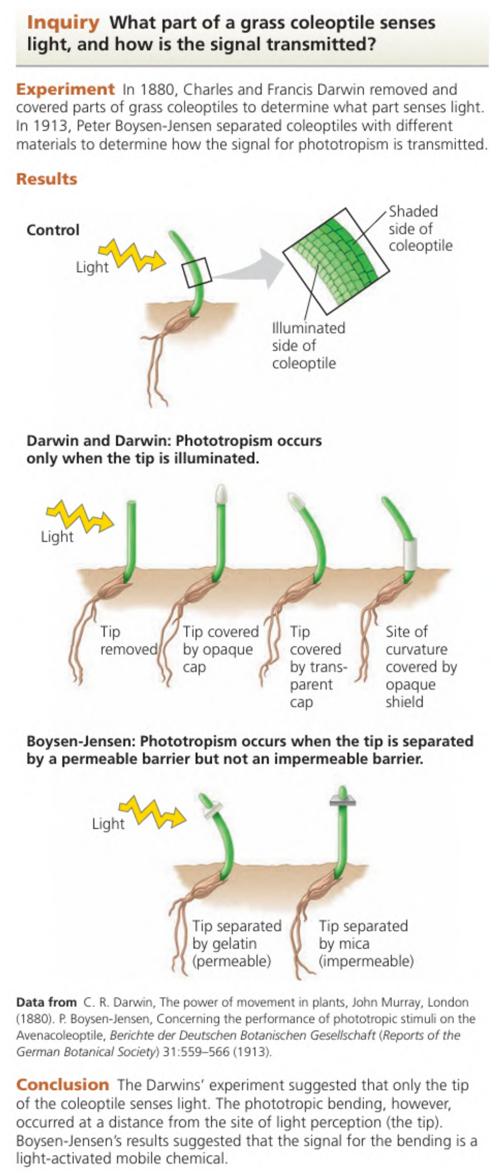


Figure 103. Charles and Francis Darwin experiment

Gibberellins

1. Stem elongation
2. Fruit Growth
3. Germination

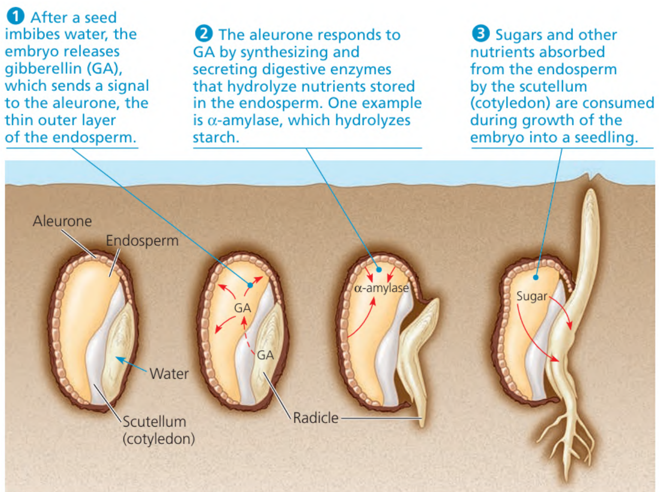
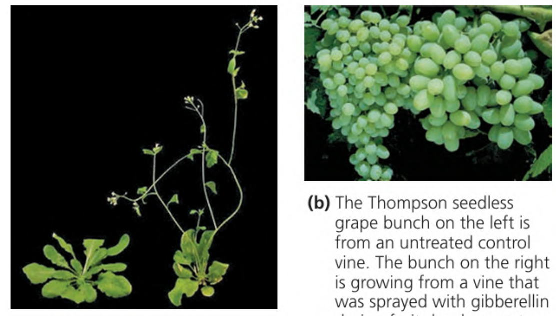


Figure 104. Mobilization of nutrients by gibberellins during the germination of grain seeds such as barley.



(a) Some plants develop in a rosette form, low to the ground with very short internodes, as in the *Arabidopsis* plant shown at the left. As the plant switches to reproductive growth, a surge of gibberellins induces bolting: Internodes elongate rapidly, elevating floral buds that develop at stem tips (right).

(b) The Thompson seedless grape bunch on the left is from an untreated control vine. The bunch on the right is growing from a vine that was sprayed with gibberellin during fruit development.

Figure 105. Effects of gibberellins on stem elongation and fruit growth.

Abscisic Acid:

1. Seed Dormancy
2. Drought tolerance

Ethylene:

1. The triple response to mechanical Stress
2. Senescence
3. Leaf abscission
4. Fruit ripening

More Recently Discovered Plant Hormones:

1. Brassinosteroids
2. Jasmonates
3. Strigolactones

Responses to light are critical for plant success

Light is an especially important environmental factor in the lives of plants. In addition to being required for photosynthesis, light triggers many key events in plant growth and development, collectively known as photomorphogenesis. Light reception also allows plants to measure the passage of days and seasons.

Phytochrome Photoreceptors

Phytochromes and Seed Germination

many types of seeds, especially small ones, germinate only when the light environment and other conditions are near optimal. Such seeds often remain dormant for years until light conditions change.

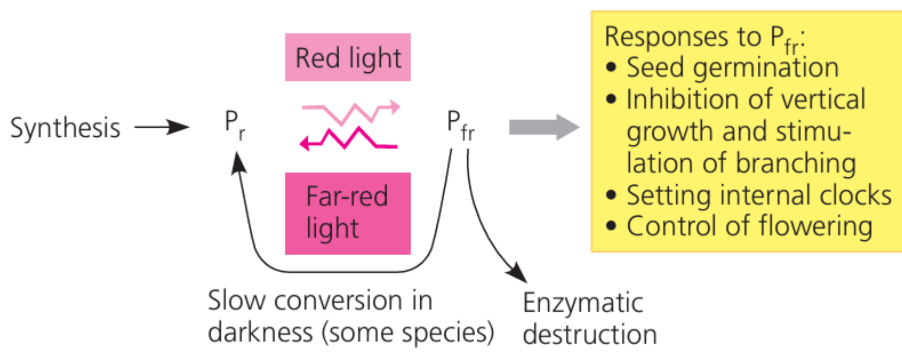


Figure 106. Phytochrome: a molecular switching mechanism.

Photoperiodism and responses to Seasons:

Seasonal events are of critical importance in the life cycles of most plants. Seed germination, flowering, and the onset and breaking of bud dormancy are all stages that usually occur at specific times of the year. The environmental cue that plants use to detect the time of year is the change in day length (photoperiod). A physiological response to specific night or day lengths, such as flowering, is called photoperiodism.

Critical night Length

- In the 1940s, researchers discovered that flowering in short-day and long-day plants is controlled by night length, not by day length (the photoperiod).
- Many of these scientists worked with Cocklebur (*Xanthium strumarium*), a short-day plant that flowers only when daytime lasts 16 hours or less (and nights are at least 8 hours long).
- They found that if the photoperiod is interrupted by a brief dark period, flowering proceeds.
- However, if the night period is interrupted by even a few minutes of dim light, the Cocklebur plant will not flower — a phenomenon also observed in other short-day plants (see Figure a).
- The Cocklebur does not respond to day length; instead, it requires at least 8 hours of continuous darkness to flower.
- Thus, short-day plants are in fact long-night plants, but the older terminology remains deeply rooted in the vocabulary of plant physiology.
- Similarly, long-day plants are short-night plants.
- A long-day plant placed under long-night conditions, which normally do not induce flowering, will flower only if the night is interrupted by a few minutes of light (see Figure b).
- Note that long-day plants and short-day plants do not differ in their absolute night length.
- Instead, they are distinguished by whether the critical night length determines the maximum number of hours of darkness required for flowering (long-day plants) or the minimum number of hours of darkness required for flowering (short-day plants).

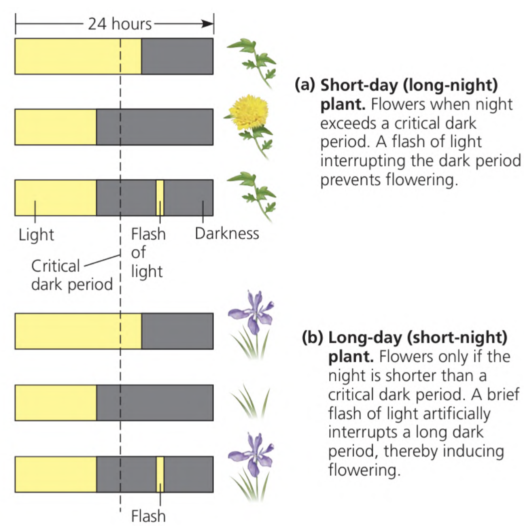


Figure 107. Photoperiodic control of flowering.

- Red light is the most effective color for interrupting the night period. Action spectra and photo reversibility experiments show that phytochrome is the pigment that detects red light (see next figure).
- Red light is the most effective color for interrupting the night period. Action spectra and photo reversibility experiments show that phytochrome is the pigment that detects red light (see next figure).
- For example, if a flash of red light occurs during a long night but is immediately followed by a flash of far-red light, the plant detects no interruption in night length. As in phytochrome-mediated seed germination, red/far-red photo reversibility occurs.
- Plants measure night length with remarkable precision; some short-day plants will not flower if the night is shorter by even one minute than the critical night length.
- Certain plant species flower on the same day each year. It appears that plants use their biological clock, entrained by night length and assisted by phytochrome, to determine the season of the year.
- The floriculture industry (the commercial cultivation of flowers) applies this knowledge to produce blooms out of season.
- Some plants flower after a single exposure to the appropriate photoperiod, while others require several consecutive days of the correct light period.

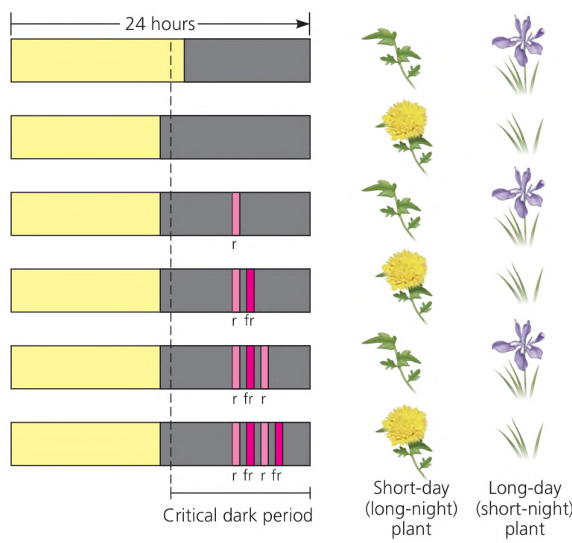


Figure 108. Reversible effects of red and far-red light on photoperiodic response.

- In some plants, light alone is not sufficient to induce flowering; these plants respond to a specific photoperiod only after prior exposure to another environmental stimulus, such as a period of cold. For example, winter wheat will not flower unless it has experienced several weeks of temperatures below 10°C.

- This process, in which cold treatment induces the ability to flower, is called vernalization. After several weeks of vernalization, exposure to a long photoperiod (short night) then induces flowering in winter wheat.

Plants respond to a wide variety of stimuli other than light:

Gravity

Plants may detect gravity by the settling of statoliths, dense cytoplasmic components that settle under the influence of gravity to the lower portions of the root cover cells.

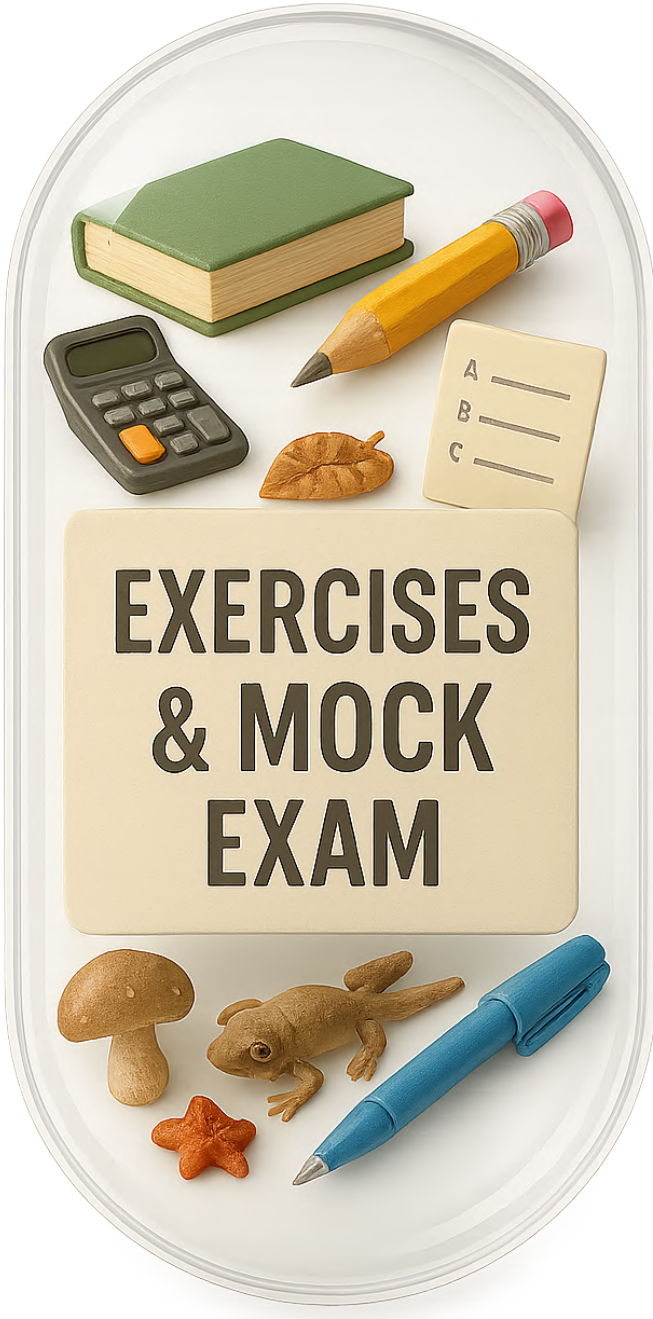
Mechanical Stimuli:

Trees in windy environments usually have shorter, stockier trunks than a tree of the same species growing in more sheltered locations.

Environmental Exhaustion:

Drought
Water deficit stimulates increased synthesis and release of abscisic acid in the leaves; this hormone helps keep stomata closed by acting on guard cell membranes
Flooding
Oxygen deprivation stimulates the production of ethylene. Ethylene-stimulated apoptosis (programmed cell death) creates the air tubes
Salt Exhaustion
Many plants can respond to moderate soil salinity by producing solutes that are well tolerated at high concentrations: These mostly organic compounds keep the water potential of cells more negative than that of the soil solution
Heat Exhaustion
Above a certain temperature—about 40 C^0 for most plants in temperate regions—plant cells begin synthesizing heat-shock proteins, which help protect other proteins from heat stress.

Cold Exhaustion
Plants respond to cold stress by altering the lipid composition of their membranes. For example, membrane lipids increase in their proportion of unsaturated fatty acids, which have shapes that help keep membranes more fluid at low temperatures.

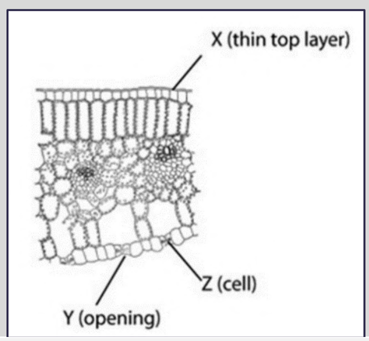

EXERCISES
& MOCK
EXAM
A
B
C

Exercises

1	**Which of the following is correctly paired with its structure and function?**
A	Sclerenchyma—supporting cells with thick secondary walls
B	Ground meristem—protective coat of woody stems and roots
C	Guard cells—waterproof ring of cells surrounding the central stele in roots
D	Periderm—parenchyma cells functioning in photosynthesis in leaves
2	**Which of the following is the correct sequence of the zones in the primary growth of a root, moving from the root cap inward?**
A	Zone of cell division, zone of elongation, zone of differentiation.
B	Zone of differentiation, zone of elongation, zone of cell division
C	Zone of elongation, zone of cell division, zone of differentiation
D	Zone of cell division, zone of differentiation, zone of elongation
3	**The veins of leaves are ________.** I. Composed of xylem and phloem II. Continuous, with vascular bundles in the stem and roots III. Finely branched to be in close contact with photosynthesizing cells

A	B	C	D
only I	only II	only III	I, II, and III

4	**The main function associated with structure X is ________.**



A	Absorption of carbon dioxide
B	Retention of water
C	Collection of light
D	Release of carbon dioxide

5	**Which of the following would be least likely to affect osmosis in plants?**
A	A difference in solute concentrations.
B	Receptor proteins in the membrane
C	Aquaporins.
D	A difference in water potential
6	**If isolated plant cells with a water potential averaging -0.5 MPa are placed into a solution with a water potential of -0.3 MPa, which of the following would be the most likely outcome?**
A	The pressure potential of the cells would increase
B	Water would move out of the cells
C	The cell walls would rupture, killing the cells.
D	Solutes would move out of the cells.
7	**Arrange the following five events in an order that explains the mass flow of materials in the phloem.** 1. Water diffuses into the sieve tubes. 2. Leaf cells produce sugar by photosynthesis. 3. Solutes are actively transported into sieve tubes. 4. Sugar is transported from cell to cell in the leaf. 5. Sugar moves down the stem.

A	B	C	D
1, 2, 3, 4, 5	2, 4, 3, 1, 5	4, 2, 1, 3, 5	2, 4, 1, 3, 5

8	**The value for Ψ in root tissue was found to be -0.15 MPa. If you take the root tissue and place it in a 0.1 M solution of sucrose (Ψ = -0.23 MPa), the net water flow would ________.**
A	be from the tissue into the sucrose solution
B	be from the sucrose solution into the tissue
C	be in both directions, and the concentration of water would remain equal
D	be impossible to determine from the values given here

9	**If an ovary contains 50 ovules, what is the minimum number of pollen grains that must land to form 50 mature seeds?**		
A	**B**	**C**	**D**
25	50	100	500

10	**Which of the following is a primary difference between ectomycorrhizae and endomycorrhizae?**
A	Endomycorrhizae have thicker, shorter hyphae than ectomycorrhizae.
B	Ectomycorrhizae do not penetrate root cells, whereas endomycorrhizae grow into invaginations of the root cell membranes.
C	Endomycorrhizae are more common than ectomycorrhizae
D	There are no significant differences between ectomycorrhizae and endomycorrhizae.
11	**Some dioecious species have the XY genotype for male and XX for female. After double fertilization, what would be the genotypes of the embryos and endosperm nuclei?**
A	embryo XY/endosperm XXX or embryo XX/endosperm XXY
B	embryo XX/endosperm XX or embryo XY/endosperm XY.
C	embryo XX/endosperm XXX or embryo XY/endosperm XYY.
D	embryo XX/endosperm XXX or embryo XY/endosperm XXY
12	**What adaptations should one expect of the seed coats of angiosperm species whose seeds are dispersed by frugivorous (fruit-eating) animals, as opposed to angiosperm species whose seeds are dispersed by other means?** 1. The exterior of the seed coat should have barbs or hooks. 2. The seed coat should contain secondary compounds that irritate the lining of the animal's mouth. 3. The seed coat should be able to withstand low pHs. 4. The seed coat, upon its complete digestion, should provide vitamins or nutrients to animals. 5. The seed coat should be resistant to the animals' digestive enzymes.

A	**B**	**C**	**D**
4 only	1 and 2	3 and 5	3,4, and 5

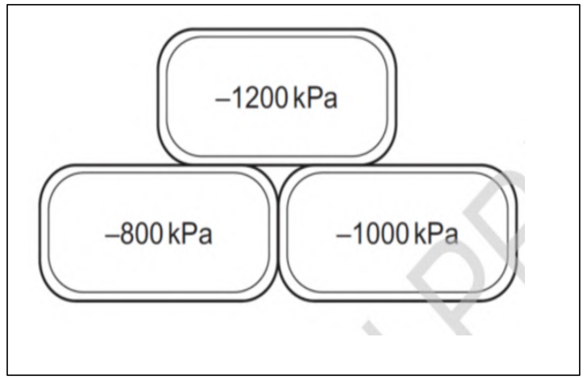
13	**Which of the following mechanisms is the correct sequence of events that takes place during the plant responses to internal and external signals?**
A	transduction, reception, and response
B	reception and transduction
C	reception, transduction, and response
D	reception and response

14	**Plant hormones produce their effects by ________.** I. altering the expression of genes II. modifying the permeability of the plasma membrane III. modifying the structure of the nuclear envelope membrane?

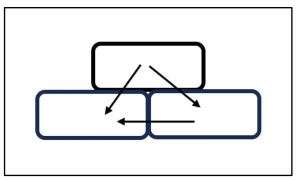
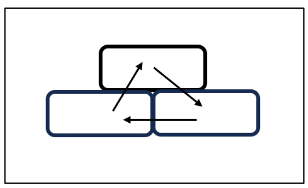
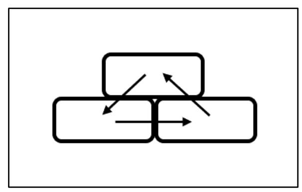
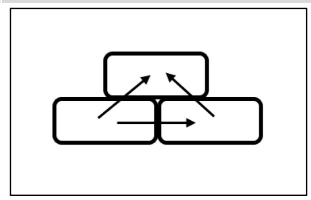
A	**B**	**C**	**D**
Only I	Only II	Only III	Only I and II

Mock Exam

1- **The diagram shows the water potentials of 3 adjacent plant cells (the water potential of pure water is 0).**



Determine for each of the following figures whether the direction of water movement due to osmosis is depicted correctly?

A	B	C	D
			

2- **On a warm summer's day, the transpiration pull is the main force that drives water from root parenchyma into the root xylem. The table shows values of ψ_p (pressure potential) and ψ_s (solute potential) in root xylem and root parenchyma, in kPa.**
In which of the following options would transpiration pull cause water to move from root parenchyma into the root xylem?

	Root parenchyma		Root xylem	
	Ψ_p	Ψ_s	Ψ_p	Ψ_s
A	200	-190	-200	5
B	-200	220	65	-5
C	200	-220	65	-5
D	200	-220	-65	-5

3- To examine the effect of phytohormones P1 and P2 in plant tissue culture, leaf segments were excised from plants grown under the light, placed on medium that contained P1 and/or P2, and cultured in the dark. As a control experiment, leaf segments were cultured without P1 or P2 in the dark.

(a) When only P1 was added to the medium, adventitious roots formed on the explants.

(b) When only P2 was added to the medium, neither organogenesis nor callus formation occurred. The explants retained green color for a longer period than the explants of the control experiment.

(c) When both P1 and P2 were added to the medium, callus formed on the explants.

Based on this information, P1 and P2 were:

P2	P1	
Gibberellin	Auxin	**A**
Cytokinin	Auxin	**B**
Auxin	Gibberellin	**C**
Cytokinin	Gibberellin	**D**

4- In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as:

"a" If both Assertion and Reason are true, and the Reason is the correct explanation of Assertion.

"b" If both Assertion and Reason are true, but Reason is not the correct explanation of Assertion.

"c" If Assertion is true, but Reason is false.

"d" If the Assertion is false.

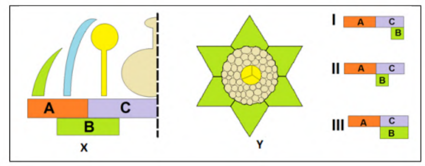
		Marks
1	Assertion: Cytokinin exhibit polar transport in plants	

	Reason: By using the polar transport system, cytokinin movement can be maintained regardless of changes in phloem transport caused by carbohydrate and mineral sinks and sources.	
2	Assertion: There is a meristematic phase of growth, both at the root apex and at the shoot apex, because the cells are constantly dividing. Reason: There is a lot of protoplasm in the cells of this region, but no nucleus.	
3	Assertion: A plant exposed to high salinity stress exhibits reduced transpiration rate than a plant growing under normal conditions. Reason: Water conduction in plant tissues is regulated by an equilibrium between water absorbed by the roots and water transpired from the leav	
4	Assertion: It is not possible for plants to utilize atmospheric nitrogen for their metabolism. As a result, they require nitrogen-fixing microorganisms (e.g. rhizobia) in the soil to provide nitrogen in usable form. Reason: The nitrogen fixed by Rhizobium is used in their own metabolism and becomes available to plants and fungi only when they die and decay	
5	Assertion: Plant cells may die if they are exposed to severe abiotic stress like heat, salinity, drought etc. for a long period. Reason: In response to abiotic stresses, among other pathologies, plants produce reactive oxygen species (ROS	
6	Assertion: Sepals, petals, stamens and pistils are parts of a flower. Reason: The petiole and lamina are parts of the stem.	
7	Assertion: Hydroponically grown plants (grown in the absence of soil) are grown in a nutrient solution in which air is bubbled. Reason: The bubbling solution increases the relative humidity within the plant chamber which is needed for plant growth.	
8	Assertion: In general, dicotyledonous mesophytes leaves have fewer stomata and thicker cuticle on their upper surface, compared to their lower surface. Reason: The upper surface of the leaves is exposed to greater light intensity	

5- The ABC-model of flower development explains the regulation of whorl differentiation in flower meristems.

There are three groups of master genes, A, B and C genes, each determining a type of whorl:

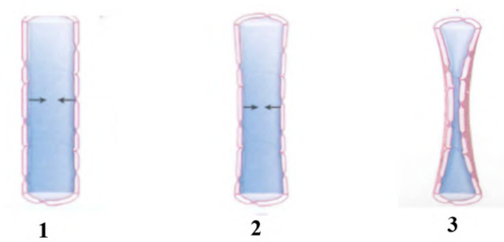
- Sepals need only A gene expression.
- Petals need simultaneous expression of A and B genes.
- Stamens need simultaneous expression of B and C genes.
- Carpels need only C gene expression.
- The tropical American plant, *Lacandonia schismatica*, has inverted flowers (see Figure), with stamens located in the center of flower, and individual carpels located between petals and stamens True or false?



X	ABC - model
Y	Lacandonia flower

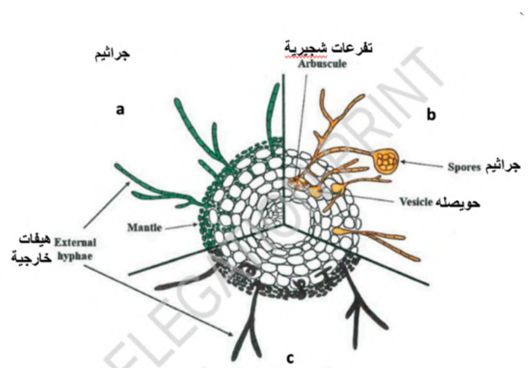
	Statements	T or F
1	*Lacandonia schismatica* flower morphology could be explained by gene expression pattern I	
2	Flowers of *Lacandonia schismatica* would have neither petals nor carpels, if flowers followed gene expression pattern II	
3	The only whorls flowers of *Lacandonia schismatica* would be missing, if they followed expression pattern III, is petal	
4	petals, like sepals, need only A gene expression.	

6- **The picture below shows the steps of the collapse of xylem vessels in plants. What is the correct explanation for such a collapse?**



A	Deficient in lignin on cell walls.
B	Increasing the concentration of solutes in xylem sap
C	Shifting the transmission mechanism from negative pressure to positive pressure
D	Many water bubbles collect inside xylem vessels

7- **The following schematic image shows the transverse cut of root showing symbiosis with 3 different groups of organisms (a, b, and c).**



Using the schematic image, determine whether the following statements are true or false.

	Statements	**T or F**
A	Diagram (a) shows ectomycorrhiza.	
B	Diagram (b) shows endomycorrhiza.	
C	Diagram (c) shows ectendomycorrhiza.	
D	One of the diagrams indicates a symbiosis of nitrogen-fixing bacteria and plant.	

8- Many climbing plants have tendrils, a thread-like organ specialized for winding around or clinging to a support. While tendrils are typically modified leaves, some tendrils are modified stems, which can be distinguished by morphological inspection.

For a tendril sample, answer which of the following observations is most informative for judging whether it is a modified leaf or a modified stem.

Vicia sativa

Cayratia japonica

Mark true or false in the appropriate box.

1	Observation of the surface to examine the presence/absence of stomata	
2	Observation of the surface to examine the thickness of the cuticular wax layer	
3	Observation of the surface to examine the shape of epidermal cells	
4	Observation of the cross section to examine the positional arrangement of the xylem and phloem	
5	Observation of the inner tissue to examine the presence/absence of developed chloroplasts	

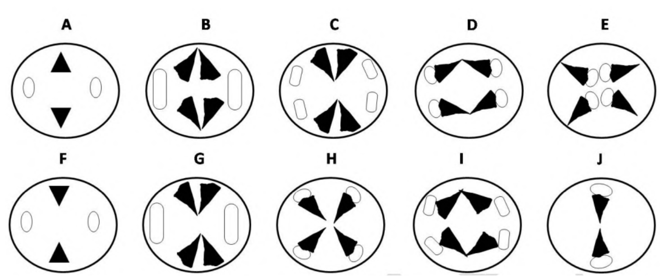
9- Following are the depictions of the arrangement of the vascular tissues seen in the cross sections from various parts of a dicot seedling. Choose the option that correctly depicts the transition from root tip to stem

a. A→B→I→D→H

b. F→G→C→H→J

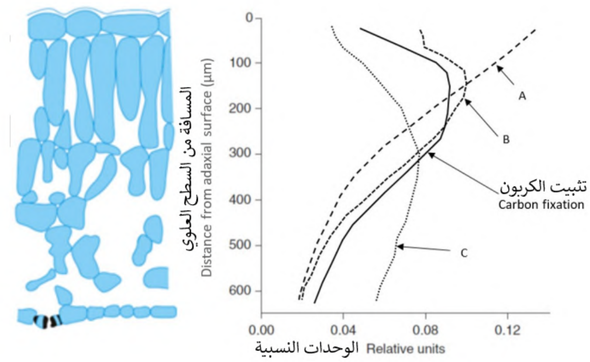
c. F→B→C→E→J

d. A→G→I→E→D



10- The figure below depicts a cross section of a spinach leaf (approximately 650 µm thick) .

The profiles of photosynthetic carbon fixation and the following three parameters are shown in the graph.



i. Intensity of incident light
ii. Light absorbed
iii. Amount of chlorophyll

Match the curves A to C with the correct parameters I, II and III.

- **a.** A-I, B-II, C-III
- **b.** A-III, B-I, C-II
- **c.** A-I, B-III, C-II
- **d.** A-II, B-I, C-III

Answer key for exercises

1	A	8	A
2	A	9	B
3	D	10	C
4	C	11	D
5	B	12	C
6	A	13	C
7	B	14	D

Answer key for the Mock Exam

<table>
<tr><td>1</td><td colspan="40">A</td></tr>
<tr><td>2</td><td colspan="40">C</td></tr>
<tr><td>3</td><td colspan="40">D</td></tr>
<tr><td rowspan="2">4</td><td colspan="5">1</td><td colspan="5">2</td><td colspan="5">3</td><td colspan="5">4</td><td colspan="5">5</td><td colspan="5">6</td><td colspan="5">7</td><td colspan="5">8</td></tr>
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<tr><td>5</td><td colspan="10">T</td><td colspan="10">F</td><td colspan="10">F</td><td colspan="10">T</td></tr>
<tr><td>6</td><td colspan="40">A</td></tr>
<tr><td>7</td><td colspan="10">T</td><td colspan="10">T</td><td colspan="10">T</td><td colspan="10">F</td></tr>
<tr><td>8</td><td colspan="8">F</td><td colspan="8">F</td><td colspan="8">F</td><td colspan="8">T</td><td colspan="8">F</td></tr>
<tr><td>9</td><td colspan="40">A</td></tr>
<tr><td>10</td><td colspan="40">A</td></tr>
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