COURSE MATERIAL

COURSE TITLE **GENERAL BIOLOGY**

Goal: This course is designed to equip the student with the knowledge of the fundamental principles of biology and their relationships to society

CHAPTER 1: THE SCIENCE OF LIFE

1.1 Definition of Biology

Biology is the scientific study of life and living organisms. It involves the observation, identification, classification, description, experimental investigation, and theoretical explanation of natural phenomena related to life. Biology seeks to understand the structure, function, growth, origin, evolution, and distribution of living organisms in both their natural and modified environments.

The term "biology" is derived from the Greek words *bios* (meaning "life") and *logos* (meaning "study" or "discourse"). This field is both descriptive and experimental and integrates principles from chemistry, physics, and mathematics to elucidate the functioning of life.

Historical Background of Biology

Biology as a science has ancient roots, but it began to take its modern form in the 19th century:

- **Aristotle (384–322 BC)** is considered the father of biology. He classified animals based on their habitat and method of reproduction.
- **Hippocrates (460–370 BC)** emphasized the role of natural causes in disease.
- **Carolus Linnaeus (1707–1778)** introduced the binomial nomenclature system.
- **Charles Darwin (1809–1882)** developed the theory of evolution by natural selection.
- **Gregor Mendel (1822–1884)** founded the principles of genetics through his experiments with pea plants.

Branches and Sub-disciplines of Biology

Sub-discipline	Description
Anatomy	Study of the structure of organisms and their parts
Botany	Study of plant life
Zoology	Study of animal life

Sub-discipline	Description
Microbiology	Study of microscopic organisms, including bacteria and viruses
Cytology	Study of cells, their structure and function
Genetics	Study of heredity and gene function
Molecular Biology	Study of biological molecules and the molecular basis of biological activity
Physiology	Study of the physical and chemical functions of organisms
Ecology	Study of interactions among organisms and their environments
Evolutionary Biology	Study of the origin and descent of species over time

Biology in Relation to Society

Biology impacts every aspect of life and society. Some applications include:

- **Medicine**: Understanding diseases, their causes, and treatments.
- **Agriculture**: Improving crop yield and pest resistance.
- **Public Health**: Controlling disease outbreaks and ensuring food safety.
- **Environmental Conservation**: Protecting biodiversity and ecosystems.
- **Forensics**: Applying biology in crime investigations.

1.2 Characteristics of Life

To distinguish living organisms from non-living matter, biologists identify a set of fundamental properties:

1. Organization and Cellular Structure

Life is highly organized, beginning at the molecular level and progressing to the biosphere.

- **Cell Theory**: All living organisms are composed of one or more cells. The cell is the basic unit of structure and function in organisms.
- *Unicellular organisms* (e.g., bacteria) consist of a single cell.
- *Multicellular organisms* (e.g., humans, trees) have specialized cells grouped into tissues and organs.

2. Metabolism

Metabolism encompasses all chemical reactions within an organism. It is divided into:

- **Anabolism**: Synthesis of complex molecules from simpler ones (e.g., protein synthesis).
- **Catabolism**: Breakdown of complex molecules into simpler ones to release energy (e.g., digestion, respiration).

These reactions are catalyzed by biological molecules called **enzymes** and are essential for growth, repair, and energy provision.

3. Homeostasis

This is the ability to maintain a stable internal environment. Examples include:

- Regulation of body temperature
- Water and electrolyte balance
- pH stability in cells
- Blood pressure control

Failure of homeostatic systems results in disease or death.

4. Growth and Development

- **Growth**: Increase in size or number of cells.
- **Development**: Series of changes an organism undergoes to reach maturity.
  These processes are controlled by genetic instructions and influenced by environmental factors.

5. Reproduction

The biological process by which new individuals are produced:

- **Asexual reproduction**: Involves a single parent; offspring are clones (e.g., binary fission in bacteria).
- **Sexual reproduction**: Involves two parents; offspring inherit genetic material from both, increasing genetic diversity.

6. Response to Stimuli

Organisms respond to environmental stimuli to survive:

- Tropisms in plants (e.g., phototropism)
- Reflex actions in animals
- Behavioral responses (e.g., migration, hibernation)

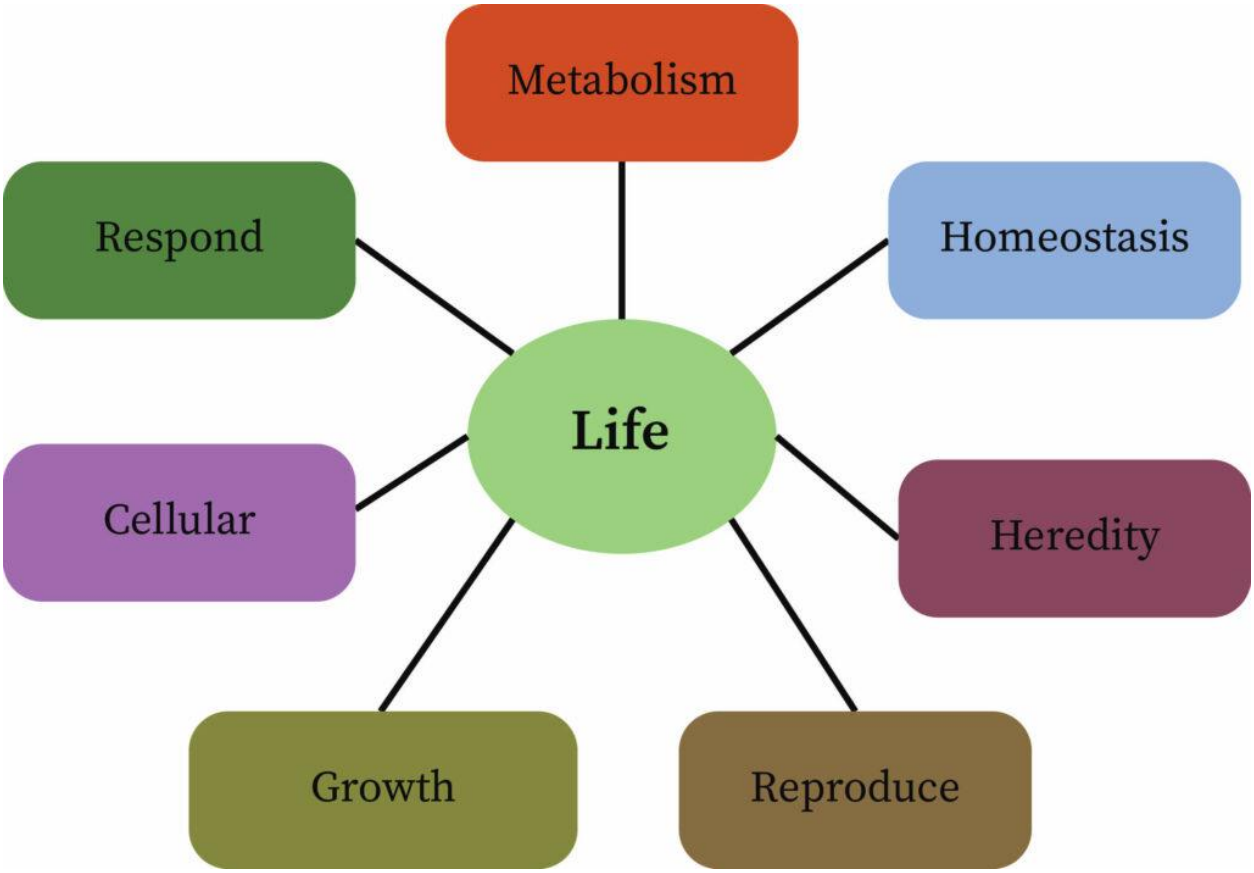
7. Adaptation and Evolution

Through the process of **natural selection**, organisms better adapted to their environments tend to survive and reproduce. Evolution leads to the diversity of life forms seen today.

8. Heredity and Genetic Information

Life is based on the transfer of genetic information. DNA carries instructions for building and maintaining an organism. Genes are passed from parents to offspring, ensuring continuity of traits.

Diagram: Characteristics of Life



1.3 Diversity of Life

Biological diversity, or biodiversity, refers to the variety and variability of life forms. Life on Earth includes millions of species, from microscopic bacteria to massive whales and giant sequoia trees.

Systematics and Taxonomy

Systematics is the scientific study of biological diversity and classification. **Taxonomy** is the branch of biology that names and classifies species.

Hierarchical Classification System

Each organism is given a scientific name (binomial nomenclature) and is classified into hierarchical ranks:

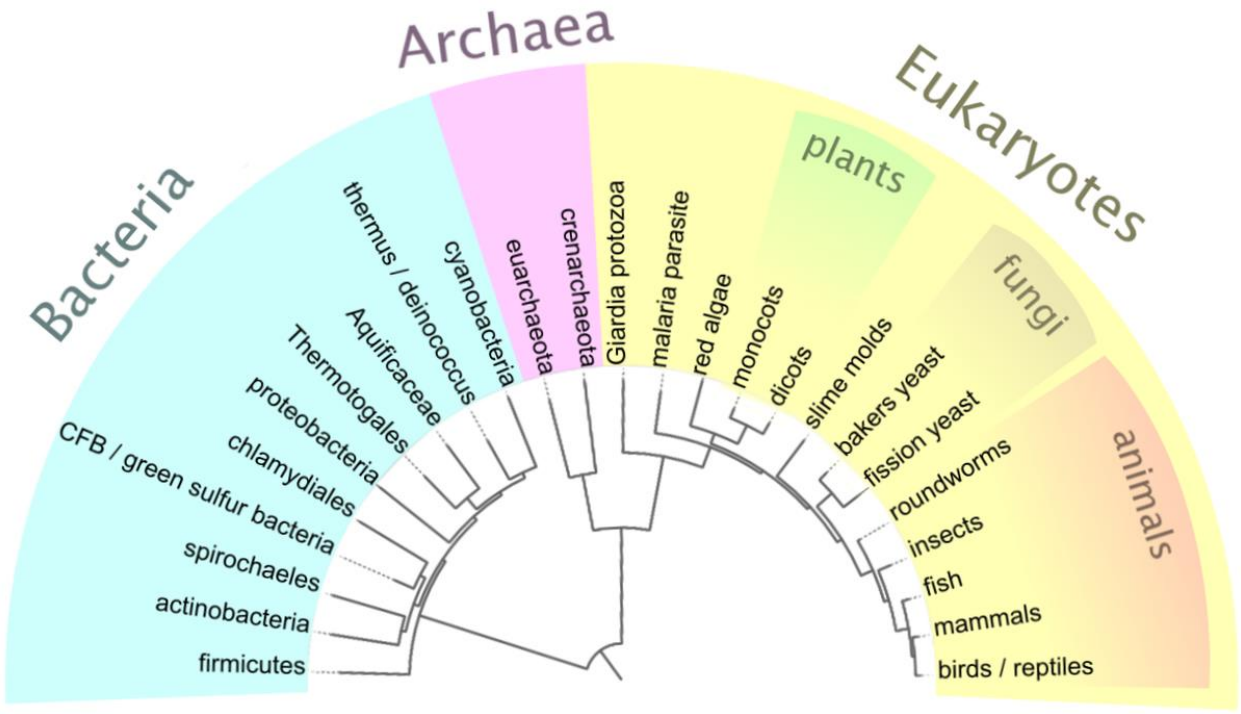
Rank	**Human Example**
Domain	Eukarya
Kingdom	Animalia
Phylum	Chordata
Class	Mammalia
Order	Primates
Family	Hominidae
Genus	Homo
Species	sapiens

Three-Domain System

Life is divided into three domains based on molecular evidence:

1. **Bacteria**:
    - Unicellular prokaryotes
    - Cell walls with peptidoglycan
    - Examples: *E. coli*, *Lactobacillus*
2. **Archaea**:
    - Unicellular prokaryotes
    - Cell walls lack peptidoglycan
    - Live in extreme environments (thermophiles, halophiles)
    - Genetically distinct from bacteria
3. **Eukarya**:
    - Eukaryotic cells with membrane-bound organelles
    - Includes four kingdoms: Protista, Fungi, Plantae, Animalia

Diagram: Tree of Life



Kingdoms within Eukarya

Kingdom	Characteristics	Examples
Protista	Mostly unicellular, autotrophic or heterotrophic	Amoeba, Paramecium
Fungi	Multicellular (except yeast), decomposers, cell walls of chitin	Mushrooms, Yeast
Plantae	Multicellular, photosynthetic, cell walls of cellulose	Mosses, Ferns, Trees
Animalia	Multicellular, heterotrophic, no cell walls	Humans, Insects, Birds

Importance of Biological Classification

- Organizes vast diversity into a manageable system
- Helps in identifying and naming organisms
- Reveals evolutionary relationships
- Aids in predicting characteristics shared among species

Biodiversity and Its Importance

- Provides ecosystem services (e.g., oxygen production, pollination)
- Ensures food security
- Offers potential sources for pharmaceuticals
- Maintains ecological balance

Chart: Domains of Life Comparison

Feature	Bacteria	Archaea	Eukarya
Cell Type	Prokaryotic	Prokaryotic	Eukaryotic
Cell Wall	Peptidoglycan	No peptidoglycan	Cellulose/Chitin
Membrane Lipids	Unbranched fatty acids	Branched hydrocarbons	Unbranched fatty acids
Genetic Material	Circular DNA	Circular DNA	Linear DNA
Introns	Rare	Present	Common
Organelles	Absent	Absent	Present
Examples	*E. coli*	*Methanogens*	Humans, Plants

CHAPTER 2: THE CELL

2.1 DEFINITION OF THE CELL

Definition and Importance of the Cell

The **cell** is defined as the smallest unit of structure and function in living organisms that exhibits all the characteristics of life. It is often referred to as the fundamental building block of life. Every organism, from the simplest bacterium to the most complex multicellular organism like a human, is made up of cells. Cells are capable of carrying out various life processes such as respiration, digestion, reproduction, and excretion.

Cells are the basis for all biological structure and activity. Even within multicellular organisms, different cells are specialized to perform particular functions, such as nerve conduction, contraction (in muscle cells), or secretion (in glandular cells). Despite their specialization, all cells share certain features that link them to a common origin and to each other.

Levels of Biological Organization Involving Cells

1. **Cells** → Basic unit of life
2. **Tissues** → Groups of similar cells performing a common function
3. **Organs** → Structures composed of different tissues performing specific tasks
4. **Organ Systems** → Groups of organs working together
5. **Organism** → An individual living being

Types of Organisms Based on Cell Number

- **Unicellular Organisms:** Organisms that consist of a single cell which performs all life functions. Examples: *Amoeba, Euglena, Bacteria.*
- **Multicellular Organisms:** Composed of many cells which may be specialized and organized into tissues and organs. Examples: *Humans, Oak trees, Frogs.*

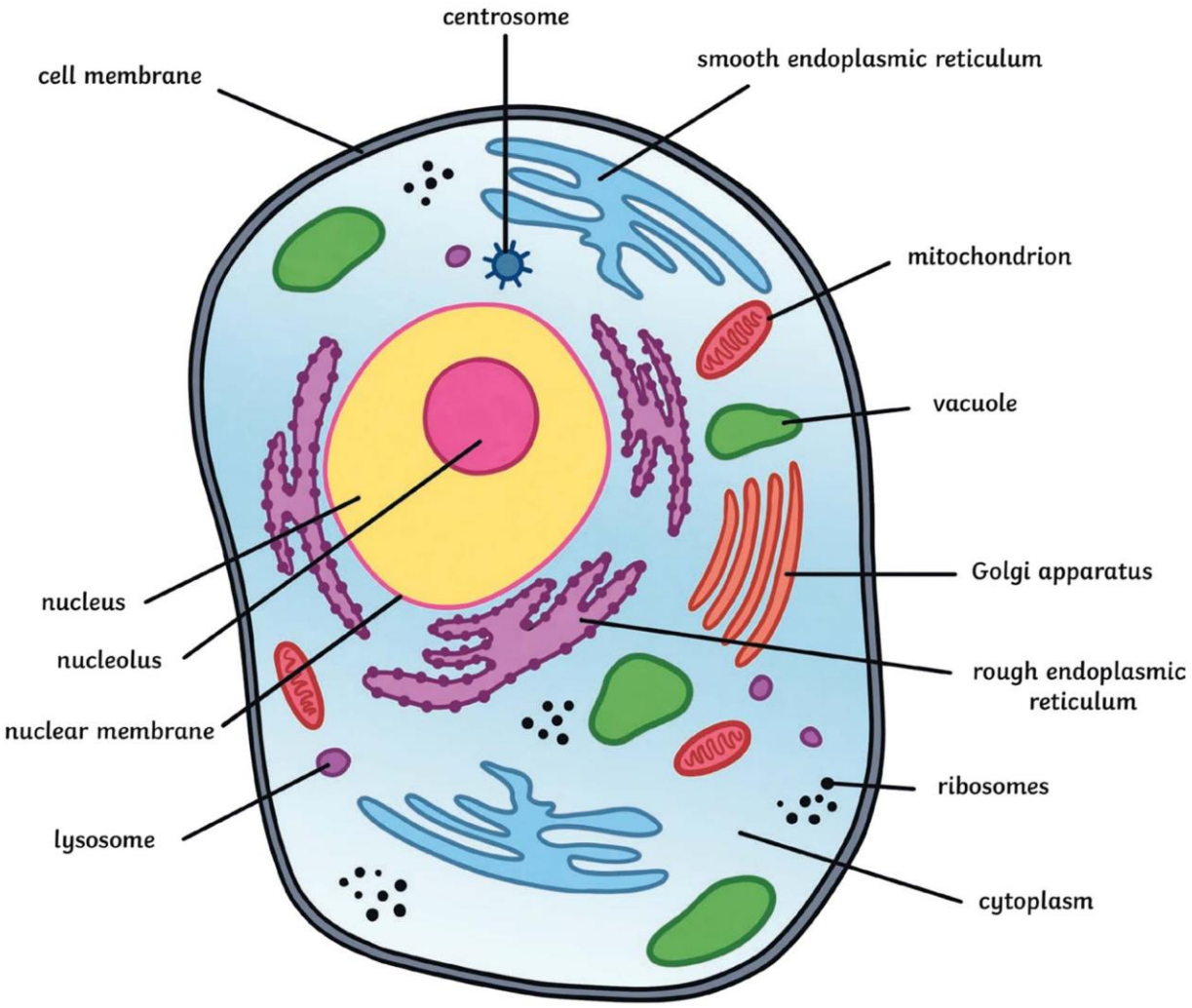
General Functions of Cells

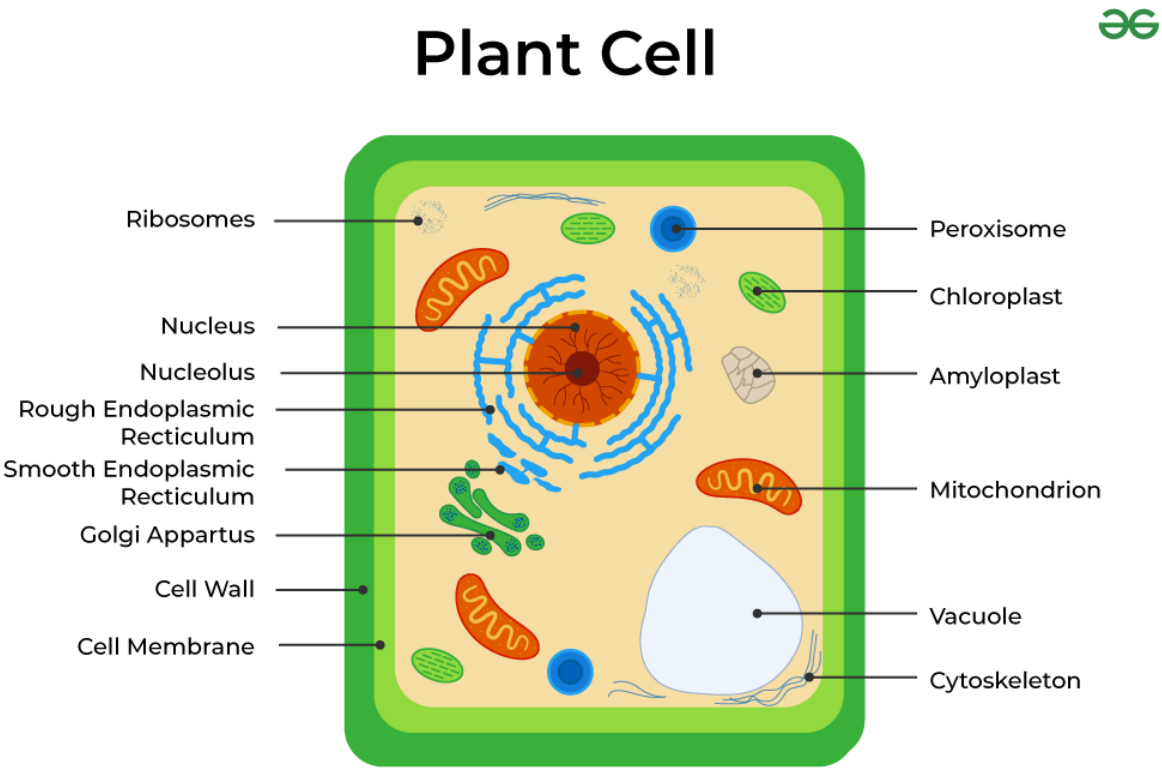
- **Metabolism:** Chemical reactions within cells that sustain life.
- **Growth:** Increase in size and volume by cell enlargement and division.
- **Reproduction:** Production of new cells via mitosis (somatic cells) or meiosis (gametes).
- **Irritability:** Ability to respond to environmental stimuli.
- **Homeostasis:** Maintenance of a stable internal environment.
- **Movement:** Some cells (e.g., sperm cells, some protozoa) exhibit mobility.
- **Nutrition and Waste Removal:** Uptake of nutrients and elimination of waste products.

Microscopy and Discovery of Cells

- **Robert Hooke (1665):** First observed cells in cork tissue using a compound microscope. Coined the term "cell" (from Latin *cella*, meaning small room).
- **Anton van Leeuwenhoek:** Developed a simple microscope with high magnification and observed living cells such as bacteria and protozoa, which he called "animalcules."

Diagram: Generalized Cell Structure





2.2 CELL THEORY

Historical Development

The evolution of the cell theory was a gradual process influenced by the development of microscopy and the meticulous work of several scientists:

- **1665:** Robert Hooke discovers the cell.
- **1838:** Matthias Schleiden concludes all plants are made of cells.
- **1839:** Theodor Schwann states that all animals are made of cells.
- **1855:** Rudolf Virchow proposes that all cells come from pre-existing cells, opposing the theory of spontaneous generation.

The Classical Cell Theory

The classical version of cell theory includes three central tenets:

1. All living organisms are composed of one or more cells.
2. The cell is the most basic unit of life.
3. All cells arise from pre-existing, living cells.

Modern Additions to Cell Theory

With the advent of molecular biology and biochemistry, the cell theory has been expanded to include:

4. All cells contain hereditary information (DNA) which is passed from cell to cell.
5. All cells are essentially the same in chemical composition and metabolic processes.
6. Energy flow (metabolism and biochemistry) occurs within cells.

Implications of Cell Theory

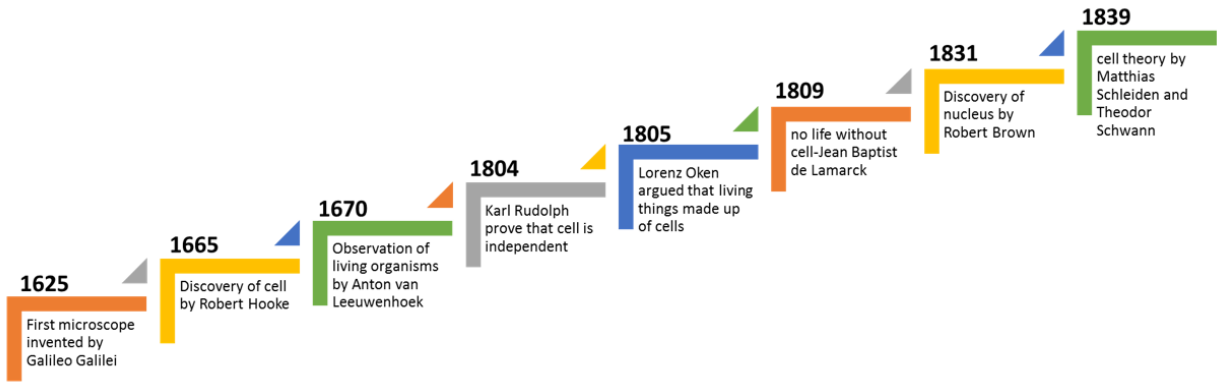
- **Unity of Life:** The theory suggests a universal structural and functional basis for all living organisms.
- **Basis for Medical Science:** Diseases such as cancer can be understood at the cellular level.
- **Biotechnology:** Modern applications such as cloning, tissue engineering, and genetic engineering are rooted in cell biology.

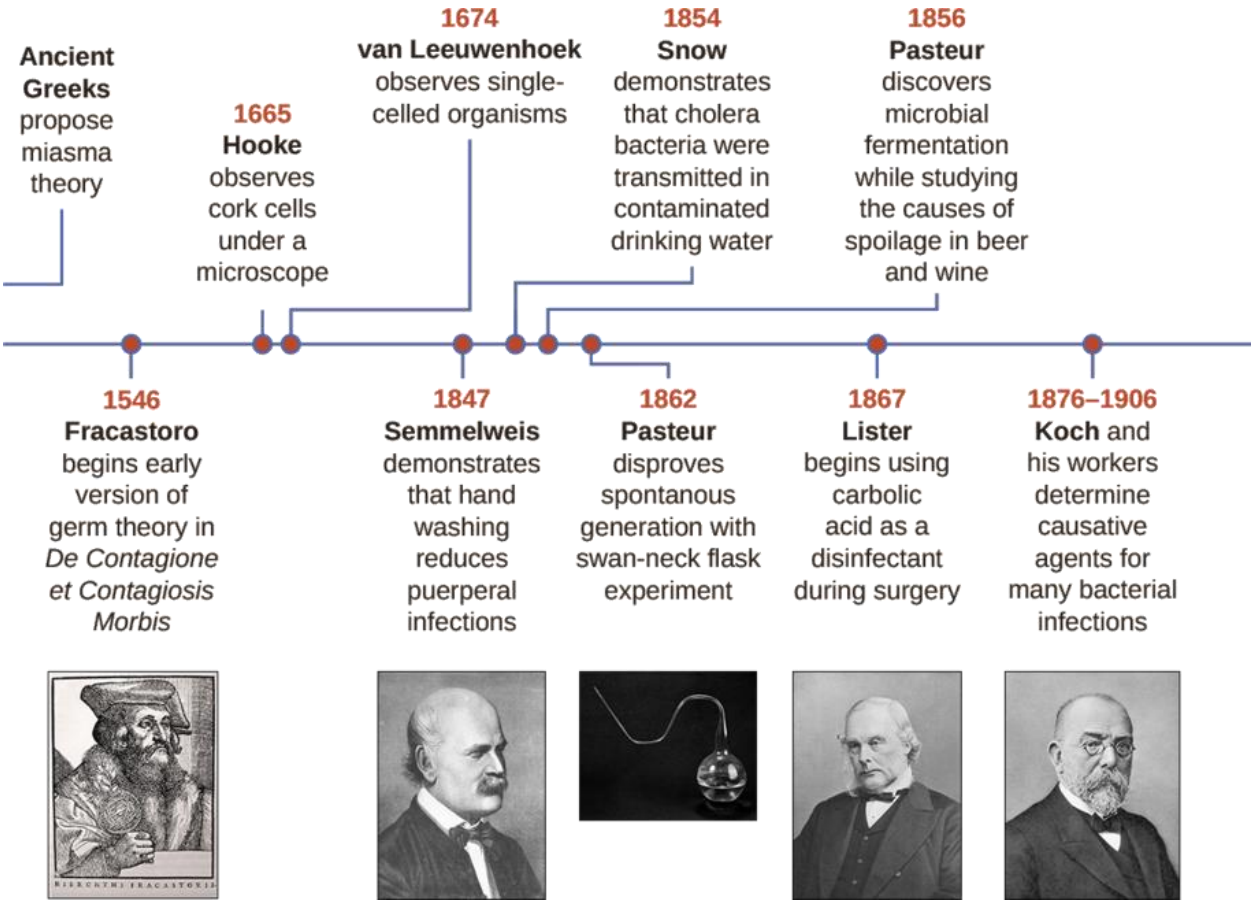
Timeline of Major Contributors:

Year	Scientist	Contribution
1665	Robert Hooke	First to observe and name cells in cork
1674	Anton van Leeuwenhoek	Observed living cells (bacteria and protozoa)
1838	Matthias Schleiden	Declared all plants are composed of cells

Year	Scientist	Contribution
1839	Theodor Schwann	Declared all animals are composed of cells
1855	Rudolf Virchow	Stated that all cells come from existing cells

Illustration: Timeline and Milestones in Cell Theory





2.3 DIFFERENCES BETWEEN PROKARYOTIC AND EUKARYOTIC CELLS

Cells exist in two fundamentally different forms — **prokaryotic** and **eukaryotic** — based on structural and functional organization.

A. Prokaryotic Cells

Definition:

Prokaryotic cells are cells that do not contain a nucleus or other membrane-bound organelles. The term "prokaryote" comes from Greek "pro" (before) and "karyon" (nucleus).

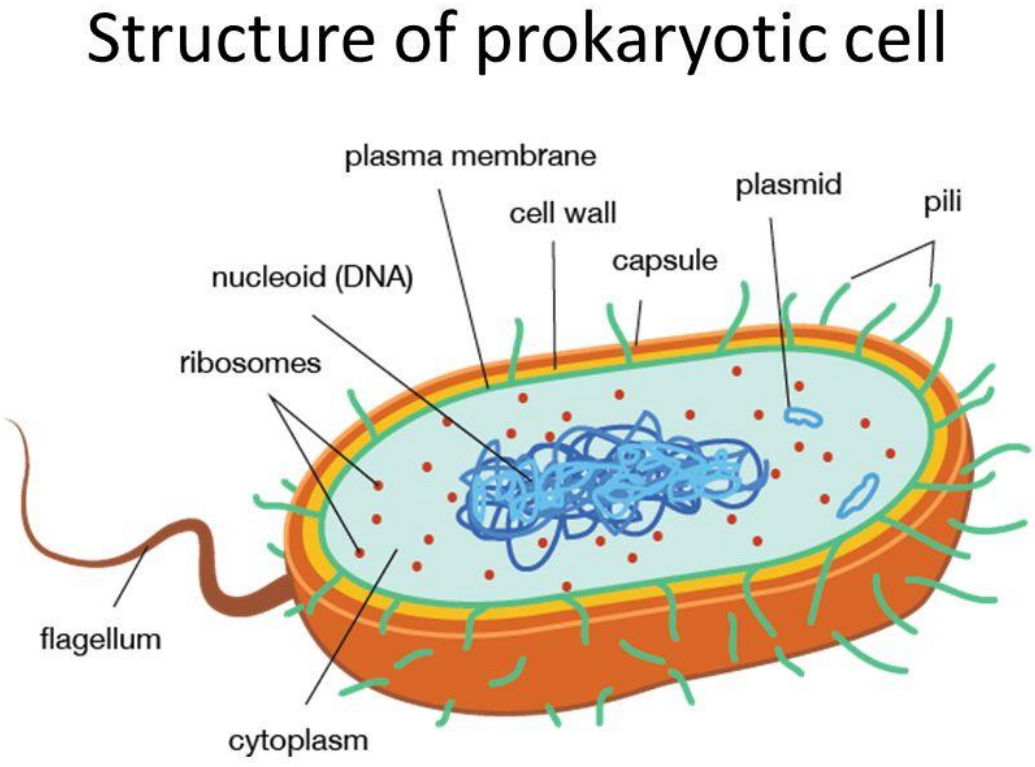
Examples: *Escherichia coli, Staphylococcus aureus, Cyanobacteria.*

Structural Features:

- **Cell membrane:** Phospholipid bilayer controlling movement in and out.
- **Cell wall:** Provides shape and protection (made of peptidoglycan in bacteria).
- **Cytoplasm:** Semi-fluid substance containing enzymes and nutrients.
- **Nucleoid:** Irregular region containing circular DNA.
- **Plasmids:** Small, circular DNA fragments with extra genes.
- **Ribosomes (70S):** Site of protein synthesis.
- **Flagella/Pili:** Structures used for locomotion and conjugation.

Reproduction: Binary fission — an asexual form of reproduction.

Diagram: Structure of a Prokaryotic Cell



B. Eukaryotic Cells

Definition:

Eukaryotic cells possess a true nucleus enclosed in a nuclear membrane and contain multiple membrane-bound organelles. "Eu" means true, and "karyon" means nucleus.

Examples: *Animal cells, plant cells, fungal cells, protozoans.*

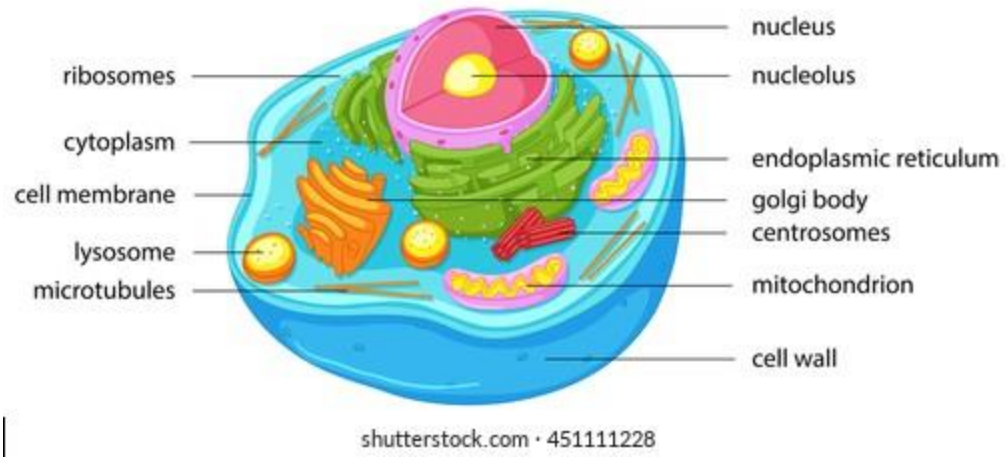
Structural Features:

- **Nucleus:** Contains DNA organized into chromosomes.
- **Mitochondria:** Site of ATP production (powerhouse of the cell).
- **Endoplasmic Reticulum:** Rough ER (with ribosomes) and Smooth ER (without ribosomes) for protein and lipid synthesis.
- **Golgi apparatus:** Modifies, packages, and ships proteins and lipids.
- **Lysosomes and peroxisomes:** Involved in digestion and detoxification.
- **Cytoskeleton:** Provides cell shape and facilitates movement.
- **Chloroplasts:** Present in plant cells, site of photosynthesis.
- **Vacuoles:** Storage of nutrients, water, and waste.

Reproduction: Via mitosis (somatic cells) and meiosis (gametes).

Diagrams:

Anatomy of an Animal Cell



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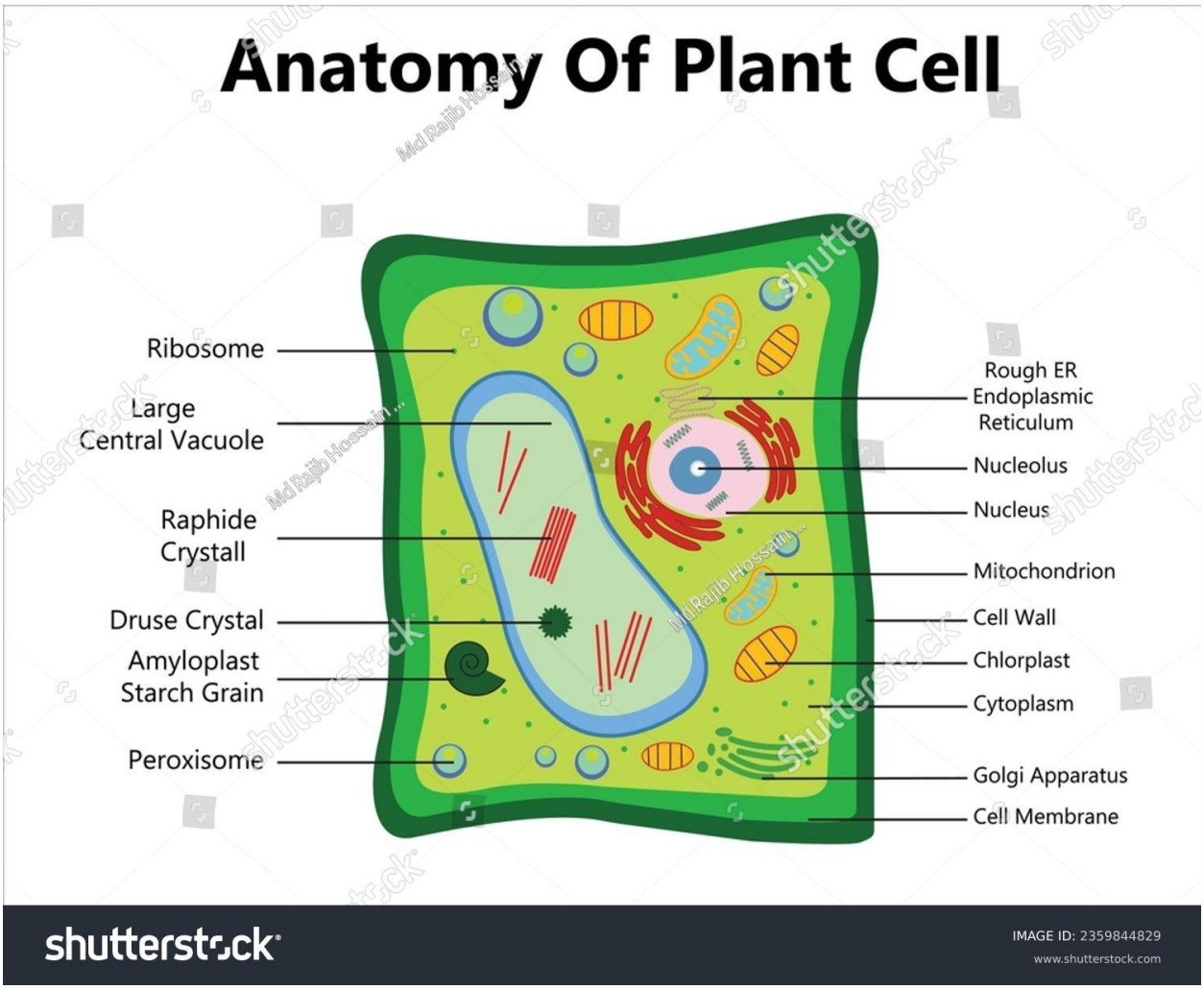
Anatomy Of Plant Cell



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C. Comparison Table: Prokaryotic vs. Eukaryotic Cells

Feature	Prokaryotic Cells	Eukaryotic Cells
Nucleus	Absent	Present
DNA Form	Circular, in nucleoid	Linear, in nucleus
Membrane-bound organelles	Absent	Present (ER, Golgi, etc.)
Cell Size	0.1 – 5.0 µm	10 – 100 µm
Ribosomes	70S	80S
Reproduction	Binary fission	Mitosis/Meiosis
Cell wall composition	Peptidoglycan (bacteria)	Cellulose (plants), chitin (fungi), absent (animals)
Complexity	Simple	Complex

2.4 Cell Structures and Their Functions

Cells are the building blocks of all life forms. All biological functions necessary for life occur within cells or are carried out by cells. The study of cell structures, also known as **cytology**, enables us to understand how life is organized, maintained, and propagated. Cells can exist as independent units of life (as in unicellular organisms like bacteria) or as part of multicellular organisms (as in plants, animals, fungi, and protists).

2.4.1 Classification of Cells

All living organisms are made up of either **prokaryotic** or **eukaryotic** cells. This classification is based on structural complexity.

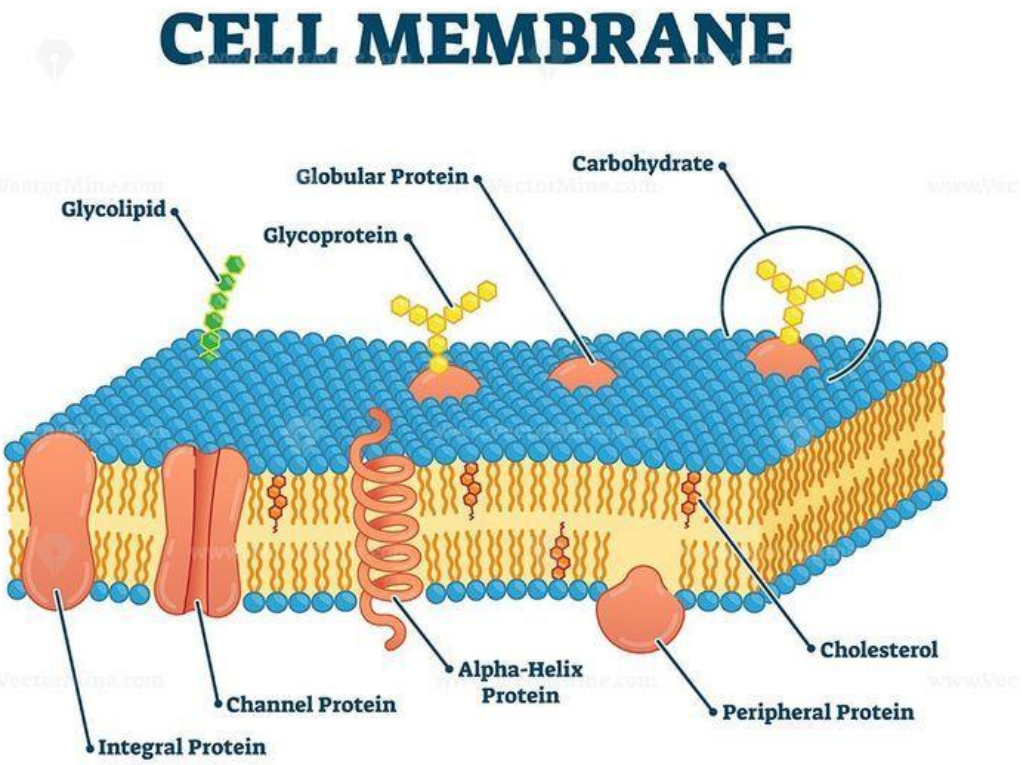
Feature	Prokaryotic Cells	Eukaryotic Cells
Nucleus	No true nucleus; DNA in nucleoid region	True nucleus enclosed by a nuclear membrane
Membrane-bound Organelles	Absent	Present (e.g., mitochondria, ER, Golgi body)
Cell Size	Typically 1–10 µm	Typically 10–100 µm
Genetic Material	Circular DNA molecule	Linear DNA molecules organized in chromosomes
Examples	Bacteria, Archaea	Plants, Animals, Fungi, Protists

2.4.2 Structure and Function of Cell Organelles

Below is a detailed description of major cellular organelles and their specific roles.

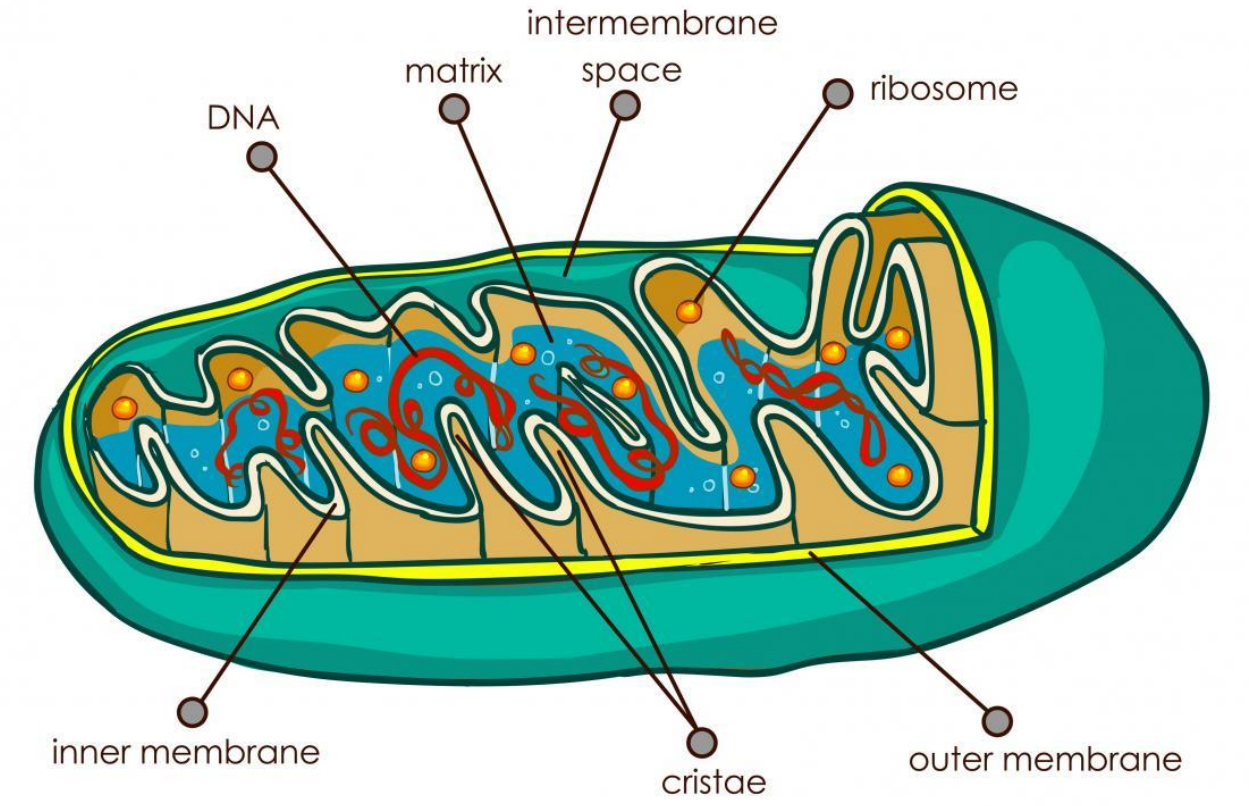
1. **Plasma (Cell) Membrane**
    - **Structure**: Composed primarily of a phospholipid bilayer with embedded proteins, cholesterol, and carbohydrates.
    - **Function**: Serves as a selectively permeable barrier, regulating the entry and exit of substances. Also involved in cell signaling and cell recognition.
    - **Special Features**: Contains receptors for signal transduction; exhibits fluid mosaic model.

- **Visual Aid**:



2. **Nucleus**
    - **Structure**: Surrounded by a double-layered nuclear envelope perforated with nuclear pores. Contains nucleoplasm, nucleolus, and chromatin.
    - **Function**: Acts as the control center of the cell by storing genetic information (DNA) and coordinating activities like growth, metabolism, protein synthesis, and reproduction (cell division).
    - **Nucleolus**: Responsible for synthesis of ribosomal RNA (rRNA) and ribosome assembly.
3. **Cytoplasm**
    - **Structure**: Gel-like matrix (cytosol) filling the cell and suspending organelles.
    - **Function**: Site of many metabolic pathways; facilitates movement of materials within the cell.

4. **Mitochondria**
    - **Structure**: Double membrane; inner membrane forms cristae to increase surface area; contains its own DNA and ribosomes.
    - **Function**: Powerhouse of the cell; site of aerobic respiration and ATP production.
5. **Visual Aid**:



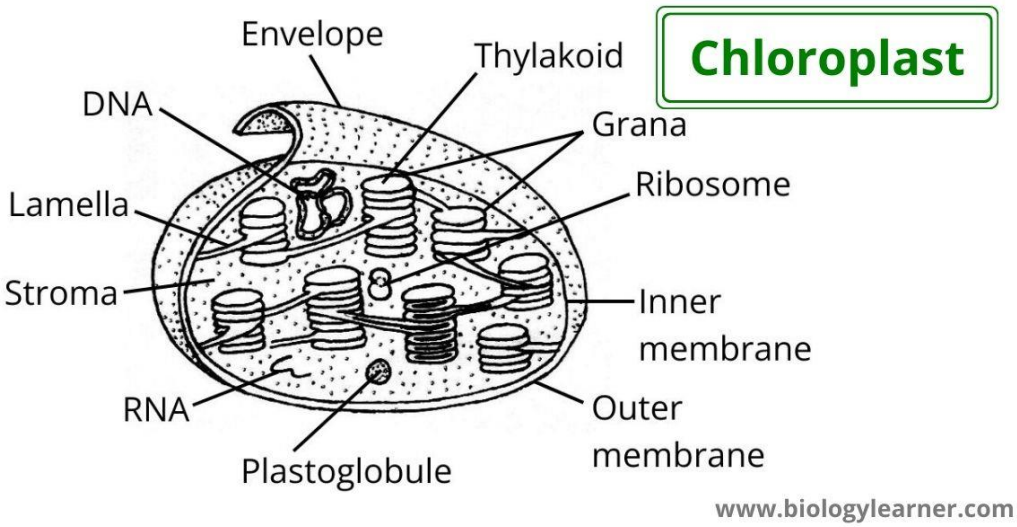
Endoplasmic Reticulum (ER)

- **Rough ER**: Studded with ribosomes. Synthesizes and processes proteins.
- **Smooth ER**: Lacks ribosomes. Synthesizes lipids, detoxifies drugs and poisons, stores calcium ions.

6. **Golgi Apparatus (Golgi Complex)**
    - **Structure**: Flattened membranous sacs called cisternae.
    - **Function**: Modifies, sorts, and packages proteins and lipids received from ER for secretion or use within the cell.

7. **Ribosomes**
    - **Structure**: Composed of rRNA and protein; found free in the cytosol or bound to rough ER.
    - **Function**: Site of protein synthesis by translating messenger RNA (mRNA).
8. **Lysosomes**
    - **Structure**: Small vesicles containing hydrolytic enzymes.
    - **Function**: Digestion of macromolecules, old organelles, and pathogens. Important for cellular clean-up.
9. **Peroxisomes**
    - **Function**: Contain enzymes that break down fatty acids and detoxify harmful substances. Generate and decompose hydrogen peroxide (H2O2).
10. **Vacuoles**
    - **Structure**: Membrane-bound sacs.
    - **Function**: Storage of water, ions, nutrients, and waste. In plant cells, the central vacuole maintains turgor pressure.
11. **Chloroplasts** (in plant and algal cells)
    - **Structure**: Double membrane with internal thylakoid membranes containing chlorophyll.
    - **Function**: Site of photosynthesis; converts solar energy into chemical energy (glucose).

- **Visual Aid**:



12. **Cytoskeleton**
    - **Structure**: Network of protein filaments—microfilaments, intermediate filaments, and microtubules.
    - **Function**: Maintains cell shape, enables cellular motion, and facilitates intracellular transport.
13. **Centrosomes and Centrioles** (in animal cells)
    - **Function**: Organize microtubules; important in cell division.
14. **Cell Wall** (in plants, fungi, some protists, and bacteria)
    - **Structure**: Rigid outer layer; made of cellulose in plants.
    - **Function**: Provides structural support and protection; maintains shape.

2.5 Modes of Cellular Transport

Cell transport is essential for maintaining cellular homeostasis and responding to environmental changes. The plasma membrane's semi-permeable nature allows selective transport of substances.

2.5.1 Passive Transport (No Energy Required)

Principle: Substances move from regions of high concentration to low concentration (down their concentration gradient).

1. **Simple Diffusion**
    - Movement of small, nonpolar molecules (e.g., O2, CO2).
    - Occurs directly through the phospholipid bilayer.
2. **Facilitated Diffusion**
    - Movement of larger or charged molecules (e.g., glucose, ions) via specific carrier or channel proteins.
    - No energy required but relies on concentration gradients.
3. **Osmosis**
    - Diffusion of water across a semi-permeable membrane.
    - Water moves toward higher solute concentrations.

Examples of Passive Transport:

Substance	Transport Type	Example
Oxygen	Simple Diffusion	Alveoli to blood capillaries
Glucose	Facilitated Diffusion	Bloodstream to muscle cells
Water	Osmosis	Uptake by root cells in plants

2.5.2 Active Transport (Requires Energy – ATP)

Principle: Moves substances against their concentration gradient (low to high).

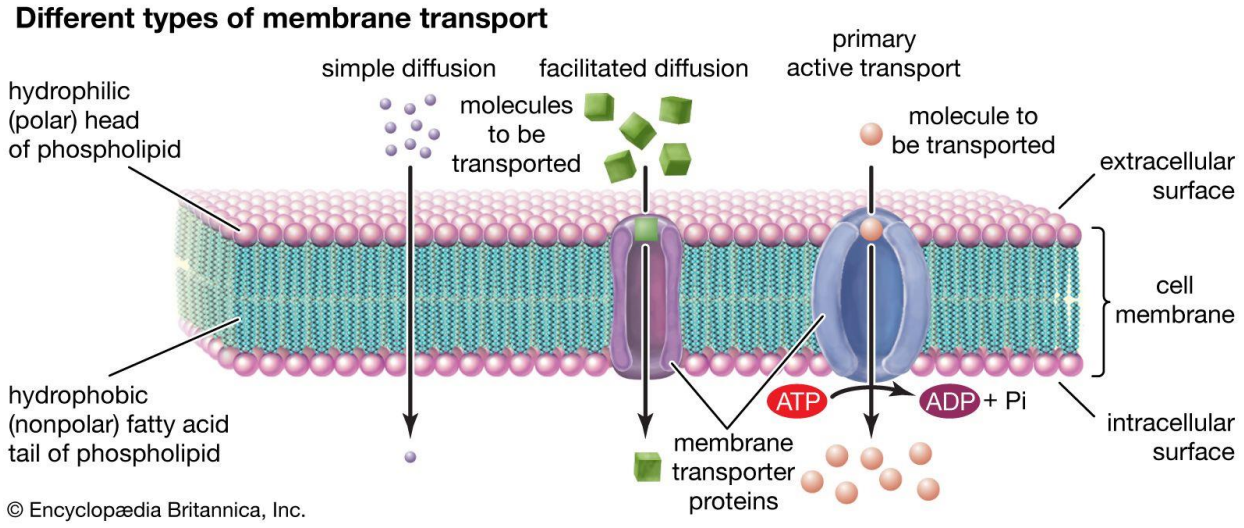
1. **Primary Active Transport**
    - Direct use of ATP.
    - Example: Sodium-Potassium Pump (Na+/K+ pump) – pumps 3 Na+ out and 2 K+ into the cell per ATP.

2. **Secondary Active Transport (Cotransport)**
    - Uses energy from ion gradients created by primary transport.
    - Example: Glucose absorption in the intestines using Na+ gradient.

2.5.3 Bulk Transport (Vesicular Transport)

1. **Endocytosis**: Internalizing substances by engulfing them with the membrane.
    - **Phagocytosis**: Ingestion of large particles or microorganisms.
    - **Pinocytosis**: Ingestion of extracellular fluids.
    - **Receptor-Mediated Endocytosis**: Specific uptake via receptor binding.
2. **Exocytosis**: Release of substances via vesicle fusion with plasma membrane.
    - Example: Secretion of hormones, neurotransmitters.

Visual Guide to Transport Mechanisms:



2.6 Cellular Energy Processes

Living organisms require energy to maintain internal order and perform biological functions. This energy is derived from the breakdown of molecules or the capture of sunlight.

2.6.1 ATP – Adenosine Triphosphate

ATP is the universal energy currency of the cell. It is composed of:

- Adenine (a nitrogenous base)
- Ribose (a sugar)
- Three phosphate groups

ATP Function:

- Energy is stored in the high-energy phosphate bonds.
- ATP → ADP + Pi releases energy for cellular work.

2.6.2 Photosynthesis

Occurs in autotrophs like plants and algae within chloroplasts.

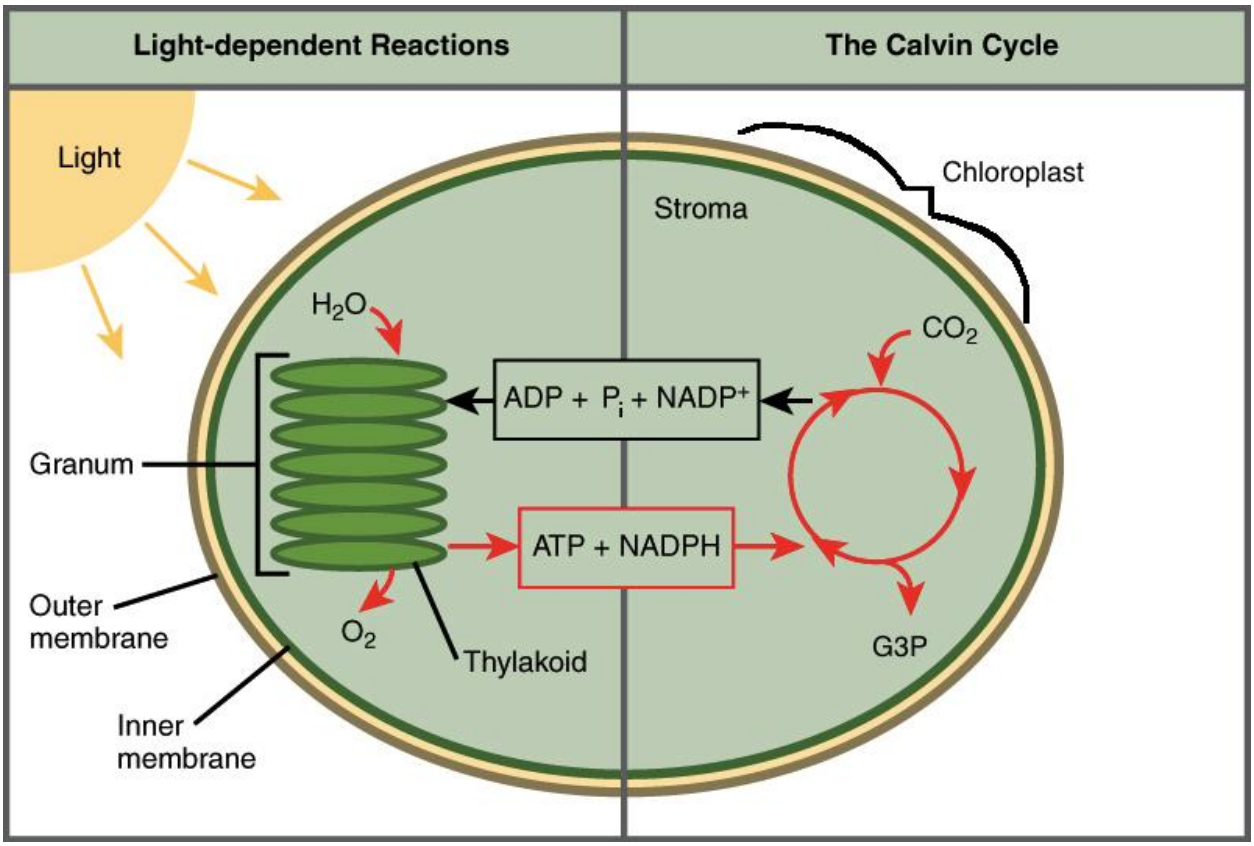
Equation:

$6CO_2 + 6H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6O_2$

Stages:

1. **Light-Dependent Reactions**
    - Location: Thylakoid membranes
    - Inputs: Water, light energy
    - Outputs: ATP, NADPH, O_2
2. **Calvin Cycle (Light-Independent)**
    - Location: Stroma
    - Inputs: CO_2, ATP, NADPH
    - Outputs: Glucose

Visual Aid:



2.6.3 Cellular Respiration

Breakdown of glucose to produce ATP. Occurs in all living cells.

Equation:

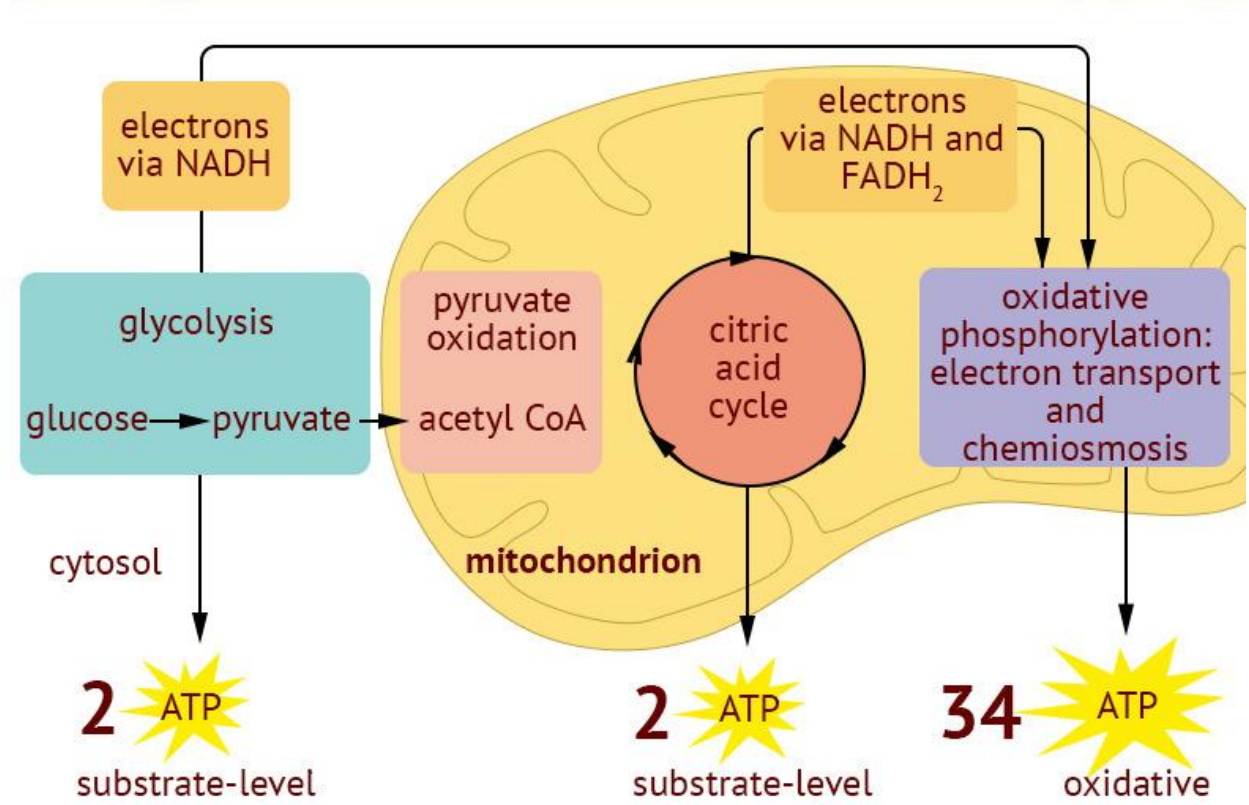
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + ~36-38 ATP

Stages:

1. **Glycolysis** (Cytoplasm)
    - Glucose → 2 Pyruvate + 2 ATP + 2 NADH
2. **Krebs Cycle** (Mitochondrial Matrix)
    - Pyruvate → CO_2 + NADH + $FADH_2$ + 2 ATP
3. **Electron Transport Chain (ETC)** (Inner Mitochondrial Membrane)
    - NADH and $FADH_2$ donate electrons
    - Oxygen is the final electron acceptor

- Produces ~32-34 ATP

Visual Aid:



2.6.4 Anaerobic Respiration / Fermentation

Occurs when oxygen is scarce or absent.

Lactic Acid Fermentation (Animals):

- Glucose → Lactic Acid + 2 ATP

Alcoholic Fermentation (Yeast):

- Glucose → Ethanol + CO_2 + 2 ATP

Comparison Table:

Feature	Aerobic Respiration	Anaerobic Respiration
Oxygen	Required	Not required
ATP Yield	36–38	2
By-products	CO_2, H_2O	Lactic acid or Ethanol + CO_2
Efficiency	High	Low

2.7 Photosynthesis

Introduction to Photosynthesis

Photosynthesis is the cornerstone biological process that sustains life on Earth by transforming solar energy into chemical energy. It is carried out by photoautotrophic organisms such as green plants, algae, and some bacteria. These organisms use light energy to synthesize carbohydrates from carbon dioxide and water, releasing oxygen as a by-product.

This process not only provides the glucose necessary for metabolic activities and growth of autotrophs themselves, but it also forms the base of the food chain, supporting all heterotrophic life forms. The oxygen released is essential for aerobic respiration, making photosynthesis both an energy-supplying and oxygen-generating process vital to ecosystems and atmospheric balance.

Photosynthetic Equation

The general chemical equation for photosynthesis can be written as:

6CO2+6H2O+light energy →chlorophyll C6H12O6+6O2

This reaction demonstrates the transformation of inorganic molecules (carbon dioxide and water) into an organic molecule (glucose) with the release of oxygen gas.

Cellular Site of Photosynthesis: The Chloroplast

Chloroplasts are specialized organelles within plant and algal cells that facilitate photosynthesis. Each chloroplast is enclosed by a double membrane and contains a fluid-filled interior called the stroma. Inside the stroma are stacks of thylakoids known as grana. The thylakoid membranes contain chlorophyll pigments and the photosystems where the light-dependent reactions occur.

- **Outer Membrane**: Permeable to small molecules and ions.
- **Inner Membrane**: Less permeable; regulates transport into the stroma.
- **Thylakoid Membranes**: Contain photosynthetic pigments.
- **Grana**: Stacks of thylakoids that increase surface area.
- **Stroma**: Site of the Calvin Cycle, contains enzymes and chloroplast DNA.

Pigments in Photosynthesis

Photosynthetic pigments are molecules that absorb specific wavelengths of light energy. The primary pigment is **chlorophyll a**, which absorbs light mostly in the blue-violet and red wavelengths.

Other pigments include:

- **Chlorophyll b** – broadens the spectrum of absorbed light.
- **Carotenoids** – absorb blue-green light and protect chlorophyll from photo-damage.
- **Xanthophylls** – yellow pigments involved in light absorption and photo-protection.

Stages of Photosynthesis

Photosynthesis consists of two main stages:

1. Light-Dependent Reactions

Location: Thylakoid membranes of the chloroplast
Requirements: Light energy, water
Products: ATP, NADPH, O_2

Steps:

- Light energy is absorbed by chlorophyll in photosystem II, exciting electrons.
- Water molecules are split (photolysis), releasing oxygen, protons, and electrons:

$2H2O \rightarrow$ light $4H+ +4e- + O2$

- Electrons pass through an electron transport chain (ETC), releasing energy to pump protons and generate ATP (chemiosmosis).
- Electrons are passed to photosystem I, re-energized, and transferred to $NADP^+$ to form NADPH.

Summary: Converts solar energy into chemical energy (ATP and NADPH) and releases O_2.

2. Light-Independent Reactions (Calvin Cycle)

Location: Stroma
Requirements: ATP, NADPH, CO_2
Products: Glucose (G3P), ADP, $NADP^+$

Steps:

1. **Carbon Fixation**: CO_2 is attached to ribulose bisphosphate (RuBP) by the enzyme RuBisCO to form 3-phosphoglycerate (3-PGA).
2. **Reduction Phase**: ATP and NADPH convert 3-PGA into glyceraldehyde-3-phosphate (G3P).
3. **Regeneration Phase**: Some G3P regenerate RuBP; the rest form glucose and other carbohydrates.

Importance: Synthesizes glucose for energy storage and structural integrity (e.g., cellulose).

Factors Influencing Photosynthesis

Factor	Influence on Rate
Light Intensity	Increases rate up to saturation point
Carbon Dioxide Concentration	Directly proportional to rate until saturation
Temperature	Rate increases up to an optimum (usually ~30–35°C), then declines due to enzyme denaturation
Water Availability	Essential as a substrate; deficiency reduces rate and can cause stomatal closure

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Significance of Photosynthesis

- **Ecological**: Supports food webs, maintains oxygen levels.
- **Biochemical**: Provides carbohydrates, precursor molecules for lipids, amino acids.
- **Environmental**: Acts as a carbon sink; mitigates greenhouse gas effects.
- **Agricultural**: Understanding enhances crop productivity and food security.

2.8 Cellular Reproduction

Introduction to Cellular Reproduction

Cellular reproduction refers to the process by which cells duplicate to produce new cells. It is essential for growth, development, tissue repair, and reproduction. Cells reproduce through two main mechanisms: **mitosis**, for somatic cell division, and **meiosis**, for the production of gametes in sexually reproducing organisms.

The Cell Cycle

The life of a cell is divided into a repeating cycle known as the **cell cycle**, which has two major phases:

1. **Interphase** (90% of cell cycle):
    - **G_1 Phase (Gap 1):** Cellular growth and preparation for DNA replication.
    - **S Phase (Synthesis):** DNA replication; each chromosome duplicates.
    - **G_2 Phase (Gap 2):** Final preparation for mitosis; synthesis of proteins and organelles.
2. **Mitotic Phase (M Phase):**
    - Includes **mitosis** (nuclear division) and **cytokinesis** (cytoplasmic division).

Mitosis

Mitosis is the process of nuclear division resulting in two genetically identical daughter cells. It is essential for:

- Growth
- Cellular repair and replacement
- Asexual reproduction (e.g., binary fission in unicellular organisms)

Phases of Mitosis:

1. **Prophase:**
    - Chromosomes condense and become visible.
    - Nuclear envelope disintegrates.
    - Spindle fibers begin to form from centrosomes.
2. **Metaphase:**
    - Chromosomes align along the metaphase plate (equator).
3. **Anaphase:**
    - Sister chromatids are pulled apart toward opposite poles.
4. **Telophase:**
    - Chromatids arrive at poles and de-condense.
    - Nuclear envelopes reform.
5. **Cytokinesis:**
    - Cytoplasm divides.
    - Animal cells: Cleavage furrow forms.
    - Plant cells: Cell plate forms due to rigid cell wall.

Meiosis

Meiosis is a reductional division process occurring in the gonads, producing four haploid gametes. It ensures genetic diversity and is central to sexual reproduction.

Meiosis I (Reduction Division):

1. **Prophase I:**
    - Synapsis and crossing over between homologous chromosomes.
2. **Metaphase I:**
    - Homologous pairs align at equator.

3. **Anaphase I:**
    - Homologs separate (sister chromatids remain attached).
4. **Telophase I:**
    - Two haploid cells form.

Meiosis II (Equational Division):

1. **Prophase II:** Chromosomes condense again.
2. **Metaphase II:** Chromosomes align at the equator.
3. **Anaphase II:** Sister chromatids separate.
4. **Telophase II and Cytokinesis:** Four genetically distinct haploid cells are formed.

Comparison: Mitosis vs Meiosis

Feature	Mitosis	Meiosis
Purpose	Growth and repair	Sexual reproduction
Number of Divisions	1	2
Daughter Cells	2	4
Chromosome Number	Diploid (2n)	Haploid (n)
Genetic Identity	Identical	Unique due to crossing over and independent assortment

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Significance of Cellular Reproduction

- **Mitosis:** Ensures continuity of genetic information, replaces worn-out cells, heals injuries.
- **Meiosis:** Introduces genetic variation through recombination and independent assortment, a prerequisite for evolution and adaptability.
- **Medical Implications:** Errors in cell division can lead to cancer (uncontrolled mitosis), infertility, or genetic disorders (e.g., Down syndrome due to nondisjunction in meiosis).

CHAPTER 3: HEREDITY AND EVOLUTION

3.1 Principles and Terminologies Used in Genetics

Introduction to Genetics

Genetics is the scientific study of heredity and variation in living organisms. It seeks to understand the structure and function of genes, how traits are inherited from one generation to another, and how genetic information governs the development, physiology, and behavior of organisms. This field has profound implications across medicine, agriculture, biotechnology, and evolutionary biology.

Historical Background

- The concept of heredity dates back to ancient times, but it was not until the 19th century that scientific approaches to genetics began to emerge.
- The discovery of DNA as the hereditary material in the 20th century revolutionized biology and led to the development of molecular genetics.

Core Terminologies in Genetics

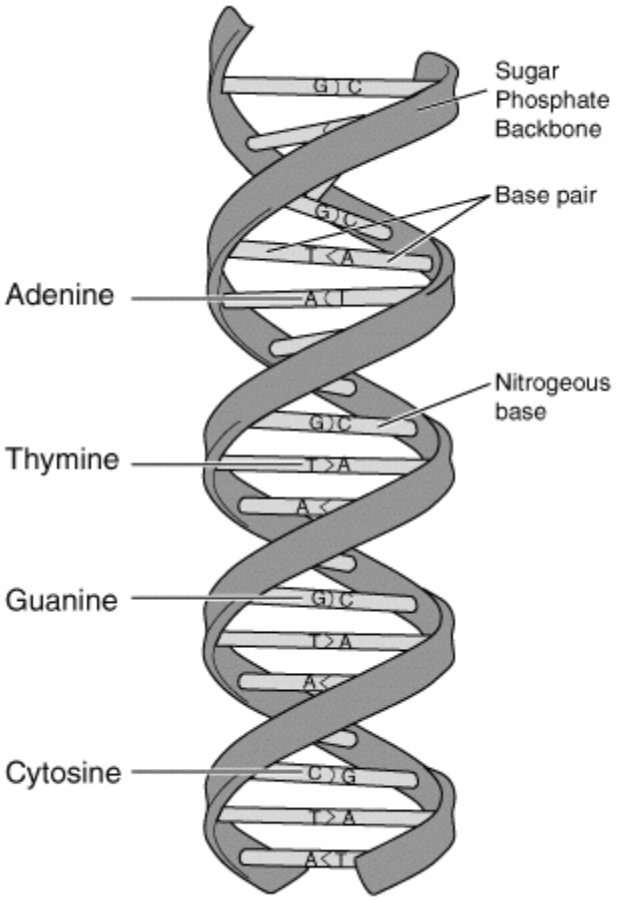
Term	Definition	Explanation/Example
Gene	A unit of heredity made of DNA that encodes a specific protein or function.	Genes control traits like eye color or blood type.
Allele	Alternative forms of the same gene found at the same locus on homologous chromosomes.	The gene for flower color may have a red or white allele.
Locus	The specific, fixed position on a chromosome where a gene or genetic marker is located.	Each gene occupies a unique locus.

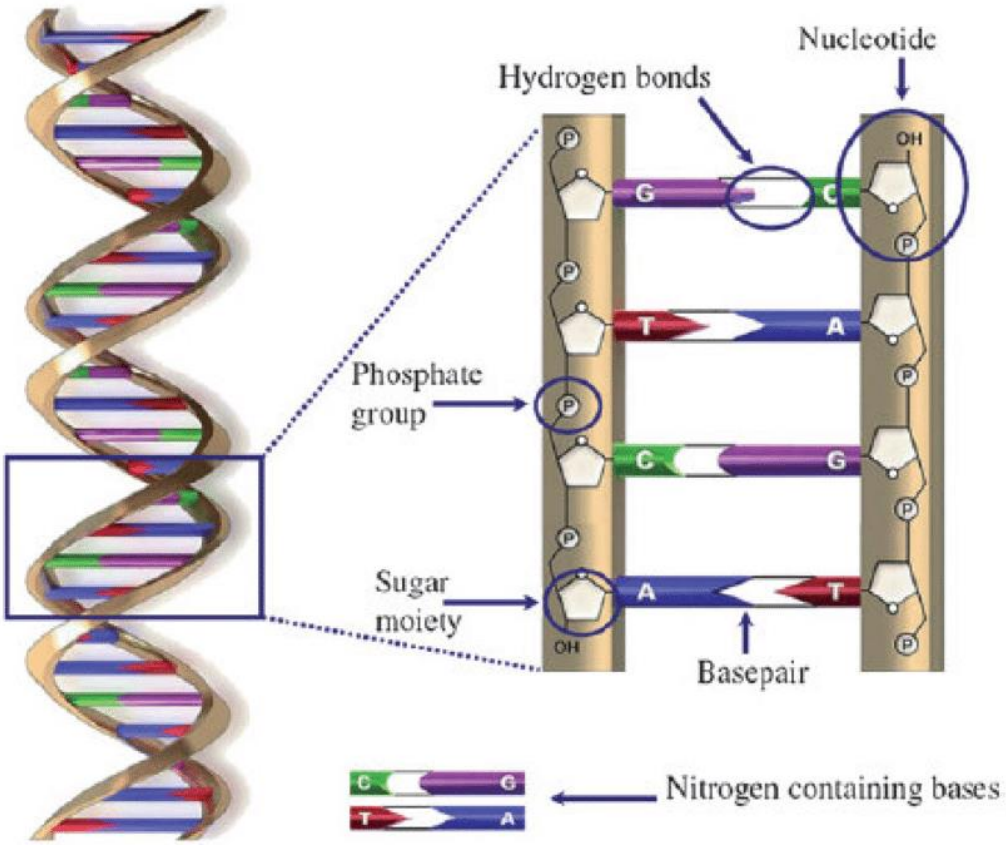
Term	Definition	Explanation/Example
Genotype	The genetic makeup of an organism in terms of its alleles.	A pea plant might have a genotype of Tt (heterozygous tall).
Phenotype	The observable traits or characteristics of an organism.	The phenotype of Tt or TT is tallness in pea plants.
Homozygous	Having two identical alleles of a gene.	TT (homozygous dominant) or tt (homozygous recessive).
Heterozygous	Possessing two different alleles of a gene.	Tt (tall phenotype, one dominant and one recessive allele).
Dominant Allele	An allele that expresses its phenotype even when heterozygous.	The T allele for tallness in peas is dominant over t.
Recessive Allele	An allele that is masked in the presence of a dominant allele.	The t allele only shows when in tt genotype.
Chromosome	Thread-like structure of nucleic acids and proteins that carries genetic information.	Humans have 23 pairs of chromosomes.
Mutation	A permanent change in the DNA sequence of a gene.	Can result in genetic disorders or evolutionary changes.

Structure and Function of DNA

- DNA (Deoxyribonucleic acid) is the hereditary molecule in almost all living organisms.
- Double-helix structure discovered by Watson and Crick in 1953.
- Composed of nucleotide units: a phosphate group, a deoxyribose sugar, and a nitrogenous base (adenine, thymine, cytosine, guanine).
- Base-pairing rules: A-T and C-G.

Illustration:


Sugar
Phosphate
Backbone
Base pair
Adenine
Nitrogeous
base
Thymine
Guanine
Cytosine



Chromosomes and Genes

- Each chromosome carries many genes.
- Humans have 46 chromosomes (23 pairs), with one set inherited from each parent.
- Autosomes (22 pairs) and sex chromosomes (1 pair: XX or XY).

Protein Synthesis: Central Dogma of Molecular Biology

1. **Replication**: DNA copies itself during cell division.
2. **Transcription**: A gene's DNA sequence is copied into mRNA.
3. **Translation**: Ribosomes read mRNA to synthesize proteins from amino acids.

The Genetic Code

- Triplet code: Each set of three nucleotides (codon) corresponds to a specific amino acid.
- Universal and redundant, but not ambiguous.

Table: Simplified Genetic Code

Codon	Amino Acid
AUG	Methionine (Start)
UUU	Phenylalanine
UGA	Stop codon

Genetic Inheritance

- Traits are inherited via gametes (sperm and egg).
- Sexual reproduction involves the fusion of gametes, restoring diploid chromosome number.
- Genetic variation arises from meiosis (crossing over, independent assortment) and fertilization.

3.2 Mendelian Genetics and Mendel's Laws of Inheritance

Gregor Mendel's Contributions

- Conducted hybridization experiments on pea plants in the 1860s.
- Identified predictable patterns in trait inheritance.
- Published his findings in *Experiments on Plant Hybridization* (1866).

Mendel's Experimental Approach

- Chose traits with clear binary outcomes (e.g., tall vs dwarf).
- Ensured controlled breeding (self- and cross-pollination).
- Analyzed large sample sizes for statistical validity.

Mendel’s Three Laws

1. Law of Segregation

- Each organism carries two alleles for each trait.
- During gamete formation, these alleles segregate so each gamete carries one allele.
- Fertilization restores the pair.

Example: Cross between Tt x Tt

Punnett Square:

	T	**t**
T	TT	Tt
t	Tt	tt

Genotype Ratio: 1 TT : 2 Tt : 1 tt

Phenotype Ratio: 3 Tall : 1 Dwarf

2. Law of Independent Assortment

- Genes for different traits assort independently if they are on different chromosomes.
- Allows for new combinations of traits.

Dihybrid Cross: YyRr x YyRr (Yellow-Round x Yellow-Round)

Phenotypic Ratio: 9 Yellow-Round : 3 Yellow-Wrinkled : 3 Green-Round : 1 Green-Wrinkled

3. Law of Dominance

- In a heterozygote, one trait (dominant) masks the expression of the other (recessive).
- Only the dominant trait is visible in the F1 generation.

Extensions and Modifications of Mendelian Genetics

Inheritance Type	Description	Example
Incomplete Dominance	Intermediate phenotype in heterozygotes	Red + White = Pink flowers in snapdragons
Codominance	Both alleles are fully expressed	AB blood type (A and B both expressed)
Multiple Alleles	More than two alleles exist in a population	ABO blood group (A, B, O)
Polygenic Inheritance	Multiple genes affect a single trait	Height, skin color
Pleiotropy	A single gene affects multiple traits	Sickle cell disease affects red blood cells and organs
Epistasis	One gene masks the effect of another	Coat color in mice
Sex-linked Inheritance	Traits carried on sex chromosomes	Color blindness, hemophilia (X-linked)

3.3 Principles of Evolution

Definition and Scope

Evolution refers to the heritable changes in the genetic makeup of populations over generations. It is the cornerstone of modern biology, explaining the unity and diversity of life and providing the framework for understanding the development of complex life forms.

Pre-Darwinian Views

- Early ideas of species fixity (e.g., creationism).
- Lamarck's Theory of Use and Disuse: Acquired traits are passed to offspring (disproven).

Darwin's Theory of Natural Selection

- Based on observations made during the HMS Beagle voyage.
- Key work: *On the Origin of Species* (1859).

Principles:

1. **Variation** exists among individuals.
2. **Inheritance**: Traits must be heritable.
3. **Overproduction**: More offspring are produced than can survive.
4. **Differential Survival and Reproduction**: Individuals with advantageous traits (adaptations) are more likely to survive and reproduce.
5. **Accumulation of Favorable Traits**: Leads to gradual changes in populations.

Mechanisms of Evolution

Mechanism	Description	Example
Mutation	Random changes in DNA	Sickle cell allele in malaria-endemic areas
Natural Selection	Survival and reproduction of the fittest	Beak variation in Galapagos finches
Genetic Drift	Random changes in allele frequency	Founder effect, bottleneck effect
Gene Flow	Migration of individuals between populations	Pollen carried between plant populations
Non-random Mating	Preference in mate selection	Sexual selection in peacocks

Speciation and Evolutionary Patterns

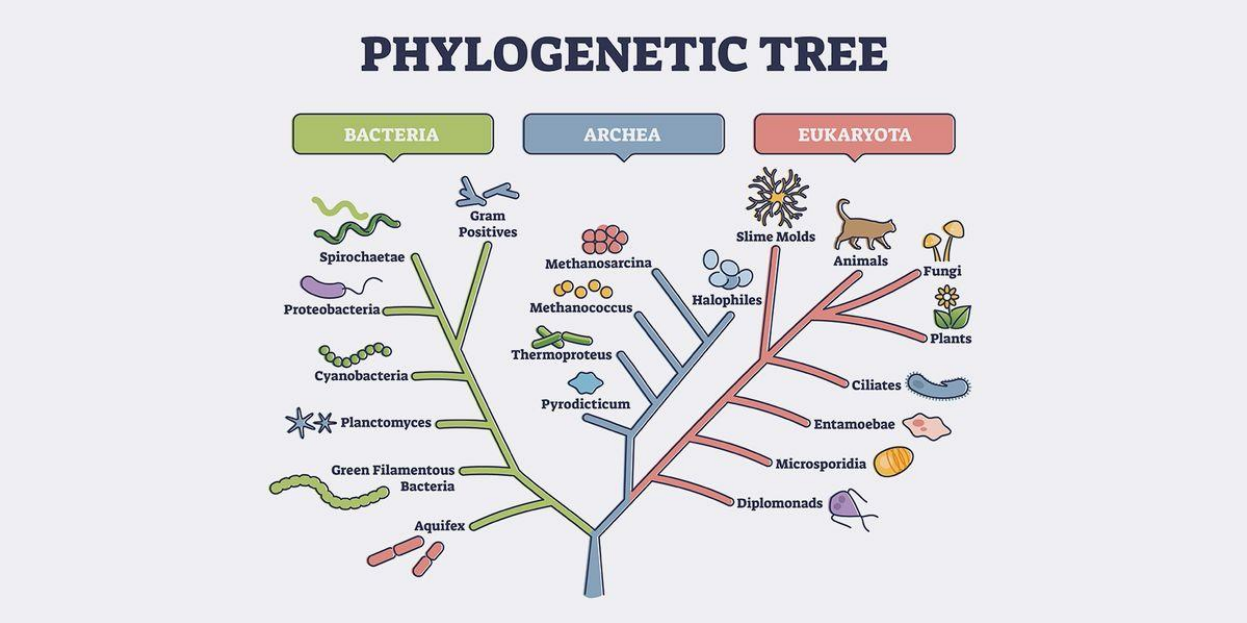
- **Speciation**: Formation of new species.
    - **Allopatric**: Geographical isolation.
    - **Sympatric**: Reproductive isolation without physical barriers.
- **Adaptive Radiation**: Rapid emergence of multiple species from a common ancestor.
- **Convergent Evolution**: Unrelated species evolve similar traits.
- **Divergent Evolution**: Related species become more different.

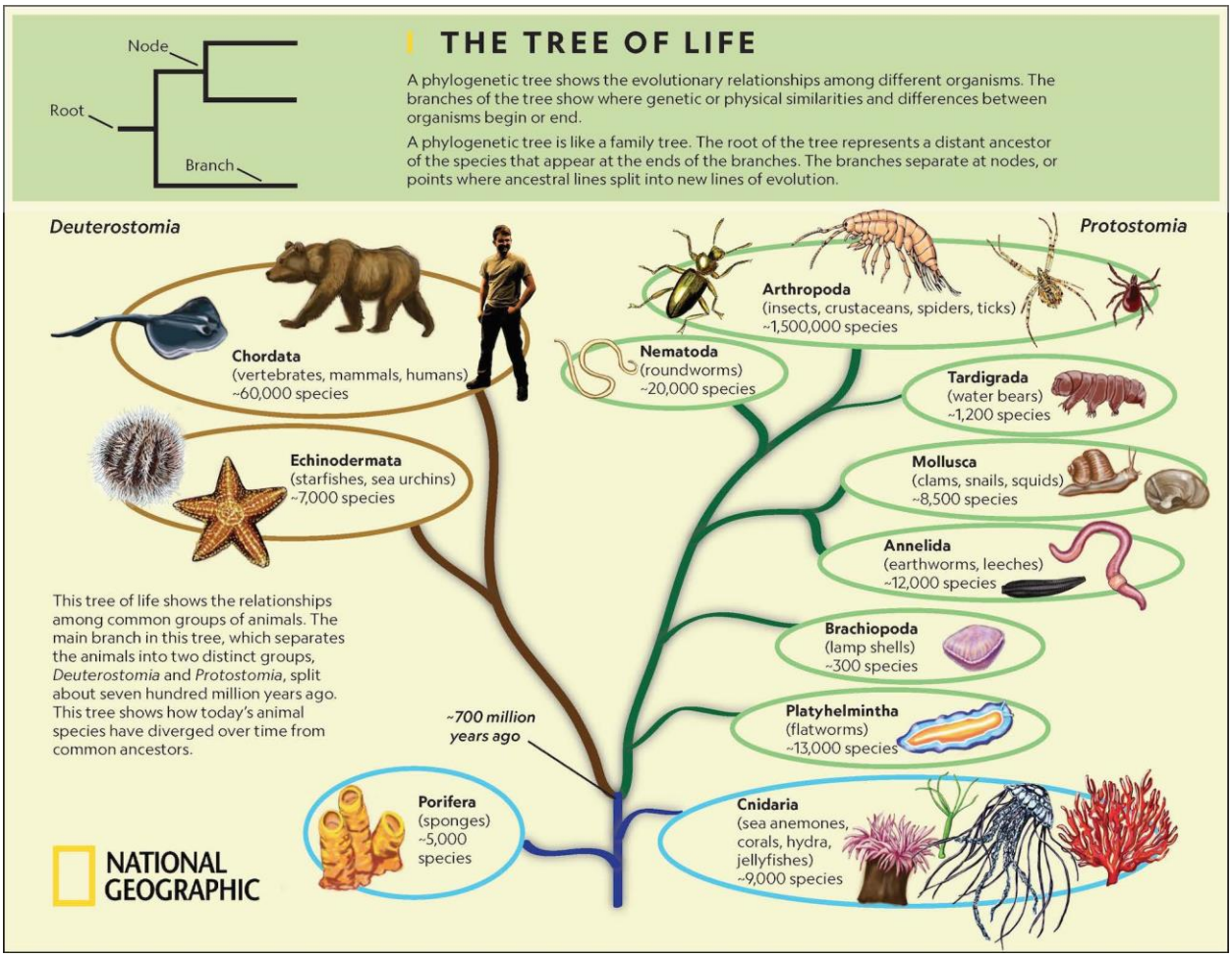
Evidence Supporting Evolution

1. **Fossils**: Document transitional forms.
2. **Comparative Anatomy**:
    - **Homologous structures** (same origin, different function).
    - **Analogous structures** (different origin, similar function).
3. **Embryology**: Similar early development.
4. **Biogeography**: Geographic distribution of species.

5. **Molecular Biology**: DNA, RNA, and protein similarities.

Illustration:





3.4 Darwin's Laws of Evolution

Introduction to Charles Darwin and the Evolutionary Paradigm

Charles Robert Darwin (1809–1882), an eminent English naturalist, revolutionized the study of life with his groundbreaking theory of biological evolution through natural selection. His seminal book *On the Origin of Species by Means of Natural Selection* (1859) provided compelling evidence and theoretical groundwork for the process of evolution, introducing the concept that species are not immutable but change over time through heritable traits that offer survival advantages.

Darwin's theory laid the foundation for modern biology and reshaped our understanding of life sciences by integrating ecology, genetics, anatomy, and paleontology into a cohesive explanatory framework. His ideas introduced a naturalistic mechanism for biological diversity that did not rely on supernatural causation, making the study of life deeply empirical and mechanistically grounded.

Historical Context and Pre-Darwinian Thought

Prior to Darwin, the prevailing belief in Europe was fixity of species: the idea that all organisms were created as they currently exist. Naturalists such as Carolus Linnaeus categorized species, while others like Georges Cuvier emphasized catastrophism to explain fossil records. Jean-Baptiste Lamarck also proposed one of the first cohesive theories of evolution, albeit flawed in mechanism.

Darwin's voyage on the HMS Beagle (1831-1836) was pivotal in shaping his views. Observations in the Galápagos Islands, especially concerning finches and tortoises, illuminated the role of environmental pressures in shaping morphological traits.

The Core Principles of Darwin’s Theory of Evolution

Darwin did not originally list his principles as formal "laws," but biologists have synthesized his insights into five foundational tenets:

1. Variation Among Individuals

- Every population contains individuals that differ in morphology, physiology, and behavior.
- These variations may be discrete (e.g., blood types) or continuous (e.g., height, beak length).
- Crucially, some of these differences are heritable and encoded genetically.
- **Example:** In a population of moths, coloration may range from light to dark. These variations affect visibility to predators.

2. Overproduction of Offspring

- Organisms produce more offspring than can survive due to limited resources.
- This excess leads to competition and a filtering process where not all individuals reach reproductive age.
- **Illustration:** A single pair of salmon can produce thousands of eggs, but only a few reach adulthood.

3. Struggle for Existence

- Limited resources, predators, diseases, and environmental pressures result in a constant struggle for survival.
- Individuals with advantageous traits are more likely to survive this struggle.

4. Differential Reproduction and Natural Selection

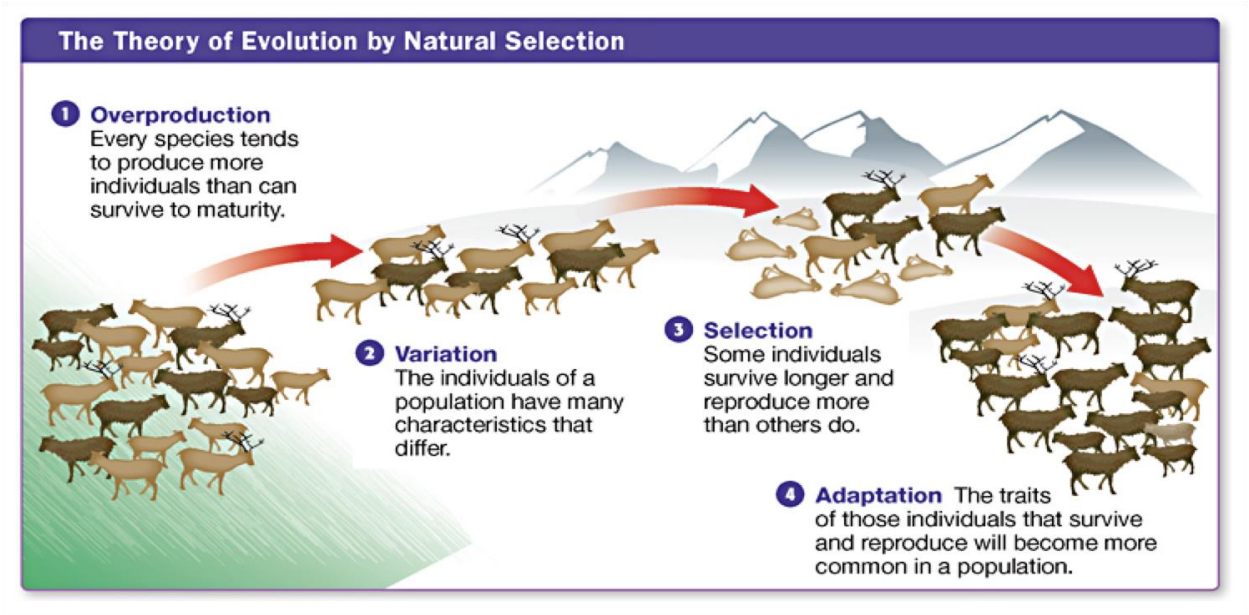
- Those individuals better suited to the environment tend to survive and reproduce, passing on beneficial traits.
- Over generations, these traits become more common, altering the population's genetic composition.
- This process is termed *natural selection*, often paraphrased as "survival of the fittest."

5. Speciation and Descent with Modification

- As genetic differences accumulate, populations may diverge significantly to form new species.
- This concept, known as *descent with modification*, explains the common ancestry and diversity of life.

Diagram: Summary of Darwinian Natural Selection

- Natural Selection Process:



- Visualizes how variation, selection pressure, and heredity lead to adaptive evolution over time.

Evidence Supporting Darwin's Theory

1. **Fossil Record** — Shows progressive changes in species across geologic time.
2. **Comparative Anatomy** — Homologous structures (e.g., vertebrate forelimbs) suggest common ancestry.
3. **Embryology** — Similar embryonic stages in different vertebrates reflect evolutionary history.
4. **Molecular Biology** — DNA and protein similarities affirm evolutionary relationships.
5. **Biogeography** — Island species illustrate adaptive radiation and convergent evolution.

Case Study: Darwin's Finches

Darwin documented over a dozen species of finches on the Galápagos Islands, each with distinct beak shapes adapted to different food sources:

- Thick, crushing beaks for seeds
- Thin, probing beaks for insects or nectar

- These differences arose from adaptive radiation, a process where species evolve from a common ancestor to exploit different ecological niches.

3.5 Lamarck's Theory of Evolution

Introduction to Jean-Baptiste Lamarck

Jean-Baptiste Lamarck (1744–1829) was among the first scientists to propose a formal theory of evolution. His theory, articulated in *Philosophie Zoologique* (1809), attempted to explain the diversity of life through natural processes and was a significant intellectual precursor to Darwin's work.

Lamarck's evolutionary mechanism centered on the organism's interaction with its environment and the subsequent modification of traits during an organism's lifetime. His theory rests primarily on two principles:

The Two Fundamental Principles of Lamarckism

1. Law of Use and Disuse

- Organs and structures become more developed with frequent use and atrophy when unused.
- Traits change during the organism's lifetime based on behavioral habits.
- **Example:** The neck of a giraffe becomes elongated as the animal stretches to reach high leaves. Over generations, this trait becomes more pronounced due to habitual use.

2. Inheritance of Acquired Characteristics

- Traits that an organism develops through use or environmental interaction are passed to offspring.
- **Example:** A blacksmith develops strong arm muscles through work. According to Lamarck, his children would inherit this muscular build.

Strengths and Contributions of Lamarckism

- Pioneered the concept of adaptation as a mechanism of evolutionary change.
- Proposed a dynamic relationship between organism and environment.
- Emphasized gradual change and continuity in life forms.

Weaknesses and Criticisms

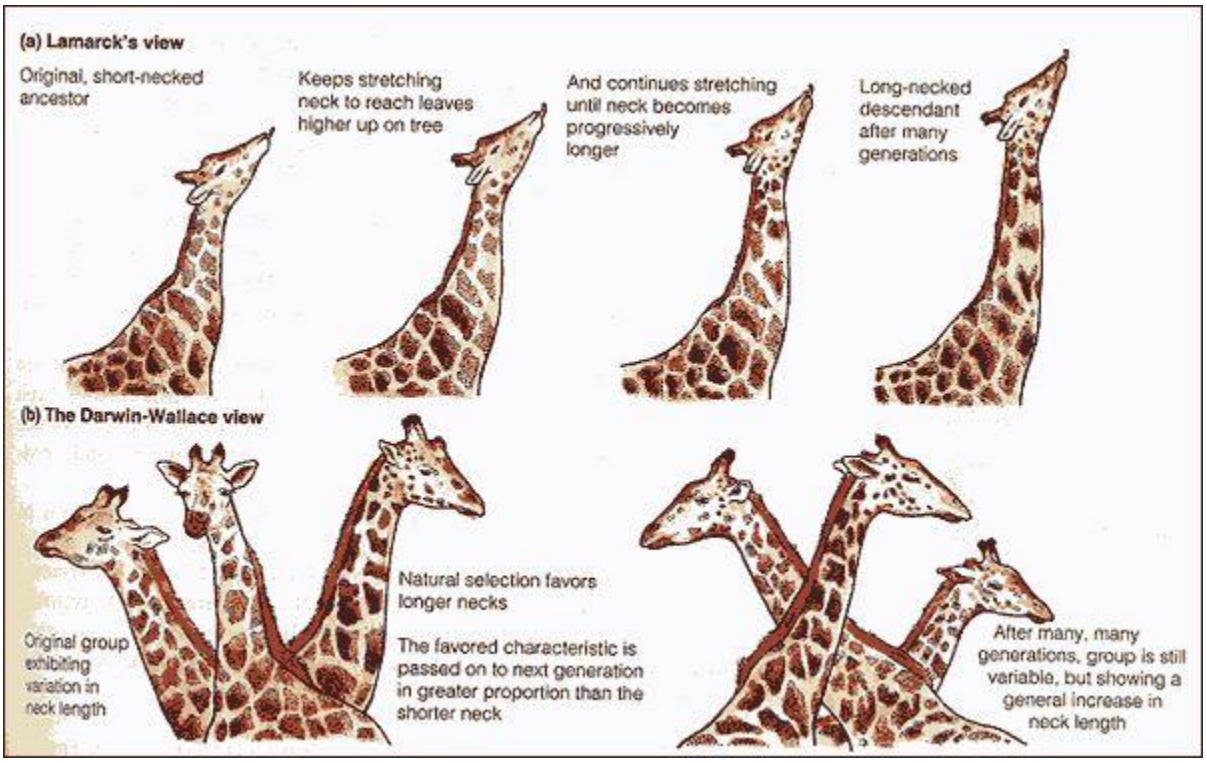
- Lack of genetic mechanism: Modern genetics has demonstrated that acquired traits do not alter DNA in germ cells.
- Discredited by experimental evidence: For instance, removing the tails of mice for generations did not result in tailless offspring.

Lamarckian vs. Darwinian Evolution

Feature	Lamarck's Theory	Darwin's Theory
Source of Variation	Acquired traits during lifetime	Inherited genetic differences
Mechanism of Evolution	Use and disuse; inheritance of acquired characteristics	Natural selection based on heritable traits
Timescale	Rapid, generational changes	Gradual changes over many generations
Empirical Support	Minimal; not supported by molecular genetics	Strongly supported by fossil, genetic, and anatomical evidence
Role of Environment	Directly induces changes in organism	Indirectly shapes survival via selection pressure

Diagram: Giraffe Neck Evolution — Lamarck vs. Darwin

- View Diagram:



Shows contrasting mechanisms: acquired use-based elongation (Lamarck) vs. selection of naturally longer necks (Darwin).

Modern Reappraisal: Epigenetics and Lamarckian Ideas

Although Lamarck's mechanism is largely invalidated, modern epigenetics has revitalized interest in the environment's influence on heritable traits:

- **Epigenetics**: Chemical modifications to DNA (e.g., methylation) can influence gene expression without altering the underlying sequence.
- **Transgenerational Epigenetic Inheritance**: Some of these modifications may be passed to offspring, echoing a modified form of Lamarckian inheritance.

CHAPTER 4: TAXONOMY OF LIFE AND BINOMIAL NOMENCLATURE

4.1 Taxonomy of Life

What is Taxonomy?

Taxonomy is a branch of biology that deals with identifying, naming, describing, and classifying organisms into an organized system. It plays a crucial role in helping scientists understand and communicate the relationships between different forms of life on Earth.

Objectives of Taxonomy:

1. To classify organisms based on shared characteristics and evolutionary ancestry.
2. To provide a universal naming system.
3. To assist in understanding biodiversity and the relationships among organisms.
4. To facilitate communication and information retrieval in biological sciences.

Historical Development of Taxonomy

- **Aristotle**: One of the earliest attempts at classification. Divided organisms into two major groups: plants and animals. Animals were further classified based on habitat.
- **Theophrastus**: Considered the "father of botany," further refined plant classification.
- **Carl Linnaeus**: A Swedish botanist who introduced the modern system of taxonomy. He formalized the use of hierarchical categories and developed binomial nomenclature in his work *Systema Naturae* (1735).

Major Taxonomic Categories (Ranks)

Taxonomy uses a hierarchical structure to classify organisms. The primary taxonomic ranks are:

Rank	Description	Example (Human)
Domain	Broadest category, reflects major cell types	Eukarya
Kingdom	Groups based on fundamental traits	Animalia
Phylum	Body plan and organization	Chordata
Class	Shared characteristics within a phylum	Mammalia
Order	Groups of related families	Primates
Family	Groups of related genera	Hominidae
Genus	Closely related species	Homo
Species	Basic unit of classification; interbreeding group	Homo sapiens

Mnemonic Device

To remember the order of ranks:
Dear **K**ing **P**hilip **C**ame **O**ver **F**or **G**ood **S**oup.

Domains of Life

In modern taxonomy, all life forms are classified into three **Domains** based on molecular biology and evolutionary relationships:

1. **Domain Bacteria**: Prokaryotic, unicellular organisms with peptidoglycan in cell walls.
2. **Domain Archaea**: Prokaryotic, similar in structure to bacteria but genetically distinct; often found in extreme environments.
3. **Domain Eukarya**: Eukaryotic organisms; includes protists, fungi, plants, and animals.

The Six Kingdom System

Domain	Kingdom	Characteristics
Bacteria	Eubacteria	Unicellular, prokaryotic, cell wall with peptidoglycan
Archaea	Archaebacteria	Unicellular, prokaryotic, extremophiles
Eukarya	Protista	Mostly unicellular, eukaryotic, autotrophs or heterotrophs
	Fungi	Mostly multicellular, chitin cell walls, heterotrophic
	Plantae	Multicellular, cellulose walls, autotrophic via photosynthesis
	Animalia	Multicellular, no cell walls, heterotrophic

4.2 Structure of Bacteria, Viruses, Protists, and Fungi

Bacteria

Cell Type: Prokaryotic

Structure:

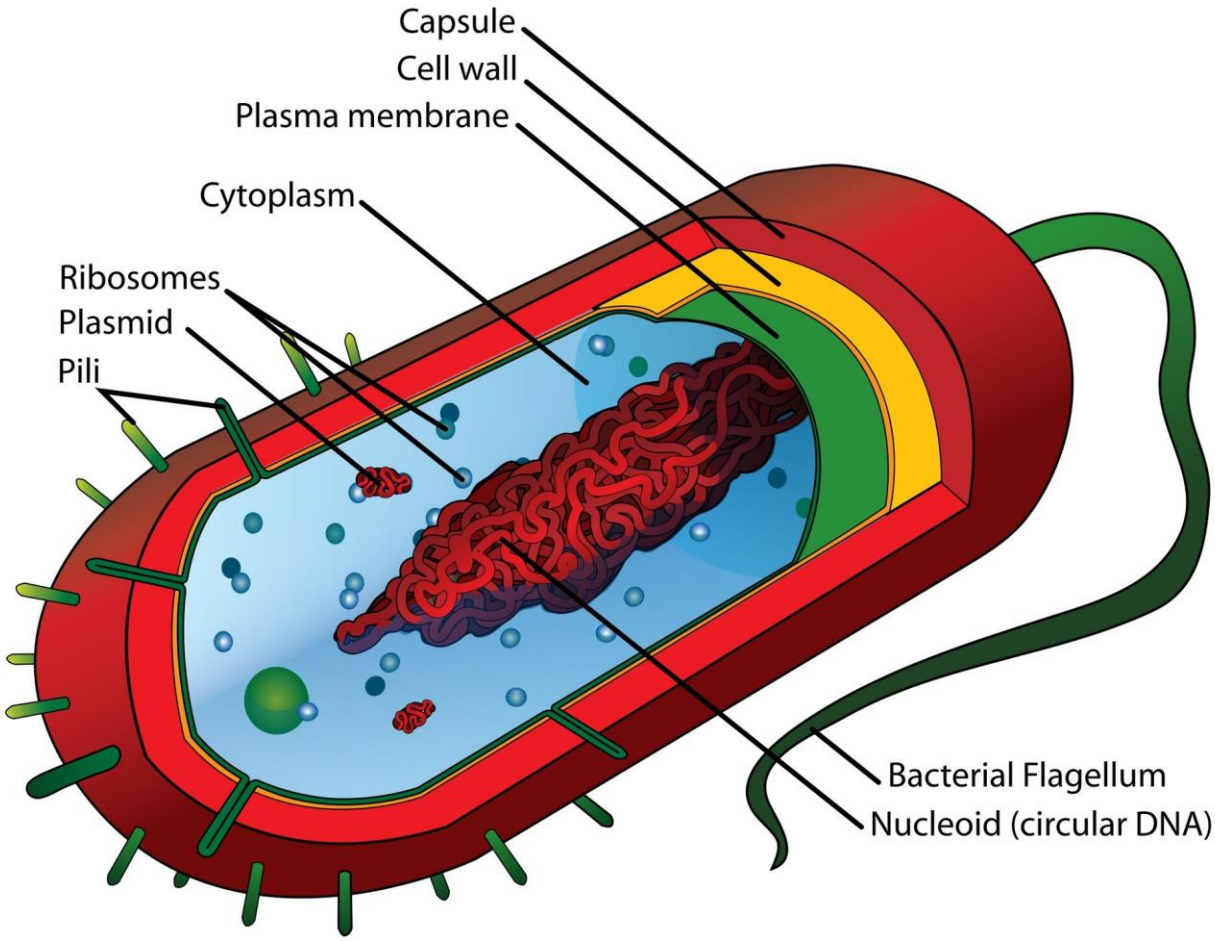
- **Cell Wall**: Made of peptidoglycan
- **Plasma Membrane**: Controls substance movement
- **Cytoplasm**: Contains enzymes and ribosomes
- **Ribosomes**: Protein synthesis
- **Nucleoid Region**: Circular DNA
- **Pili and Flagella**: Attachment and movement

Shapes:

- **Coccus** (spherical)
- **Bacillus** (rod-shaped)
- **Spirillum** (spiral-shaped)

Reproduction:

- **Asexual** via binary fission
- Genetic recombination via conjugation, transformation, and transduction



Viruses

Cell Type: Not considered living; acellular

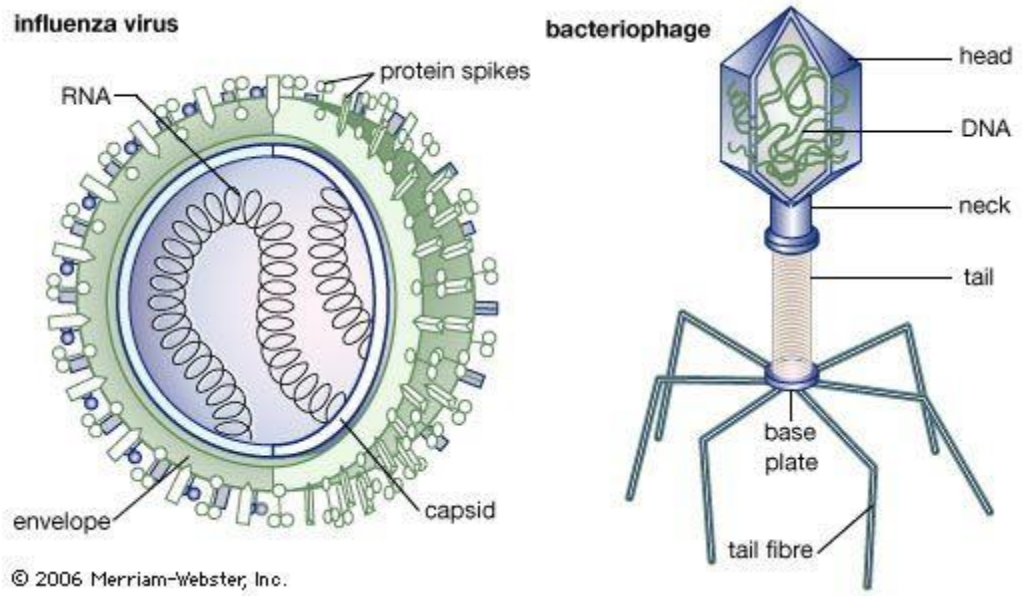
Structure:

- **Capsid**: Protein shell
- **Genetic Material**: DNA or RNA

- **Envelope** (in some viruses): Lipid bilayer derived from host
- **Spikes**: Protein structures for host attachment

Life Cycle:

- **Lytic Cycle**: Immediate replication and host cell destruction
- **Lysogenic Cycle**: Viral genome integrates with host DNA



Protists

Cell Type: Eukaryotic

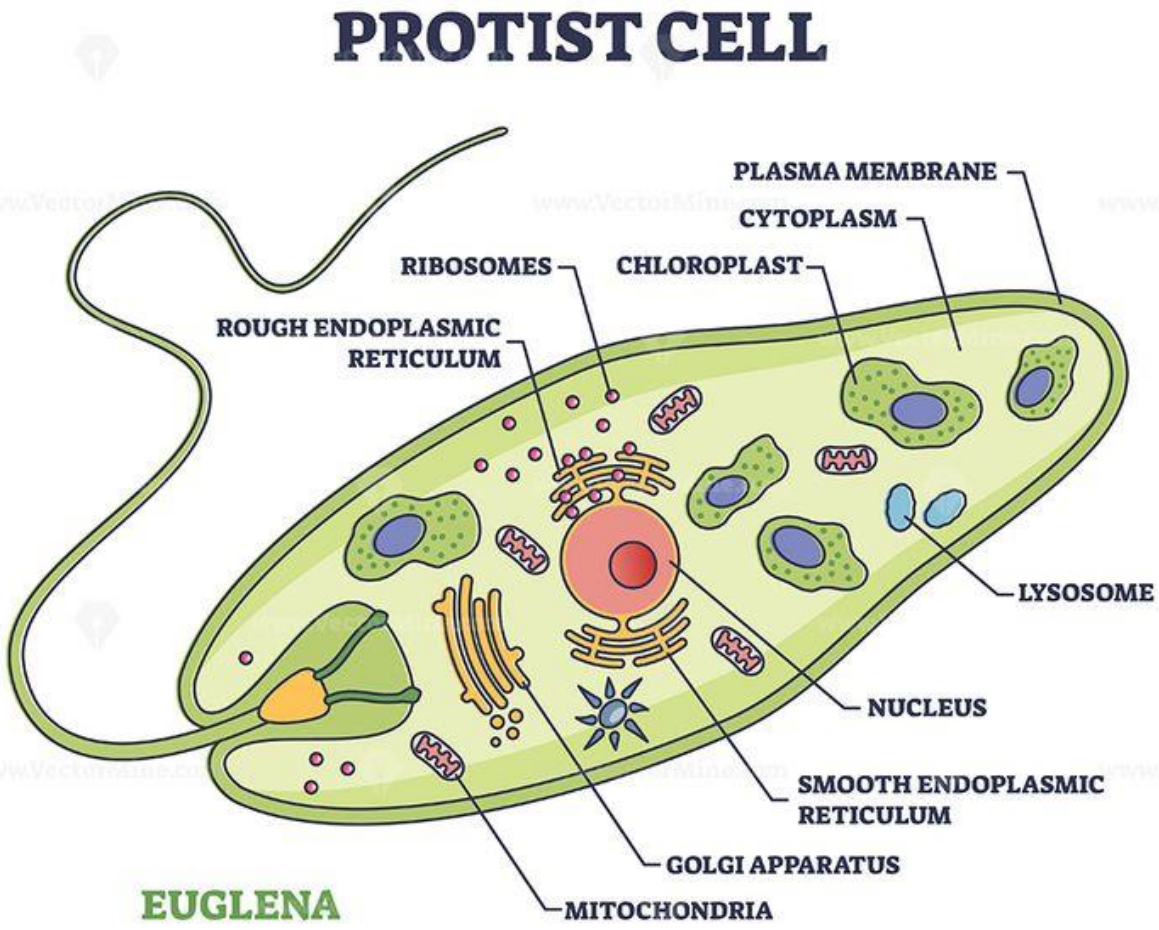
Characteristics:

- Highly diverse group
- **Unicellular or simple multicellular**
- Can be autotrophic (algae) or heterotrophic (protozoa)
- Move using cilia, flagella, or pseudopodia

Examples:

- **Amoeba** (pseudopodia)

- **Paramecium** (cilia)
- **Euglena** (flagella, photosynthetic)



Fungi

Cell Type: Eukaryotic

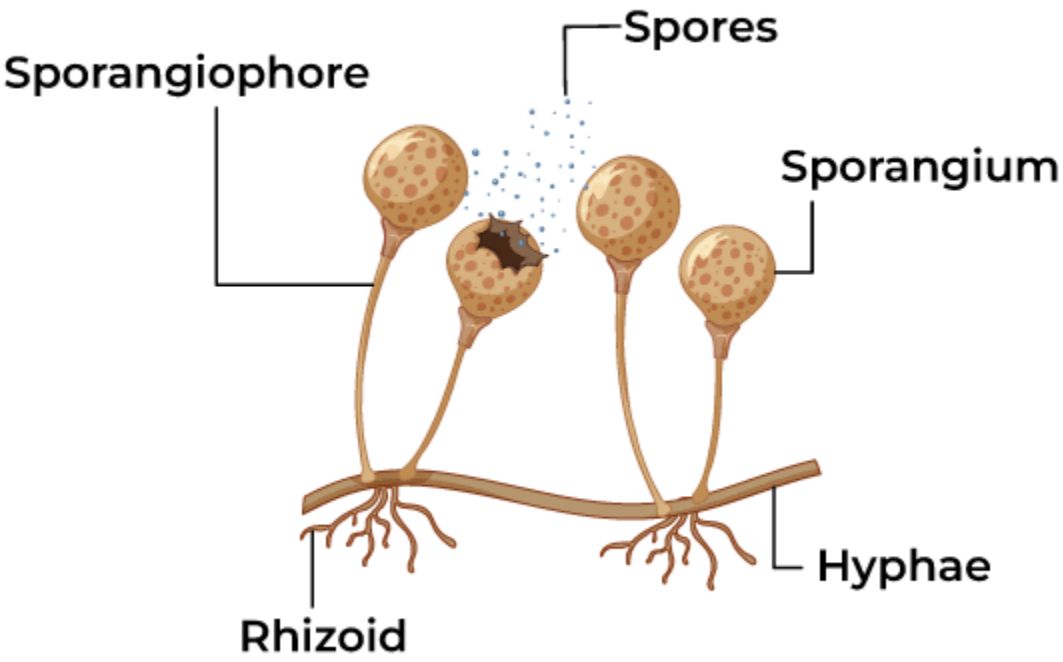
Structure:

- **Hyphae**: Filamentous structures
- **Mycelium**: Mass of hyphae
- **Cell Wall**: Made of chitin

- **Spores**: Asexual or sexual reproductive units

Nutrition:

- **Saprophytic**: Decompose dead matter
- **Parasitic**: Live on host
- **Mutualistic**: E.g., mycorrhizae with plants



4.3 Plant Structure

Plant Tissue Systems

Plants have three primary tissue systems:

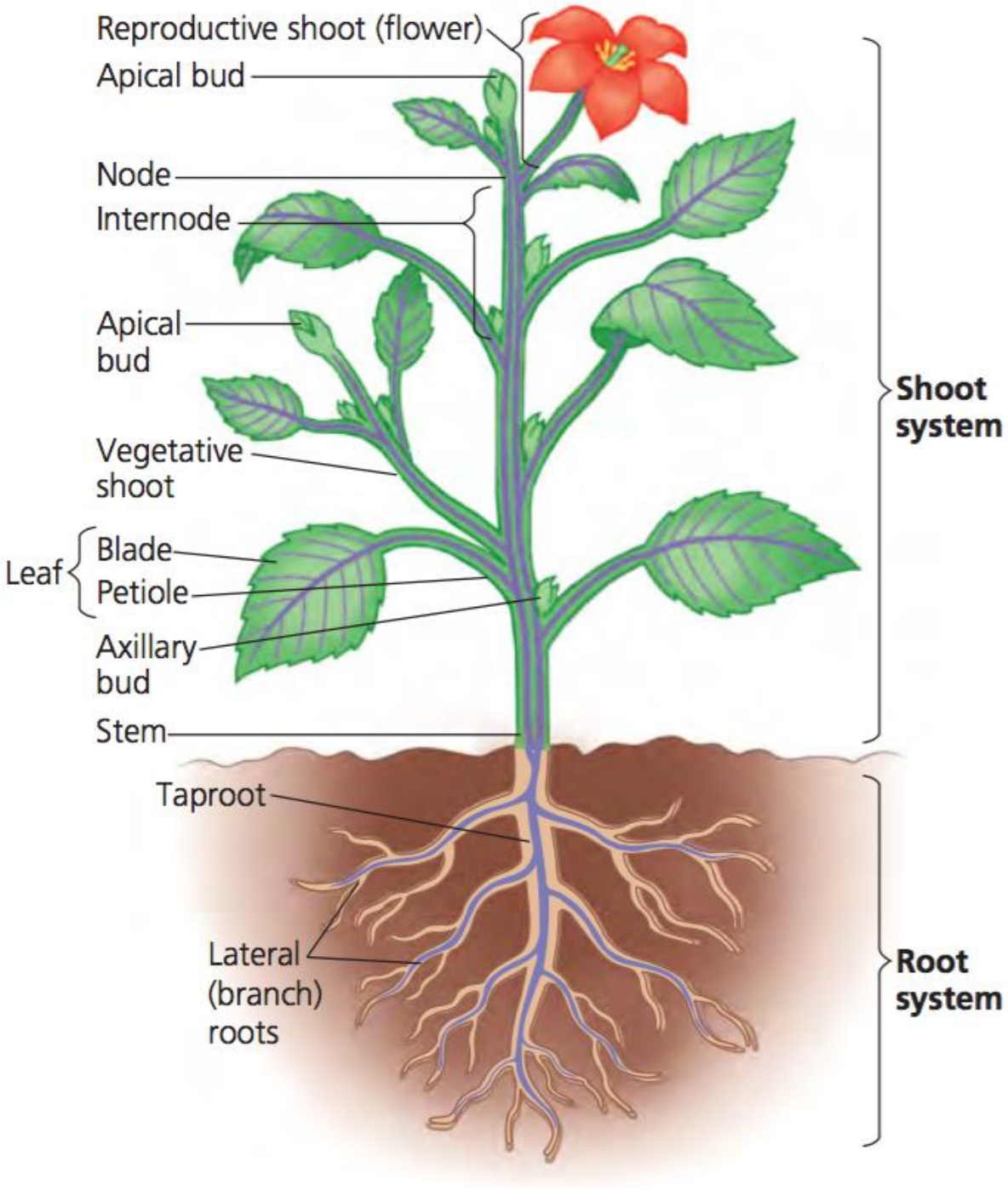
1. **Dermal Tissue**: Protective outer covering

- Epidermis
- Cuticle (waxy layer)

2. **Vascular Tissue**:
    - **Xylem**: Transports water and minerals from roots to leaves
    - **Phloem**: Distributes sugars and nutrients throughout plant
3. **Ground Tissue**:
    - **Parenchyma**: Photosynthesis, storage
    - **Collenchyma**: Flexible support
    - **Sclerenchyma**: Rigid support

Major Plant Organs

1. **Roots**:
    - Absorb water/minerals
    - Anchor plant
    - Store nutrients
    - Root hairs increase surface area
2. **Stems**:
    - Support leaves/flowers
    - Transport fluids
    - Can be herbaceous or woody
3. **Leaves**:
    - Primary site of photosynthesis
    - Anatomy: Cuticle, epidermis, mesophyll (palisade/spongy), veins, stomata


Reproductive shoot (flower)
Apical bud
Node
Internode
Apical bud
Vegetative shoot
Leaf
Blade
Petiole
Axillary bud
Stem
Shoot system
Taproot
Lateral (branch) roots
Root system

4.4 Reproduction in Plants

Asexual Reproduction

Advantages:

- Rapid population increase
- No need for pollinators
- Genetically identical offspring (clones)

Mechanisms:

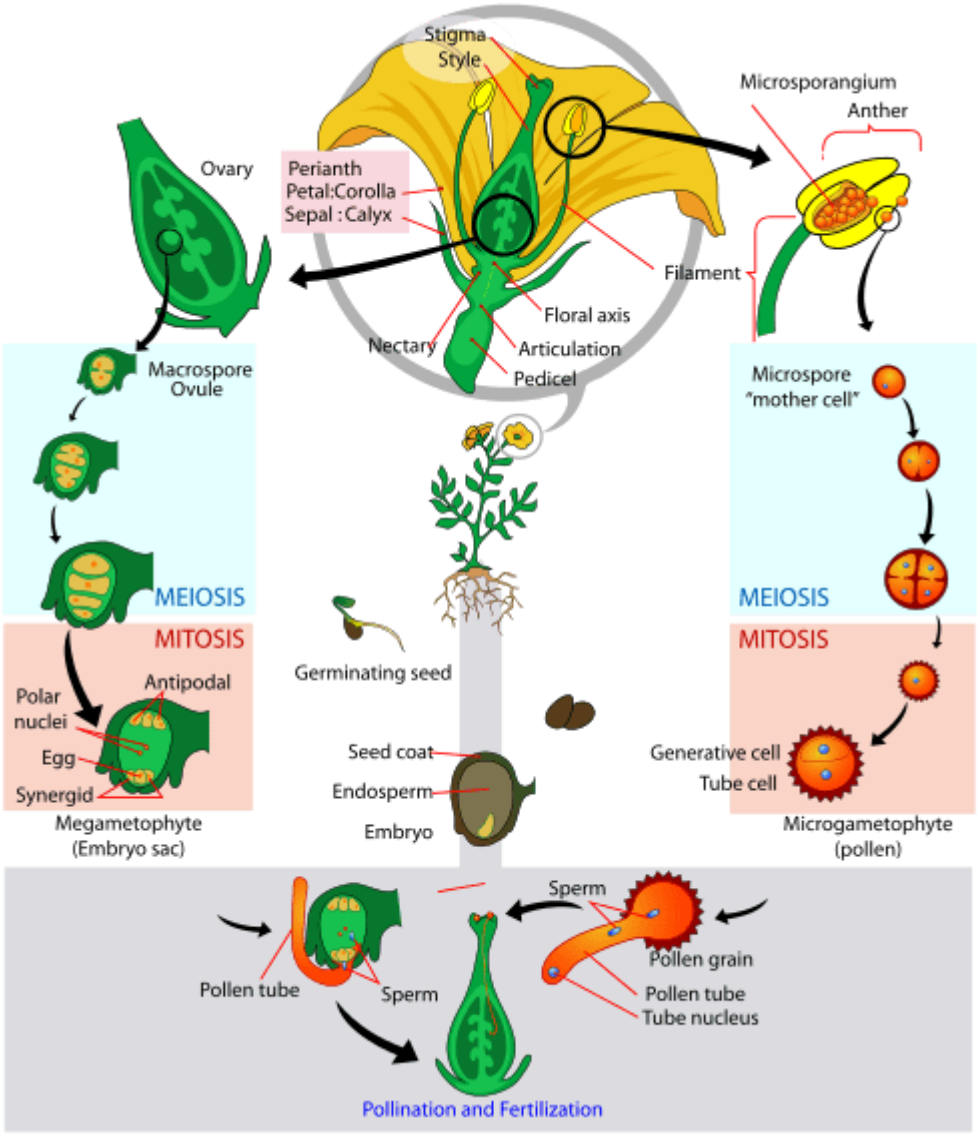
- **Runners**: Horizontal stems (e.g., strawberry)
- **Rhizomes/Tubers**: Underground stems (e.g., potato)
- **Bulbs**: Layered storage organs (e.g., onion)
- **Cuttings**: New plants from stems/leaves

Sexual Reproduction

Occurs mainly in angiosperms (flowering plants)

Flower Anatomy

- **Sepals**: Protect flower before opening
- **Petals**: Colorful, attract pollinators
- **Stamens**: Male organs (anther + filament)
- **Carpels/Pistil**: Female organs (stigma + style + ovary)



Pollination

- **Self-pollination**: Same flower or same plant
- **Cross-pollination**: Between different plants

Agents: Wind, insects, birds, bats

Fertilization

- Pollen grain germinates, grows pollen tube
- Sperm nuclei travel to ovule

- **Double fertilization**: One sperm fertilizes egg; other forms endosperm

Seed and Fruit Formation

- **Seed**: Contains embryo, endosperm, seed coat
- **Fruit**: Mature ovary, aids seed dispersal

Germination Process

- Imbibition (water uptake)
- Activation of enzymes
- Growth of radicle (root) and plumule (shoot)

4.5 Vertebrates and Invertebrates

I. Introduction to Animal Classification

The biological classification of organisms is an essential aspect of the science of taxonomy. In the Kingdom Animalia, organisms are primarily classified into two major categories based on the presence or absence of a vertebral column: **Vertebrates** and **Invertebrates**. This dichotomy not only aids in understanding the complexity of animal body structures but also facilitates the study of evolutionary relationships, ecological roles, and physiological adaptations across different species.

The division is foundational in comparative anatomy, evolutionary biology, and animal physiology. While vertebrates make up only a small fraction of all animal species, their structural complexity and advanced organ systems make them a central focus of vertebrate zoology. In contrast, invertebrates comprise a vast and diverse group of species that demonstrate a wide range of morphological adaptations to every conceivable habitat on Earth.

II. Vertebrates

Definition: Vertebrates are organisms within the subphylum **Vertebrata**, characterized by a segmented spinal column or backbone made of vertebrae, which protects the spinal cord — a part of the central nervous system.

Core Characteristics:

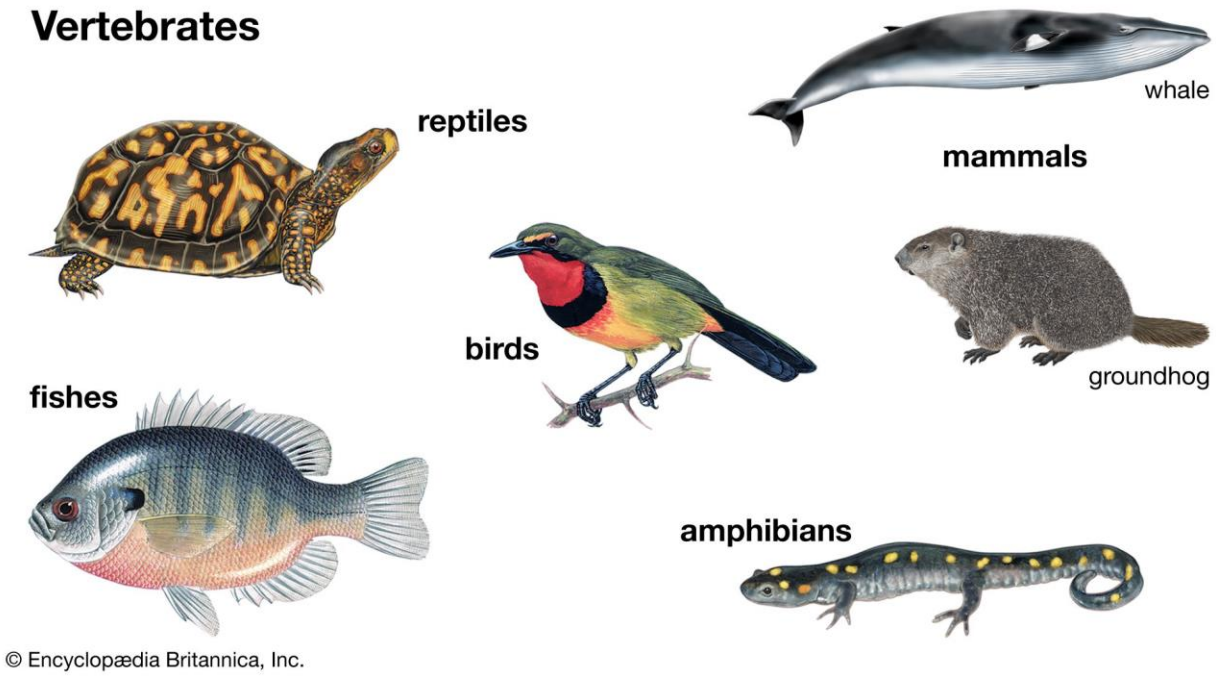
- Possess an **endoskeleton** composed of either cartilage or bone
- Bilateral symmetry and a well-differentiated head region
- Highly developed organ systems including:
    - Centralized nervous system enclosed in a cranium (braincase)
    - Closed circulatory system with a ventral heart
    - Advanced respiratory systems (lungs or gills)
- Internal fertilization (in most groups) and complex reproductive systems
- Locomotion achieved through jointed appendages and muscle coordination

Subcategories (Classes of Vertebrates):

Class	Common Name	Environment	Example Species	Distinguishing Features
Pisces	Fishes	Aquatic	Salmon, Shark, Goldfish	Gills, fins, ectothermic, swim bladder for buoyancy
Amphibia	Amphibians	Aquatic/Terrestrial	Frog, Salamander	Dual life cycle, moist permeable skin, external fertilization
Reptilia	Reptiles	Terrestrial/Aquatic	Snake, Lizard, Turtle	Keratinized scaly skin, ectothermic, oviparous/ovoviviparous
Aves	Birds	Aerial/Terrestrial	Sparrow, Eagle, Penguin	Feathers, beaks, hollow bones, oviparous, endothermic

Class	Common Name	Environment	Example Species	Distinguishing Features
Mammalia	Mammals	Terrestrial/Aquatic	Human, Dog, Whale	Hair/fur, mammary glands, placenta in eutherians, endothermic

Diagram: Vertebrate Classes and Key Characteristics



Classification of Vertebrates

Vertebrate class	Body covering	Movement	Reproduction	Sense organs	Other details	Examples
Fish	Scales	Fins (also used for balance)	Usually produces jelly-covered eggs in water	Eyes but no ears, lateral line along body for detecting vibrations in water	Cold-blooded, gills for breathing	Herring, perch, shark
Amphibians	Moist skin	Four limbs, back feet often webbed to make swimming more efficient	Produces jelly-covered eggs in water	Eyes and ears	Cold-blooded, lungs and skin for breathing	Frog, toad, salamander
Reptiles	Dry, with scales	Four legs (apart from snakes)	Eggs with rubbery, waterproof shell – laid on land	Eyes and ears	Cold-blooded, lungs for breathing	Crocodile, python
Birds	Feathers, scales on legs	Wings, two legs	Eggs with hard shell	Eyes and ears	Warm-blooded, lungs for breathing, beak	Flamingo, pigeon
Mammals	Fur	Four limbs	Live young	Eyes, ears with pinna (external flap)	Warm-blooded, lungs for breathing, females have mammary glands to produce milk to feed young, four types of teeth	Elephant, mouse

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III. Invertebrates

Definition: Invertebrates are members of the Animal Kingdom that do **not possess a vertebral column**. This group includes the majority of animal phyla and constitutes over 95% of all known animal species. Invertebrates display a remarkable diversity in size, shape, structure, and habitat.

General Features:

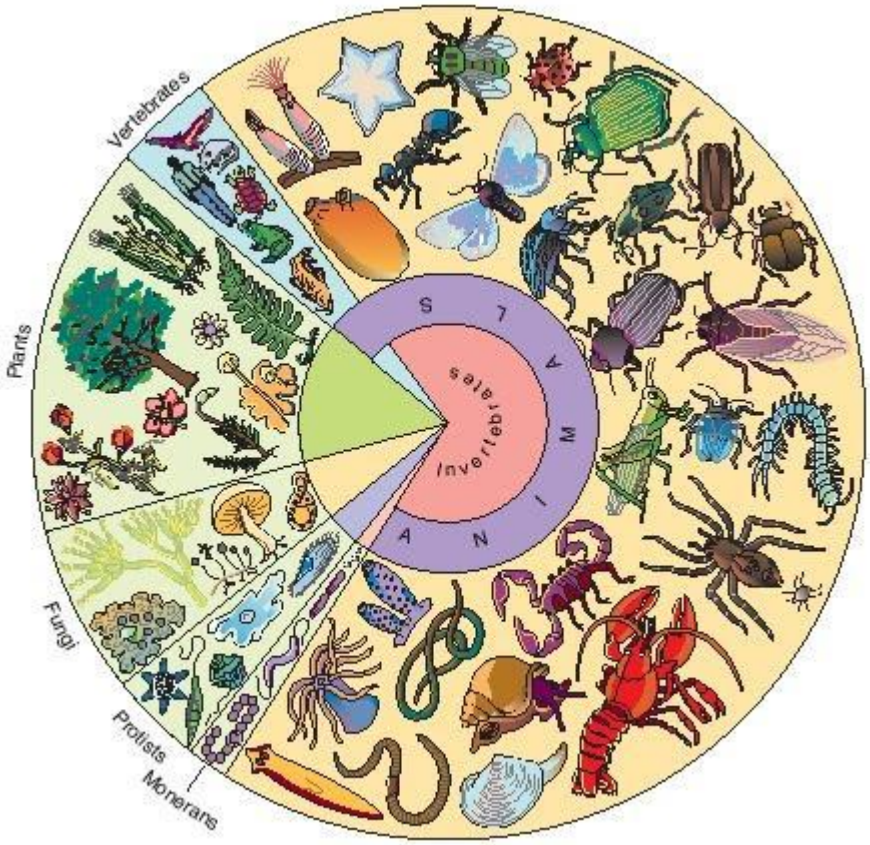
- Lack of internal skeletal structure based on vertebrae
- Body plans range from simple (sponges) to highly complex (arthropods, mollusks)

- Nervous systems may be rudimentary (nerve nets in cnidarians) or advanced (compound eyes in arthropods)
- Circulatory systems may be open or closed
- Reproduction may be sexual, asexual, or hermaphroditic
- Exhibit various modes of locomotion (cilia, muscular contractions, jointed limbs)

Major Phyla of Invertebrates:

Phylum	Habitat	Examples	Distinctive Features
Porifera	Aquatic	Sponges	Asymmetrical, pores, filter feeders, no true tissues
Cnidaria	Aquatic	Jellyfish, Sea Anemones	Radial symmetry, cnidocytes (stinging cells)
Platyhelminthes	Aquatic/Terrestrial	Tapeworms, Planarians	Flat body, bilateral symmetry, acoelomate
Nematoda	Aquatic/Soil	Roundworms, Hookworms	Unsegmented, pseudocoelomates, complete gut
Annelida	Soil/Freshwater	Earthworms, Leeches	Segmented body, true coelom, setae for locomotion
Mollusca	Marine/Terrestrial	Snails, Clams, Octopuses	Soft bodies, most with shells, radula in many species
Arthropoda	All environments	Insects, Crustaceans, Spiders	Exoskeleton, jointed limbs, segmented body, metamorphosis
Echinodermata	Marine	Starfish, Sea Cucumbers	Radial symmetry (adults), water vascular system

Diagram: Diversity of Invertebrates



4.6 Binomial Nomenclature

I. Historical Development and Significance

Binomial nomenclature, introduced by Swedish naturalist **Carl Linnaeus** in 1753 through his work *Species Plantarum*, revolutionized the classification of living organisms by providing a consistent and standardized naming system. Prior to this system, names were long, descriptive phrases prone to regional variations and misinterpretation.

Linnaeus's method gave each species a unique, universally accepted name composed of two Latin words: the **genus** and the **species epithet**. This has become the cornerstone of modern taxonomy.

II. Functions of Binomial Nomenclature

- **Standardization**: Provides uniformity in species identification worldwide
- **Clarity**: Prevents confusion due to local or vernacular names
- **Hierarchical Insight**: Shows relatedness through genus-level grouping
- **Scientific Communication**: Allows biologists globally to refer unambiguously to species

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4.7 Rules of Binomial Nomenclature

I. Formal Guidelines

The naming conventions are governed by several international codes:

- **ICZN**: International Code of Zoological Nomenclature
- **ICNafp**: International Code of Nomenclature for algae, fungi, and plants

Core Rules of the System:

1. **Binarity**: Each organism is assigned a name with two parts—Genus and species.
2. **Typography**:
    - Italicize both names when typed (e.g., *Felis catus*)
    - Underline when handwritten (*Felis catus*)
3. **Capitalization**:
    - Genus: First letter capitalized
    - Species epithet: Lowercase
4. **Uniqueness and Stability**: Each name is exclusive to a single species.
5. **Name Authorship and Date**: Can include the authority and year for credibility (e.g., *Quercus robur* L. 1753)

6. **Latinization**: Latin or Latinized words are used regardless of the native origin of the species
7. **Gender Concordance**: The species epithet must grammatically agree in gender with the genus
8. **Principle of Priority**: The earliest validly published name is retained in case of duplication

II. Example Breakdown

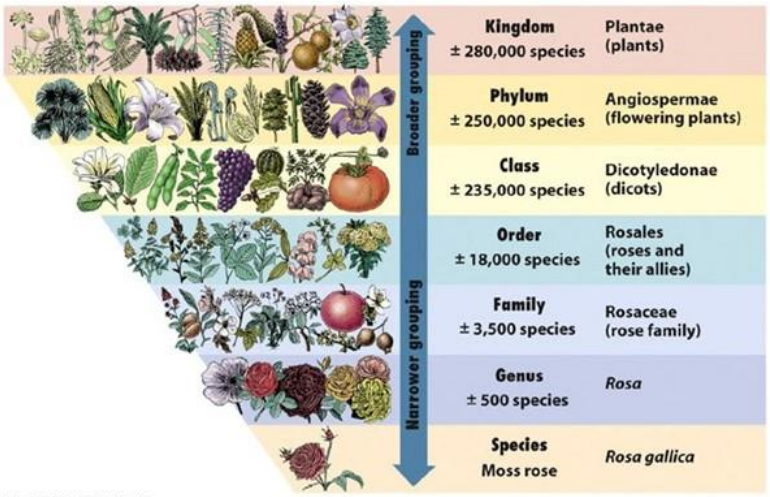
- **Scientific Name**: *Canis lupus*
    - **Genus**: *Canis* (includes dogs, wolves, etc.)
    - **Species**: *lupus* (refers specifically to the gray wolf)

III. Table of Examples from Various Kingdoms

Common Name	Scientific Name	Kingdom	Genus	Species	Authority
Human	*Homo sapiens*	Animalia	Homo	sapiens	Linnaeus, 1758
Rice	*Oryza sativa*	Plantae	Oryza	sativa	Linnaeus, 1753
Housefly	*Musca domestica*	Animalia	Musca	domestica	Linnaeus, 1758
Apple Tree	*Malus domestica*	Plantae	Malus	domestica	Borkh., 1803
Gray Wolf	*Canis lupus*	Animalia	Canis	lupus	Linnaeus, 1758

Diagram: Structure and Typing Conventions of Scientific Names

Plant Taxonomic Hierarchy



= "Division" for plants (Phylum are used in other Kingdoms)

Most botanists focus only on family, genus and species.

Figure 2-6 Discover Biology 3/e
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Using this ranked system:

- A "species" consists of both a genus and species epithet taken together.
- Each broader grouping (higher up in this diagram) includes <u>all</u> of the shared characteristics of the narrower (lower) groupings.

REVIEW QUESTION

THE SCIENCE OF LIFE

Short Answer

1. Define biology and explain its scope.
2. List and describe three historical figures who significantly contributed to the development of biology.
3. Differentiate between botany and zoology.

Multiple Choice

4. Who is considered the father of biology?
    - A. Hippocrates
    - B. Linnaeus
    - C. Aristotle
    - D. Darwin

    Answer: C
5. Which sub-discipline of biology studies cells?
    - A. Ecology
    - B. Cytology
    - C. Physiology
    - D. Anatomy

    Answer: B

Essay

6. Discuss the importance of biology in society with examples from at least three fields.

THE CELL

Short Answer

1. What are the main tenets of the classical cell theory?
2. Compare and contrast prokaryotic and eukaryotic cells.

True/False

3. The cell wall is present in all eukaryotic cells.

   Answer: False
4. Mitochondria are the sites of photosynthesis in plant cells.

   Answer: False

Matching

Match the organelle to its function:

- A. Golgi Apparatus
- B. Ribosome
- C. Nucleus
- D. Lysosome

1. Protein synthesis
2. Packaging and transport
3. Genetic control center
4. Digestion of waste

   Answers: A–2, B–1, C–3, D–4

HEREDITY AND EVOLUTION

Short Answer

1. Define gene, allele, and chromosome.
2. What are Mendel’s three laws of inheritance?

Multiple Choice

3. In which phase of meiosis does crossing over occur?
    - A. Metaphase I
    - B. Anaphase II
    - C. Prophase I
    - D. Telophase I

    Answer: C
4. Which of the following best describes codominance?
    - A. One allele masks another
    - B. Both alleles express equally
    - C. Neither allele is expressed
    - D. Traits blend together

    Answer: B

Essay

5. Compare Darwin's theory of natural selection with Lamarck's theory of acquired traits.

TAXONOMY AND CLASSIFICATION

Short Answer

1. What is binomial nomenclature? Provide an example.
2. List the taxonomic hierarchy from domain to species.

Multiple Choice

3. Which domain includes multicellular eukaryotes?

- A. Bacteria
- B. Archaea
- C. Eukarya
- D. Protista

  Answer: C

4. Which of the following is a correct scientific name?
   - A. canis Lupus
   - B. Canis Lupus
   - C. Canis lupus
   - D. canis lupus

     Answer: C

PLANT AND ANIMAL BIOLOGY

Short Answer

1. What are the main differences between monocots and dicots?
2. Describe the structure and function of xylem and phloem.

Matching

Match each class of vertebrates with a key feature:

- A. Mammalia
- B. Aves
- C. Reptilia
- D. Amphibia

1. Hair and mammary glands
2. Feathers and hollow bones
3. Moist skin and metamorphosis

4. Scales and egg-laying

   Answers: A–1, B–2, C–4, D–3

LIST OF ABBREVIATIONS

Abbreviation	Full Term
ATP	Adenosine Triphosphate
DNA	Deoxyribonucleic Acid
RNA	Ribonucleic Acid
ER	Endoplasmic Reticulum
rRNA	Ribosomal Ribonucleic Acid
mRNA	Messenger Ribonucleic Acid
tRNA	Transfer Ribonucleic Acid
NADPH	Nicotinamide Adenine Dinucleotide Phosphate
NADH	Nicotinamide Adenine Dinucleotide
FADH2	Flavin Adenine Dinucleotide (reduced)
CO2	Carbon Dioxide
O2	Oxygen
H2O	Water
ADP	Adenosine Diphosphate
Pi	Inorganic Phosphate
ETC	Electron Transport Chain
G3P	Glyceraldehyde-3-Phosphate
RuBP	Ribulose-1,5-bisphosphate
3-PGA	3-Phosphoglycerate
ICZN	International Code of Zoological Nomenclature
ICNafp	International Code of Nomenclature for Algae, Fungi, and Plants

Abbreviation	Full Term
HCl	Hydrochloric Acid
Na+/K+ pump	Sodium-Potassium Pump
µm	Micrometer
Tt	Heterozygous Tall genotype
TT	Homozygous Dominant genotype
tt	Homozygous Recessive genotype
F1	First Filial Generation
F2	Second Filial Generation
X-linked	Sex-linked inheritance on the X chromosome

GLOSSARY OF KEY TERMS

Adaptation – A heritable trait that improves an organism's chances of survival and reproduction in a specific environment.

Allele – One of two or more alternative forms of a gene found at the same locus on homologous chromosomes.

ATP (Adenosine Triphosphate) – The primary energy carrier in cells, storing and transferring energy for various cellular processes.

Autotroph – An organism capable of producing its own food using light (photosynthesis) or chemical energy (chemosynthesis).

Biodiversity – The variety and variability of life forms, including species diversity, genetic diversity, and ecosystem diversity.

Cell – The basic structural, functional, and biological unit of all living organisms.

Chloroplast – A plant organelle where photosynthesis takes place.

Chromosome – A thread-like structure made of DNA and protein that carries genetic information.

Cytoplasm – The jelly-like substance within a cell that holds organelles and is the site of many metabolic reactions.

Diffusion – The passive movement of molecules from an area of higher concentration to one of lower concentration.

DNA (Deoxyribonucleic Acid) – The molecule that stores genetic information in all living organisms.

Ecosystem – A community of organisms interacting with each other and with their physical environment.

Enzyme – A biological catalyst that speeds up chemical reactions in cells without being consumed.

Eukaryote – An organism whose cells contain a nucleus and other membrane-bound organelles.

Gene – A segment of DNA that encodes instructions for making a specific protein or trait.

Genotype – The genetic makeup of an organism, consisting of all the alleles present.

Homeostasis – The ability of an organism to maintain a stable internal environment despite external changes.

Meiosis – A type of cell division that reduces the chromosome number by half, producing four genetically unique gametes.

Mitochondrion – The organelle known as the powerhouse of the cell; site of aerobic respiration and ATP production.

Mutation – A change in the DNA sequence that may result in altered gene function or expression.

Natural Selection – The process by which individuals with advantageous traits survive and reproduce more successfully.

Nucleus – A membrane-bound organelle that houses the cell's genetic material (DNA).

Osmosis – The diffusion of water molecules across a semi-permeable membrane.

Phenotype – The observable traits or characteristics of an organism resulting from its genotype and environment.

Photosynthesis – The process by which green plants and some organisms use sunlight to synthesize glucose from carbon dioxide and water.

Prokaryote – A unicellular organism that lacks a nucleus and membrane-bound organelles.

Protein – A biological macromolecule composed of amino acids; essential for structure, function, and regulation in cells.

Respiration – The process of breaking down glucose to produce energy (ATP) in cells.

Ribosome – A cell organelle involved in protein synthesis.

Taxonomy – The science of classifying and naming organisms.

Tissue – A group of similar cells that work together to perform a specific function.

Virus – A microscopic infectious agent composed of genetic material (DNA or RNA) enclosed in a protein coat; not considered a living organism.

Zygote – A fertilized egg cell resulting from the union of a sperm and an egg.

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