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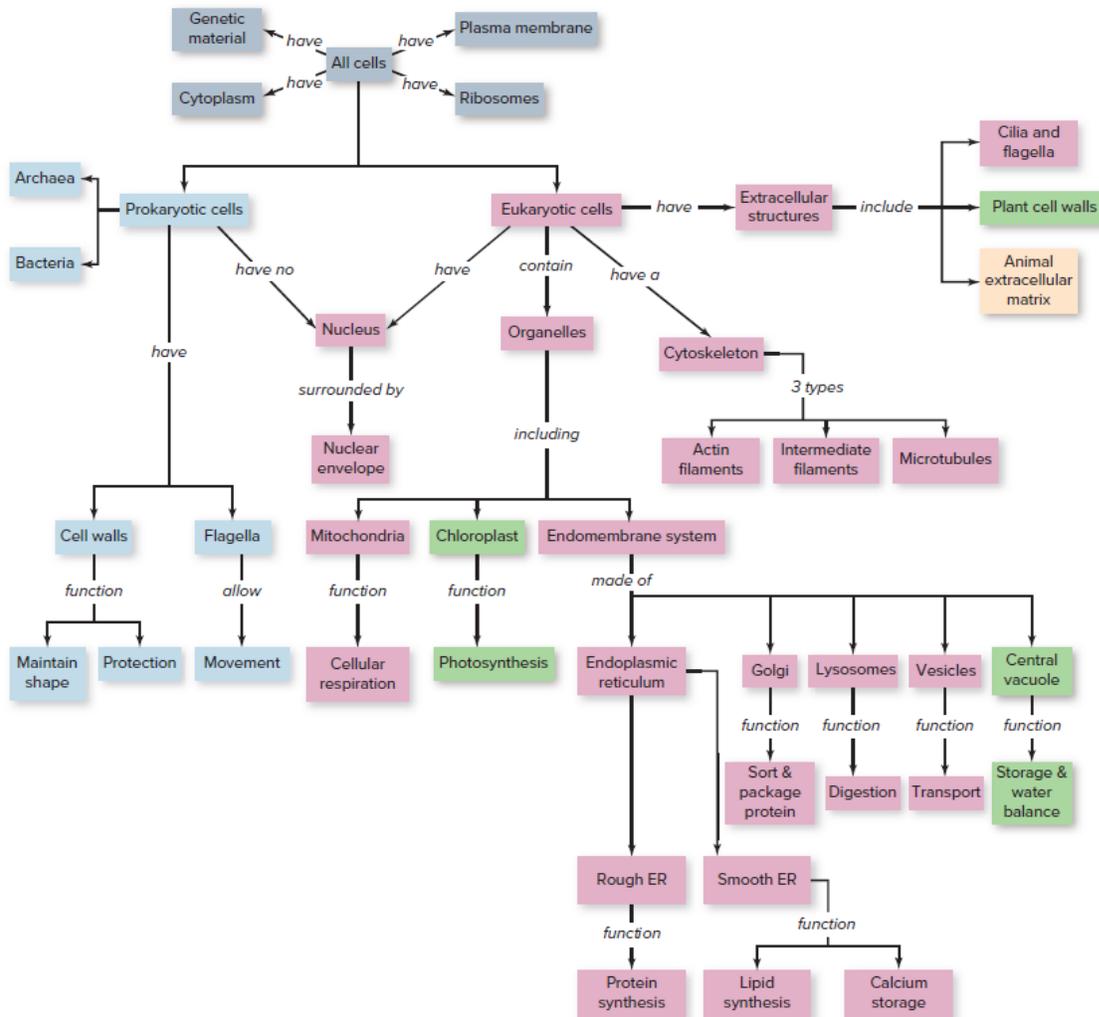
Chapter: 1

Cell Biology (Cytology)

Cell biology (cytology) is the interdisciplinary study of cell structure, function, and behavior, integrating microscopy, biochemistry, genetics, and computational biology. The **cell** is the smallest unit capable of performing all activities associated with life and serves as the fundamental **structural and functional unit** of all living organisms. While the components of a cell cannot survive independently, the cell operates as an integrated system, and groups of cells form tissues, organs, and organisms, demonstrating biological complexity.

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1. Cell Biology (Cytology)



Cell Theory

The **Cell Theory** is the foundational principle of modern biology, formalized by **Matthias Schleiden** (1838), **Theodor Schwann** (1839), and **Rudolf Virchow** (1855). **August Weismann** later contributed the concept of common descent.

Salient Features of Modern Cell Theory:

- All living organisms are composed of one or more cells.
- The cell is the basic unit of structure, function, and organization in all organisms.
- All cells arise from pre-existing cells through cell division (**Principle of Biogenesis**).

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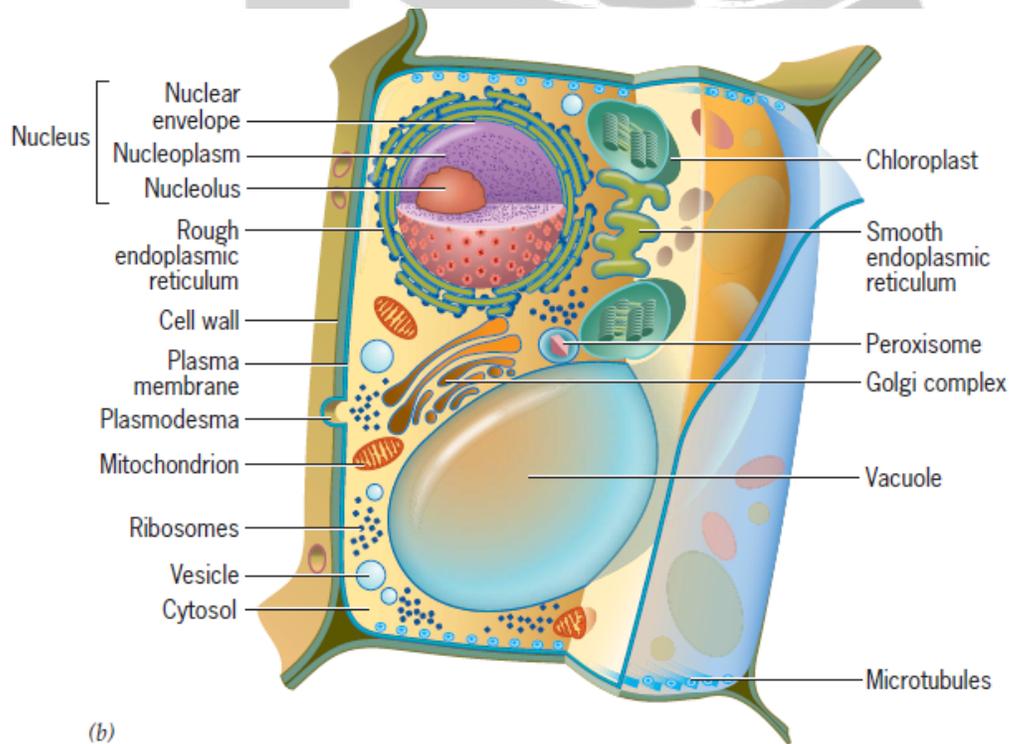
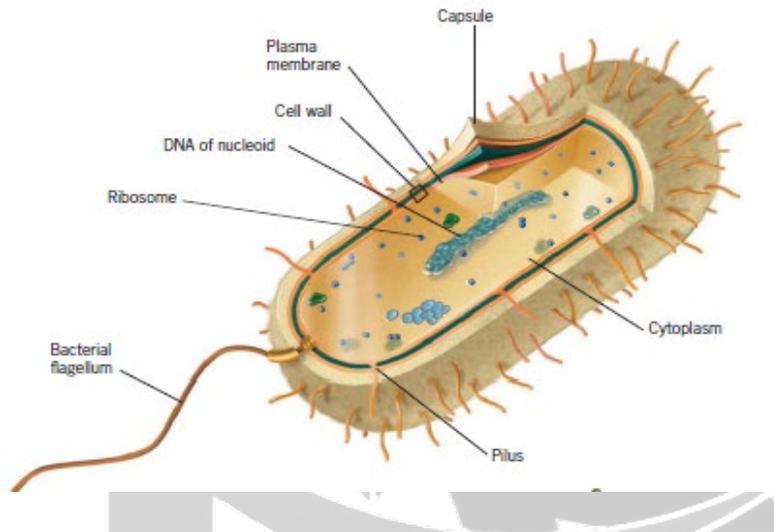
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Feature	Bacteria	Archaea
Cell Wall	Contains peptidoglycan	No peptidoglycan; diverse composition
Membrane Lipids	Ester-linked fatty acids to glycerol	Ether-linked hydrocarbons; can form lipid monolayers for thermal stability
Genetic Machinery	Distinct	More similar to eukaryotes (e.g., RNA polymerase, transcription factors)
Flagella	Bacterial Flagellum: Hollow filament of flagellin; rotary motor powered by proton (H^+) gradient.	Archaeum: Structurally distinct, related to type IV pili; powered by ATP hydrolysis . (Example of convergent evolution)

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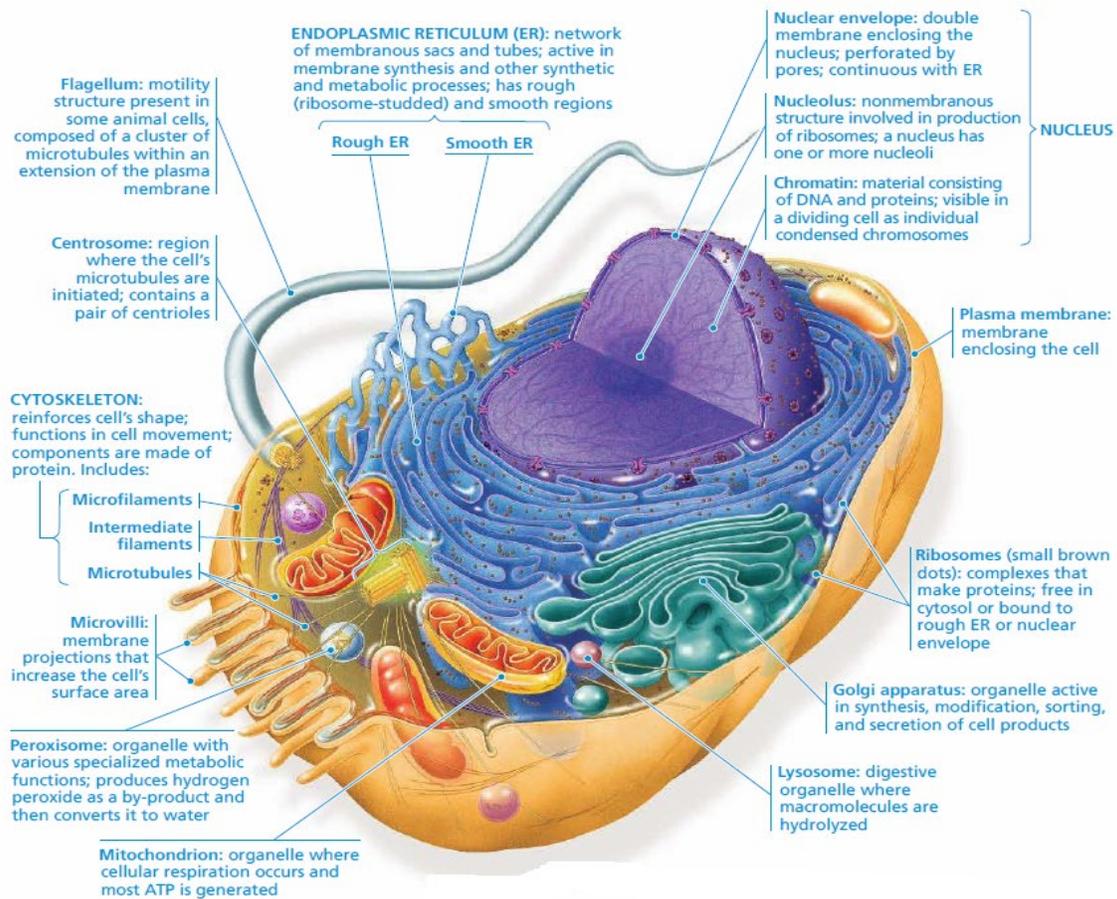
Prokaryotic cell & Plant Cell

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(b)

Animal Cell (cutaway view of generalized cell)



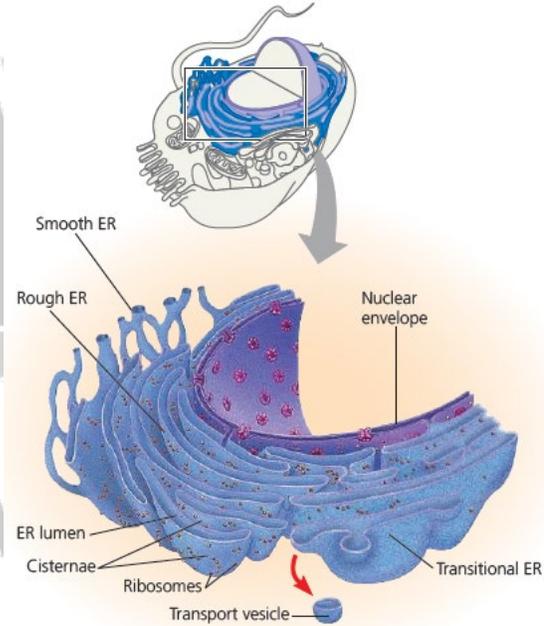
Prokaryotic vs. Eukaryotic Cells

Feature	Prokaryotic Cell (Bacteria/Archaea)	Eukaryotic Cell (Protists, Fungi, Plants, Animals)
Nucleus	Absent. DNA in a nucleoid region (not membrane-bound).	Present. DNA enclosed within a double-membrane nuclear envelope .
Membrane-Bound Organelles	Absent. (e.g., No mitochondria, ER, Golgi).	Present. Extensive compartmentalization (e.g., ER, Golgi, lysosomes, peroxisomes).
Cell Size	Generally small (0.5 – 5.0 μm).	Generally larger (10 – 100 μm).
Cytoskeleton	Primitive. Contains homologs of actin (MreB) and tubulin (FtsZ) for shape and division, but not a complex network.	Present. Complex, dynamic network of microtubules, microfilaments, and intermediate filaments.
Ribosomes	70S (50S + 30S subunits).	80S in cytosol (60S + 40S). 70S in mitochondria & chloroplasts.
Cell Division	Binary Fission. Simple division after DNA replication.	Mitosis (for growth/repair) or Meiosis (for gamete formation).
DNA Form	Single, circular chromosome. May have small circular plasmids.	Multiple, linear chromosomes complexed with histone proteins to form chromatin.

1. **Signal Sequence:** An N-terminal **16-30 hydrophobic amino acid signal peptide** emerges from a free ribosome.
2. **SRP Binding: Signal Recognition Particle (SRP)** binds the signal peptide, **halts translation**.
3. **Docking:** SRP-ribosome complex binds **SRP Receptor** on the RER membrane.
4. **Translocation:** Ribosome docks onto **Sec61 translocon** (protein channel). Translation resumes, and the growing polypeptide is **cotranslationally** threaded into the ER lumen or integrated into the membrane.
5. **Signal Cleavage:** Signal peptidase cleaves off the signal peptide inside the lumen.

B. Key Functions in the RER Lumen

1. **Protein Folding:** Chaperones (e.g., **BiP/GRP78**) assist in proper folding.
2. **Post-Translational Modifications:**
 - o **N-linked Glycosylation:** Addition of a pre-formed oligosaccharide core to asparagine residues (Asn-X-Ser/Thr). Critical for stability, recognition, and quality control.
 - o **Disulfide Bond Formation:** Catalyzed by **Protein Disulfide Isomerase (PDI)**. Stabilizes tertiary/quaternary structure.
 - o **Proteolytic Cleavage:** Signal peptide removal; pro-protein cleavage (e.g., proinsulin → insulin).
3. **Quality Control (ER-Associated Degradation - ERAD):**
 - o Misfolded/unfolded proteins are retrotranslocated to the cytosol, **ubiquitinated**, and degraded by the **proteasome**.



SMOOTH ER (SER)

A. Lipid & Steroid Synthesis

- **Phospholipid Synthesis:** Enzymes in the **cytosolic leaflet of SER** synthesize new phospholipids. **Flippases** transfer some to the luminal leaflet for membrane asymmetry.
- **Cholesterol & Steroid Hormone Synthesis:** SER contains enzymes for cholesterol synthesis and its conversion to steroids (testosterone, estrogen, cortisol). **Abundant in adrenal cortex, gonads.**
- **Lipid Droplet Formation:** Neutral lipids are synthesized and stored between the bilayer leaflets, budding off as lipid droplets.

B. Detoxification & Metabolism

- **Cytochrome P450 Enzymes:** A large family of **membrane-bound oxidases**. They hydroxylate hydrophobic drugs/toxins (e.g., phenobarbital, carcinogens) to make them more water-soluble for excretion.
- **Consequence:** SER **proliferates** in response to toxins (e.g., in hepatocytes of alcoholics). This increases detox capacity but also alters drug metabolism.

C. Calcium Storage & Signaling

- **Sarcoplasmic Reticulum (SR):** Specialized SER in muscle cells. Stores **Ca²⁺ ions** via **SERCA pumps**.
- **Release:** In response to a nerve signal, **ryanodine/IP₃ receptors** open, flooding cytosol with Ca²⁺ to trigger **muscle contraction**.
- **General Signaling:** SER in other cells acts as a dynamic Ca²⁺ store for intracellular signaling.

- **Autolysis:** Rupture of lysosomes leading to total cell destruction (e.g., during metamorphosis, programmed cell death).
- **Clinical Relevance: Lysosomal Storage Diseases** are caused by inherited deficiencies of specific lysosomal enzymes, leading to substrate accumulation. Examples: **Tay-Sachs disease** (hexosaminidase A deficiency, GM2 ganglioside accumulation), **Gaucher's disease** (glucocerebrosidase deficiency).

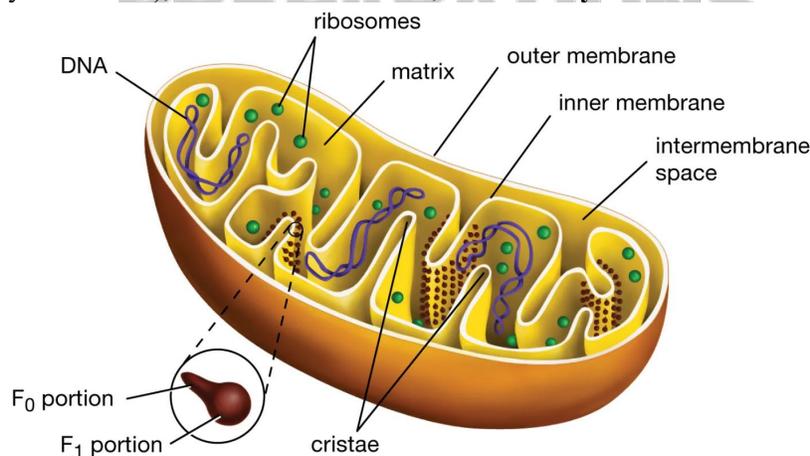
4. Vacuoles:

- **Structure:** Large, membrane-bound sacs. The membrane is called the **tonoplast** in plant cells.
- **Types:**
 - **Central Vacuole (Plant Cells):** Can occupy up to 90% of cell volume. Contains **cell sap** (water, ions, sugars, pigments like anthocyanins, and toxins). Maintains **turgor pressure** for structural support.
 - **Food Vacuoles:** Form by phagocytosis in protists (e.g., amoeba) and some animal cells.
 - **Contractile Vacuoles:** Found in freshwater protists (e.g., *Paramecium*). Actively pump out excess water for **osmoregulation**.

Energy-Transducing Organelles

1. Mitochondria:

- **Discovery:** Observed in the 19th century; named "bioblasts" by Altmann (1890), term "mitochondrion" coined by Benda (1898).
- **Structure:** Double-membrane bound, dynamic organelles that fuse and divide.
 - **Outer Membrane:** Smooth, contains **porin** proteins, making it permeable to small molecules.
 - **Intermembrane Space:** Between the two membranes.
 - **Inner Membrane:** Highly folded into **cristae**, dramatically increasing surface area. Contains proteins for the **Electron Transport Chain (ETC)** and **ATP synthase (F₀F₁ complex)**. Impermeable to ions; requires specific transporters.
 - **Matrix:** Innermost compartment. Contains mitochondrial DNA (mtDNA, circular), 70S ribosomes, granules (Ca²⁺, phosphate), and enzymes for the **Krebs (TCA) Cycle** and **β-oxidation of fatty acids**.
- **Function:** Site of **aerobic cellular respiration** and **ATP synthesis via oxidative phosphorylation** (Chemiosmotic Theory, Peter Mitchell). Also involved in **apoptosis** (by releasing cytochrome c), **calcium homeostasis**, and **heme synthesis**.

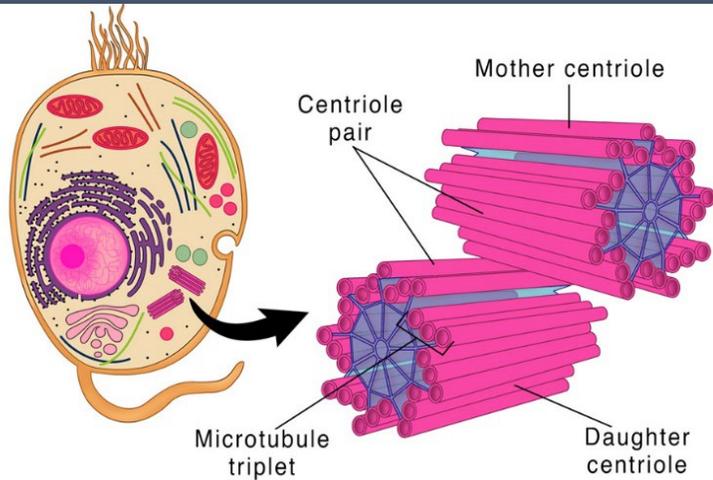


2. Chloroplasts (& other Plastids):

- **Discovery:** Described in plant cells in the 19th century.
- **Structure (Chloroplast):** Double-membrane bound.

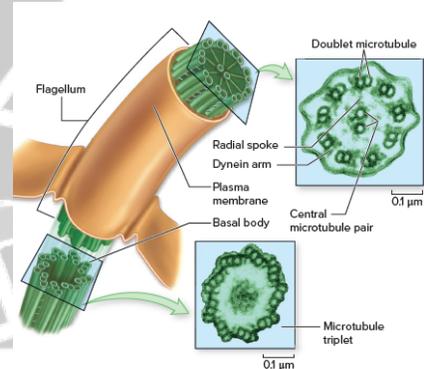
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Cilia & Flagella:

- **Structure:** Membrane-bound projections with a core **axoneme**. The axoneme has a "**9 + 2**" **pattern**: nine outer doublet microtubules surrounding a central pair of singlet microtubules. Connected by **nexin links**. Outer doublets have **dynein arms** (motor proteins).
- **Mechanism of Movement:** **Dynein "walking"** on adjacent microtubule doublets causes sliding. Nexin links convert this sliding into coordinated bending of the entire structure. Requires ATP.
- **Differences:** **Cilia** are numerous, short (5-10 μm), and beat in coordinated waves (e.g., respiratory epithelium). **Flagella** are typically 1-2 per cell, long (up to 200 μm), and exhibit undulatory or whip-like motion (e.g., sperm).
- **Primary Cilium:** A single, non-motile sensory organelle on most vertebrate cells. Has a "9+0" axoneme. Acts as a **cellular antenna** for chemical and mechanical signals (e.g., Hedgehog signaling pathway).



Flagella and cilia. A eukaryotic flagellum originates directly from a basal body. The flagellum has two microtubules in its core connected by radial spokes to an outer ring of nine paired microtubules with dynein arms (9 + 2 structure). The basal body consists of nine microtubule triplets connected by short protein segments. The structure of cilia is similar to that of flagella, but cilia are usually shorter.

Plasma Membrane: Structure and Transport

1. The First Glimpse: The Cell Wall

- **1665: Robert Hooke**
 - Using a crude microscope, Hooke observed thin slices of cork.
 - He saw tiny, box-like compartments which he named "**cells**" (from the Latin *cella*, meaning "small room").
 - What Hooke actually saw were the rigid **cell walls** of dead plant cells. He did not see a living membrane, but his work marked the discovery of the basic structural unit of life and set the stage for future inquiry.

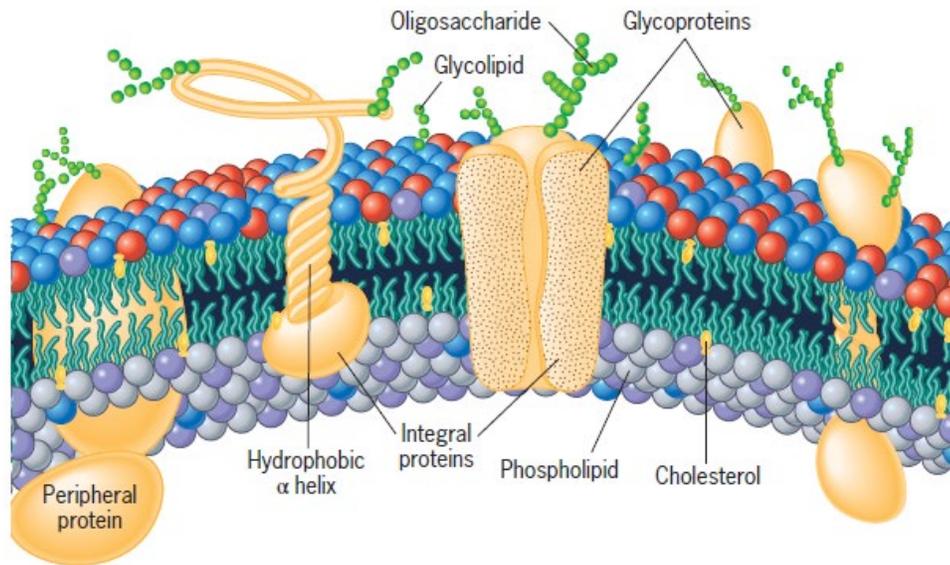
2. The Idea of a Boundary: The Membrane is Inferred (19th Century)

For nearly 200 years, the focus was on the inside of the cell (the protoplasm). The idea of a distinct outer layer was a theoretical necessity before it was a visual reality.

- **1840s: The Naked Cell Problem**

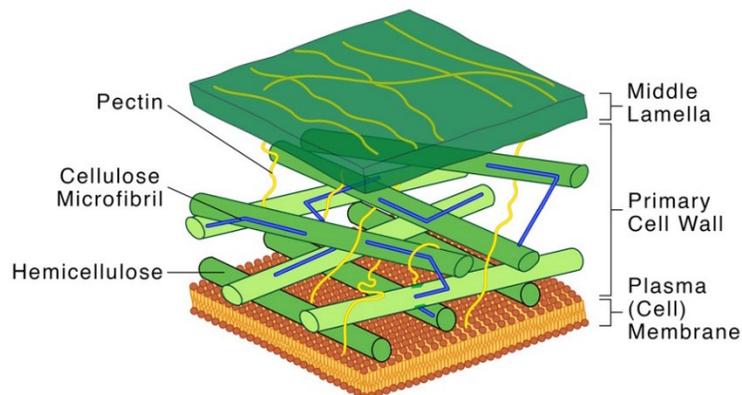
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Plant Cell Walls

- **Primary Cell Wall:** Flexible, thin. Contains **cellulose microfibrils** embedded in a matrix of **hemicellulose**, **pectin**, and structural glycoproteins.
- **Middle Lamella:** Outermost layer, rich in **pectin**, glues adjacent plant cells together.
- **Secondary Cell Wall:** Deposited inside the primary wall in some cells (e.g., xylem vessels, fibers). Contains more cellulose and is impregnated with **lignin** for extreme strength and waterproofing.
- **Plasmodesmata:** Cytoplasmic channels lined with plasma membrane that traverse cell walls, connecting the cytosol of adjacent cells. Contain a central **desmotubule** (derived from ER). Allow transport of water, small solutes, proteins, and even RNA (**symplastic transport**).



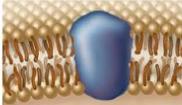
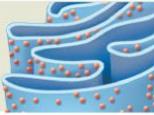
Extracellular Matrix (ECM) of Animal Cells

A complex meshwork secreted by the cells.

- **Components:** **Collagen** (provides tensile strength), **Elastin** (elasticity), **Proteoglycans** (protein cores with long GAG chains; form a hydrated gel resisting compression), **Glycoproteins** (e.g., **Fibronectin**, **Laminin** - facilitate adhesion).
- **Integrins:** Transmembrane receptor proteins. Their extracellular domains bind to ECM components (e.g., fibronectin); their intracellular domains link to the **cytoskeleton** (via **talin**, **vinculin**) and signaling molecules. Mediate **mechanotransduction** (converting mechanical force into biochemical signals) and **outside-in/inside-out signaling**.

Animal vs. Plant Cell

Feature	Animal Cell	Plant Cell
Cell Wall	Absent	Present (Cellulose)
Plastids	Absent	Present (Chloroplasts, etc.)
Centrioles	Present	Absent
Vacuoles	Small, numerous	Single, large central vacuole
Lysosomes	Present	Usually absent
Shape	Irregular, round	Fixed, rectangular
Storage Product	Glycogen	Starch
Mode of Nutrition	Heterotrophic	Autotrophic (primarily)

Structure		Description	Function
Plasma membrane		Phospholipid bilayer with embedded proteins	Regulates what passes into and out of cell; cell-to-cell recognition; connection and adhesion; cell communication
Nucleus		Structure (usually spherical) that contains chromosomes and is surrounded by double membrane	Instructions for protein synthesis and cell reproduction; contains genetic information
Chromosomes		Long threads of DNA that form a complex with protein	Contain hereditary information used to direct synthesis of proteins
Nucleolus		Site of genes for rRNA synthesis	Synthesis of rRNA and ribosome assembly
Ribosomes		Small, complex assemblies of protein and RNA, often bound to ER	Sites of protein synthesis
Endoplasmic reticulum (ER)		Network of internal membranes	Intracellular compartment forms transport vesicles; participates in lipid synthesis and synthesis of membrane or secreted proteins
Golgi apparatus		Stacks of flattened vesicles	Packages proteins for export from cell; forms secretory vesicles
Lysosomes		Vesicles derived from Golgi apparatus that contain hydrolytic digestive enzymes	Digest worn-out organelles and cell debris; digest material taken up by endocytosis

Microbodies		Vesicles that are formed from incorporation of lipids and proteins and that contain oxidative and other enzymes	Isolate particular chemical activities from rest of cell
Mitochondria		Bacteria-like elements with double membrane	"Power plants" of the cell; sites of oxidative metabolism
Chloroplasts		Bacteria-like elements with double membrane surrounding a third, thylakoid membrane containing chlorophyll, a photosynthetic pigment	Sites of photosynthesis
Cytoskeleton		Network of protein filaments	Structural support; cell movement; movement of vesicles within cells
Flagella (cilia)		Cellular extensions with 9 + 2 arrangement of pairs of microtubules	Motility or moving fluids over surfaces
Cell wall		Outer layer of cellulose or chitin; or absent	Protection; support

Practice MCQs

1. Which scientist first coined the term "cell" after observing cork under a microscope?

- A) Anton van Leeuwenhoek
- B) Robert Brown
- C) Matthias Schleiden
- D) Robert Hooke

Answer: Robert Hooke

2. The principle "Omnis cellula e cellula" (all cells come from cells) was proposed by:

- A) Rudolf Virchow
- B) Louis Pasteur
- C) Theodor Schwann
- D) August Weismann

Answer: Rudolf Virchow

3. Which of the following is NOT a tenet of modern cell theory?

- A) All living organisms are composed of one or more cells.
- B) All cells arise from pre-existing cells.
- C) All cells contain a membrane-bound nucleus.
- D) Cells contain hereditary material (DNA) passed to daughter cells.

Answer: All cells contain a membrane-bound nucleus.

4. The maximum theoretical resolution of a standard light microscope is approximately:

- A) 0.2 nm
- B) 200 nm
- C) 2 μ m
- D) 0.2 μ m

Answer: 200 nm

5. Which microscopy technique enhances contrast in unstained, living cells by converting differences in refractive index into brightness variations?

- A) Bright-field microscopy
- B) Dark-field microscopy
- C) Phase-contrast microscopy
- D) Fluorescence microscopy

Answer: Phase-contrast microscopy

6. Transmission Electron Microscopy (TEM) is primarily used to study:

- A) Surface topography of specimens
- B) Internal ultrastructure of thin sections
- C) Living cellular processes
- D) Fluorescently tagged proteins

Answer: Internal ultrastructure of thin sections

7. Cryo-electron microscopy (cryo-EM) is notable for:

- A) Using heavy metal stains to enhance contrast
- B) Visualizing specimens in a near-native, hydrated state



Chapter 2

Biological Membranes

Biological membranes are dynamic, selectively permeable barriers that form the boundary of all cells (**plasma membrane**) and internal organelles. They are fundamental to cellular life, enabling:

- **Compartmentalization** and maintenance of distinct internal environments.
- **Regulation of molecular traffic** in and out of the cell/organelle.
- **Communication** via signal transduction.
- **Surface for biochemical reactions** (e.g., electron transport chain, photosynthesis).

Evolutionary Significance: The emergence of lipid membranes was a critical step in the origin of life, allowing protocells to maintain chemical gradients and perform metabolic functions.

Membrane Structure: The Fluid Mosaic Model

Historical Development of Membrane Models

- **Danielli-Davson Sandwich Model (1935):** Proposed a lipid bilayer coated on both sides by a layer of globular proteins. Incorrect—proteins were shown to be embedded.
- **Singer-Nicolson Fluid Mosaic Model (1972):** The accepted model describing the membrane as a **fluid lipid bilayer** with a **mosaic of proteins** embedded or attached.

Key Principles of the Fluid Mosaic Model

1. **Lipid Bilayer as a Fluid Matrix:**
 - Phospholipids move laterally within their own leaflet (~10⁷ times per second).
 - **Flip-flop** (transverse movement between leaflets) is slow (half-life of weeks) and requires enzymes (**flippases, floppases**).
2. **Protein Mosaic:**
 - Proteins are embedded (**integral**) or peripherally attached.
 - They exhibit **lateral mobility**, though often restricted by cytoskeletal fences or lipid domain associations.
3. **Membrane Asymmetry:**
 - The two leaflets differ in lipid, protein, and carbohydrate composition.
4. **Selective Permeability:**
 - Governed by the hydrophobic interior and specific transport proteins.

Supporting Evidence:

- **Freeze-Fracture Electron Microscopy:** Reveals intramembrane particles (integral proteins) within the bilayer plane.
- **Fluorescence Recovery After Photobleaching (FRAP):** Demonstrates lateral mobility of lipids and proteins.

Membrane Lipids: The Fluid Foundation

Lipids form the matrix of the membrane and are diverse in composition.

Lipid Type	Key Features	Example & Role
Glycerophospholipids	Most diverse class; glycerol backbone with two fatty acid tails and a phosphate-linked head group.	Phosphatidylcholine (PC): Major outer leaflet component. Phosphatidylserine (PS): Inner leaflet; externalization signals apoptosis.
Sphingolipids	Built on a sphingosine backbone; often have saturated chains.	Sphingomyelin: Enriched in myelin sheaths and lipid rafts . Gangliosides: Cell recognition in neural tissues.

2. Biological Membranes

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Sterols	Rigid planar molecules that modulate membrane properties.	Cholesterol (animals): Acts as a " fluidity buffer ", increasing packing order and mechanical strength. Plant cells use other sterols (e.g., sitosterol).
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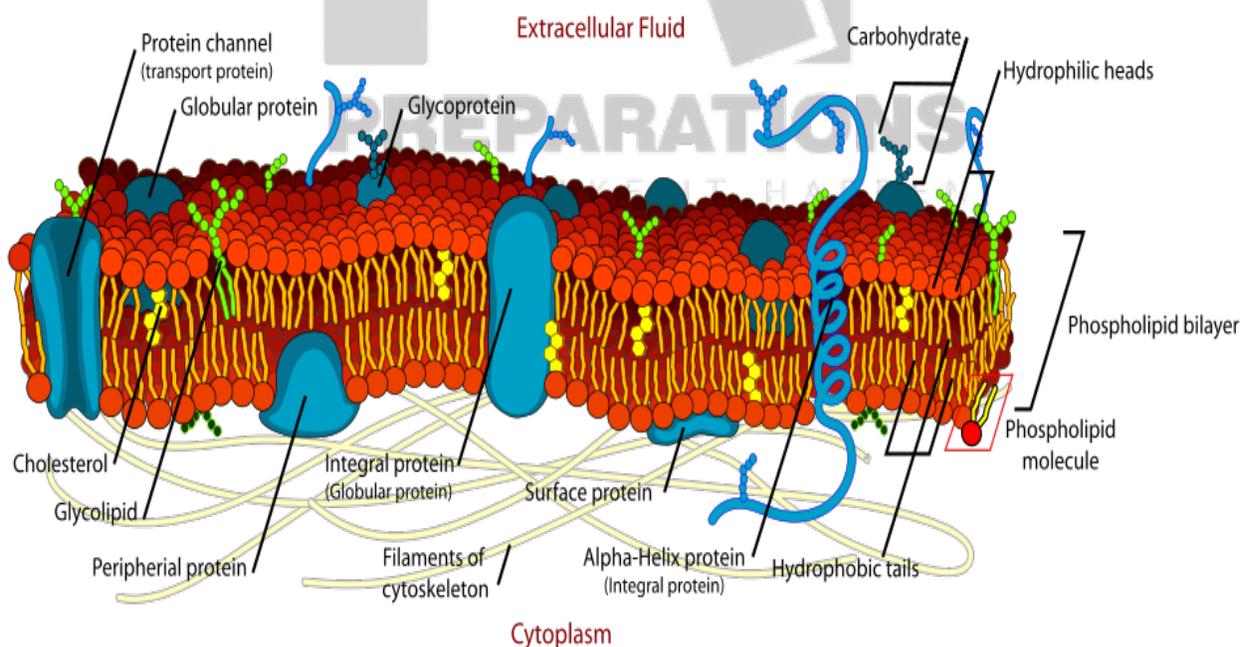
Factors Affecting Membrane Fluidity

Fluidity is crucial for protein function, permeability, and membrane trafficking.

Factor	Effect on Fluidity	Mechanism & Adaptation
Fatty Acid Saturation	Unsaturated tails INCREASE fluidity. Saturated tails DECREASE fluidity.	Kinks from <i>cis</i> double bonds prevent tight packing. Cold-adapted organisms (e.g., arctic fish) increase unsaturated lipid content.
Cholesterol Content	Acts as a " fluidity buffer ".	At high temps: Restricts phospholipid movement, reducing fluidity . At low temps: Prevents tight packing, hindering solidification .
Temperature	Increases with higher temperature.	Thermal energy increases molecular motion. Organisms undergo homeoviscous adaptation (alter lipid composition to maintain optimal fluidity).
Fatty Acid Chain Length	Shorter chains increase fluidity.	Reduced hydrophobic interactions between shorter tails.

Membrane Proteins: The Functional Workforce

Proteins are responsible for most specialized membrane functions and are asymmetrically distributed.



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Practice MCQs

1. What is the primary function of the plasma membrane in a cell?

- A) ATP synthesis
- B) Protein synthesis
- C) Compartmentalization and regulation of molecular traffic
- D) DNA replication

Answer: Compartmentalization and regulation of molecular traffic

2. Who proposed the Fluid Mosaic Model of membrane structure?

- A) Watson and Crick
- B) Danielli and Davson
- C) Singer and Nicolson
- D) Frye and Edidin

Answer: Singer and Nicolson

3. Which type of lipid acts as a 'fluidity buffer' in animal cell membranes?

- A) Phosphatidylcholine
- B) Cholesterol
- C) Sphingomyelin
- D) Phosphatidylserine

Answer: Cholesterol

4. What is the term for the movement of a phospholipid from one leaflet to the opposite leaflet of the bilayer?

- A) Lateral diffusion
- B) Rotation
- C) Flip-flop
- D) Swaying

Answer: Flip-flop

5. Which membrane proteins are firmly embedded in the hydrophobic core and require detergents for extraction?

- A) Peripheral proteins
- B) Lipid-anchored proteins
- C) Integral proteins
- D) Glycoproteins

Answer: Integral proteins

6. The carbohydrate-rich coating on the extracellular surface of the plasma membrane is called the:

- A) Cell wall

- B) Glycocalyx

- C) Cortex

- D) Capsule

Answer: Glycocalyx

7. Which factor increases membrane fluidity?

- A) Long, saturated fatty acid chains

- B) High cholesterol content at high temperatures

- C) Short, unsaturated fatty acid chains

- D) Low temperature

Answer: Short, unsaturated fatty acid chains

8. What is the primary role of aquaporins?

- A) Active transport of ions

- B) Facilitated diffusion of glucose

- C) Passive transport of water

- D) Endocytosis

Answer: Passive transport of water

9. In osmosis, water moves across a selectively permeable membrane from an area of:

- A) Lower solute concentration to higher solute concentration

- B) Higher solute concentration to lower solute concentration

- C) Lower free water concentration to higher free water concentration

- D) Higher pressure to lower pressure

Answer: Lower solute concentration to higher solute concentration

10. A red blood cell placed in a hypertonic solution will:

- A) Swell and burst

- B) Remain the same size

- C) Shrink or crenate

- D) Become turgid

Answer: Shrink or crenate

11. What is the immediate source of energy for primary active transport?

- A) Proton gradient

- B) Sodium gradient

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2. Biological Membranes

Chapter 3

Cell Division

Cell division is the fundamental process where a parent cell divides into two or more daughter cells.

Essential for:

- **Growth & Development**
- **Tissue Repair & Renewal**
- **Reproduction** (asexual & sexual)

Two main types in eukaryotes:

- **Mitosis:** Produces genetically identical somatic cells
- **Meiosis:** Produces genetically diverse gametes

Eukaryotic Chromosome Structure & Packaging

Chromosome Composition

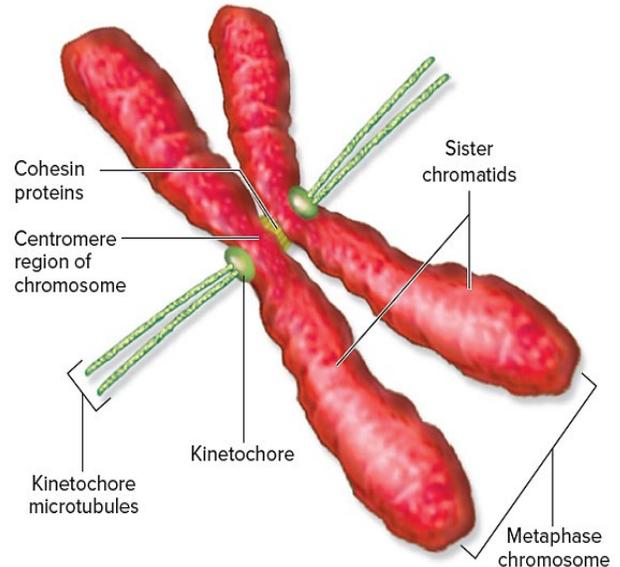
- Made of **chromatin** = DNA + proteins (histones & non-histones)
- **Histones** (H2A, H2B, H3, H4): Positively charged proteins for DNA wrapping
- **Non-histone proteins:** Structural & regulatory functions

Levels of Chromatin Packaging

Level	Structure	Description
1°	Nucleosome	146 bp DNA wrapped around histone octamer (2 each: H2A, H2B, H3, H4)
2°	30-nm Fiber	Nucleosomes packed with linker histone H1
3°	Looped Domains	30-nm fibers form loops attached to protein scaffold
4°	Metaphase Chromosome	Maximum condensation via condensin proteins

Chromosome Terminology

- **Diploid (2n):** Two sets of chromosomes (human somatic cells: 2n=46)
- **Haploid (n):** One set of chromosomes (human gametes: n=23)
- **Homologous Chromosomes:** Paired chromosomes (one maternal, one paternal) with same genes at same loci
- **Sister Chromatids:** Two identical copies of a chromosome after S phase, held by **cohesin**
- **Centromere:** Constricted region where sister chromatids attach
- **Kinetochores:** Protein complex on centromere for microtubule attachment
- **Telomeres:** Repetitive DNA sequences at chromosome ends, prevent degradation



The Cell Cycle: Phases & Regulation

Cell Cycle Overview

Cyclic process between end of one division and beginning of next:

INTERPHASE (90% of cycle)

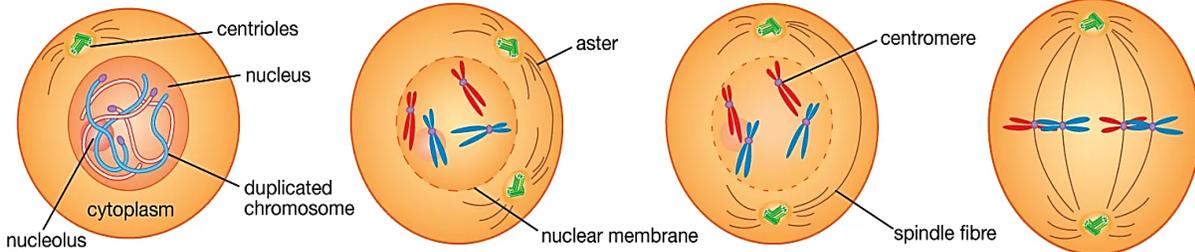
- The cell cycle is the **ordered series of events** that leads to **cell growth and division** into two daughter cells.
- It ensures **faithful duplication of genetic material (DNA)** and **equal partitioning** into daughter cells.
- **Two main phases:**

Telophase

Chromosomes decondense, nuclear envelope reforms, nucleolus reappears

Spindle disassembles

Mitosis, or somatic cell division

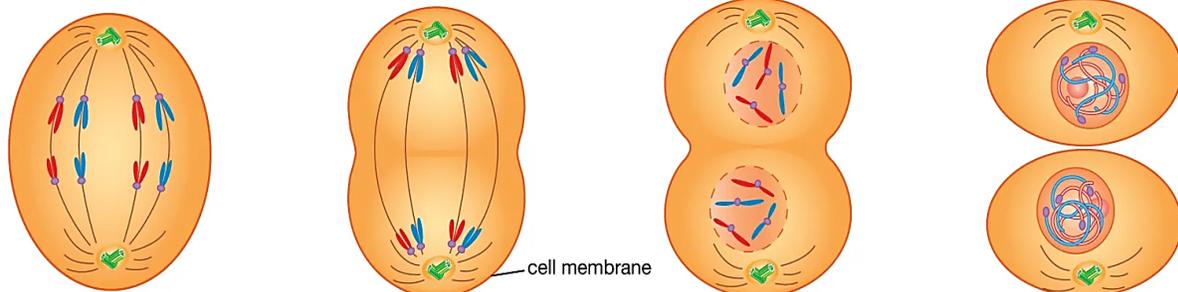


Prior to mitosis, each chromosome makes an exact duplicate of itself. The chromosomes then thicken and coil.

In early prophase the centrioles, which have divided, form asters and move apart. The nuclear membrane begins to disintegrate.

In late prophase the centrioles and asters are at opposite poles. The nucleolus and nuclear membrane have almost completely disappeared.

The doubled chromosomes—their centromeres attached to the spindle fibres—line up at mid-cell in metaphase.



In early anaphase the centromeres split. Half the chromosomes move to one pole, half to the other pole.

In late anaphase the chromosomes have almost reached their respective poles. The cell membrane begins to pinch at the centre.

The cell membrane completes constriction in telophase. Nuclear membranes form around the separated chromosomes.

At mitosis completion, there are two cells with the same structures and number of chromosomes as the parent cell.

Meiosis: Reduction Division

Unique Features of Meiosis

- **Two divisions** (Meiosis I & II) with **one DNA replication**
- **Genetic variation** via:
 1. Crossing Over (Prophase I)
 2. Independent Assortment (Metaphase I)
 3. Random Fertilization

Meiosis is a special type of cell division that reduces the chromosome number by half ($2n \rightarrow n$) and produces four genetically different haploid cells. It is essential for sexual reproduction and formation of gametes.

Meiosis consists of two successive divisions:

1. Meiosis I – Reductional division
2. Meiosis II – Equational division

MEIOSIS I (Reduction Division)

Chromosome number is reduced from diploid ($2n$) to haploid (n).

1. Prophase I (Longest and Most Complex Stage)

Divided into five substages:

Leptotene

- Chromosomes become visible as thin threads.
- Each chromosome consists of two sister chromatids (replicated during S-phase).
- Chromosomes begin condensation.

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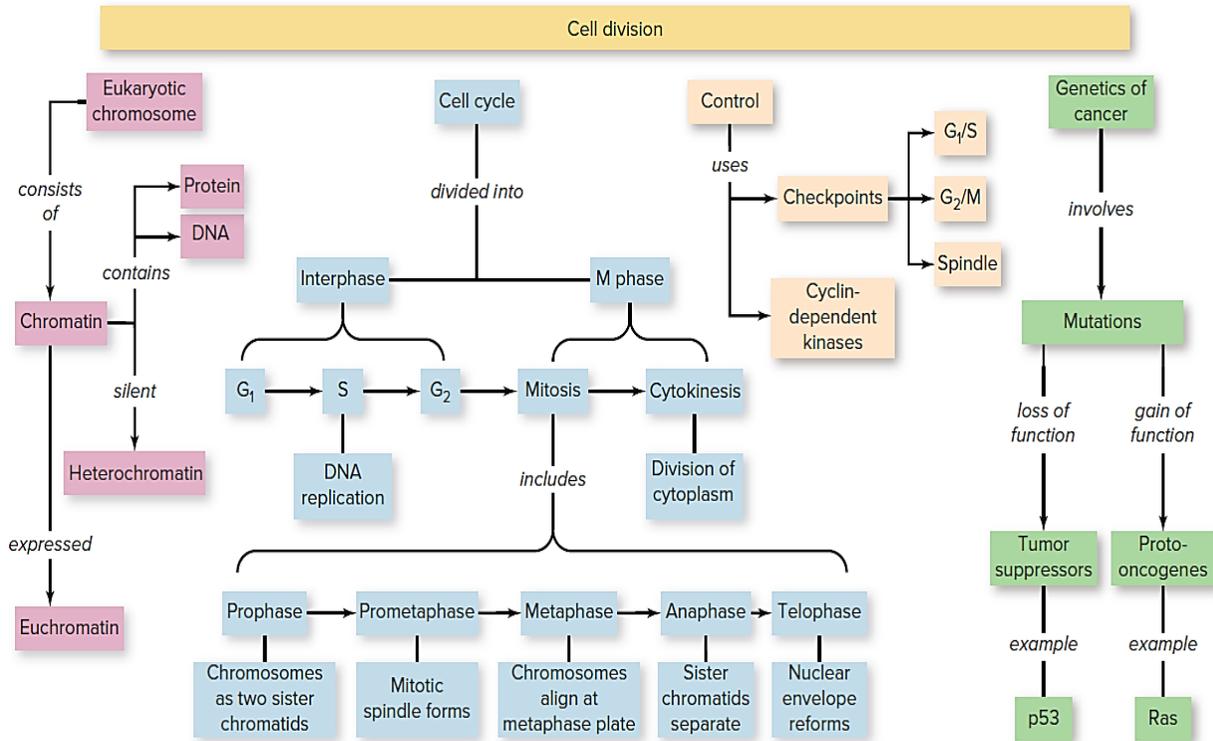
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3. Cell Division

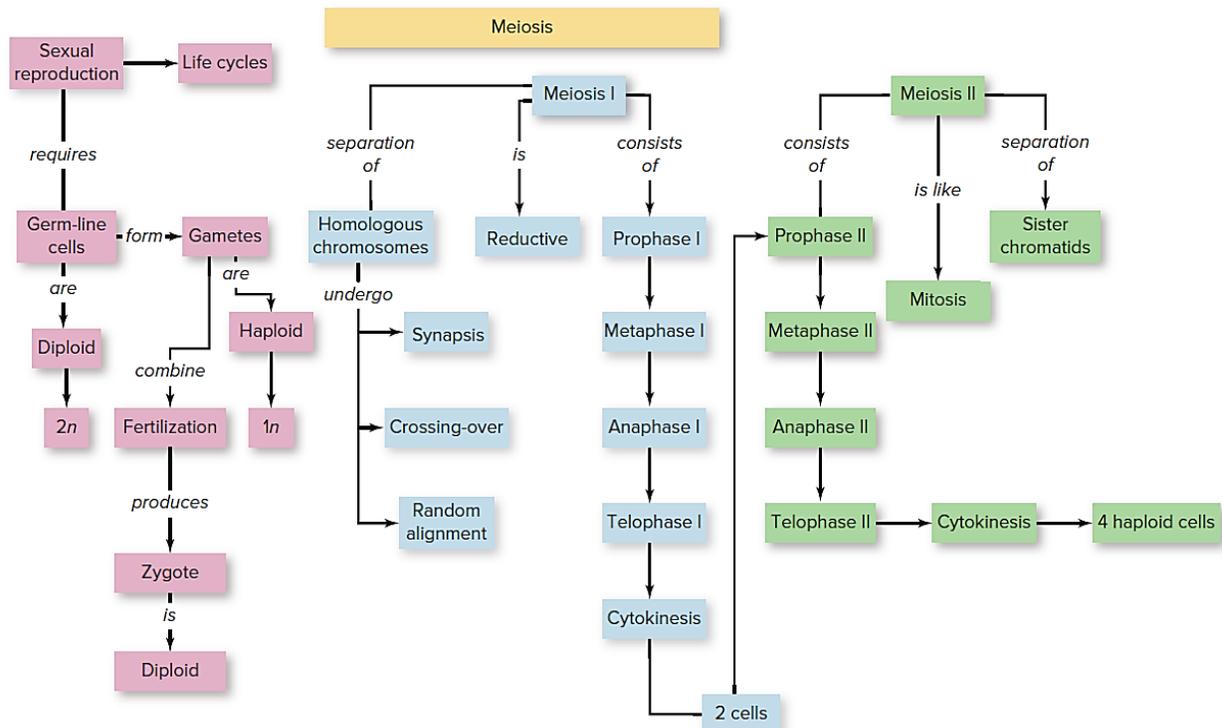
Down Syndrome	Meiotic nondisjunction	Trisomy 21	1:700	ID, flat face, epic. fold, heart defects
Edwards Syndrome	Meiotic nondisjunction	Trisomy 18	1:5000	Clenched fists, rocker-bottom feet
Triploidy	Fertilization error	3n	1-3% pregnancies	Large placenta, multiple anomalies
Microdeletion Syndromes	Unequal crossing over	e.g., 22q11.2	Variable	DiGeorge, velocardiofacial syndrome

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3. Cell Division



LET'S MAKE IT HAPPEN



3. Cell Division

Cell Cycle: One Liners

- The ordered sequence of events from one cell division to the next is the **cell cycle**.
- The **mitotic (M) phase** alternates with the much longer **interphase**.
- **Interphase** accounts for about 90% of the cell cycle and is a period of growth and preparation.
- Interphase is divided into the **G₁ phase** (first gap, cell growth), **S phase** (synthesis, DNA replication), and **G₂ phase** (second gap, preparation for division).
- The **M phase** includes **mitosis** (nuclear division) and **cytokinesis** (cytoplasmic division).
- Cells that are not dividing exit the cycle into a nondividing state called the **G₀ phase**.
- In humans, the entire cell cycle may take about 24 hours, with M phase lasting less than an hour.
- The **S phase** may occupy 10-12 hours, while **G₁** is typically the most variable in length.
- A cell's DNA is called its **genome**; eukaryotic genomes consist of multiple DNA molecules.
- DNA is packaged with proteins into structures called **chromosomes**.
- The entire complex of DNA and proteins is called **chromatin**.
- Each eukaryotic species has a characteristic number of chromosomes in its somatic cells.
- **Human somatic cells** are **diploid (2n)**, with **46 chromosomes** (two sets of 23).
- **Human gametes** are **haploid (n)**, with **23 chromosomes** (one set).
- The two chromosomes of a pair are called **homologous chromosomes (homologs)**; one from each parent.
- **Sex chromosomes** (X and Y) determine sex; the others are **autosomes**.
- Before division, each chromosome is **duplicated** and consists of two identical **sister chromatids**.
- Sister chromatids are joined copies of the original chromosome, held together by **cohesin** proteins.
- The region where sister chromatids are most closely attached is the **centromere**.
- A **kinetochore** is a protein structure that assembles on the centromere and attaches to spindle microtubules.
- When sister chromatids separate, they are considered individual **daughter chromosomes**.

Practice MCQs

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1. What is the primary purpose of mitosis in multicellular organisms?

- A) To produce genetically diverse gametes
- B) To reduce the chromosome number by half
- C) To promote growth, tissue repair, and asexual reproduction
- D) To allow for genetic recombination through crossing over

Answer: To promote growth, tissue repair, and asexual reproduction

2. During which phase of the cell cycle does DNA replication occur?

- A) G₁ phase
- B) G₂ phase
- C) M phase
- D) S phase

Answer: S phase

3. Which protein forms a contractile ring during cytokinesis in animal cells?

- A) Tubulin
- B) Actin
- C) Keratin
- D) Collagen

Answer: Actin

4. What is the term for the paired maternal and paternal chromosomes that carry the same genes?

- A) Sister chromatids
- B) Homologous chromosomes
- C) Sex chromosomes
- D) Recombinant chromosomes

Answer: Homologous chromosomes

5. The point of constriction on a chromosome that holds sister chromatids together is called the:

- A) Kinetochore
- B) Telomere
- C) Centromere
- D) Centrosome

Answer: Centromere

6. Which of the following is a key feature of prophase I of meiosis that does NOT

occur in mitosis?

- A) Chromosome condensation
- B) Breakdown of the nuclear envelope
- C) Synapsis and crossing over
- D) Formation of the mitotic spindle

Answer: Synapsis and crossing over

7. What is the haploid (n) number of chromosomes in a human somatic cell?

- A) 23
- B) 46
- C) 92
- D) 2

Answer: 23

8. The enzyme that adds DNA sequences to telomeres to counteract shortening is:

- A) DNA polymerase
- B) Telomerase
- C) Ligase
- D) Primase

Answer: Telomerase

9. Which checkpoint ensures that all chromosomes are properly attached to the spindle before anaphase?

- A) G₁/S checkpoint
- B) G₂/M checkpoint
- C) Spindle assembly checkpoint
- D) Post-replication checkpoint

Answer: Spindle assembly checkpoint

10. What is the correct order of the mitotic phases?

- A) Prophase, Metaphase, Anaphase, Telophase, Prometaphase
- B) Prophase, Prometaphase, Metaphase, Anaphase, Telophase
- C) Interphase, Prophase, Metaphase, Anaphase, Telophase
- D) Prophase, Anaphase, Metaphase, Telophase, Cytokinesis

Answer: Prophase, Prometaphase, Metaphase, Anaphase, Telophase

11. Binary fission in bacteria is most similar to which eukaryotic process?

- A) Mitosis

Chapter 4

Nucleic Acids and Chromosomes

Nucleic Acids

Nucleic acids are large, complex macromolecules that are essential for all known forms of life. They are biopolymers composed of repeating monomeric units called **nucleotides**. Their primary function is to store, transmit, and express genetic information.

Types of Nucleic Acids

There are two main types of nucleic acids, which differ in their structure, sugar component, and specific roles within the cell:

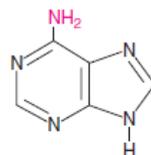
Feature	DNA (Deoxyribonucleic Acid)	RNA (Ribonucleic Acid)
Full Name	Deoxyribonucleic Acid	Ribonucleic Acid
Sugar	Deoxyribose	Ribose
Bases	Adenine (A), Guanine (G), Cytosine (C), Thymine (T)	Adenine (A), Guanine (G), Cytosine (C), Uracil (U)
Structure	Typically double-stranded (double helix)	Typically single-stranded (but can fold)
Stability	More chemically stable	Less chemically stable
Primary Role	Long-term storage of genetic blueprints; hereditary material	Involved in the process of decoding DNA into proteins; various functional roles

- **DNA** serves as the permanent, archival repository of genetic instructions for an organism's development, functioning, and reproduction. It is located in the cell nucleus (and mitochondria/chloroplasts).
- **RNA** acts as a messenger and helper molecule, carrying out the instructions encoded in DNA. It is involved in protein synthesis (gene expression) and has other regulatory and catalytic functions.

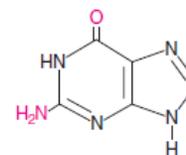
Structure of Nucleotides

The nucleotide is the fundamental building block of all nucleic acids. Each nucleotide consists of three components:

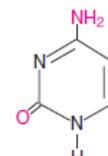
1. **A Pentose Sugar:** This is a 5-carbon sugar.
 - In **DNA**, the sugar is **deoxyribose** (lacks an oxygen atom on the 2' carbon).
 - In **RNA**, the sugar is **ribose** (has a hydroxyl group on the 2' carbon).
2. **A Phosphate Group:** A phosphorus atom bonded to four oxygen atoms. This group is attached to the 5' carbon of the sugar. The phosphate group gives nucleic acids their acidic character and allows nucleotides to link together via **phosphodiester bonds**.
3. **A Nitrogenous Base:** A nitrogen-containing molecule attached to the 1' carbon of the sugar. There are two categories of bases:
 - **Purines** (double-ring structures): **Adenine (A)** and **Guanine (G)**.
 - **Pyrimidines** (single-ring structures): **Cytosine (C)**, **Thymine (T)** (found only in DNA), and **Uracil (U)** (found only in RNA).



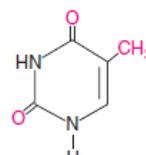
Adenine (A)
(6-aminopurine)



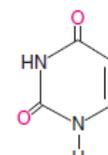
Guanine (G)
(2-amino 6-oxypurine)



Cytosine (C)
(2-oxo 4-aminopyrimidine)



Thymine (T)
(2,4-dioxo-5 methylpyrimidine)



Uracil (U)
(2,4-dioxypyrimidine)

Formation of a Nucleic Acid Strand: Nucleotides link together via **phosphodiester bonds**, which form between the



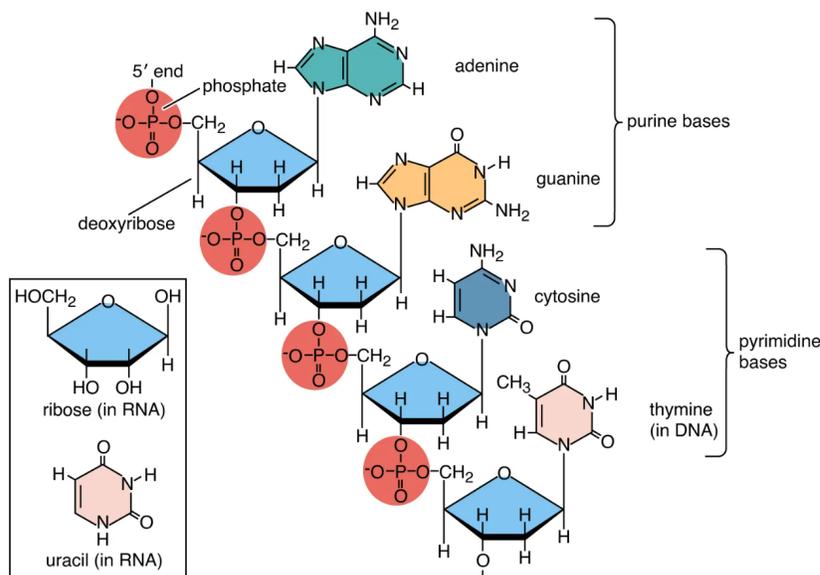
		alternating purines/pyrimidines (e.g., GCGCGC).	
Based on Functional Role	Coding DNA	Sequences of genes that are transcribed into mRNA and ultimately translated into amino acid sequences (proteins).	Makes up a small percentage of the genome (~1-2% in humans). Directly determines an organism's traits via proteins.
	Non-Coding DNA	Sequences that are not translated into proteins. Includes a variety of functional and non-functional elements.	Comprises the vast majority of eukaryotic genomes. Includes regulatory sequences, introns, and repetitive DNA.
	Regulatory DNA	A subset of non-coding DNA that controls gene expression (e.g., promoters, enhancers, silencers).	Acts as binding sites for transcription factors and other proteins to turn genes on/off.
Based on Sequence & Location in Genome	Unique (Single-Copy) DNA	Sequences that appear only once or a few times in the genome. Includes most protein-coding genes.	Forms the basis of genetic individuality and codes for most functional products.
	Repetitive DNA	Sequences repeated hundreds to millions of times throughout the genome. Two main classes:	Involved in chromosome structure, evolution, and some diseases.
	• Tandem Repeats	Short sequences repeated head-to-tail in clusters (e.g., satellite, minisatellite, microsatellite DNA).	Satellite DNA: Found at centromeres & telomeres (structural). Microsatellites: Used in DNA fingerprinting.
	• Interspersed Repeats	Repeated sequences scattered across the genome, derived from transposable elements (e.g., SINEs like <i>Alu</i> , LINEs).	Makes up a large fraction of mammalian genomes (~45% in humans). Can influence gene expression and genome evolution.
Based on Cellular Location	Nuclear DNA (nDNA)	DNA enclosed within the cell nucleus. Organized into linear chromosomes and complexed with histones into chromatin.	Contains the vast majority of an organism's genetic material. Inherited from both parents (biparental inheritance).

- Contains the **exit tunnel** for the nascent polypeptide.

Key Features:

- **Extensive Secondary/Tertiary Structure:** rRNA is highly folded with numerous stem-loops, creating precise 3D scaffolds.
- **Ribozymatic Activity:** The **peptidyl transferase** reaction (forming the peptide bond) is catalyzed by the rRNA itself, not the ribosomal proteins.
- **Ribosome Assembly:** rRNAs act as a "backbone" around which ribosomal proteins assemble. The three-dimensional structure creates distinct functional sites: **A site** (aminoacyl-tRNA binding), **P site** (peptidyl-tRNA binding), **E site** (exit).

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4. Nucleic Acids and Chromosomes

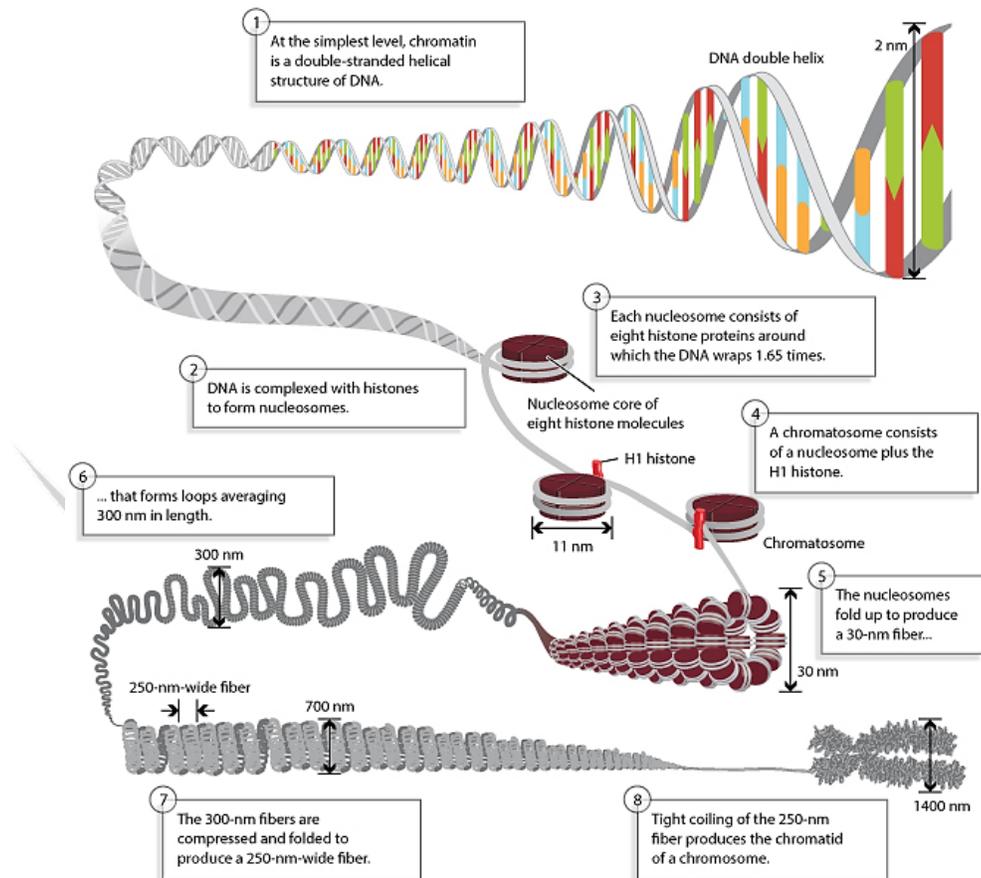
III. Other Crucial Functional RNAs

Type	Full Name	Size & Structure	Primary Function
snRNA	Small Nuclear RNA	100-200 nt; complex with proteins to form snRNPs ("snurps").	Key components of the spliceosome ; catalyze the removal of introns from pre-mRNA in eukaryotes.
snoRNA	Small Nucleolar RNA	60-300 nt; found in the nucleolus.	Guide the chemical modification (e.g., methylation, pseudouridylation) of other RNAs, primarily rRNAs and tRNAs.
miRNA	MicroRNA	~22 nt; form imperfect duplexes with target mRNA.	Gene regulation. Bind to complementary sequences in the 3'UTR of target mRNAs, leading to translational repression or mRNA degradation.
siRNA	Small Interfering RNA	~21-23 nt; form perfect duplexes.	Gene silencing. Derived from long double-stranded RNA, they guide the RISC complex to cleave complementary viral or transposon mRNA. Also used in RNAi technology.

- **Melting temperature (T_m):** Dependent on G-C content (higher G-C = higher T_m).
- **Renaturation (annealing/ hybridization):** Complementary strands reassociate.
 - **Applications:** Southern blot, PCR, DNA microarray, FISH.

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4. Nucleic Acids and Chromosomes

CHROMOSOMES: STRUCTURE, CLASSIFICATION AND FUNCTION

Historical Background and Composition

- **Walther Flemming (1882):** First described chromatin in salamander cells.
- **Heinrich Waldeyer (1888):** Coined term "chromosome."
- **Composition:** DNA (30-40%), histones (30-40%), non-histone proteins (20-30%), RNA (<10%).

General Morphology of Metaphase Chromosome

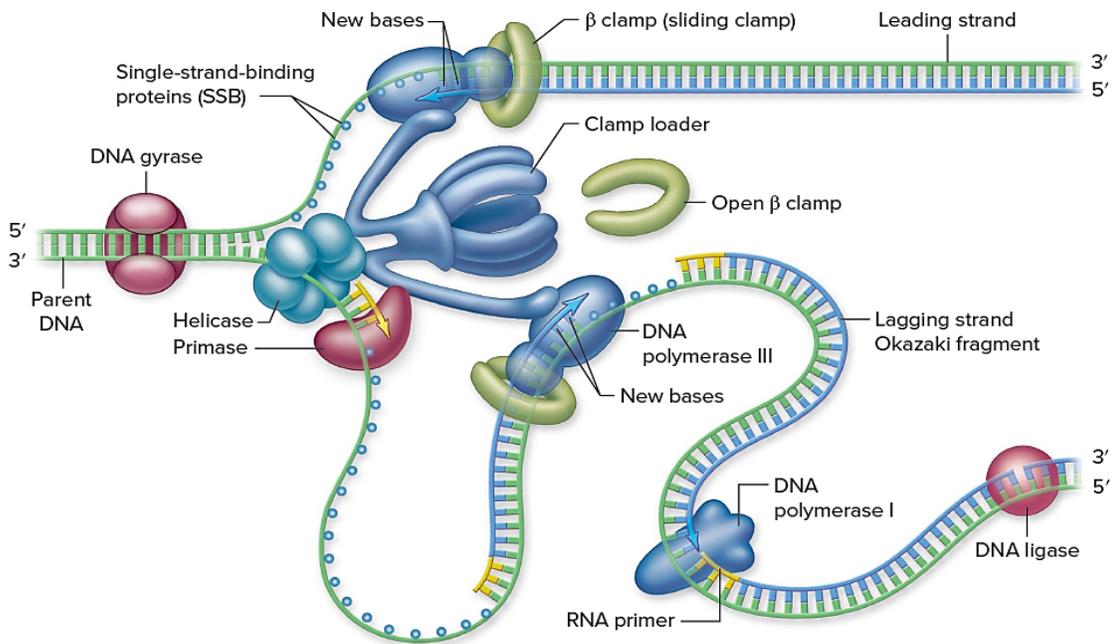
- **Sister chromatids:** Two identical copies held at centromere.
- **Centromere (primary constriction):** Kinetochore assembly site.
- **Chromosome arms:** p (short) and q (long) arms.
- **Secondary constriction:** Often associated with **NOR** (nucleolar organizer region).
- **Satellite:** Terminal segment beyond secondary constriction.
- **Telomeres:** Terminal TTAGGG repeats + shelterin complex.

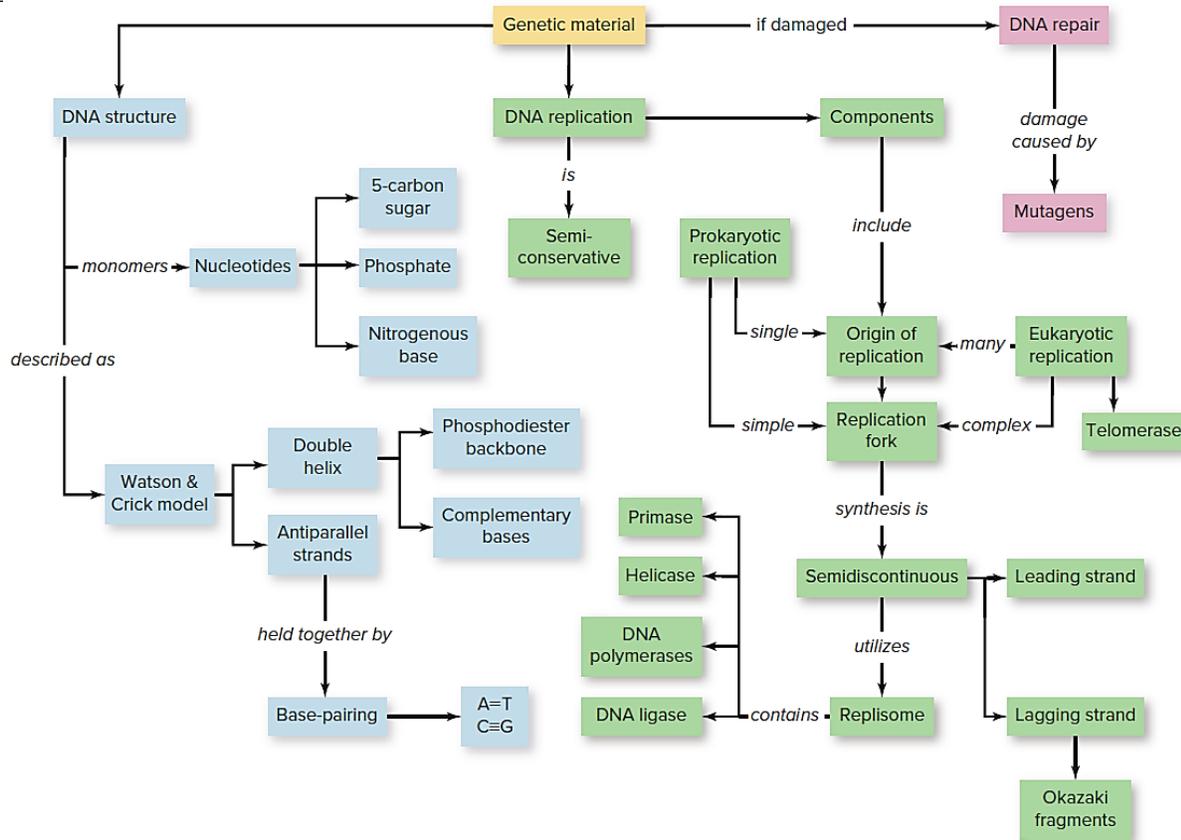
Chromosome Classification

Based on Centromere Position:

Type	Centromere	Arm Ratio	Anaphase Shape	Examples in Humans
Metacentric	Median	1:1	V-shaped	Chromosomes 1, 3, 16, 19, 20

Replisome Organization	Single, large complex. Dimeric Pol III synthesizes both strands simultaneously via a looping lagging strand.	More complex and less understood. Lik involves separate but coordinated polymerases for each strand.
Sliding Clamp	β_2 clamp (homodimer).	Proliferating Cell Nuclear Antigen (PCNA) (homotrimer).
Clamp Loader	γ complex .	Replication Factor C (RFC) complex.
End-Replication Problem	Not applicable (circular chromosome).	Present due to linear chromosomes.
Solution to End Problem	N/A.	Telomeres & Telomerase. Telomerase adds repeats to the 3' overhang in specific cells.
Chromatin Handling	Not applicable (no nucleosomes).	Major challenge. Histones are disassembled ahead of the fork and reassembled behind it, involving chaperones (FACT, CAF-1) and histone recycling.
Cell Cycle Coordination	Replication initiation is the key regulated event for cell division.	Tightly integrated into cell cycle phases . Origins are licensed in G1 and fired throughout S-phase in a regulated order.
Primary Regulatory Protein	DnaA protein binds OriC to initiate replication.	Origin Recognition Complex (ORC) binds origins to license them. Activation involves CDKs and DDK kinases.





TRANSCRIPTION: DNA-DIRECTED RNA SYNTHESIS

Transcription is the **enzyme-catalyzed process** by which the **nucleotide sequence of a gene** on the DNA template strand is copied into a complementary **RNA molecule** (mRNA, tRNA, rRNA, or other non-coding RNA). It is the **first step of gene expression**, where specific genetic information is selected and made accessible for translation or functional use.

Central Dogma of Molecular Biology

The fundamental principle describing the flow of genetic information:

DNA → RNA → Protein

- **Transcription** accomplishes the **DNA → RNA** step.
- **Translation** (protein synthesis) accomplishes the **RNA → Protein** step.
- **Important Notes:** The dogma is unidirectional under normal cellular conditions (information does not flow from protein back to RNA or DNA). Exceptions exist (e.g., reverse transcription in retroviruses: **RNA → DNA**).

Role of Transcription in Gene Expression

- **Primary Control Point:** Transcription is the **most critical and highly regulated** stage in determining when, where, and how much of a gene product is made. Regulation occurs through transcription factors, promoters, and enhancers.
- **Selective Activation:** In any given cell, only a specific subset of genes is transcribed, defining the cell's identity and function (e.g., insulin is transcribed in pancreatic β-cells but not in neurons).
- **Amplification:** A single gene can be transcribed repeatedly, producing many RNA copies, which allows for efficient protein synthesis.

2. Basic Features of Transcription

Template Strand vs. Coding Strand (Sense/Antisense Strands)

MK PREPARATIONS: Let's Make It Happen

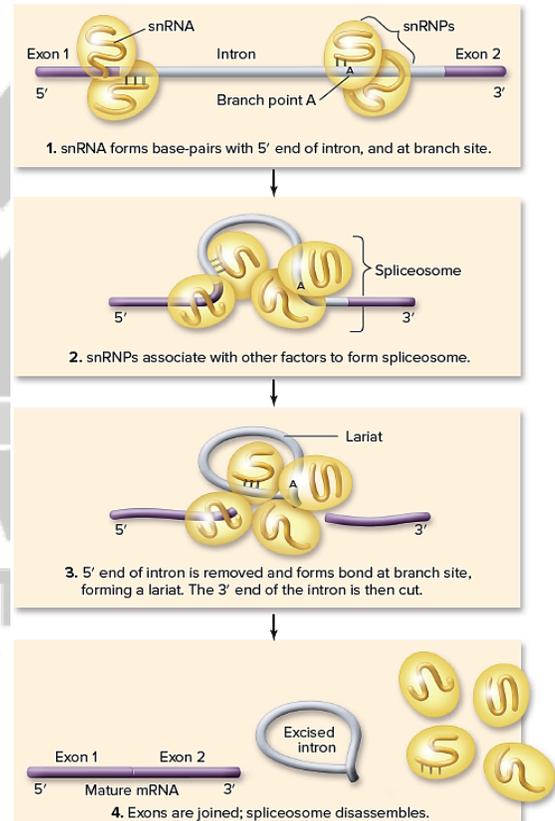
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- **Branch Point:** An adenine (A) residue ~20-50 nucleotides upstream of the 3' splice site.
- **Two-Step Transesterification:**
 1. The **2'-OH of the branch point A** attacks the 5' splice site, cutting it and forming a **lariat structure**.
 2. The newly freed **3'-OH of the 5' exon** attacks the 3' splice site, joining the exons and releasing the intron lariat (later degraded).
- **Importance:** Enables **alternative splicing**, where different combinations of exons are joined, allowing **one gene to produce multiple protein variants (isoforms)**, vastly increasing proteomic diversity.

10. Regulation of Transcription

Operon Model (Lac Operon)

- **Concept (Prokaryotes):** An **operon** is a cluster of functionally related genes under the control of a single promoter, transcribed into a **polycistronic mRNA**. It allows coordinated regulation.
- **Lac Operon (Inducible System):** Controls genes for lactose metabolism.
 - **Genes:** *lacZ* (β -galactosidase), *lacY* (permease), *lacA* (transacetylase).
 - **Regulatory Elements:**
 - **Promoter (P):** Binding site for RNA polymerase.
 - **Operator (O):** Binding site for the **repressor protein**.
 - ***lacI* Gene:** Encodes the **Lac repressor** (constitutively expressed).
 - **Mechanism:**
 - **No Lactose:** Repressor binds the operator, **blocks transcription**.
 - **Lactose Present:** The inducer **allolactose** binds the repressor, causing a conformational change that **prevents it from binding the operator**. Transcription proceeds.
 - **Additional Layer (Catabolite Repression):** When glucose (preferred carbon source) is low, **cAMP levels are high**. cAMP binds **CAP (Catabolite Activator Protein)**, which binds upstream of the promoter and **strongly activates transcription** (only if repressor is also inactivated).

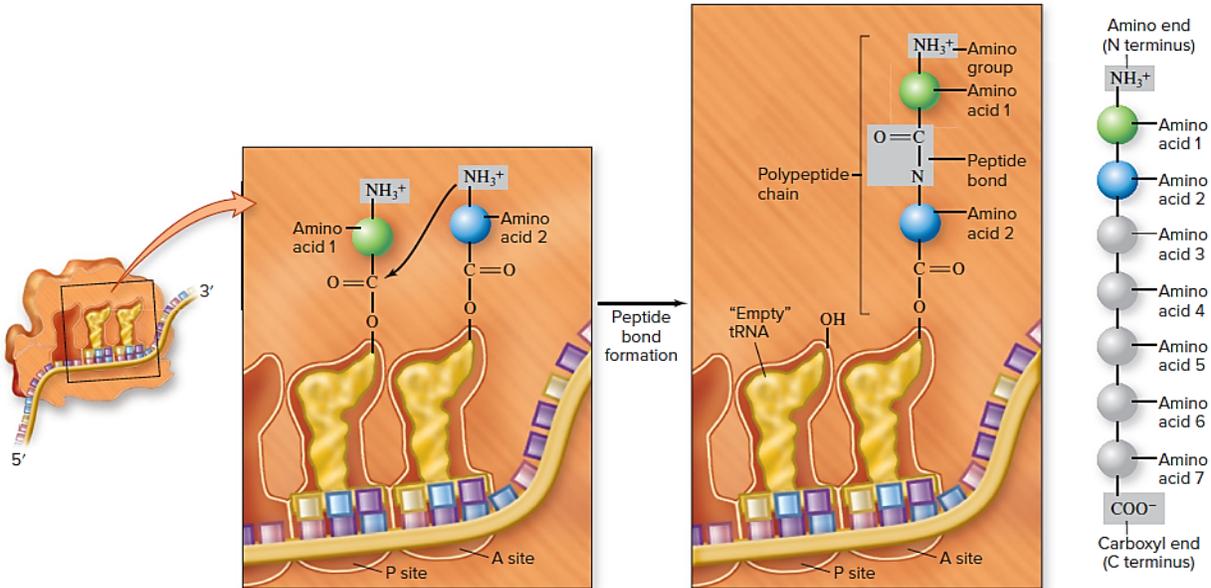


Enhancers and Silencers

- **Definition:** **Distal regulatory DNA sequences** (can be thousands of base pairs away from the promoter) that dramatically **increase (enhancers)** or **decrease (silencers)** transcription rates.
- **Key Properties:**
 - **Orientation & Distance Independent:** They function in either orientation (forward or backward) and over long distances.
 - **Tissue/Cell-Type Specific:** Bound by specific **activator** or **repressor** proteins that define when/where a gene is expressed.
- **Mechanism (Enhancer Loop Model):** Proteins bound to the enhancer interact with proteins at the promoter via **DNA looping**, bringing the enhancer close to the promoter. This recruits

Elongation Factors:

- **EF-Tu/eEF1 α** : Delivers aminoacyl-tRNA to A site.
- **EF-Ts/eEF1 $\beta\gamma$** : Recycles EF-Tu by exchanging its GDP for GTP.
- **EF-G/eEF2**: Catalyzes translocation.



Peptide bond formation. Peptide bonds are formed between a “new” charged tRNA in the A site and the growing chain attached to the tRNA in the P site. The bond forms between the amino group of the new amino acid and the carboxyl group of the growing chain. This breaks the bond between the growing chain and its tRNA, transferring it to the A site as the new amino acid remains attached to its tRNA.

C. Termination: Releasing the Finished Protein

1. Recognition of Stop Codon:

- When a **stop codon (UAA, UAG, UGA)** enters the A site, it is **not recognized by any tRNA**.

2. Release Factors (RFs):

- **Prokaryotes:**
 - **RF1** recognizes UAA/UAG.
 - **RF2** recognizes UAA/UGA.
 - **RF3** is a GTPase that stimulates RF1/RF2 release.
- **Eukaryotes:**
 - **eRF1** recognizes all three stop codons.
 - **eRF3** is a GTPase that assists.

3. Release of Polypeptide Chain:

- The release factor binds the stop codon in the A site.
- It induces the peptidyl transferase center to **hydrolyze** the bond linking the polypeptide to the tRNA in the P site.
- The **completed polypeptide is released**.
- **Ribosome Recycling:** The ribosome dissociates into its subunits, aided by **RRF (Ribosome Recycling Factor)** and EF-G in prokaryotes (similar factors in eukaryotes), ready for a new round of translation.

8. Translation in Prokaryotes

Shine-Dalgarno Sequence

- **What:** A purine-rich consensus sequence (**AGGAGG**) located **~10 nucleotides upstream** of the start codon (AUG) on prokaryotic mRNA.

- These are numerous proteins required for the complex initiation process. Key examples:
 - **eIF2**: Delivers the initiator Met-tRNA to the small subunit. **Phosphorylation of eIF2** is a major regulatory mechanism that globally inhibits translation under stress.
 - **eIF4E**: The cap-binding protein (part of eIF4F). Its activity is a frequent target for regulation.
 - **eIF5**: Promotes GTP hydrolysis by eIF2, leading to factor release and subunit joining.
 - **eIF6**: Binds to the large subunit, preventing premature association with the small subunit in the cytoplasm.

10. Post-Translational Modifications (PTMs)

These are covalent modifications that occur **after** the polypeptide chain is synthesized, crucial for protein function, localization, stability, and activity.

Folding (Chaperone Proteins)

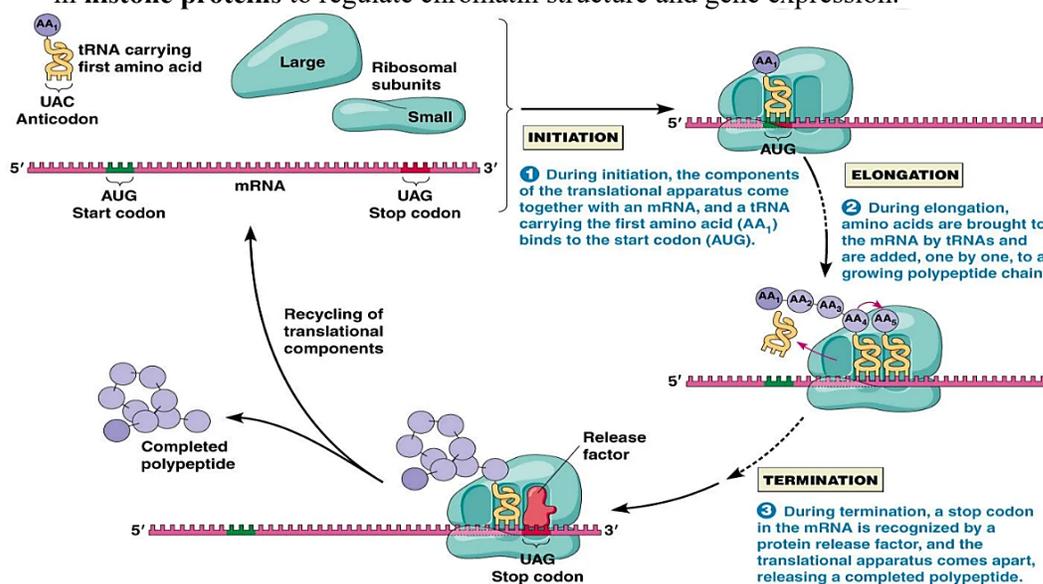
- **Problem**: Newly synthesized polypeptides emerge from the ribosome as an unstructured chain and must fold into a precise 3D shape.
- **Solution**: **Molecular chaperones** (e.g., **Hsp70**, **chaperonins** like GroEL/GroES) bind to hydrophobic regions of the unfolded chain, preventing aggregation and providing a protected environment to facilitate correct folding.

Cleavage of Signal Peptides

- **What**: Many proteins destined for secretion or specific organelles (ER, mitochondria) have an N-terminal **signal peptide** (15-30 hydrophobic amino acids).
- **Process**: As translation begins, the signal peptide is recognized by the **Signal Recognition Particle (SRP)**, which directs the ribosome to the **ER membrane**. The peptide is then **cleaved off** by a **signal peptidase** in the ER lumen.

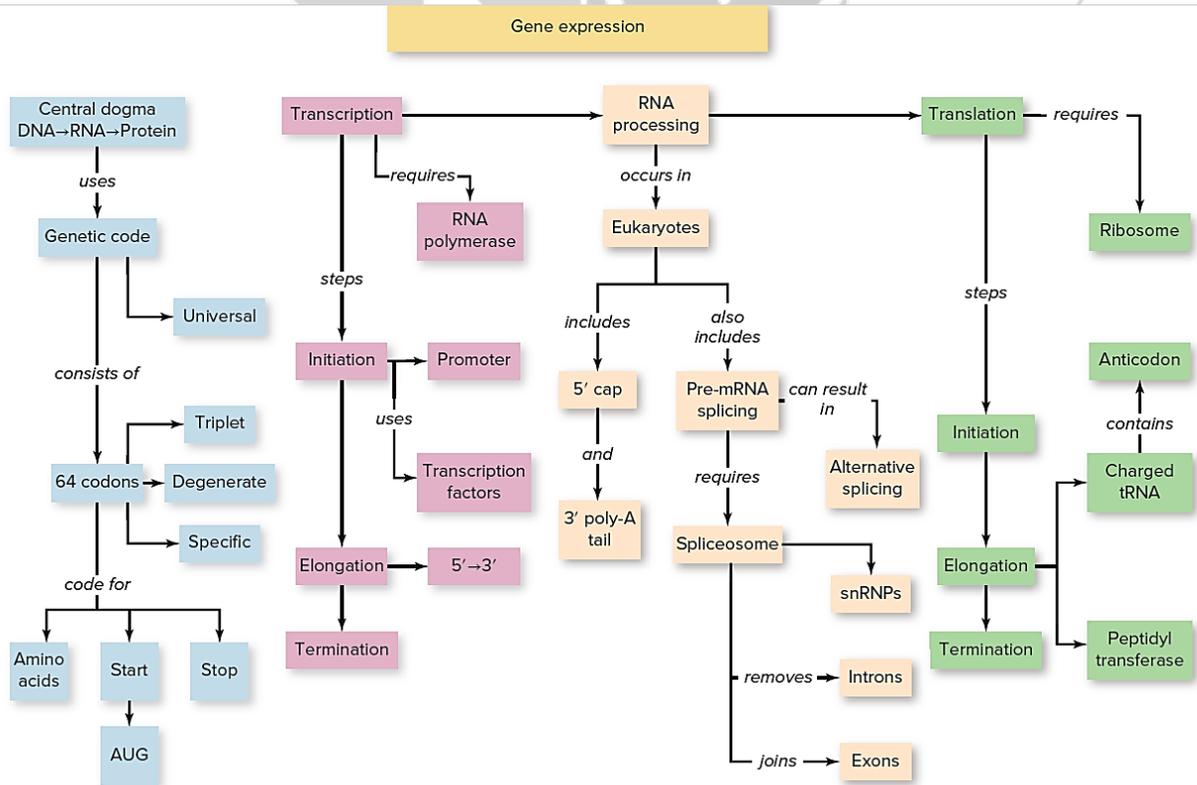
Chemical Modifications

- **Phosphorylation**: Addition of a phosphate group (PO_4^{3-}) to serine, threonine, or tyrosine residues. A major mechanism for **regulating protein activity** (turning enzymes on/off), often mediated by kinases and phosphatases.
- **Glycosylation**: Addition of carbohydrate chains to asparagine (N-linked) or serine/threonine (O-linked). Critical for protein **stability, targeting, and cell-cell recognition** (e.g., in cell surface receptors).
- **Methylation**: Addition of a methyl group ($-\text{CH}_3$) to lysine or arginine residues, common in **histone proteins** to regulate chromatin structure and gene expression.



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Polymerase Chain Reaction (PCR)	Amplifies specific DNA sequences using primers, Taq polymerase, thermal cycling.	Species identification, population genetics, ancient DNA analysis.
Gel Electrophoresis	Separates nucleic acids by size in agarose/polyacrylamide matrix.	Analysis of PCR products, restriction fragments.
DNA Sequencing	Sanger: Chain termination with ddNTPs. NGS: Massively parallel sequencing (Illumina, Nanopore).	Whole genome sequencing, phylogenomics, SNP discovery.
Hybridization Techniques	Southern blot (DNA), Northern blot (RNA), FISH (chromosomal localization).	Gene mapping, chromosomal abnormalities, gene expression.
Recombinant DNA Technology	Restriction enzymes, ligation, cloning vectors (plasmids, BACs, YACs).	Gene cloning, transgenic animal production.
CRISPR-Cas9	RNA-guided DNA endonuclease for targeted genome editing.	Gene knockout/knockin in model organisms, functional genomics.
RNA-seq	NGS of cDNA from RNA population.	Transcriptome analysis, differential gene expression, non-coding RNA discovery.



Practice MCQs

1. Which nitrogenous base is found in RNA but not in DNA?

- A) Adenine
- B) Guanine
- C) Thymine
- D) Uracil

Answer: Uracil

2. The Meselson-Stahl experiment demonstrated that DNA replication is:

- A) Conservative
- B) Dispersive
- C) Semiconservative
- D) Non-conservative

Answer: Semiconservative

3. Which enzyme is responsible for synthesizing RNA primers during DNA replication?

- A) DNA polymerase I
- B) DNA polymerase III
- C) Primase
- D) Ligase

Answer: Primase

4. In the Watson-Crick model of DNA, adenine pairs with:

- A) Guanine
- B) Cytosine
- C) Thymine
- D) Uracil

Answer: Thymine

5. Which type of RNA carries amino acids to the ribosome during translation?

- A) mRNA
- B) tRNA
- C) rRNA
- D) snRNA

Answer: tRNA

6. The condition characterized by trisomy 21 is:

- A) Turner syndrome
- B) Klinefelter syndrome
- C) Down syndrome
- D) Cri-du-chat syndrome

Answer: Down syndrome

7. Which of the following is a purine base?

- A) Cytosine
- B) Thymine
- C) Uracil
- D) Adenine

Answer: Adenine

8. The Hershey-Chase experiment used which isotopes to label DNA and protein?

- A) ^{14}C and ^3H
- B) ^{32}P and ^{35}S
- C) ^{15}N and ^{14}N
- D) ^{18}O and ^2H

Answer: ^{32}P and ^{35}S

9. Which enzyme relieves supercoiling ahead of the replication fork?

- A) Helicase
- B) Topoisomerase
- C) Primase
- D) Ligase

Answer: Topoisomerase

10. The genetic code is said to be degenerate because:

- A) One codon codes for multiple amino acids
- B) One amino acid can be coded by multiple codons
- C) It is the same in all organisms
- D) It has start and stop signals

Answer: One amino acid can be coded by multiple codons

11. Which histone protein is not part of the nucleosome core octamer?

- A) H1
- B) H2A
- C) H3
- D) H4

Answer: H1

12. Transcription in eukaryotes is carried out by which RNA polymerase for mRNA?

- A) RNA polymerase I
- B) RNA polymerase II
- C) RNA polymerase III
- D) RNA polymerase IV

Answer: RNA polymerase II

13. Which of the following mutations changes a codon to a stop codon?

- A) Missense
- B) Nonsense
- C) Silent
- D) Frameshift

Answer: Nonsense

14. The "beads-on-a-string" structure of chromatin refers to:

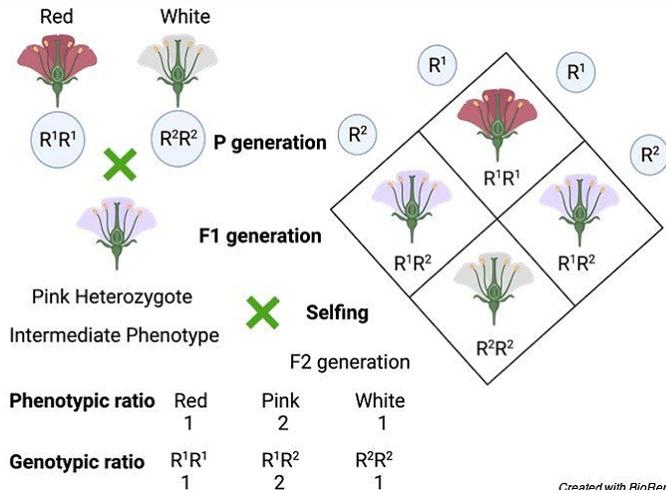
- A) Nucleosomes
- B) Solenoid fibers
- C) Radial loop domains



Chapter 5

Classical Genetics

- **Genetics** is the scientific study of **heredity** (transmission of traits from parents to offspring) and **variation** (differences among individuals).
- **Inheritance**, the process encompassing both heredity and variation, is crucial for evolution and speciation.
- Since **genes** control heredity and variation, genetics is fundamentally the study of genes.
- **Molecular Basis:** A gene is a specific DNA sequence that codes for a polypeptide via **transcription** (DNA to mRNA in nucleus) and **translation** (mRNA to protein at ribosome).
- **Gene** – Basic unit of heredity; a segment of DNA coding for a polypeptide/trait. (*Example: The gene for flower color in peas.*)
- **Allele** – Alternative form of a gene at the same locus. (*Example: The alleles for purple (P) or white (p) flowers.*)
- **Locus** – Specific position of a gene on a chromosome.
- **Genotype** – Genetic makeup of an individual. (*Example: PP, Pp, or pp.*)
- **Phenotype** – Observable expression of a trait. (*Example: Purple or white flowers.*)
- **Homozygous** – Having two identical alleles for a gene. (*Example: PP or pp.*)
- **Heterozygous** – Having two different alleles for a gene. (*Example: Pp.*)
- **Hemizygous** – Having only one allele for a gene (e.g., X-linked genes in males).
- **Wild type** – Most common phenotype in natural populations.
- **Mutant phenotype** – Trait alternative to wild type.
- **Gene Pool** – All alleles present in a breeding population at a given time.
- **Law of Segregation (Principle of Segregation)** – Alleles separate during gamete formation. (*Mendel's pea plant experiments.*)
- **Law of Independent Assortment** – Genes for different traits assort independently during gamete formation.
- **P generation** – Parental generation.
- **F₁ generation** – First filial generation.
- **F₂ generation** – Second filial generation.
- **True-breeding (Pure breeding)** – Organisms that produce identical offspring when self-fertilized.
- **Monohybrid cross** – Cross involving one trait. (*Example: Crossing pure-breeding tall and dwarf pea plants.*)
- **Dihybrid cross** – Cross involving two traits. (*Example: Crossing plants differing in seed shape and color.*)
- **Testcross** – Cross between an individual with unknown genotype and a homozygous recessive individual.
- **Complete Dominance** – One allele completely masks the other. (*Example: Mendel's pea traits.*)
- **Incomplete dominance** – Heterozygote shows an intermediate phenotype. (*Example: Pink flowers from red and white snapdragons.*)
- **Codominance** – Both alleles are fully expressed in the heterozygote. (*Example: AB blood type; speckled chicken feathers.*)
- **Multiple alleles** – More than two alleles exist for a gene in a population. (*Example: ABO blood group alleles: I^A, I^B, i.*)
- **Pleiotropy** – One gene affects multiple traits. (*Example: Sickle cell allele affects hemoglobin, red blood cell shape, and causes anemia.*)
- **Epistasis** – One gene affects the expression of another gene. (*Example: Coat color in Labrador retrievers, where one gene affects pigment deposition.*)



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c) Co-Dominance

In **co-dominance**, both alleles in a heterozygous organism contribute equally and visibly to the phenotype. Instead of one allele masking the other, both alleles are expressed simultaneously.

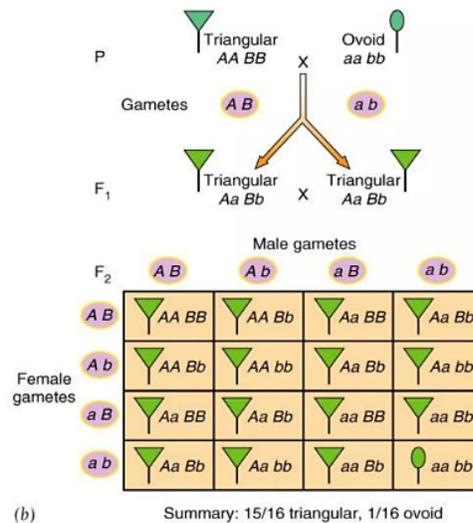
- **Example:** In human blood type inheritance, the A (I^A) and B (I^B) alleles are co-dominant. If a person inherits one A allele and one B allele ($I^A I^B$), both A and B antigens will be present on the surface of red blood cells, resulting in **AB blood type**.
- **Genotypic Ratio:** $1 I^A I^A : 2 I^A I^B : 1 I^B I^B$
- **Phenotypic Ratio:** AB : AA : BB

Phenotype (Blood type)	A	B	AB	O
Antigens present on red blood cells				
Genotype(s)	$I^A I^A$ $I^A i$	$I^B I^B$ $I^B i$	$I^A I^B$	ii

d) Recessive Alleles

In **recessive inheritance**, the recessive allele only manifests its trait when an individual inherits two copies of it (homozygous recessive). If only one copy of the recessive allele is present (heterozygous), the dominant allele will express its trait, and the recessive allele will be masked.

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2. Complementary Gene Action

A subset of epistasis where **two genes work together to produce a single trait**. The classic 9:7 ratio is a prime example (as in sweet peas above).

3. Suppression

A specific type of interaction where one gene (**suppressor gene**) reverses the effect of a mutation at another locus, often restoring the wild-type phenotype.

- **Example:** In *Drosophila*, a mutation causing abnormal bristles can be suppressed by a mutation in a second, unrelated gene, leading to normal-looking flies.

4. Modifier Genes

Genes that **alter the expression or severity** of a phenotype caused by a major gene, but do not determine the trait's presence/absence.

- **Example:** The degree of spotting in piebald animals or the expressivity of genetic disorders in humans (e.g., variable severity of Marfan syndrome).

5. Redundant Genes (Duplicate Genes)

Two genes perform the **same function**. Loss of function in one can be compensated by the other. Phenotypic effects are only seen when both are mutated.

- **Example:** In *Arabidopsis*, many genes involved in developmental pathways have redundant paralogs.

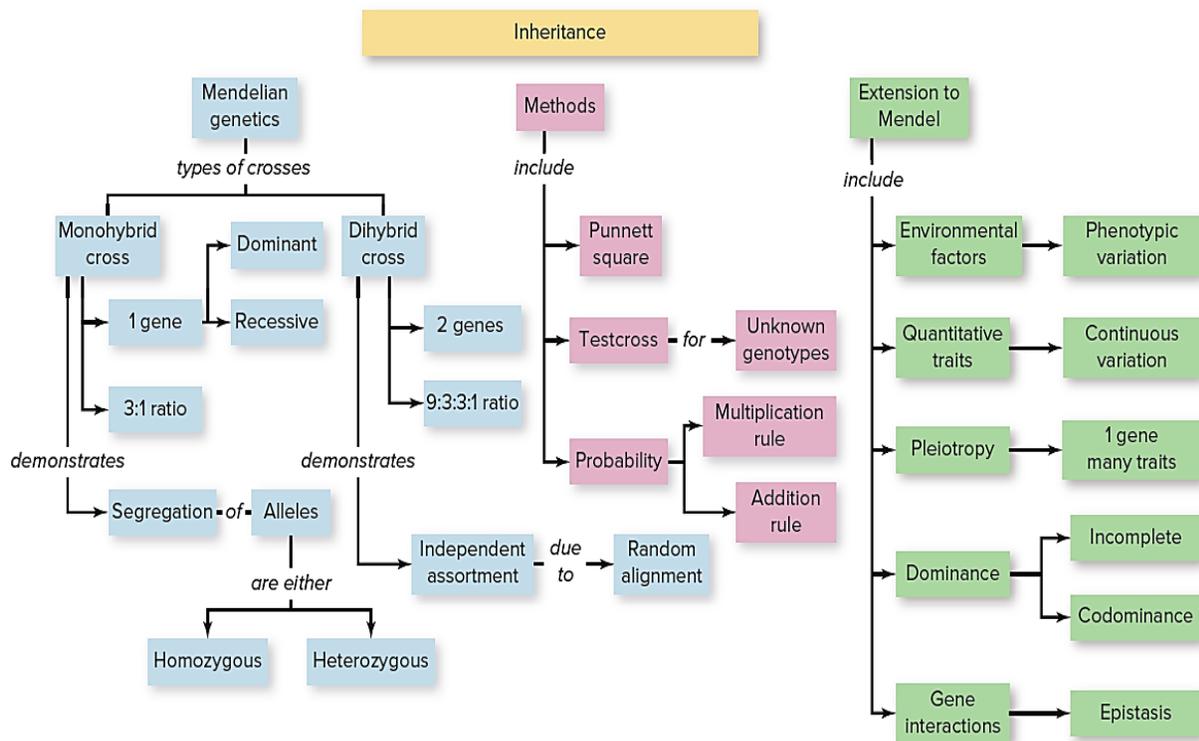
6. Collaborative (Additive) Interaction

Two or more genes contribute **additively** to a quantitative trait (e.g., height, skin color). This is the basis of **polygenic inheritance**.

- **Example:** Human skin pigmentation is influenced by alleles at multiple loci (MC1R, SLC24A5, etc.), each adding a small amount of pigment.

III. Distinguishing Related Concepts

- **Gene Interaction vs. Pleiotropy:**
 - **Gene Interaction:** Multiple genes → **One trait**.
 - **Pleiotropy:** **One gene** → Multiple, seemingly unrelated traits (e.g., mutation in the *CFTR* gene affects lungs, pancreas, sweat glands).
- **Gene Interaction vs. Linkage:**
 - **Gene Interaction:** Concerned with **functional relationships** between gene products.
 - **Linkage:** Concerned with the **physical proximity** of genes on the same chromosome, affecting their inheritance patterns together.
- **Gene Interaction vs. Environmental Influence:**



Practice MCQs

- What is the basic unit of heredity that codes for a functional product like a protein?
A) Allele
B) Locus
C) Gene
D) Chromosome
Answer: Gene
- The specific physical location of a gene on a chromosome is called its:
A) Allele
B) Genome
C) Locus
D) Phenotype
Answer: Locus
- Alternative forms of the same gene that occupy corresponding loci on homologous chromosomes are known as:
A) Genotypes
B) Phenotypes
C) Alleles
D) Linkage groups
Answer: Alleles
- The complete set of all alleles present in all individuals of a breeding population at a given time is the:
A) Genome
B) Karyotype
C) Gene pool
D) Genotype frequency
Answer: Gene pool
- The genetic constitution of an organism for a particular trait is its:
A) Phenotype
B) Allele
C) Genotype
D) Karyotype
Answer: Genotype
- The observable characteristics resulting from genotype and environment define the:
A) Genotype
B) Allele
C) Phenotype
D) Locus
Answer: Phenotype



Chapter: 6

Ecology & Ecosystems

- **Ecology:** Scientific study of interactions between organisms and their biotic and abiotic environment. Coined by Ernst Haeckel from Greek *oikos* (household) + *logy* (study).
- **Ecosystem:** Dynamic complex of biotic communities and their abiotic environment interacting as a functional unit through energy flows and biogeochemical cycles. Coined by Arthur Tansley (1935) to emphasize interconnectedness.
- **Environment:** All abiotic (non-living: climate, soil, water) and biotic (living: plants, animals, microbes) factors influencing an organism.
- **Biosphere:** Thin, life-supporting layer of Earth where all ecosystems exist.

M Levels of Ecological Organization

1. **Organism:** Individual living entity.
2. **Population:** Group of interbreeding individuals of the same species in a specific area.
3. **Community:** Assemblage of different populations living and interacting in a defined area.
4. **Ecosystem:** Community + physical environment, interacting through nutrient cycling and energy flow.
5. **Biome:** Large geographical region with distinct climate and characteristic community.
6. **Biosphere:** All ecosystems collectively.

K Key Ecological Concepts

- **Habitat:** Physical space where an organism lives.
- **Ecological Niche:** Multidimensional concept describing the functional role of a species (resources used, conditions tolerated).
 - *Fundamental Niche:* Full range theoretically usable.
 - *Realized Niche:* Actual range occupied due to interspecific interactions.
- **Metapopulation:** Set of local populations linked by immigration/emigration. The **Glanville fritillary butterfly** in Finland exists as scattered local populations in dry meadows, connected by occasional migration.
- **Symbiosis:** Close, long-term biological interaction between two different species (parasitic, mutualistic, or commensal).
- **Mutualism:** Clownfish and sea anemones.
- **Parasitism:** Tapeworms in mammals.
- **Commensalism:** Barnacles on whales.

P ECOSYSTEM STRUCTURE

R A. Abiotic Components

- **Physical Factors:**
 - Solar radiation (1–2% converted via photosynthesis).
 - Temperature (affects metabolic rates via Q_{10} relationships).
 - Water availability (creates productivity gradients).
 - Soil texture (water holding capacity, nutrient retention).
- **Chemical Factors:**
 - Nutrient availability (Liebig's Law of the Minimum).
 - Redox potential (influences nutrient speciation).
 - pH, salinity, oxygen availability.

T Food Chain

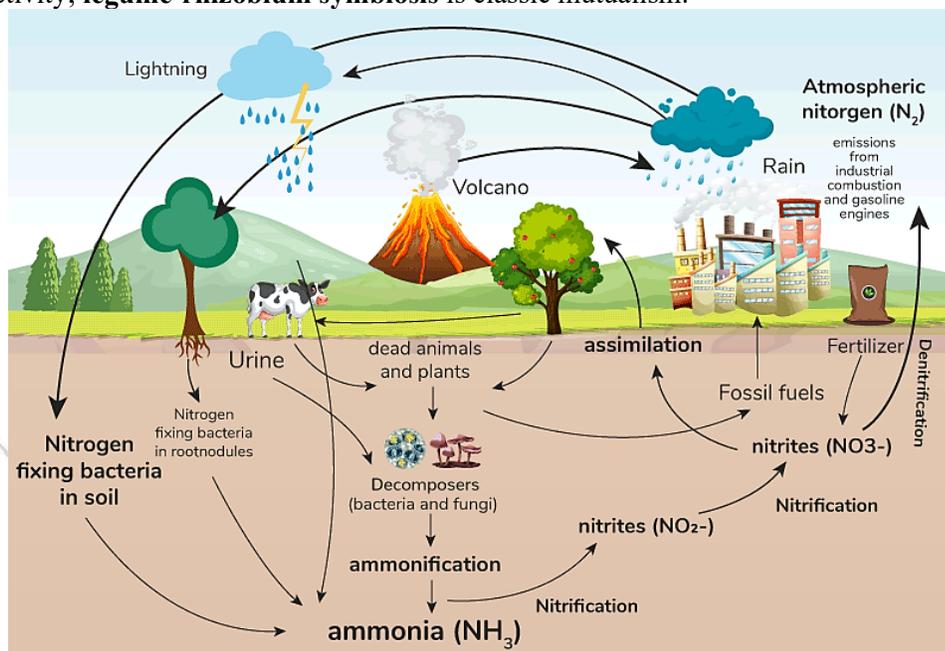
A **food chain** is a **linear sequence** showing how energy and nutrients move from one organism to another in an ecosystem. It follows a single path.

I Example of a simple food chain:

Grass → Grasshopper → Frog → Snake → Hawk

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- **Human Impact:** Human creation of reactive N exceeds natural fixation; nitrate pollution in groundwater (>10 mg/L is unsafe); N-based smog and aerosols; **biological magnification** not significant for N.
- **Ecological Role:** Limiting nutrient in most terrestrial/marine systems; determines primary productivity; **legume-rhizobium symbiosis** is classic mutualism.



Phosphorus Cycle

- **Major Reservoirs:** Sedimentary rocks (apatite – primary source), soil (bound to Fe, Al, Ca ions), ocean sediments, living biomass.
- **Core Processes:** Geological uplift & weathering (slow, limiting step), mineralization (by decomposers), plant uptake, immobilization (into microbial biomass), sedimentation, and no gaseous loss phase.
- **Key Compounds:** Orthophosphate ($H_2PO_4^-/HPO_4^{2-}$ – plant available), organic phosphates (in DNA, ATP, phospholipids), and insoluble mineral phosphates.
- **Human Impact:** Mined for fertilizers (guano, rock phosphate); runoff causes cultural eutrophication (P is typical limiting factor in freshwater); detergent phosphates banned in many regions.
- **Ecological Role:** Component of ATP (energy currency), nucleic acids, phospholipid bilayers, and bones/teeth (apatite).
- **MCQ Points:** Cycle is slowest and mostly sedimentary; Mycorrhizal fungi massively increase plant P uptake; P availability is pH-dependent (max at pH 6.5); N:P Redfield Ratio in oceans is 16:1.

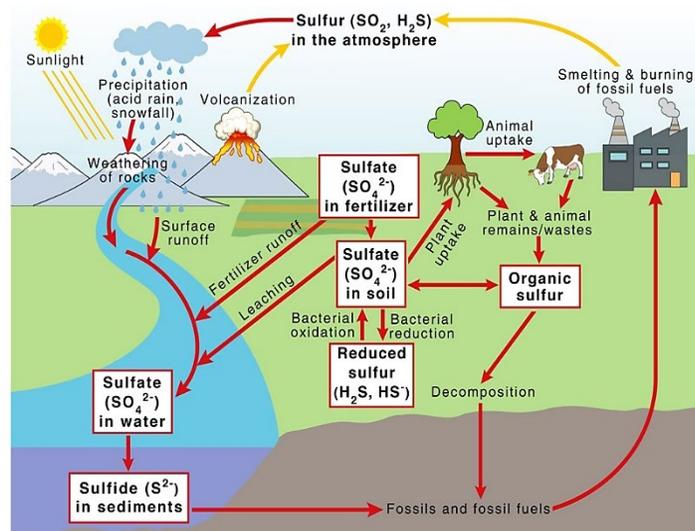
Water (Hydrological) Cycle

- **Major Reservoirs:** Oceans (97.5% of total, saline), Icecaps/Glaciers (1.74%, 68.7% of freshwater), Groundwater (0.76%, 30.1% of freshwater), Lakes/Rivers (0.01%), Atmosphere (0.001%).
- **Core Processes:** Evapotranspiration (combined evaporation + plant transpiration), condensation (cloud formation), precipitation, infiltration/percolation (recharges groundwater), surface/sub-surface runoff, and storage (in ice, aquifers).

- **Key Pathways:** Green water flow (soil moisture for plants), Blue water flow (rivers, lakes, aquifers).
- **Human Impact:** Aquifer overdraft (e.g., Ogallala, India's Punjab); river fragmentation by dams; thermal pollution alters evaporation; deforestation reduces infiltration, increases flood risk.

Sulfur Cycle

- **Major Reservoirs:** Lithosphere (rocks, minerals, fossil fuels), oceans (SO_4^{2-} – major reservoir), atmosphere (trace gases), biosphere.
- **Core Processes:** Volcanic outgassing (H_2S , SO_2), weathering, bacterial sulfate reduction ($\text{SO}_4^{2-} \rightarrow \text{H}_2\text{S}$ by *Desulfovibrio* in anoxic muds), bacterial sulfide oxidation ($\text{H}_2\text{S} \rightarrow \text{S}^0 \rightarrow \text{SO}_4^{2-}$), combustion of fossil fuels, and precipitation as acid rain (H_2SO_4).
- **Key Compounds:** Hydrogen sulfide (H_2S – toxic, rotten egg smell), sulfur dioxide (SO_2 – air pollutant), sulfate (SO_4^{2-}), dimethyl sulfide [$(\text{CH}_3)_2\text{S}$] – from phytoplankton, affects cloud formation.
- **Human Impact:** Acid rain (pH < 5.6) damages forests, acidifies lakes, corrodes buildings; Flue Gas Desulfurization (FGD) in industries; sulfur aerosols cause global dimming (cooling effect).



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Oxygen Cycle

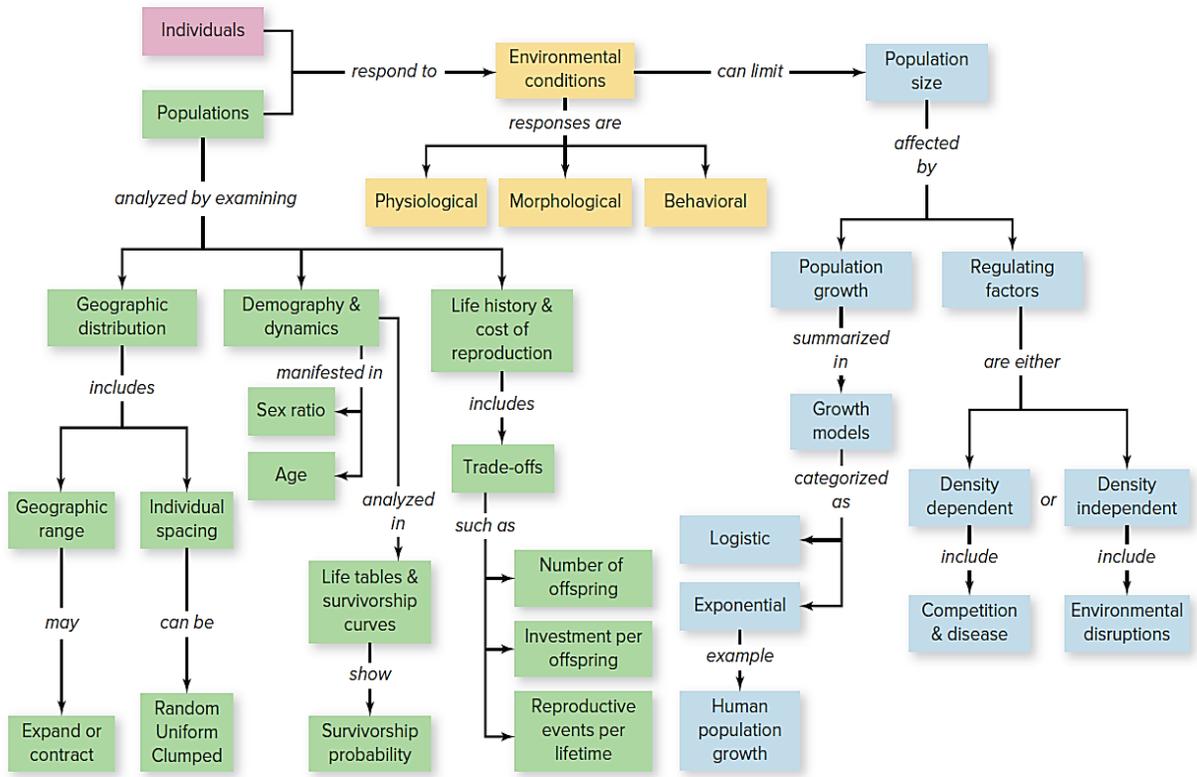
- **Major Reservoirs:** Lithosphere (silicate & oxide minerals – largest pool), atmosphere (O_2 – 20.95%, O_3 – trace), hydrosphere (dissolved O_2), biosphere.
- **Core Processes:** Photosynthesis (main source), respiration/decomposition (main sinks), photolysis of water/ H_2O in upper atmosphere, ozone formation/destruction ($\text{O}_2 + \text{O} \rightarrow \text{O}_3$), weathering (oxidation of rocks), and fossil fuel combustion.
- **Key Compounds:** Dioxygen (O_2), ozone (O_3 – stratospheric shield, tropospheric pollutant), oxides ($\text{CO}_2, \text{H}_2\text{O}, \text{SiO}_2, \text{Fe}_2\text{O}_3$).
- **Human Impact:** Stratospheric O_3 depletion by CFCs (forming "ozone hole"); tropospheric O_3 increase (smog) harms health/plants; hypoxia/anoxia in water bodies from eutrophication.
- **Ecological Role:** Terminal electron acceptor in aerobic respiration; ozone layer absorbs 97-99% of harmful UV-B/C radiation.
- **MCQ Points:** Great Oxidation Event (~2.4 Ga) enabled complex life; Dissolved Oxygen (DO) declines with temperature increase and organic pollution; BOD/COD measures water pollution; Oxygen minimum zones (OMZs) in oceans expanding.

SPECIES INTERACTIONS

A. Interspecific Interactions

Interaction	Effect on Species A	Effect on Species B	Example
Competition	–	–	Lions and hyenas competing for prey.
Predation	+	–	Fox eating rabbit.
Parasitism	+	–	Tapeworm in human.

Ecology of individuals and populations

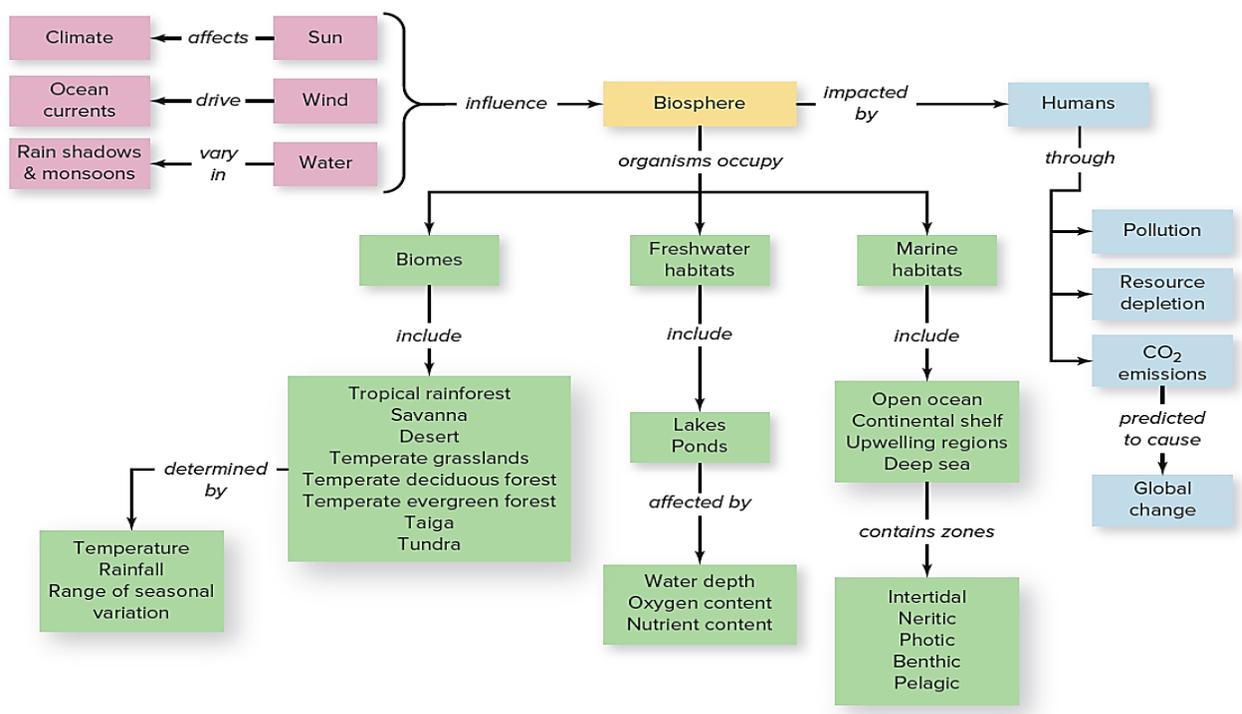
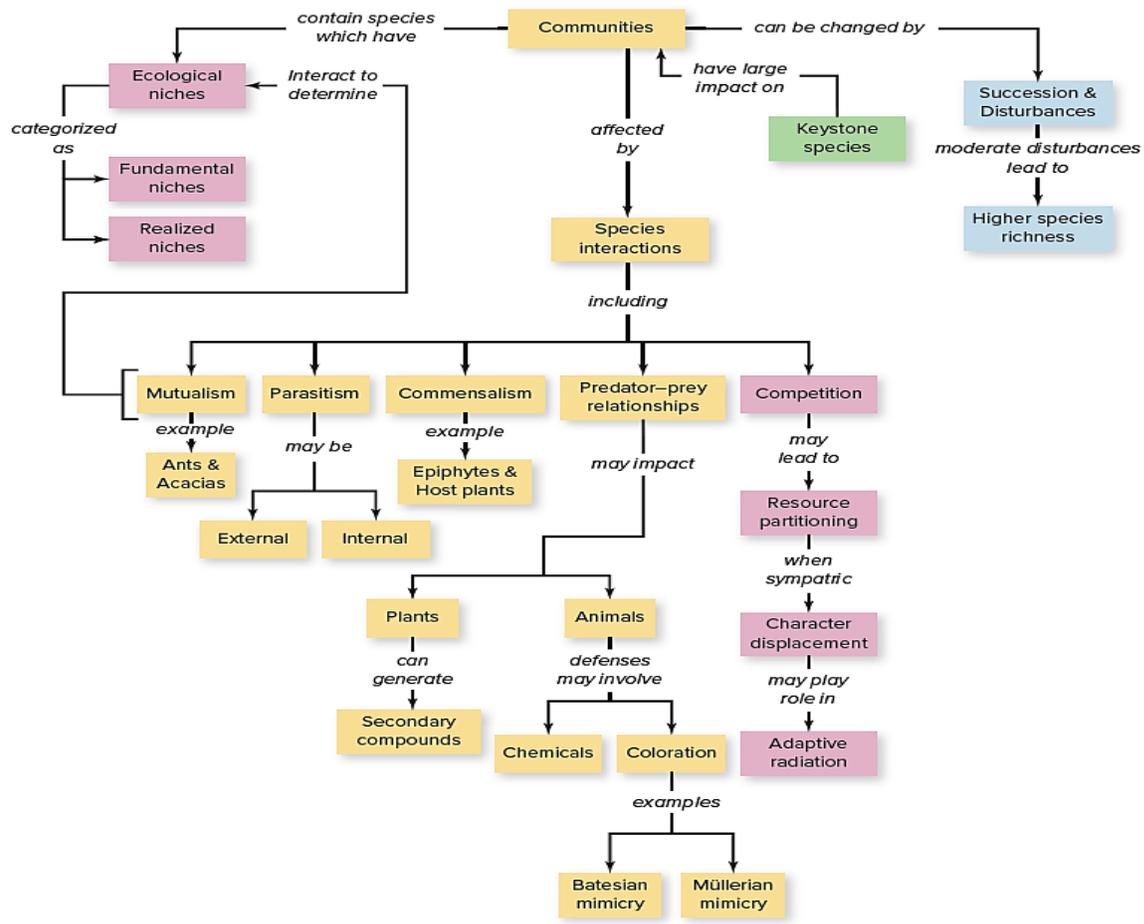


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6. Ecology & Ecosystems







Biodiversity & Environmental Biology

- Biodiversity (Biological Diversity):** The variety of life on Earth at all levels of biological organization. It encompasses the variety within and between all species of plants, animals, and microorganisms, the ecosystems they form, and the ecological and evolutionary processes that sustain them.
- Formal Definition (CBD):** "The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." (UN Convention on Biological Diversity)
- Dimensions of Biodiversity:**
 - Composition:** The identity and variety of living elements in a system (what is there).
 - Structure:** The physical organization or patterns of a system (e.g., canopy layers, soil stratification).
 - Function:** The ecological and evolutionary processes and services (e.g., nutrient cycling, energy flow).

Scope & Scale

- Taxonomic Groups:** The major classifications of life forms.
 - Plants:** Primary producers; includes flowering plants, conifers, ferns, mosses, algae.
 - Animals:** Includes invertebrates (insects, mollusks) and vertebrates (mammals, birds, reptiles, amphibians, fish).
 - Microorganisms:** Includes bacteria, archaea, protists, fungi, and viruses; crucial for decomposition and nutrient cycling.
- Scale of Biodiversity:**
 - Alpha (α) Diversity:** The diversity of species within a specific, localized habitat or community (local species richness and evenness).
 - Beta (β) Diversity:** The rate of change or turnover in species composition across different habitats within a larger geographic region (measures how communities differ).
 - Gamma (γ) Diversity:** The total biodiversity across a broad geographic area, continent, or the entire planet.

Levels of Biodiversity

- Genetic Diversity:** The total genetic information contained within all individuals of a species, population, or group of species. It is the variation in alleles and genes.
 - Key Aspect - Endemism (Genetic):** Unique genetic adaptations found only in specific populations.
- Species Diversity:** The variety and abundance of different species within a defined biological community or area.
 - Species Richness:** The simple count of different species present.
 - Species Evenness (Equitability):** The relative abundance of each species.
 - Taxonomic Diversity:** Considers the phylogenetic relationships (evolutionary distances) between species.
 - Functional Diversity:** The variety of ecological roles (functional traits) performed by species in a community.
- Ecosystem Diversity:** The variety of ecosystems, habitats, biotic communities, and ecological processes within a region or across the globe.
 - Habitat Heterogeneity:** The physical complexity and variety of microhabitats within an ecosystem.
 - Biome:** A major ecological community type extending over a large area (e.g., tropical rainforest, tundra).

Biodiversity Hotspots

MK PREPARATIONS: Let's Make It Happen

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1. **Solar Input:** Incoming solar radiation (mostly visible light and UV) passes through the atmosphere.
2. **Surface Absorption:** About **70%** is absorbed by the Earth's surface (land and oceans), warming it.
3. **Infrared Emission:** The warmed surface emits heat energy back toward space as **infrared radiation (longwave)**.
4. **Greenhouse Gas Interaction: Greenhouse gas molecules** (CO₂, H₂O, CH₄, etc.) in the atmosphere **absorb** specific wavelengths of this outgoing infrared radiation.
5. **Re-radiation:** The excited GHG molecules re-radiate the heat energy in all directions—some back toward space, but a significant portion **back toward the Earth's surface**.
6. **Net Result:** This "blanket" of GHGs slows the rate of heat loss to space, keeping the lower atmosphere and surface warmer than they would be otherwise.

3. Major Greenhouse Gases (GHGs)

Gas	Chemical Formula	Primary Anthropogenic Sources	Global Warming Potential (GWP) over 100 years	Atmospheric Lifetime	Contribution to Warming
Carbon Dioxide	CO ₂	Fossil Fuel Combustion (coal, oil, gas), Deforestation, Cement production.	1 (The Baseline)	Centuries (20 -2000 yrs, some permanent)	~76% of total forcing (Dominant driver)
Methane	CH ₄	Agriculture (livestock digestion, rice paddies), Fossil fuel extraction (leaks), Landfills, Wastewater.	27-30 (27-30x more potent than CO ₂)	~12 years	~16% (Potent short-term forcer)
Nitrous Oxide	N ₂ O	Agricultural soils (synthetic fertilizers), Industrial processes, Fossil fuel combustion, Biomass burning.	273 (273x more potent than CO ₂)	~121 years	~6% (Long-lived & potent)
Fluorinated Gases (F-gases)	HFCs, PFCs, SF ₆ , NF ₃	Refrigerants, Aerosols, Solvents, Electrical insulation.	Thousands to tens of thousands (e.g., SF ₆ = 23,500)	Decades to millennia	~2% (Extremely potent, small but growing)
Water Vapor	H ₂ O	Feedback agent, not a primary driver. Evaporation increases in response to warming caused by other GHGs	Variable	~9 days	Major amplifier, not an initial trigger.



MK PREPARATIONS



- **Lower Restrictions on Human Activity:** Compared to national parks, they may allow existing human settlements and some sustainable resource use.

- **Examples:** Bharatpur Bird Sanctuary (India), Gombe Stream National Park (a chimpanzee sanctuary, Tanzania), many wildlife refuges in the USA.

IUCN Protected Area Categories (Simplified Overview):

- **Ia – Strict Nature Reserve:** For science only.
- **Ib – Wilderness Area:** For wilderness protection.
- **II – National Park:** For ecosystem protection and recreation.
- **III – Natural Monument or Feature:** For specific natural features.
- **IV – Habitat/Species Management Area (Wildlife Sanctuary):** For active species management.
- **V – Protected Landscape/Seascape:** Where people and nature interact harmoniously.
- **VI – Protected Area with Sustainable Use of Natural Resources:** For conservation and sustainable use.

3. Other Key Protected Area Designations

- **Biosphere Reserves (UNESCO's MAB Programme):** These are **not** strict protected areas but "**learning places for sustainable development.**" They have three interlinked zones:
 1. **Core Area:** Legally protected ecosystem (like a national park).
 2. **Buffer Zone:** Surrounds the core, used for low-impact activities (eco-tourism, research).
 3. **Transition Zone:** Outer area where sustainable communities, agriculture, and settlements work in harmony with conservation goals.
 - **Goal:** To reconcile conservation with sustainable human use.
- **Tiger Reserves, Elephant Reserves, etc.:** Country-specific designations (common in India) that provide the highest level of species-focused protection and management.

Challenges Facing Protected Areas:

- **Paper Parks:** Protected in name only, lacking effective management or enforcement.
- **Insufficient Coverage:** Many critical ecosystems and species ranges are not covered.
- **Isolation & Fragmentation:** Many parks are becoming isolated "islands" in a sea of human development, hindering migration and gene flow.
- **Climate Change:** Shifts in species ranges may mean protected areas no longer contain the species they were designed to protect.
- **Human-Wildlife Conflict:** At park boundaries, where animals damage crops or livestock.
- **Funding and Political Will:** Chronic underfunding and lack of political support.

Practice MCQs

1. Who coined the term "ecology"?

- A) Arthur Tansley
- B) Ernst Haeckel
- C) Charles Darwin
- D) Joseph Grinnell

Answer: Ernst Haeckel

2. The term "ecosystem" was coined by:

- A) Ernst Haeckel
- B) Robert Paine
- C) Arthur Tansley
- D) Eugene Odum

Answer: Arthur Tansley

3. All the ecosystems on Earth collectively form the:

- A) Community

- B) Biome

- C) Biosphere

- D) Hydrosphere

Answer: Biosphere

4. A group of interbreeding individuals of the same species in a specific area is a:

- A) Community

- B) Population

- C) Guild

- D) Ecosystem

Answer: Population

5. The physical space where an organism lives is its:

- A) Niche

- B) Territory

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6. Ecology & Ecosystems



Chapter 7

Evolution

- **Evolution:** Descent with modification; change in allele frequencies in populations over time.
- **Organic Evolution:** Biological evolution through genetic change and natural selection.
- **Microevolution:** Change in allele frequencies within a population over generations.
- **Macroevolution:** Large-scale evolutionary changes (speciation, extinction) over geological time.
- **Common Descent:** All organisms share a common ancestor.

Special Creation vs. Evolution

Aspect	Special Creation	Evolution
Origin of Species	Independently created	Descended from common ancestors
Change Over Time	Fixed, immutable	Continuously changing
Mechanism	Divine intervention	Natural processes (selection)
Evidence Base	Religious texts	Multiple scientific disciplines
Scientific Status	Non-testable, non-scientific	Well-supported scientific theory

Origin of Life & Evolution of Cellular Life

I. Origin of Life (Abiogenesis)

A. Prebiotic Conditions on Early Earth (~4.6 - 3.9 Ga)

- **Hadean Eon:** Hot, volcanic, frequent asteroid impacts, no free oxygen.
- **Atmosphere:** Reducing (H₂, CH₄, NH₃, H₂O, CO₂, N₂). No O₂ layer, high UV radiation.
- **Key Requirements for Life:**
 1. Source of organic molecules (monomers).
 2. Mechanism to polymerize monomers.
 3. Self-replication (information storage).
 4. Compartmentalization (protocell membranes).

B. Key Experiments & Hypotheses for Organic Molecule Formation

1. **Miller-Urey Experiment (1953):** Simulated early Earth atmosphere with electrical sparks produced amino acids and other organics.
2. **Extraterrestrial Origins (Panspermia/Meteorites):** Murchison meteorite contains amino acids and nucleobases.
3. **Hydrothermal Vent Hypothesis (A Primary Focus): Submarine alkaline hydrothermal vents (e.g., Lost City-type) are a leading theory.**
 - **Why Vents?** Provide a compelling environment for life's origin.
 - **Energy Gradient:** Natural proton gradient (alkaline vent fluid vs. acidic ocean) mimics modern cellular chemiosmosis (ATP production).
 - **Mineral Catalysts:** Porous chimneys of iron-sulfide (FeS) and mackinawite act as inorganic catalysts and compartment walls.
 - **Conditions:** Stable, protected from surface UV radiation and impacts.
 - **Organic Synthesis:** H₂ and CO₂/CO in vent fluids can react via Fischer-Tropsch-type reactions on catalytic mineral surfaces to form organic molecules.
 - **The "Protometabolism First" Model:** Networks of chemical reactions within vent pores could evolve complexity before the emergence of genetic code or membranes.

C. From Molecules to Cells

1. **RNA World Hypothesis:** RNA can store information (like DNA) and catalyze reactions (like proteins). Ribozymes and self-replicating RNA are central.
2. **Protocell Formation:** Fatty acids or simpler amphiphilic molecules can spontaneously form micelles and vesicles in water, capable of encapsulation and growth/division.



2. Gene Flow (Migration): Allele exchange between populations

- **Effects:** Homogenizes populations; counteracts divergence.
- **Significance:** Maintains species cohesion; prevents speciation.

3. Mutation: Ultimate source of new genetic variation

- **Characteristics:** Random with respect to need; mostly neutral/deleterious.
- **Role:** Provides raw material for selection; basis of molecular clocks.

C. Mathematical Foundation: Hardy-Weinberg Principle

- **Equation:** $p^2 + 2pq + q^2 = 1$
- **Conditions for Equilibrium (No Evolution):**
 1. No mutations
 2. Random mating
 3. No natural selection
 4. Extremely large population (no drift)
 5. No gene flow
- **Applications:**
 - Calculate allele frequencies in populations.
 - Estimate carrier rates for genetic disorders.
 - Test if evolution is occurring.

SPECIATION: ORIGIN OF NEW SPECIES

A. Species Concepts Compared

Concept	Definition	Best For	Limitations
Biological (Mayr)	Groups that interbreed in nature	Animals, sympatric species	Asexuals, fossils, geographically separated populations
Morphological	Based on physical differences	Paleontology, taxonomy	Cryptic species; subjective
Ecological	Occupies distinct niche	Plants, adaptive radiations	Niche definition subjective
Phylogenetic	Monophyletic group	Molecular systematics	Arbitrary divergence levels
Evolutionary	Lineage with unique trajectory	Paleontology	Difficult to apply

B. Reproductive Isolating Mechanisms

Prezygotic Barriers (Prevent Mating/Fertilization):

- **Habitat:** Different environments.
- **Temporal:** Different breeding times.
- **Behavioral:** Different courtship rituals.
- **Mechanical:** Physical incompatibility.
- **Gametic:** Sperm-egg incompatibility.

Postzygotic Barriers (After Fertilization):

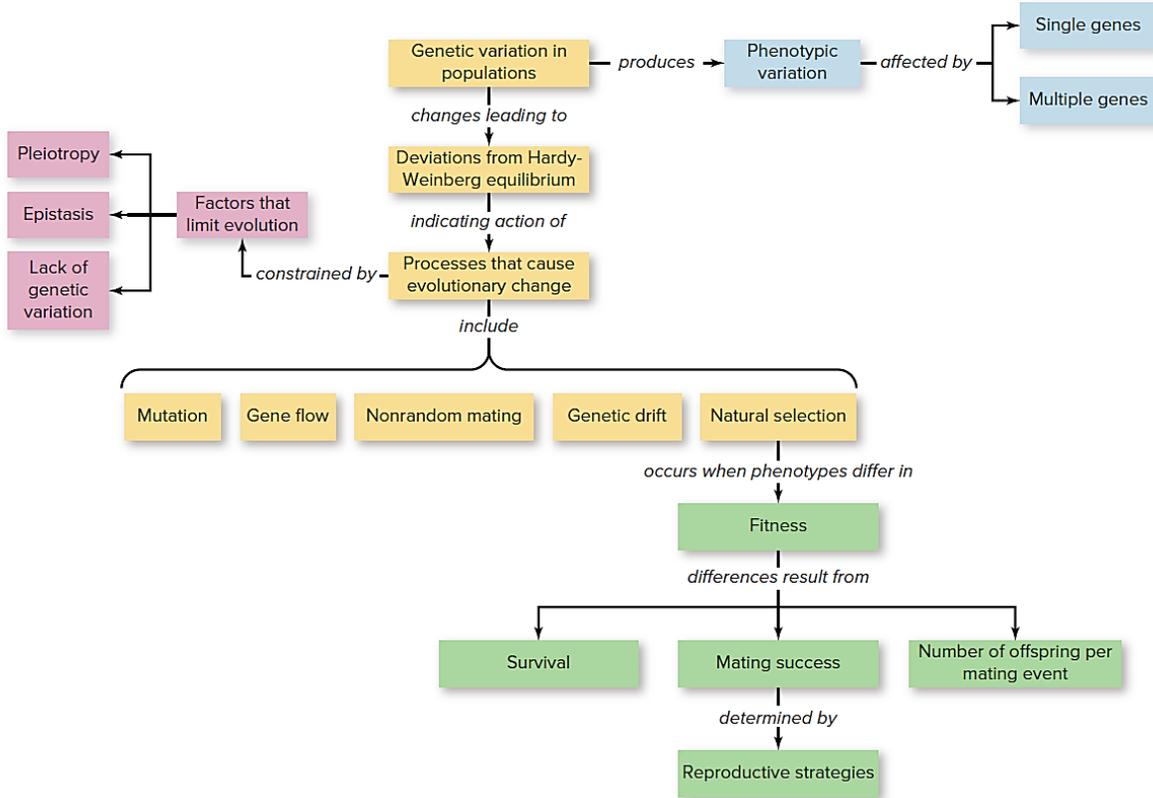
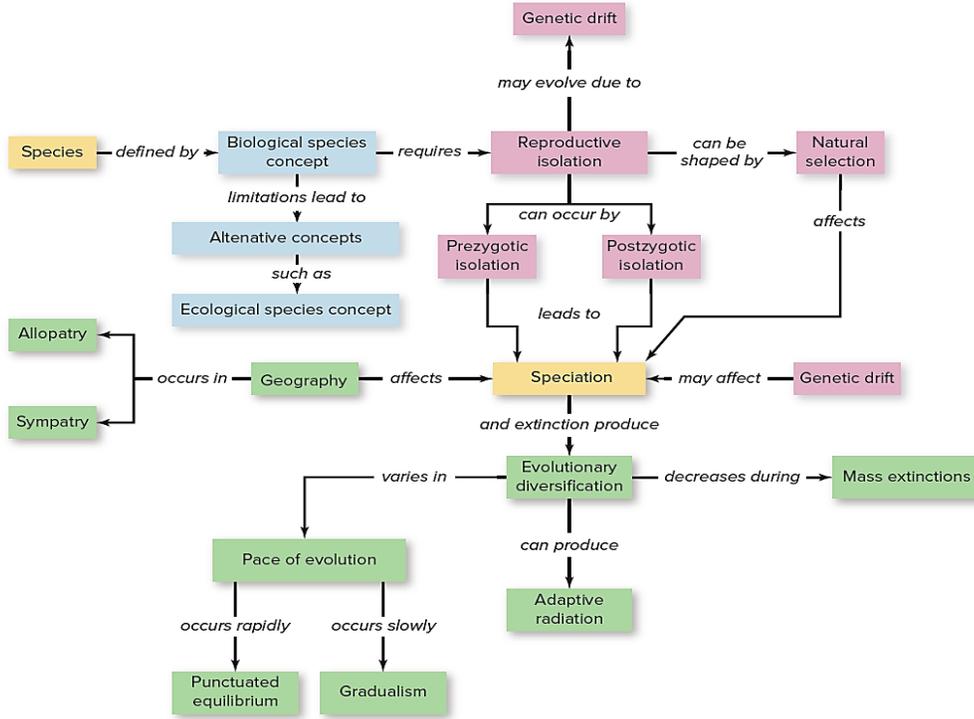
- **Hybrid Inviability:** Zygote fails to develop.
- **Hybrid Sterility:** Viable but sterile offspring (e.g., mule).
- **Hybrid Breakdown:** F₂ generation has reduced fitness.

C. Modes of Speciation

Mode	Geographic Context	Primary Mechanism	Examples	Frequency
Allopatric	Physical separation	Divergence in isolation	Galápagos finches; snapping shrimp	Most common

C. Evolutionary Biology Today

- **Robust Theory:** Supported by overwhelming evidence from multiple fields.



EVOLUTION: One-liners

- **Molecular Clocks:** Use constant mutation rates to **date evolutionary divergences**.
- **Pseudogenes:** Non-functional gene copies (e.g., vitamin C synthesis gene in primates).
- **Endogenous Retroviruses:** Identical viral DNA insertions in related species.
- **Gene Families:** Duplicated genes with related functions (e.g., hemoglobin genes).
- **Endemism on Islands:** Unique species on isolated islands indicate **adaptive radiation** (e.g., Galápagos tortoises).
- **Continental Drift Correlations:** Distribution matches geological history (e.g., marsupials mainly in Australia due to Gondwanan separation).
- **Disjunct Distributions:** Related species in separated regions (e.g., Southern beech *Nothofagus*).
- **Antibiotic resistance** in bacteria.
- **Industrial melanism** in peppered moths.
- **Beak size changes** in Galápagos finches during drought/rain cycles.
- **Life-history evolution** in guppies in response to predation.
- **Rapid evolution of HIV** within patients.
- **Punctuated Equilibrium (Eldredge & Gould):** Evolution occurs in rapid bursts of **speciation** followed by long periods of **stasis**.
- **Neutral Theory (Kimura):** Most molecular evolution is due to **genetic drift** of neutral mutations.
- **Evo-Devo (Evolutionary Developmental Biology):** Studies how changes in **developmental genes** (e.g., *Hox* genes) lead to morphological evolution.
- **Niche Construction:** Organisms modify their environments, creating **evolutionary feedback** (e.g., beaver dams).
- **Epigenetics:** Study of **heritable changes in gene expression** without DNA sequence change (e.g., DNA methylation).
- **Gene-Centered Selection (Richard Dawkins):** "Selfish gene" propagation.
- **Individual Selection:** Traditional Darwinian selection on individuals.
- **Kin Selection (W.D. Hamilton):** **Inclusive fitness** explains altruism (e.g., in social insects).
- **Group Selection (David S. Wilson):** Differential success of groups.
- Not all trends are progressive; they include **increasing complexity** (not universal), **increasing size** (Cope's Rule), **specialization**, and **adaptive radiation**.
- Five major events: **End-Ordovician, Late Devonian, End-Permian (the "Great Dying"), End-Triassic, and End-Cretaceous**.
- The **End-Cretaceous extinction** (66 mya) is associated with an **asteroid impact** and led to the demise of dinosaurs and the rise of mammals.
- A potential **sixth mass extinction** is currently driven by **human activity**.

Practice MCQs

1. What is the primary mechanism of evolution according to Darwin's theory?

- A) Inheritance of acquired characteristics
- B) Use and disuse of organs
- C) Natural selection
- D) Genetic drift

Answer: Natural selection

2. Which scientist first proposed a comprehensive theory of evolution based on the inheritance of acquired characteristics?

- A) Charles Darwin
- B) Alfred Russel Wallace
- C) Jean-Baptiste Lamarck

D) Gregor Mendel

Answer: Jean-Baptiste Lamarck

3. Structures that are similar in structure but different in function, indicating common ancestry, are called:

- A) Analogous structures
- B) Vestigial structures
- C) Homologous structures
- D) Convergent structures

Answer: Homologous structures

4. Which of the following is a condition required for Hardy-Weinberg equilibrium?

- A) Non-random mating



Chapter 8

Division of Plants

Kingdom Plantae (Embryophytes) represents multicellular, photosynthetic eukaryotes that have successfully colonized terrestrial environments. Modern classification follows a **phylogenetic system**, reflecting evolutionary relationships rather than mere morphological similarity. Plants evolved from **freshwater charophyte green algae** approximately 500 million years ago.

General Diagnostic Features Of Land Plants

- **Eukaryotic & Multicellular:** Composed of complex cells with membrane-bound organelles and true nuclei.
- **Autotrophic Nutrition:** Perform **photosynthesis** using chlorophylls *a* and *b* within chloroplasts. Storage product is **starch**.
- **Cell Wall:** Structural support provided by walls composed primarily of **cellulose**.
- **Cuticle:** A protective, **lipophilic, waxy layer** (containing cutin and waxes) covering aerial epidermal surfaces to minimize water loss.
- **Stomata (Sing. Stoma): Regulatable pores** flanked by guard cells that allow for gas exchange (CO₂ intake for photosynthesis, O₂ release) while controlling **transpirational water loss**.
- **Gametangia:** Multicellular organs that produce and protect gametes.
 - **Antheridium:** Produces numerous **flagellated sperm cells**.
 - **Archegonium:** A flask-shaped structure producing a single, non-motile **egg cell**.
- **Embryo Retention (Embryophytic Condition):** The defining plant trait. The **zygote develops into a multicellular diploid embryo** retained within and nourished by the maternal gametophyte tissue.
- **Alternation of Generations:** A life cycle with **multicellular haploid (gametophyte)** and **multicellular diploid (sporophyte)** phases.
 - **Gametophyte (n):** Develops from a spore. Produces **gametes via mitosis**.
 - **Sporophyte (2n):** Develops from the zygote. Produces **haploid spores via meiosis in sporangia**.
 - **Evolutionary Trend:** A progressive **reduction of the gametophyte and elaboration of the sporophyte**, correlating with increasing terrestriality.
- **Apical Meristems:** Localized regions of **perpetual embryonic cells** at root and shoot tips, enabling **primary growth** (extension) and complex tissue formation.
- **Secondary Metabolites:** Synthesis of diverse compounds (e.g., alkaloids, terpenes, phenolics) for defense against herbivores, pathogens, and UV radiation.

Classification of Kingdom Plantae

I. Non-Vascular Plants (Bryophytes)

- **Division: Bryophyta**
 - **Class: Hepaticae** (Liverworts) - e.g., *Marchantia*
 - **Class: Anthocerotae** (Hornworts) - e.g., *Anthoceros*
 - **Class: Musci** (Mosses) - e.g., *Funaria*

II. Vascular Plants (Tracheophyta)

A. Seedless Vascular Plants (Cryptogams)

- **Division: Pteridophyta** (Ferns & Allies)
 - **Class: Psilopsida** (Whisk ferns) - e.g., *Psilotum*
 - **Class: Lycopsidea** (Club mosses) - e.g., *Lycopodium, Selaginella*
 - **Class: Sphenopsida** (Horsetails) - e.g., *Equisetum*
 - **Class: Pteropsida** (True Ferns) - e.g., *Pteris, Adiantum*

B. Seed-Bearing Plants (Phanerogams/Spermatophytes)

- **Division: Gymnospermae** (Naked Seeds)

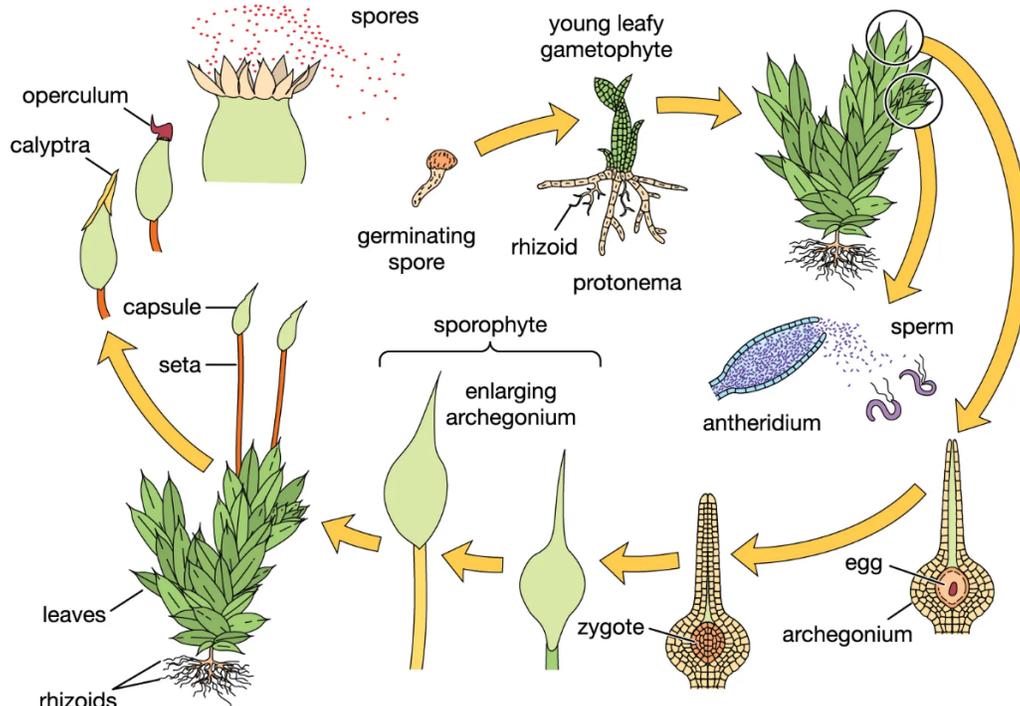
- **Class: Cycadopsida** (Cycads) - e.g., *Cycas*
- **Class: Coniferopsida** (Conifers) - e.g., *Pinus*
- **Class: Gnetopsida** (Gnetophytes) - e.g., *Gnetum*
- **Division: Angiospermae** (Flowering Plants, Enclosed Seeds)
 - **Class: Dicotyledonae** (Dicots) - 2 seed leaves; net-veined leaves
 - **Class: Monocotyledonae** (Monocots) - 1 seed leaf; parallel-veined leaves

BRYOPHYTA (NON-VASCULAR PLANTS)

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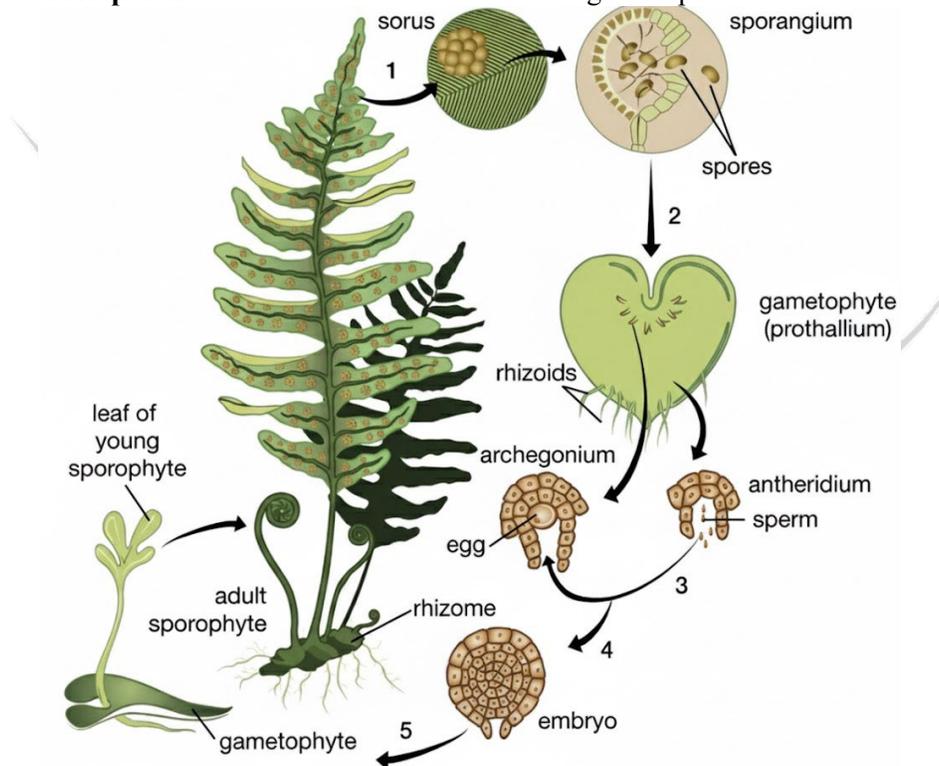
Bryophytes are a paraphyletic group representing the earliest diverging land plant lineages. They **lack true vascular tissue (xylem/phloem) and true roots, stems, and leaves**, though they may have analogous structures. They are **habitat-restricted** to moist environments due to **poikilohydric** nature (water content varies with environment) and require water for sperm motility. The **gametophyte is the dominant, persistent, photosynthetic phase**.



Feature	Mosses (Bryophyta)	Liverworts (Marchantiophyta)	Hornworts (Anthocerotophyta)
Gametophyte Form	Erect, "leafy" shoots (not true leaves). Multicellular rhizoids.	Thalloid (flat, ribbon-like, e.g., <i>Marchantia</i>) or leafy (two rows of leaves). Unicellular rhizoids.	Simple, thalloid . Cells contain a single large, plate-like chloroplast (algae-like).
Asexual Reproduction	Fragmentation.	Via gemmae cups producing discoid gemmae . Thallus branching.	Fragmentation.
Sporophyte Structure	Differentiated: Foot (absorption), Seta (stalk), Capsule (sporangium). Grows apically .	Differentiated: Foot , seta, capsule. In <i>Marchantia</i> , borne on archegoniophores . Ephemeral.	Elongated, horn-like, photosynthetic capsule . Grows from a basal intercalary meristem (indeterminat

8. Division of Plants

1. **Vascular Tissue:** Enables efficient long-distance transport.
 - **Xylem:** Conducts water and dissolved minerals **upward** from roots. Contains **tracheids** (all vascular plants) and/or **vessel elements** (angiosperms, gnetophytes); walls fortified with **lignin**.
 - **Phloem:** Conducts dissolved organic compounds **bidirectionally**. Contains **sieve tube elements with companion cells** (angiosperms) or **sieve cells** (other vascular plants).
2. **True Roots, Stems, and Leaves:** Provide anchorage, increase absorptive surface area, and enhance photosynthetic capacity.
3. **Evolution of Leaves:**
 - **Microphyll:** Small, with a **single, unbranched vascular trace**. Evolved from **enations**. Characteristic of **lycophytes**.
 - **Megaphyll:** Large, with **complex, branched venation**. Evolved via the "**Overtopping, Planation, Webbing**" model from a branched stem system. Characteristic of **ferns and seed plants**. Its evolution is linked to declining atmospheric CO₂ in the Late Paleozoic.



SEEDLESS VASCULAR PLANTS (PTERIDOPHYTES)

A paraphyletic group that reproduces via **water-dependent spores**, not seeds. They were the dominant flora during the Carboniferous period ("Coal Age").

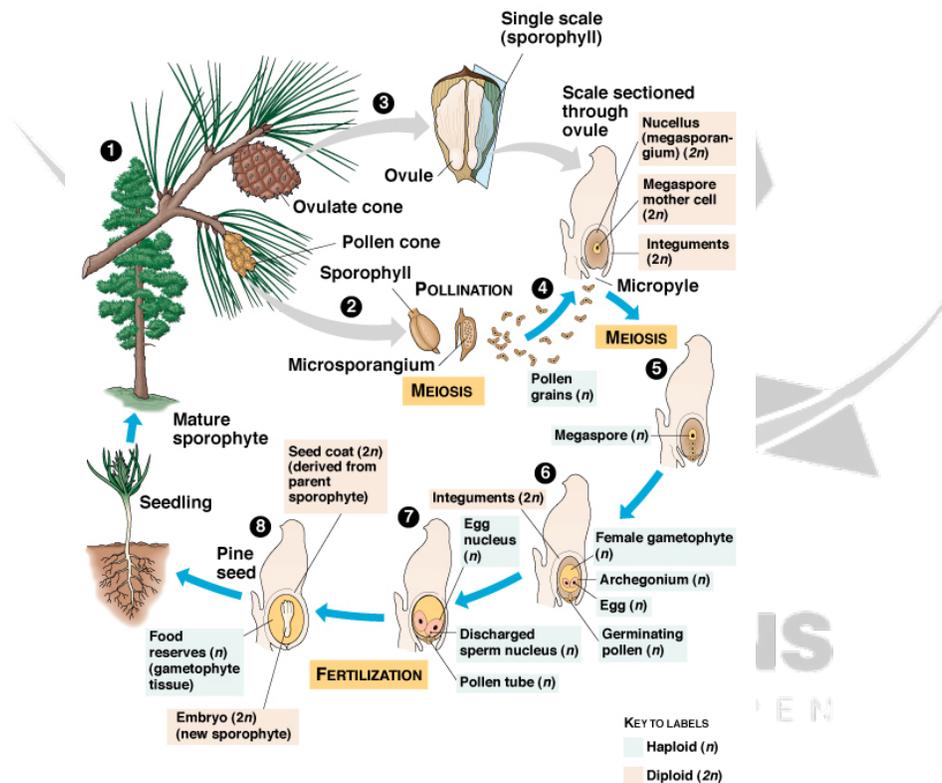
Major Clades of Seedless Vascular Plants

Group / Phylum	Sporophyte Characteristics	Reproductive Features	Key Examples & Notes
Lycophytes (Lycopodiophyta)	True roots, stems with microphylls .	Homosporous (e.g., <i>Lycopodium</i>) or heterosporous (e.g., <i>Selaginella</i>). Sporangia borne on sporophylls , often clustered into strobili (cones) .	<i>Lycopodium</i> (clubmoss), <i>Selaginella</i> (spikemoss). Ancient relatives (e.g., <i>Lepidodendron</i>) were giant trees forming Carboniferous coal.

- **Extreme Reduction of Gametophytes:** Microscopic, entirely dependent on and protected within the parental sporophyte (in cones or flowers).
- **Heterospory:** Universal.
- **Ovules:** The **integument** (protective layer) surrounds the megasporangium (**nucellus**), forming the ovule, which becomes a seed after fertilization. The opening is the **micropyle**.
- **Pollen Grains:** The male gametophyte, dispersed by wind or animals. Delivers sperm directly to the ovule via a **pollen tube**.
- **Seeds:** A dormant, dispersal-resistant structure containing: 1) An **embryo** (new sporophyte), 2) **Nutritive tissue** (female gametophyte in gymnosperms, endosperm in angiosperms), 3) A protective **seed coat** (from integuments).

GYMNOSPERMS (NAKED SEED PLANTS)

Gymnosperms have **ovules and seeds exposed** on the surface of sporophylls, usually aggregated into **cones**. They were dominant during the Mesozoic era.



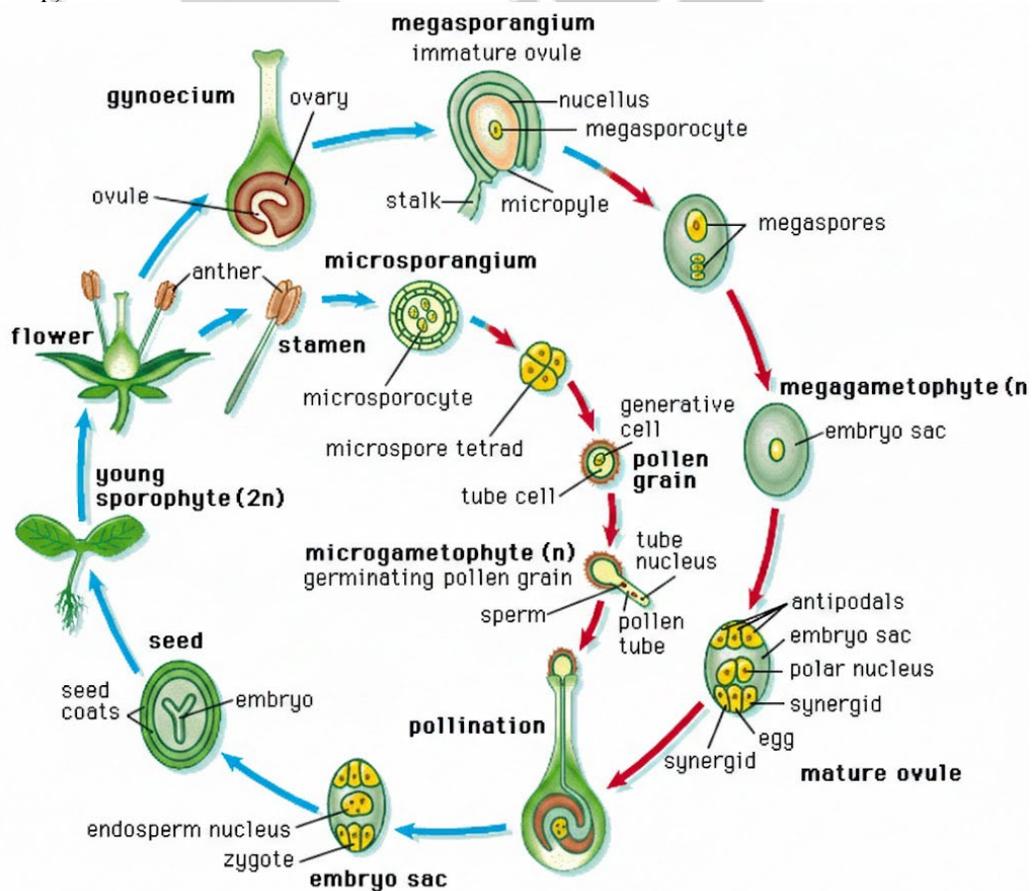
Overview of Extant Gymnosperm Phyla

Phylum	Morphology	Reproduction	Unique Traits & Examples
Coniferophyta (Conifers)	Mostly evergreen trees/shrubs. Leaves: needles or scales. Resin canals present.	Monoecious typically. Wind pollination. Non-motile sperm delivered via pollen tube .	Largest group (~630 spp.). Xylem has tracheids only (no vessels). Dominant in boreal forests. <i>Pinus</i> (pine), <i>Sequoia</i> (redwood).

- **Carpel:** Novel structure that **completely encloses the ovule(s)**. The basal ovary matures into a **fruit**.
- **Efficient Vascular System:** Xylem contains **vessel elements** (faster water flow); phloem contains **sieve tube elements with companion cells**.

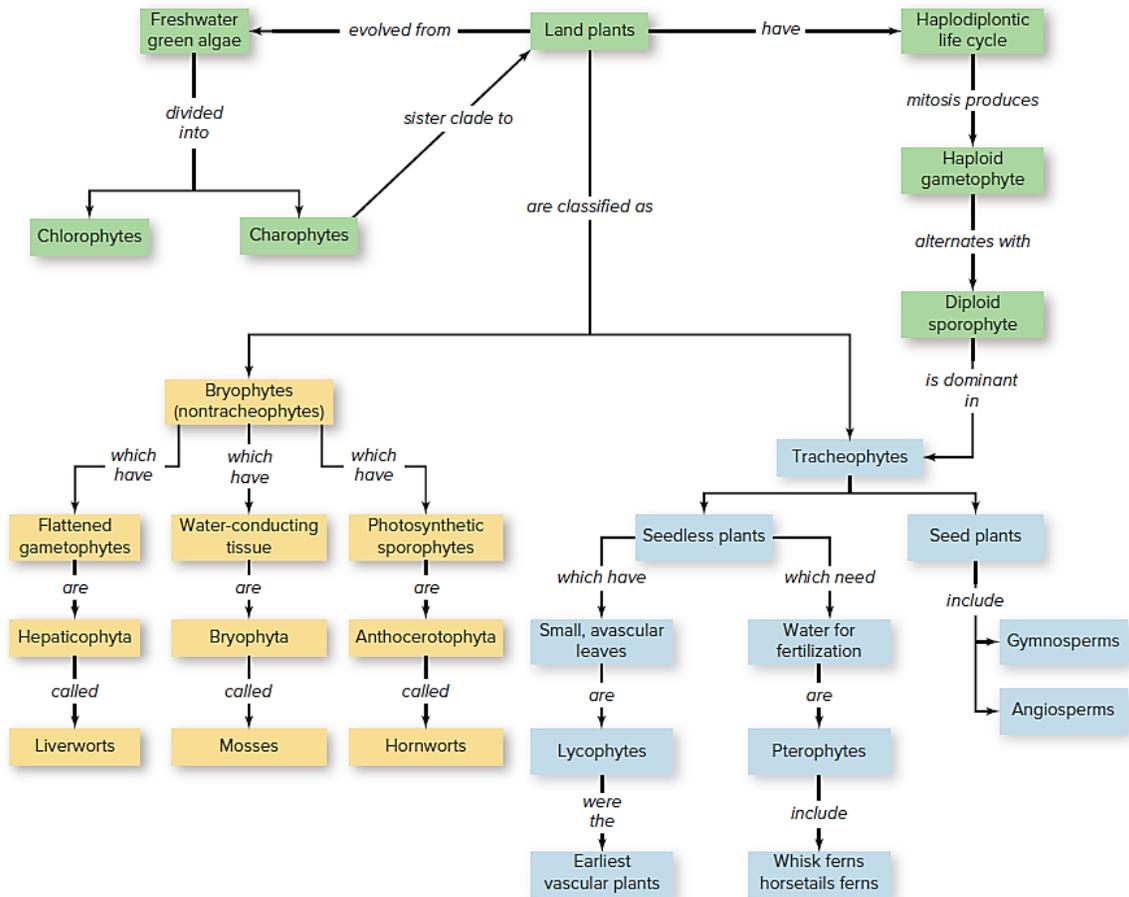
The Angiosperm Life Cycle:

1. **Male Gametophyte Development:** Microsporocyte ($2n$) in anther \rightarrow meiosis \rightarrow 4 microspores (n) \rightarrow mitosis \rightarrow **2-celled pollen grain (Vegetative cell + Generative cell)**.
2. **Female Gametophyte (Embryo Sac) Development:** Megasporocyte ($2n$) in ovule \rightarrow meiosis \rightarrow 4 megaspores (3 degenerate). Functional megaspore undergoes 3 mitoses \rightarrow **8-nucleate, 7-celled embryo sac** (Polygonum type): Egg apparatus (1 egg + 2 synergids), Central cell (2 polar nuclei), 3 antipodal cells.
3. **Pollination & Pollen Tube Growth:** Pollen lands on stigma. Generative cell divides into **two sperm**. Pollen tube grows down style to ovule.
4. **Double Fertilization:**
 - One sperm fuses with **egg** \rightarrow diploid **zygote**.
 - Other sperm fuses with **two polar nuclei** \rightarrow triploid **primary endosperm nucleus** \rightarrow **endosperm**.
5. **Seed & Fruit Development:** Ovule \rightarrow seed (embryo + endosperm + seed coat). Ovary wall (pericarp) \rightarrow **fruit**.



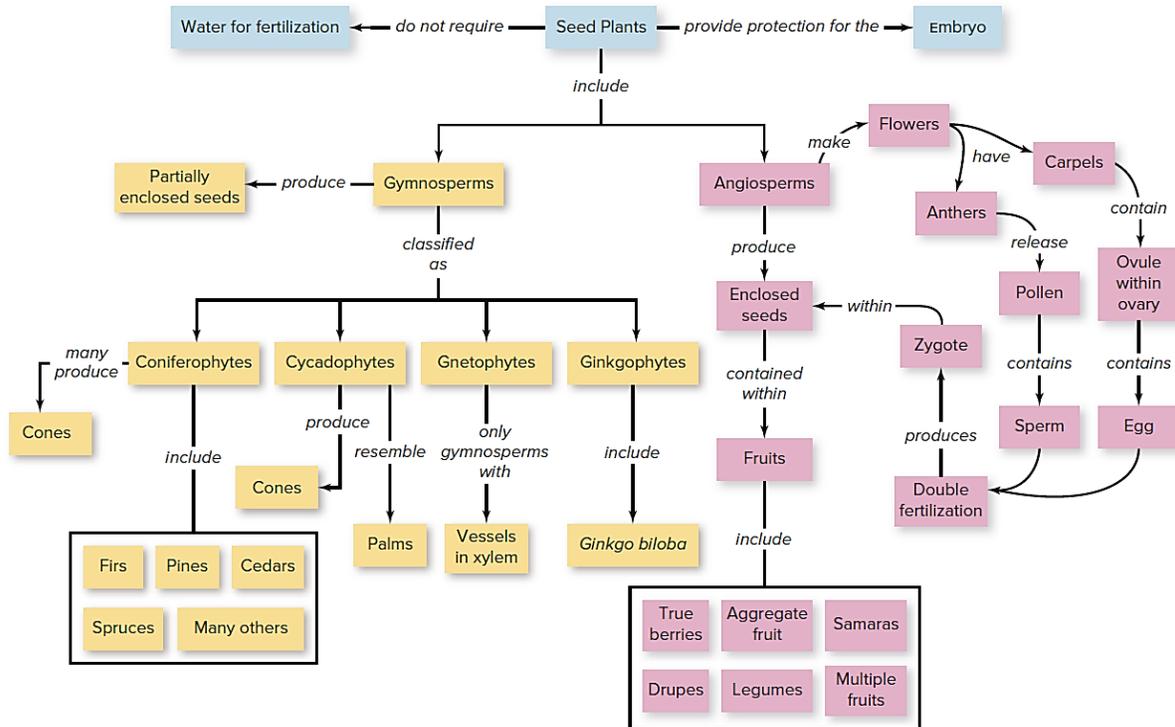
Angiosperm Phylogeny & Major Clades:

- **Basal Angiosperms (ANA Grade):** *Amborella trichopoda* (sister to all others), Nymphaeales (water lilies), Austrobaileyales.



8. Division of Plants





8. Division of Plants

MK PREPARATIONS

Practice MCQs

1. Which modern system of classification reflects evolutionary relationships among plants?

- A) Artificial system
- B) Natural system
- C) Phylogenetic system
- D) Linnaean system

Answer: Phylogenetic system

2. Plants are believed to have evolved from which group of algae?

- A) Rhodophyceae
- B) Phaeophyceae
- C) Charophyceae (Zygnematophyceae)
- D) Chlorophyceae

Answer: Charophyceae (Zygnematophyceae)

3. What is the primary storage product in plants?

- A) Glycogen
- B) Cellulose
- C) Starch
- D) Lipids

Answer: Starch

4. Which structure minimizes water loss in land plants by covering aerial epidermal

surfaces?

- A) Stomata
- B) Cuticle
- C) Lenticels
- D) Hydathodes

Answer: Cuticle

5. Regulatable pores flanked by guard cells that facilitate gas exchange are called?

- A) Hydathodes
- B) Lenticels
- C) Stomata
- D) Trichomes

Answer: Stomata

6. The multicellular organ that produces and protects the egg in plants is the?

- A) Antheridium
- B) Archegonium
- C) Sporangium
- D) Gametangium

Answer: Archegonium

7. The defining trait of embryophytes is?

- A) Presence of vascular tissue
- B) Retention of the multicellular embryo
- C) Dominant sporophyte generation



Chapter 9

BRYOPHYTES

General Characteristics of Bryophytes

I. Definition & Taxonomic Position

- **Bryophytes** are small, non-vascular, photosynthetic land plants.
- Represent the **oldest living lineage** of land plants (embryophytes), evolving from charophyte algae.
- **Three divisions**: **Bryophyta** (mosses), **Marchantiophyta** (liverworts), **Anthocerotophyta** (hornworts).
- Occupy a **transitional position** between aquatic algae and vascular land plants.

II. Habitat & Distribution

- **Primarily terrestrial** but require moisture for reproduction and often for survival.
- Found in **damp, shaded environments**: forests, riverbanks, rocks, soil, tree bark.
- Some tolerate **extreme environments**: arctic tundra, deserts (in dormant state), high altitudes.
- **Cosmopolitan distribution**, but diversity highest in humid tropical and temperate regions.
- **Ecological indicators** of air/water quality and soil conditions.

III. Morphological Characteristics

A. Plant Body

- **Thalloid or leafy structure**; lack true roots, stems, or leaves (vascular tissues absent).
- **Gametophyte dominant**: photosynthetic, independent, long-lived phase.
- **Sporophyte dependent** on gametophyte for nutrition, short-lived.
- **Rhizoids**: root-like unicellular (liverworts, hornworts) or multicellular (mosses) filaments for anchorage & absorption.
- **Leaves**: usually one cell thick (except midrib), no cuticle or stomata in many liverworts; mosses often have midrib and stomata on sporophyte.
- **No lignin** (except some support cells in moss sporophytes).

B. Size

- Generally small: a few mm to 10–20 cm tall.
- Largest mosses (e.g., *Dawsonia*) can reach ~50 cm.

IV. Reproductive Characteristics

A. Life Cycle – Heteromorphic Alternation of Generations

1. **Dominant Gametophyte (n)**:
 - Produces **gametangia**: **antheridia** (male, produce sperm) & **archegonia** (female, produce egg).
 - **Sperm biflagellate**, require water film to swim to archegonium.
 - Fertilization forms **zygote (2n)**.
2. **Dependent Sporophyte (2n)**:
 - Zygote develops into **embryo** → mature sporophyte (foot, seta, capsule).
 - **Capsule (sporangium)** produces **haploid spores** via meiosis.
 - Spores dispersed by wind/water → germinate into **protonema** (filamentous juvenile stage) → mature gametophyte.

B. Asexual Reproduction

- **Fragmentation** of gametophyte.
- **Gemmae**: multicellular asexual buds in gemma cups (e.g., *Marchantia*).
- **Tubers, stolons**.

Classification of Bryophytes

Hierarchical Classification (Traditional System)

The traditional classification divides bryophytes into three distinct classes, now often treated as separate phyla in modern systems.

MK PREPARATIONS: Let's Make It Happen

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- **Meiosis:** Each spore mother cell undergoes meiosis to produce a **tetrad of four haploid spores**.
- **Columella:** A central sterile column of cells that helps in nutrient conduction and gives structural support.

E. Spore Dispersal: The Peristome Mechanism

Funaria lacks elaters. Instead, it has a sophisticated **peristome** mechanism for controlled spore release.

1. Dehiscence:

- At maturity, the capsule dries. The **operculum** detaches along a specialized ring of cells called the **annulus**.
- This exposes the **peristome**, a ring of tooth-like structures at the capsule mouth.

2. Peristome Action (Hygroscopic):

- *Funaria* has a **double peristome**.
- **Exostome (16 teeth):** The outer teeth are highly **hygroscopic**. They bend inward (close) in humid air to block the pore and outward (open) in dry air.
- **Endostome:** A delicate, membranous inner ring.
- This hygroscopic movement acts like a **salt-shaker mechanism**, allowing spores to be ejected only during dry, windy conditions optimal for long-distance dispersal.

F. Germination & New Gametophyte

- A dispersed haploid spore lands in a suitable damp habitat.
- Under favorable conditions, it germinates to form a **branched, filamentous chloronema** (rich in chloroplasts).
- The chloronema gives rise to **caulonemal filaments** and eventually produces **buds**.
- Each bud develops an apical cell and grows into the familiar **leafy gametophore**, thus completing the cycle.

Polytrichum (Haircap Moss)

1. Scientific Classification

- **Division:** Bryophyta (Mosses)
- **Genus:** *Polytrichum*

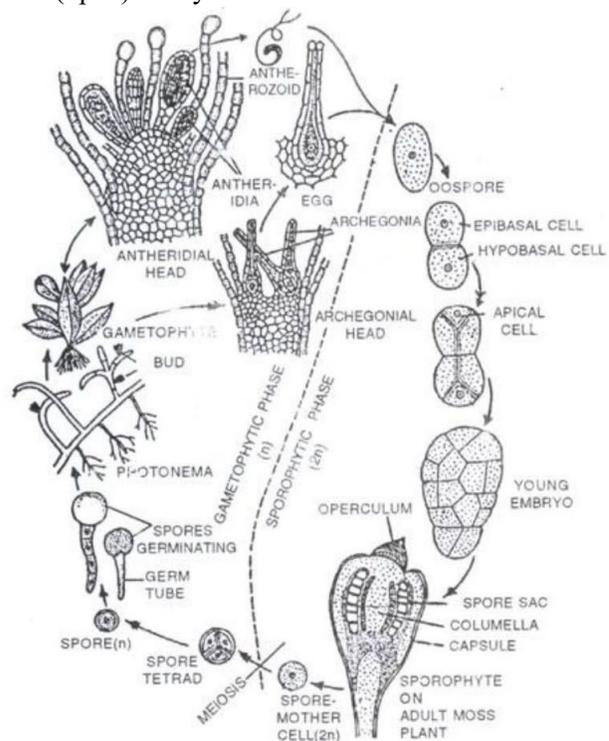
2. Occurrence & Habitat

- **Typical habitats:**
 - **Acidic, nutrient-poor soils:** Heaths, moors, coniferous forests.
 - **Damp, shaded areas:** But some species tolerate dry, exposed sites (e.g., *P. piliferum* on sandy soils).
 - **Bog edges, wet grasslands, decaying wood.**

3. Plant Body Structure

A. Gametophyte Morphology

- **Erect, leafy shoots** (gametophores) arising from **protonemal system**.
- **Stem:**
 - Upright, 5–30 cm tall (up to 50 cm in *P. commune*), unbranched or sparsely branched.
 - Covered with **rhizoids** at base (multicellular, branched, reddish-brown).
- **Leaves:**
 - **Arrangement:** Spirally arranged, dense, stiff.



- **Pseudoelaters:** Mixed with the spores are sterile, **non-hygroscopic, often branched, multicellular filaments** called **pseudoelaters**. They help **loosen the spore mass** but do NOT have the spiral thickenings or hygroscopic movements of true liverwort elaters.

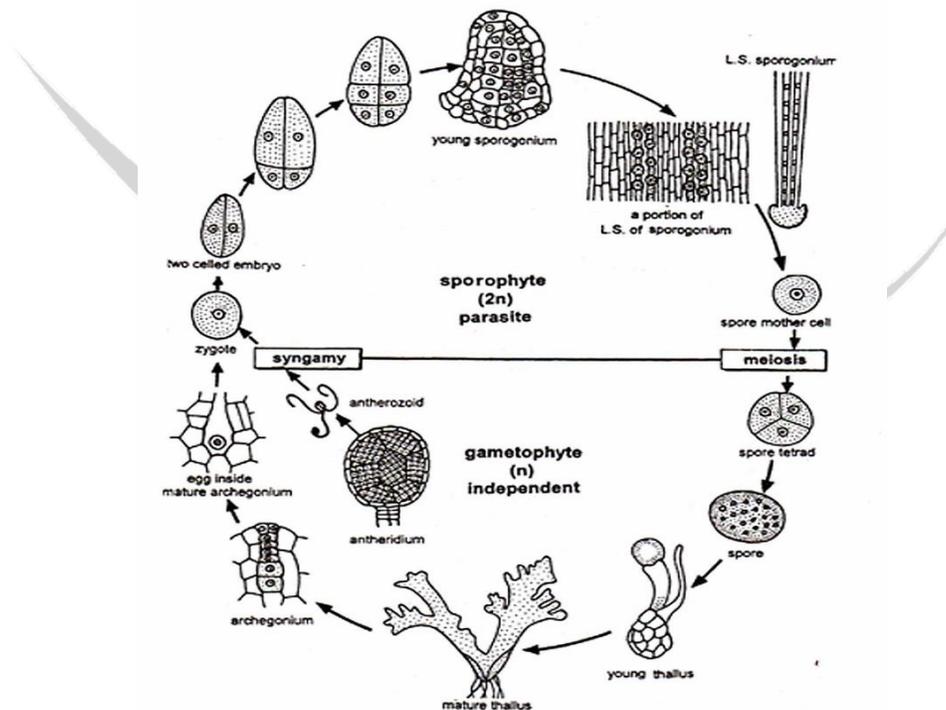
2. Dehiscence (Spore Release):

- As the capsule matures from the tip downward, it dries out.
- It splits longitudinally from the apex into **two valves (sometimes four)**, resembling opening a pea pod.
- The twisting of the drying valves, aided by the loose spore mass containing pseudoelaters, allows **spores to be gradually shaken out by wind**.
- The basal meristem continues to produce new capsule tissue above, so spore release is a **continuous process** over the life of the sporophyte.

E. Germination & New Gametophyte

- The haploid spore germinates under favorable moist conditions.
- It produces a small, initial filament that quickly develops into the **thalloid gametophyte** with a single apical cell, completing the cycle.

LIFE CYCLE



Comparative Table of Bryophyte Genera

Feature	<i>Riccia</i> (Liverwort)	<i>Marchantia</i> (Liverwort)	<i>Porella</i> (Leafy Liverwort)
1. Scientific Classification	Phylum: Marchantiophyta Class: Marchantiopsida Order: Marchantiales Family: Ricciaceae	Phylum: Marchantiophyta Class: Marchantiopsida Order: Marchantiales Family: Marchantiaceae	Phylum: Marchantiophyta Class: Jungermanniopsida Order: Porellales Family: Porellaceae
2. Gametophyte Form	Simple thalloid, dichotomously branched, rosette-like, dorsal groove. No	Complex thalloid, dichotomously branched, with dorsal air pores and ventral scales. Distinct air	Leafy (Foliose), dorsiventral, creeping. Leaves in 3 rows (2 lateral, 1 ventral -

9. Special / Unique Features	<ul style="list-style-type: none"> - Model organism for bryology. - Asymmetric, nodding capsule. - Calyptra is hairy and hood-shaped. 	<ul style="list-style-type: none"> - Lamellae on leaves (like mini-ridges) enhance photosynthesis. - Vascular-like conducting tissues (hydroids & leptoids). - Epiphragm for controlled spore dispersal. 	<ul style="list-style-type: none"> - Single chloroplast with pyrenoid per cell. - Symbiosis with Nostoc. - Basal meristem in sporophyte. - Stomata on sporophyte. - Pseudoelaters instead of true elaters.
10. Common Habitat	Pioneer on disturbed, nitrogen-rich soils (e.g., burnt ground, gardens).	Acidic, poor soils (heaths, bogs, forests), well-drained sites.	Damp, shaded, often disturbed clay or garden soils.

Practice MCQs

1. The dominant phase in the bryophyte life cycle is:

- A. Sporophyte
- B. Gametophyte
- C. Zygote
- D. Protonema

Answer: B

2. Which of these is NOT a bryophyte?

- A. *Marchantia*
- B. *Funaria*
- C. *Equisetum*
- D. *Sphagnum*

Answer: C

3. The plant body of bryophytes is:

- A. Always a thallus
- B. Differentiated into roots, stems and leaves
- C. Either thalloid or foliose but lacks true roots
- D. Always a leafy shoot

Answer: C

4. Bryophytes are called "amphibians of plant kingdom" because:

- A. They live in water
- B. They need water for fertilization
- C. They have flagellated sperms
- D. Both B and C

Answer: D

5. Which structure is responsible for attachment in bryophytes?

- A. True roots
- B. Rhizoids
- C. Holdfasts
- D. Stolons

Answer: B

6. In bryophytes, the sporophyte is:

- A. Independent and dominant
- B. Partially parasitic on gametophyte

C. Completely parasitic on gametophyte

D. Short-lived and free-living

Answer: C

7. The male sex organ in bryophytes is called:

- A. Archegonium
- B. Antheridium
- C. Oogonium
- D. Sporangium

Answer: B

8. The female sex organ in bryophytes is called:

- A. Archegonium
- B. Antheridium
- C. Oogonium
- D. Carpel

Answer: A

9. Which of these bryophytes has the simplest sporophyte?

- A. *Marchantia*
- B. *Funaria*
- C. *Riccia*
- D. *Anthoceros*

Answer: C

10. In *Riccia*, the sporophyte consists of:

- A. Foot, seta and capsule
- B. Capsule only
- C. Foot and capsule
- D. Seta and capsule

Answer: B

11. Elaters are found in the capsule of:

- A. *Funaria*
- B. *Marchantia*
- C. *Sphagnum*
- D. All mosses

Answer: B



Chapter 10

Pteridophytes

Pteridophytes are vascular, cryptogamic (spore-producing) plants that represent a crucial evolutionary link between bryophytes (non-vascular plants) and spermatophytes (seed plants). They are often called "vascular cryptogams."

1. Plant Body:

- **Sporophyte Generation is Dominant:** Unlike bryophytes, the independent, photosynthetic, and conspicuous plant body is the diploid sporophyte. It is the dominant phase in the life cycle.
- **Differentiation:** The plant body is well-differentiated into true **roots, stem, and leaves**.
- **Habit:** Most are herbaceous perennials. A few (e.g., tree ferns like *Cyathea*) are arboreal.

2. Vascular System:

- They possess a well-developed **vascular tissue system** (xylem and phloem) for conduction of water, minerals, and food.
- **Xylem:** Typically consists of **tracheids** (vessel elements are generally absent). In some groups (e.g., *Selaginella*), vessels may be present.
- **Phloem:** Composed of sieve cells.
- **Stele Types:** The arrangement of vascular tissues (the stele) varies and is an important taxonomic character. Types include:
 - **Protostele** (Solid core of xylem surrounded by phloem; e.g., *Rhynia*, *Lycopodium*)
 - **Siphonostele** (Vascular tube with a central pith; e.g., many ferns)
 - **Dictyostele** (Dissected siphonostele forming a network of vascular bundles; e.g., most ferns)

3. Leaves:

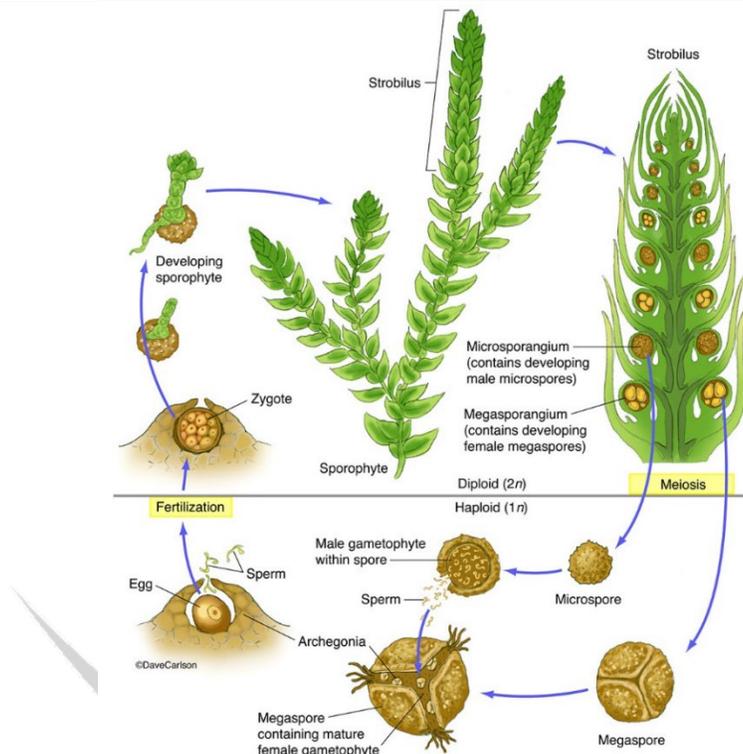
- Leaves are called **fronds**, especially in ferns.
- Two main evolutionary types exist (detailed in Section III):
 - **Microphylls:** Small, simple leaves with a single, unbranched vein. **Ligule** present in some (e.g., *Selaginella*, *Isoetes*).
 - **Megaphylls:** Large, complex leaves with branched vascular supply (veins forming a network or pattern).

4. Spore Production:

- Spores are produced inside **sporangia**.
- Sporangia are borne on leaves, which are then called **sporophylls**.
- Sporophylls may be:
 - **Similar to vegetative leaves** (homosporous ferns).
 - **Aggregated into a compact structure** called a **strobilus** or cone (e.g., *Lycopodium*, *Selaginella*, *Equisetum*).
- **Homospory vs. Heterospory:**
 - **Homosporous:** Produce only one type of spore (e.g., *Lycopodium*, most ferns). Spores germinate into bisexual gametophytes.
 - **Heterosporous:** Produce two distinct types of spores—**microspores** (male) and **megaspores** (female)—in microsporangia and megasporangia respectively (e.g., *Selaginella*, *Isoetes*, *Salvinia*, *Marsilea*). Spores germinate into unisexual gametophytes.

5. Gametophyte Generation:

- The spore germinates to form a haploid, independent **gametophyte** called a **prothallus**.
- It is small, thalloid, and short-lived.
- It bears the sex organs: **antheridia** (male) and **archegonia** (female).



5. Detailed Structure of the Sporophyte

A. External Morphology:

- The plant body is clearly differentiated into **stem, leaves, rhizophores, and roots**.
- The branching is typically **dichotomous**.
- Leaves are **microphylls** (with a single vein) and exhibit **anisophylly** (dimorphism: dorsal vs. ventral).
- The **ligule** is a secretory structure, possibly preventing desiccation of the developing sporangium.
- **Strobili** are compact, borne terminally, and consist of spirally arranged sporophylls.

Sphenopsida (Horsetails)

I. Introduction & Evolutionary Significance

- **Sphenopsida** (or Equisetopsida) is a **class of vascular cryptogams** within the division Monilophyta (ferns and allies).

II. General Characteristics

1. Sporophyte Plant Body:

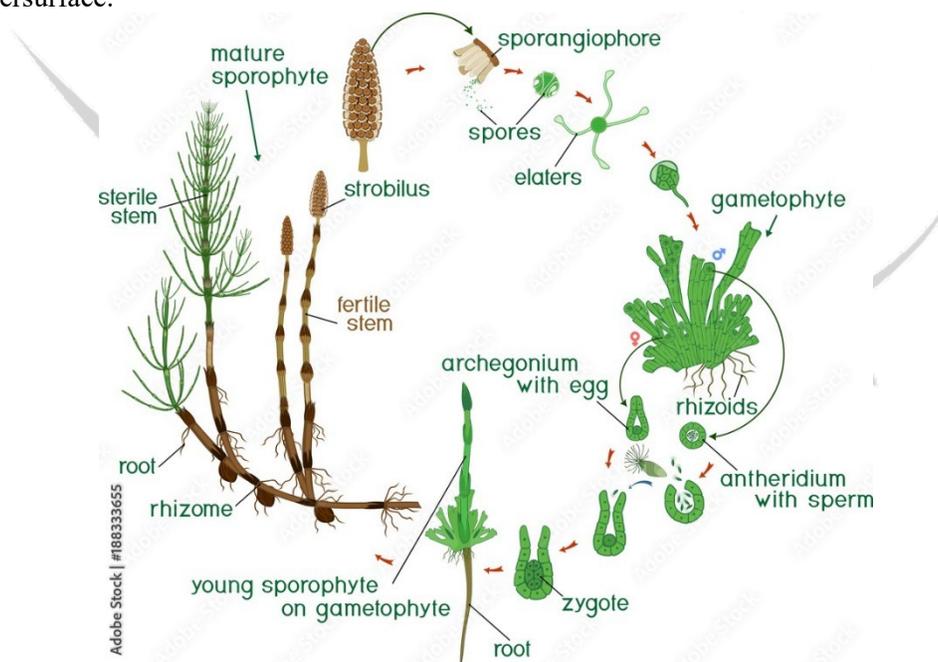
- **Stems:** The most conspicuous part.
 - **Hollow, jointed, and ridged** (with longitudinal ridges and grooves).
 - **Nodes and Internodes:** Clearly differentiated. Nodes are solid, bearing whorls of leaves and branches.
 - **Silica Deposits:** Epidermal cells are heavily impregnated with **silica**, making the stems abrasive (used for scouring).
- **Leaves:** **Microphyllous**, but highly reduced. They are small, scale-like, and form a **whorl (collar) at each node**, fused into a sheath at the base.
- **Roots:** Adventitious roots arise from the nodes of the underground rhizome.
- **Vascular Anatomy:** **Eustelic**. The vascular bundles are arranged in a ring. At each node, the bundles fuse and then re-divide, forming a **nodal canal**. The central cavity is called the **carinal canal** (related to the vascular bundle) and larger **vallecular canals** (in the cortex).

- **Antheridia** produce multiflagellate **spermatozoids**.
 - **Archegonia** have a neck and contain a single egg cell.
3. **Fertilization:** Requires water for the sperm to swim to the archegonium. The fertilized egg forms a diploid **zygote**.
 4. **Embryogeny:** The zygote develops into an embryo and then a new **sporophyte**, which initially depends on the gametophyte.

5. Detailed Structure of the Sporophyte

A. External Morphology:

- Exhibits clear **differentiation into nodes and internodes**.
- Two forms of shoots may exist in some species (e.g., *E. arvense*):
 - **Fertile Shoot:** Non-photosynthetic, flesh-colored or brown, ephemeral, bearing a terminal strobilus. Appears in early spring.
 - **Vegetative Shoot:** Green, photosynthetic, highly branched, and appears after the fertile shoot.
- The **strobilus** is a compact cone consisting of a central axis with whorls of peltate **sporangiophores** (not sporophylls). Each sporangiophore bears 5-10 sporangia on its undersurface.



Pteropsida (Ferns - The Largest Group of Vascular Cryptogams)

I. Introduction & Taxonomic Context

- **Pteropsida** is a traditional class within Pteridophyta that includes **ferns and their immediate allies**.

II. General Characteristics (Defining Features)

1. Sporophyte Plant Body:

- **Well-differentiated** into true **roots, stems (rhizomes), and leaves**.
- **Stems:** Mostly **rhizomatous** (horizontal, underground). In tree ferns, the stem is an erect, aerial trunk. Vascular tissue is complex.
- **Leaves: Megaphylls (fronds)** – large, pinnately compound leaves with **branched venation** and a **leaf gap** in the stele. Young leaves exhibit **circinate venation** (coiled like a fiddlehead, a key diagnostic feature).

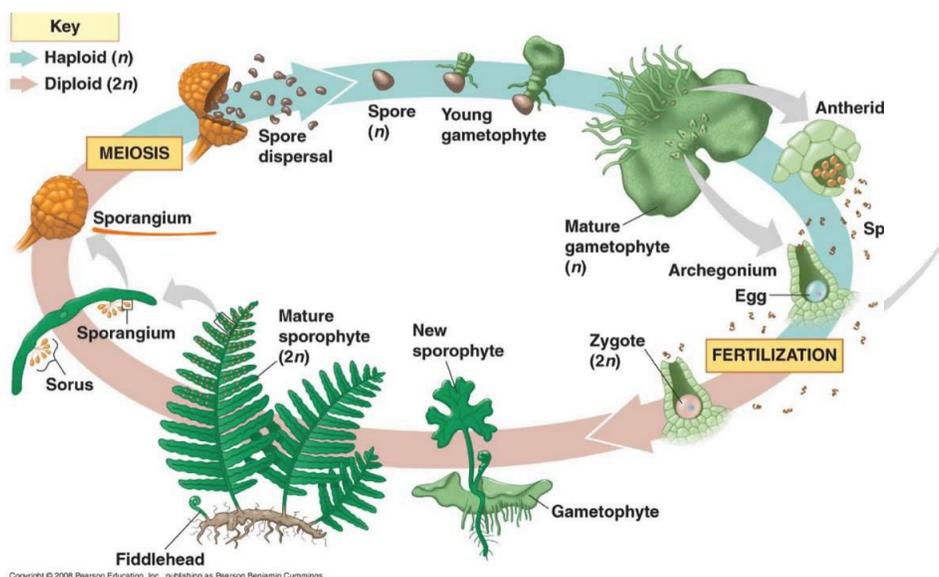
4. **Dispersal:** Sporangia dehisce via a vertical, complete **annulus** that functions as a catapult. The exposed, naked sori often appear as bright orange or yellow dots on the undersides of the fronds at maturity.

B. Sexual Reproduction (via Gametophytes):

1. **Gametophyte:** The spore germinates to form a green, photosynthetic, heart-shaped **prothallus**.
2. **Sex Organs:** The prothallus is monoecious, bearing both **archegonia** (near the notch) and **antheridia** (among the rhizoids posteriorly).
3. **Fertilization:** Requires water for the multiflagellate sperm to reach the archegonium, forming a diploid **zygote**.
4. **Embryogeny:** The zygote develops into a new **sporophyte** embryo, which initially depends on the gametophyte. The first leaf of the young sporophyte is usually non-lobed and simple, unlike the mature leaves.

5. Structure of the Sporophyte

Characterized by the **scaly, creeping rhizome** and fronds that are often **moderately thick and leathery**. The **naked, round sori** arranged in rows are the most diagnostic feature.



Comparative Table of Pteridophyte Genera: *Psilotum*, *Selaginella*, *Equisetum*, *Adiantum*, *Polypodium*, and *Marsilea*

Feature	<i>Psilotum</i> (Whisk Fern)	<i>Selaginella</i> (Spine Moss)	<i>Equisetum</i> (Horsetail)	<i>Adiantum</i> (Maidenhair Fern)	<i>Polypodium</i> (Polypody)	<i>Marsilea</i> (Water Clover)
1. Classification	Order: Psilotales Family: Psilotaceae	Order: Selaginellales Family: Selaginellaceae	Order: Equisetales Family: Equisetaceae	Order: Polypodiales Family: Pteridaceae	Order: Polypodiales Family: Polypodiaceae	Order: Salviniales Family: Marsileaceae
2. Habitat & Occurrence	Epiphytic or lithophytic; tropical/subtropical	Terrestrial, moist shaded forests; some xerophytic.	Damp, wet soils; cosmopolitan, temperate zones.	Moist, shaded rocks/ravines; cosmopolitan	Epiphytic or lithophytic; tropical to temperate.	Semi-aquatic/amphibious; edges of water bodies.
3. Plant Body (Sporophyte)	Roots: Absent (rhizoids). Stem: Aerial, dichotomously branched, green.	Roots: Present (from rhizophores). Stem: Dichotomous, dorsiventral.	Roots: Present (from rhizome). Stem: Jointed, hollow, ridged,	Roots: Present. Rhizome: Short/long creeping.	Roots: Present. Rhizome: Long, creeping, scaly.	Roots: Present. Rhizome: Creeping, slender. Leaves: Quadri-lobed.



Practice MCQs

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1. Pteridophytes are also known as:

- A. Flowering plants
- B. Vascular cryptogams
- C. Non-vascular cryptogams
- D. Seed plants

Answer: B

2. The dominant generation in pteridophytes is:

- A. Gametophyte
- B. Sporophyte
- C. Both equally dominant
- D. Zygote

Answer: B

3. Which of these is NOT a pteridophyte?

- A. *Selaginella*
- B. *Equisetum*
- C. *Dryopteris*
- D. *Cycas*

Answer: D

4. The leaves bearing sporangia are called:

- A. Sporophylls
- B. Microphylls
- C. Megaphylls
- D. Fronds

Answer: A

5. Circinate vernation is found in:

- A. *Selaginella*
- B. *Equisetum*
- C. Ferns
- D. *Psilotum*

Answer: C

6. Heterospory is found in:

- A. *Lycopodium*
- B. *Equisetum*
- C. *Selaginella*
- D. *Psilotum*

Answer: C

7. Which pteridophyte is commonly called "horsetail"?

- A. *Selaginella*
- B. *Equisetum*
- C. *Dryopteris*
- D. *Marsilea*

Answer: B

8. The stele type found in fern rhizomes is:

- A. Protostele
- B. Siphonostele
- C. Dictyostele

D. Eustele

Answer: C

9. The gametophyte of pteridophytes is called:

- A. Protonema
- B. Prothallus
- C. Thallus
- D. Mycelium

Answer: B

10. Water is essential in pteridophytes for:

- A. Photosynthesis
- B. Fertilization
- C. Spore dispersal
- D. Vegetative growth

Answer: B

11. Groups of sporangia on fern leaves are called:

- A. Strobili
- B. Sori
- C. Sporocarps
- D. Cones

Answer: B

12. The protective covering over sorus is:

- A. Annulus
- B. Indusium
- C. Stomium
- D. Operculum

Answer: B

13. Which aquatic fern has nitrogen-fixing cyanobacteria?

- A. *Salvinia*
- B. *Marsilea*
- C. *Azolla*
- D. *Isoetes*

Answer: C

14. *Selaginella* shows:

- A. Homospory
- B. Heterospory
- C. Isospory
- D. Seed formation

Answer: B

15. The sporangium development from a single initial cell is called:

- A. Eusporangiate
- B. Leptosporangiate
- C. Protosporangiate
- D. Endosporangiate

Answer: B



Chapter 11

Gymnosperms

Gymnosperms (from the Greek: *gymnos* = naked, *sperma* = seed) are a group of seed-producing plants that constitute one of the two major clades of seed plants, the other being the Angiosperms (flowering plants). They are known as "**naked seed plants**" because their seeds are not enclosed within a fruit or ovary wall; instead, they are typically borne on the surface of scales or leaves, often arranged in cones (strobili).

Evolutionary Significance:

- Gymnosperms first appeared in the late **Carboniferous Period** (around 319 million years ago) and became the dominant terrestrial plants during the **Mesozoic Era** (the "Age of Conifers" and Cycads).
- They represent a critical evolutionary advancement over the pteridophytes (ferns and allies) due to the development of the **seed**. The seed, containing an embryonic plant with stored food and a protective coat, was a key adaptation for survival in terrestrial environments, enabling colonization of drier habitats.
- They were the first plants to develop **pollen** for male gamete transfer, eliminating the need for free water for fertilization—a major limitation for ferns and mosses.

Diversity and Living Groups:

Modern gymnosperms are not as diverse as angiosperms but are ecologically and economically vital.

They are represented by four main living groups:

1. **Coniferophyta (Conifers):** The largest and most familiar group (e.g., pines, firs, spruces, cedars, redwoods).
2. **Cycadophyta (Cycads):** Palm-like plants of tropical and subtropical regions (e.g., *Cycas*).
3. **Ginkgophyta:** Represented by a single living species, *Ginkgo biloba* (maidenhair tree).
4. **Gnetophyta:** A small but evolutionarily interesting group with three distinct genera (*Gnetum*, *Welwitschia*, *Ephedra*).

2. General Characters

A. Vegetative (Sporophytic) Characters:

1. **Habit:** Mostly perennial, evergreen woody trees or shrubs. Rarely, they are lianas (e.g., *Gnetum*) or bizarre, turnip-like plants (*Welwitschia*).
2. **Root System:** A well-developed **tap root system**. Roots are often infected with symbiotic fungi, forming **mycorrhizae** (essential for conifers) or, in cycads, with nitrogen-fixing cyanobacteria.
3. **Stem:** Erect, branched (monopodial in conifers) or unbranched (in cycads), and woody. Possess **secondary growth** due to a well-developed vascular cambium, producing abundant secondary xylem (wood). The wood is typically **non-porous** (lacking vessel elements in most groups; tracheids conduct water) and is therefore often called "softwood."
4. **Leaves:** Show great variation.
 - **Conifers:** Leaves are simple, often needle-like (e.g., pine), scale-like (e.g., cypress), or strap-shaped (e.g., *Araucaria*). They are adapted to reduce water loss (xerophytic)—thick cuticle, sunken stomata.
 - **Cycads:** Large, compound pinnate leaves in a crown at the apex.
 - **Ginkgo:** Unique, fan-shaped, deciduous leaves with dichotomous venation.
 - **Gnetophytes:** *Gnetum* has broad, angiosperm-like leaves; *Ephedra* has scale-like leaves.

B. Reproductive Characters:

1. **Heterosporous:** They produce two distinct types of spores:
 - **Microspores:** Formed in **microsporangia** on **microsporophylls**. Develop into the male gametophyte (pollen grain).
 - **Megaspores:** Formed in **megasporangia** on **megasporophylls**. Develop into the female gametophyte, which is retained within the ovule.

8. It undergoes **meiosis**, typically producing a linear tetrad of four haploid **megaspores (n)**.
9. **Three megaspores degenerate**. The **lowermost (chalazal) megaspore** remains functional.
10. The functional megaspore enlarges and, *within the nucellus*, undergoes repeated mitotic divisions (free nuclear divisions) to form a multicellular, haploid **female gametophyte**. This tissue becomes the food.
11. At the micropylar end of the female gametophyte, 2-5 **archegonia** develop. Each archegonium has a large **egg cell (n)** and a small ventral canal cell.

D. Pollination & Fertilization:

12. **Pollination:** Wind-blown pollen grains are captured by a pollination drop exuded from the micropyle. The pollen is drawn into the pollen chamber of the ovule.

13. **Pollen Tube Growth:** The pollen grain germinates. The **tube cell** forms a **pollen tube** that grows slowly through the nucellus toward the archegonia. The **generative cell** divides to form a **stalk cell** and a **body cell**. The **body cell** later divides to form two **non-motile male gametes (sperm cells)**.

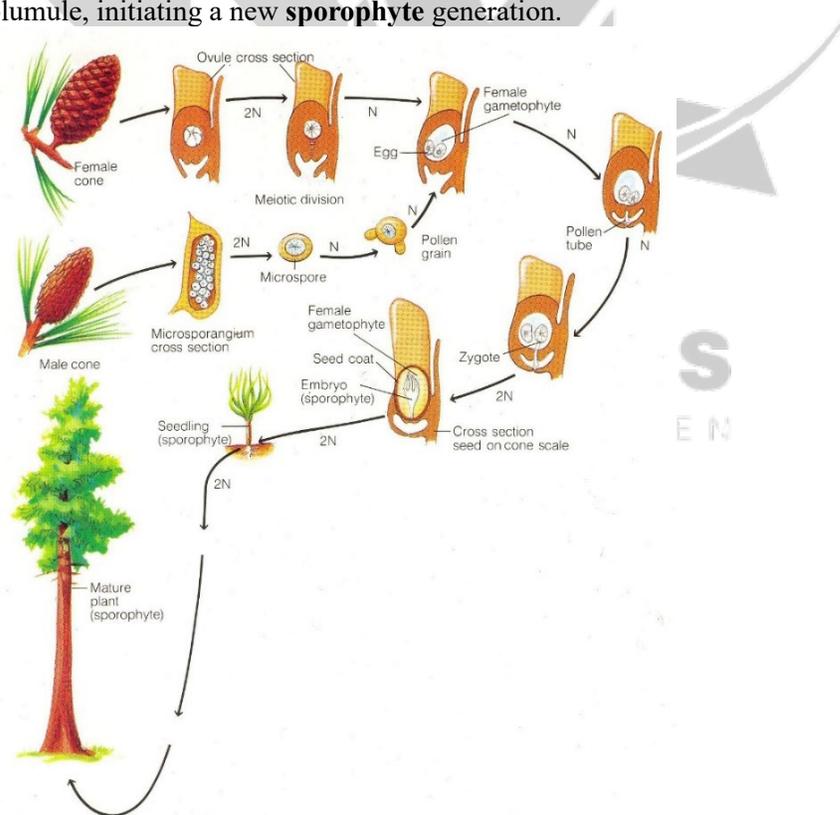
14. **Fertilization:** About **12-14 months after pollination**, the pollen tube reaches an archegonium and discharges its contents. **One sperm cell (n) fuses with the egg cell (n)** to form a **zygote (2n)**. The other sperm degenerates.

E. Seed Development & Germination:

15. **Embryogeny:** The zygote develops into an **embryo (2n)**. In pines, this results in a simple structure with a radicle, hypocotyl, several cotyledons (needles), and a plumule.

16. **Seed Maturation:** Simultaneously, the integument hardens into the **seed coat (testa)**. The female gametophyte persists as the **food reserve**. The entire ovule is now a mature **seed**.

17. **Dispersal & Germination:** The seed is shed from the cone (often with a wing). Under favorable conditions, it germinates. The radicle emerges to form the primary root, and the epicotyl elongates, raising the cotyledons and plumule, initiating a new **sporophyte** generation.



Summary of Key Points in the Life Cycle:

- **Dominant Generation:** Sporophyte (diploid, tree).
- **Spores:** Heterosporous (microspores and megaspores).

E. FERTILIZATION

1. Preparation

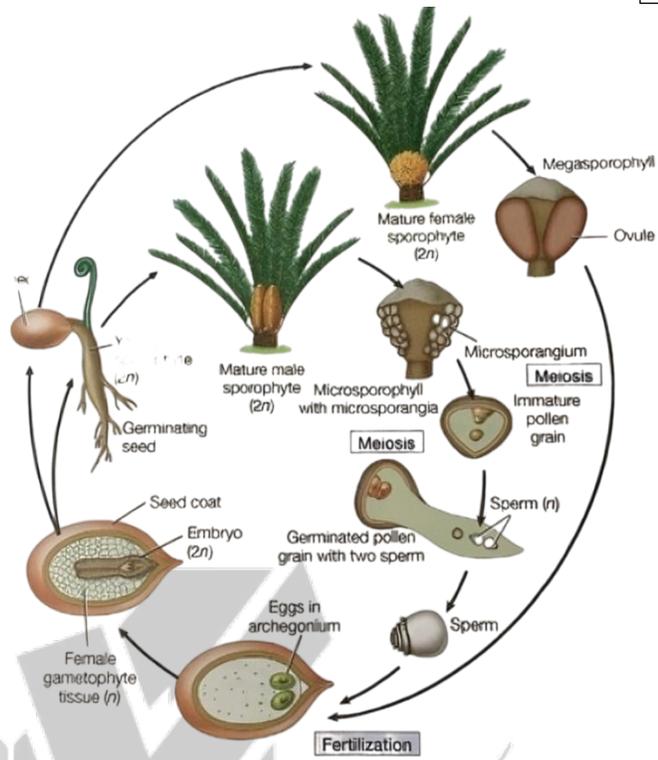
- Pollen tube grows toward archegonia but **ruptures before reaching egg**
- **Sperm released into archegonial chamber** (liquid-filled space above archegonia)

2. Sperm Movement

- **Zooidogamy**: Sperm swim using **ciliary bands** (thousands of flagella arranged in spiral bands)
- Swim for **15-30 minutes** in archegonial fluid
- One sperm enters each archegonium through **neck canal**

3. Syngamy

- **One sperm nucleus fuses with egg nucleus** → **zygote (2n)**
- Other sperm degenerate
- **Multiple fertilizations** possible (multiple archegonia), but usually only one embryo develops fully



F. EMBRYOGENESIS AND SEED DEVELOPMENT

1. Early Embryo Development

- **Zygote undergoes free nuclear divisions** (coenocytic stage)
- Forms **suspensor apparatus**: Long coiled suspensor pushes embryo deep into nutritive gametophyte
- **Cellular differentiation**: Proembryo with stem apex, root apex, and cotyledons

2. Seed Maturation

Mature seed consists of:

1. **Seed coat (2n)**: From integument (3 layers: sarcotesta, sclerotesta, endotesta)
2. **Nutritive tissue (n)**: Female gametophyte (haploid endosperm)
3. **Embryo (2n)**: With two cotyledons, plumule, radicle, and foot

3. Dispersal and Dormancy

- **Sarcotesta**: Brightly colored (orange/red), fleshy, attracts animals
- **Animal dispersal**: Birds, mammals eat fleshy layer, pass hard seed
- **Dormancy period**: 2-6 months; requires specific conditions to break dormancy

Pinus

1. Classification (Taxonomic Hierarchy)

- **Genus: *Pinus***

2. Occurrence & Distribution

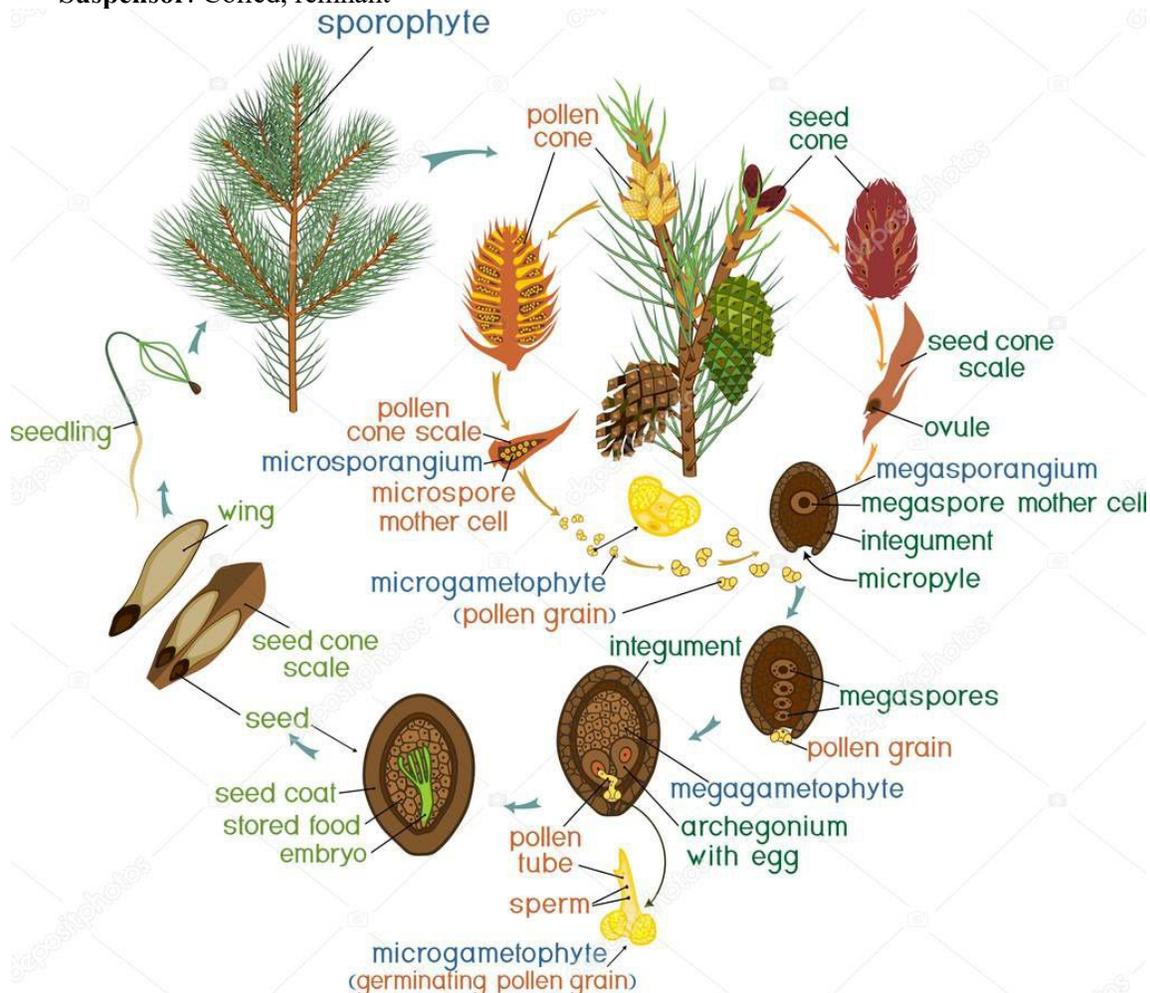
- **Habitat Adaptations**: Pines are **highly adaptable** pioneer species. They commonly thrive in:
 - **Infertile, acidic, sandy, or rocky soils** where other trees struggle.
 - **Dry, xeric conditions** (exhibiting strong drought tolerance).
 - **Fire-prone ecosystems** (many species have thick bark and serotinous cones).

3. General Structure (Vegetative Morphology)

A. Habit & Life Form

D. Mature Embryo Structure

- **Cotyledons:** 4-15, needle-like
- **Hypocotyl:** Stem region
- **Radicle:** Root apex, at chalazal end
- **Shoot apex:** Protected by cotyledons
- **Suspensor:** Coiled, remnant



VIII. SEED DEVELOPMENT AND STRUCTURE

A. Seed Maturation Components

1. **Seed coat (testa):** From integument ($2n$)
 - Outer fleshy layer (sarcotesta) - absent in most pines
 - Middle stony layer (sclerotesta)
 - Inner papery layer (endotesta)
2. **Nutritive tissue:** Female gametophyte (n) - "endosperm"
3. **Embryo ($2n$):** With multiple cotyledons

B. Cone and Seed Maturation

- Female cone becomes **woody**, scales lignify
- **Cone opens** (third year) for seed dispersal
- **Seeds often winged** (from ovuliferous scale tissue)

IX. SEED DISPERSAL AND GERMINATION

A. Dispersal Mechanisms

1. **Wind:** Winged seeds (most pines)

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- **Spermatogenous cell** gives rise to two sperm
- **Sperm size:** Large (70-90 μm), visible with hand lens
- **Flagella:** Thousands, arranged in spiral bands
- **Development completed** just before fertilization

VI. FERTILIZATION (ZOOLOGAMY)

A. Preparation for Fertilization

1. **Archegonial chamber forms:** By breakdown of cells above archegonia
2. **Fluid fills chamber:** Provides medium for sperm swimming
3. **Pollen tube ruptures:** Releases sperm into chamber

B. Sperm Movement and Fusion

1. **Sperm swim actively** using flagella (15-30 minutes)
2. **One sperm enters each archegonium** through neck canal
3. **Sperm nucleus fuses with egg nucleus** \rightarrow **zygote (2n)**
4. Multiple fertilizations possible (multiple archegonia) but usually only one embryo develops

Practice MCQs

1. What is the primary defining characteristic of gymnosperms?

- A. Presence of flowers
- B. Production of fruits
- C. Seeds not enclosed in an ovary (naked seeds)
- D. Double fertilization

Answer: C

2. The ovules of gymnosperms are borne on:

- A. Carpels
- B. Megasporophylls
- C. In an ovary
- D. Receptacle

Answer: B

3. Which of the following is NOT a gymnosperm phylum?

- A. Coniferophyta
- B. Cycadophyta
- C. Ginkgophyta
- D. Bryophyta

Answer: D

4. The most abundant and widespread group of gymnosperms is:

- A. Cycads
- B. Conifers
- C. Gnetophytes
- D. Ginkgoales

Answer: B

5. *Pinus* is an example of a:

- A. Cycad
- B. Conifer
- C. Gnetophyte

D. Fossil plant

Answer: B

6. Resin canals, common in conifers, are a feature of their:

- A. Xylem
- B. Mesophyll and vascular tissues
- C. Phloem only
- D. Epidermis

Answer: B

7. The wood of gymnosperms is commercially called 'softwood' because it lacks:

- A. Tracheids
- B. Fibers
- C. True vessels (in most)
- D. Parenchyma

Answer: C

8. The male reproductive cone in gymnosperms is also called:

- A. Ovulate cone
- B. Microsporangiate strobilus
- C. Megasporangiate strobilus
- D. Seed cone

Answer: B

9. In *Pinus*, microspores (pollen grains) are produced in:

- A. Microsporangia on microsporophylls
- B. Anthers
- C. Megasporangia
- D. Archegonia

Answer: A

10. Pollination in most gymnosperms is mediated by:

- A. Insects



Chapter 12

Angiosperms

Angiosperms (division **Anthophyta/Magnoliophyta**) are the most diverse and widespread group of land plants, characterized by the production of **flowers** and **enclosed seeds** (within a fruit). They represent the culmination of plant evolution, dominating most terrestrial ecosystems.

Life Cycle (Alternation of Generations)

Angiosperms have a **diplontic life cycle with a dominant, photosynthetic sporophyte generation**. The gametophyte generation is **highly reduced** and dependent on the sporophyte.

The Sporophyte Generation of Angiosperms

The **sporophyte generation** in angiosperms is the **diploid (2n), multicellular, dominant, and photosynthetic phase** of the life cycle. It originates from the zygote and constitutes the **entire visible plant body**—from seedling to mature flowering plant. This generation is **heterotrophic only briefly during embryogenesis**, becoming autotrophic upon germination.

Key Concept: The angiosperm sporophyte is the **most complex and dominant sporophyte** in the plant kingdom, representing an evolutionary pinnacle of **structural and functional specialization**.

II. ORIGIN AND DEVELOPMENTAL TIMELINE

- **Origin:** Formed from the **zygote (2n)** following double fertilization.
- **Developmental Journey:** Zygote → Embryo (within seed) → Seedling → Juvenile Vegetative Plant → Mature Reproductive Plant (with flowers) → Senescence.
- **Duration:** Can be annual (completes in one season), biennial (two seasons), or perennial (many years).

III. STRUCTURAL ORGANIZATION OF THE SPOROPHYTE

A. VEGETATIVE (NON-REPRODUCTIVE) ORGANS

These structures support growth, nutrition, and homeostasis.

1. Root System

- **Functions:** Anchorage, water/mineral absorption, storage, hormone synthesis (e.g., cytokinins).
- **Anatomy:**
 - **Root Cap:** Protects apical meristem; secretes mucilage; contains statocytes for gravity sensing.
 - **Zone of Cell Division:** Apical meristem produces cells.
 - **Zone of Elongation:** Cells expand, driving root tip downward.
 - **Zone of Maturation/Differentiation:** Cells develop into primary tissues; root hairs form.
- **Primary Tissues (from protoderm, ground meristem, procambium):**
 - **Epidermis:** Single cell layer with root hairs.
 - **Cortex:** Parenchyma for storage; endodermis with **Casparian strip** (suberin barrier) regulating vascular cylinder entry.
 - **Stele (Vascular Cylinder):** Pericycle (lateral root origin), vascular bundles (xylem/phloem in radial arrangement).
- **Modifications:** Taproots (carrot), fibrous roots (grass), adventitious roots (prop roots of corn), storage roots (sweet potato).

2. Shoot System

- **Functions:** Photosynthesis, support, transport, reproduction.
- **Components:** Stems, leaves, buds.

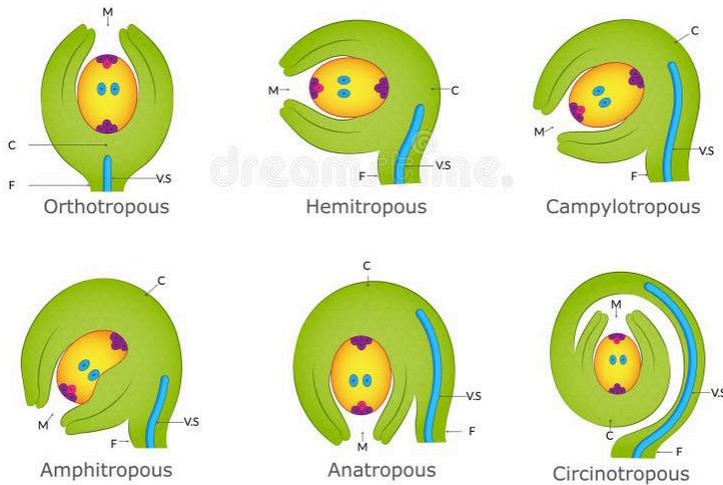
a) Stem

- **Anatomy:**
 - **Nodes** (leaf attachment), **Internodes** (between nodes), **Buds** (apical/axillary).
- **Internal Primary Structure (Dicot):**

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F - Funicle V.S- Vascular Strand M - Micropyle C - Chalaza



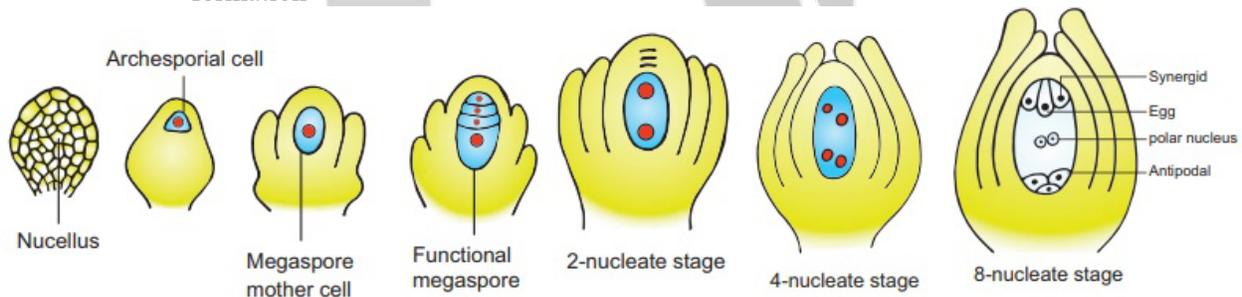
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12. Angiosperms

6. Megasporogenesis Within the Ovule

- **Archеспорial Cell:** Differentiates in nucellus
- **Megaspore Mother Cell (MMC):** Enlarges, becomes distinct
- **Meiosis:** Produces linear tetrad of 4 haploid megaspores
- **Patterns of Megaspore Selection:**
 - **Polygonum Type (Monosporic):** Chalazal megaspore functional ($\approx 70\%$ of angiosperms)
 - **Oenothera Type (Monosporic):** Micropylar megaspore functional
 - **Allium Type (Bisporic):** After meiosis I, one dyad cell degenerates; remaining cell undergoes meiosis II to form two megaspores, one functional
 - **Drusa Type (Tetrasporic):** All four megaspore nuclei participate in embryo sac formation



7. Pistil and Carpel Terminology

- **Simple Pistil:** One carpel (e.g., pea)
- **Compound Pistil:** Multiple fused carpels (e.g., tomato)
- **Apocarpous:** Multiple free carpels (e.g., buttercup)
- **Syncarpous:** Multiple fused carpels (e.g., most angiosperms)

GAMETOPHYTE GENERATION

A. Overview: Extreme Reduction of Gametophytes

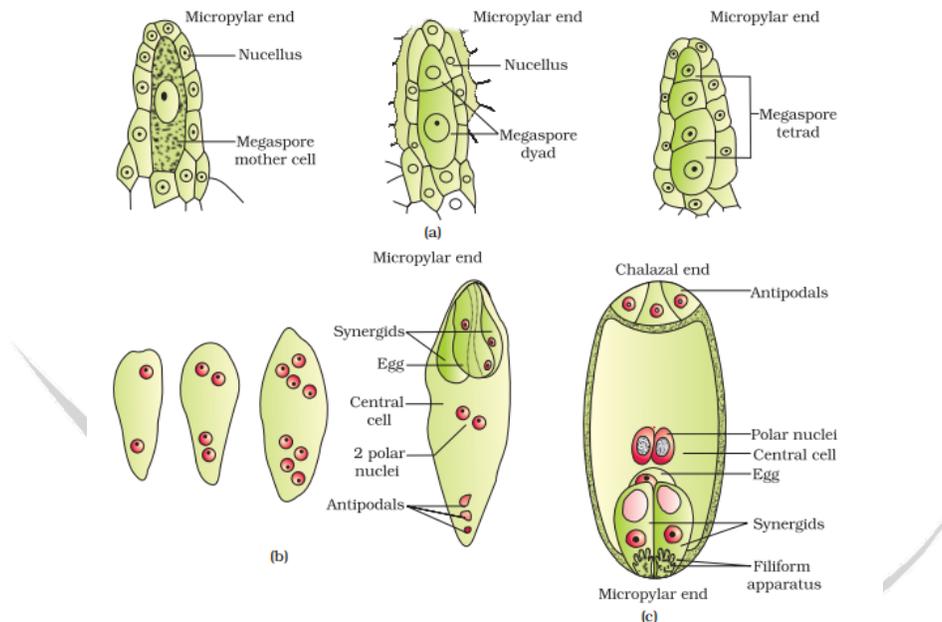
Angiosperms exhibit the **most reduced gametophytes** among land plants:

- **Totally dependent** on sporophyte
- **Short-lived** (days to weeks)
- **Microscopic** (few cells)
- **Develop within sporophytic tissues**

- Hormone production
- May proliferate (e.g., Poaceae - up to 100 cells)
- Usually degenerate during/after fertilization

3. Embryo Sac Wall Specializations

- No cell wall between central cell and egg apparatus
- Plasma membrane continuity maintained
- Specialized domains for sperm cell reception



II. DOUBLE FERTILIZATION: MECHANISTIC DETAILS

A. Pollen-Stigma Interactions

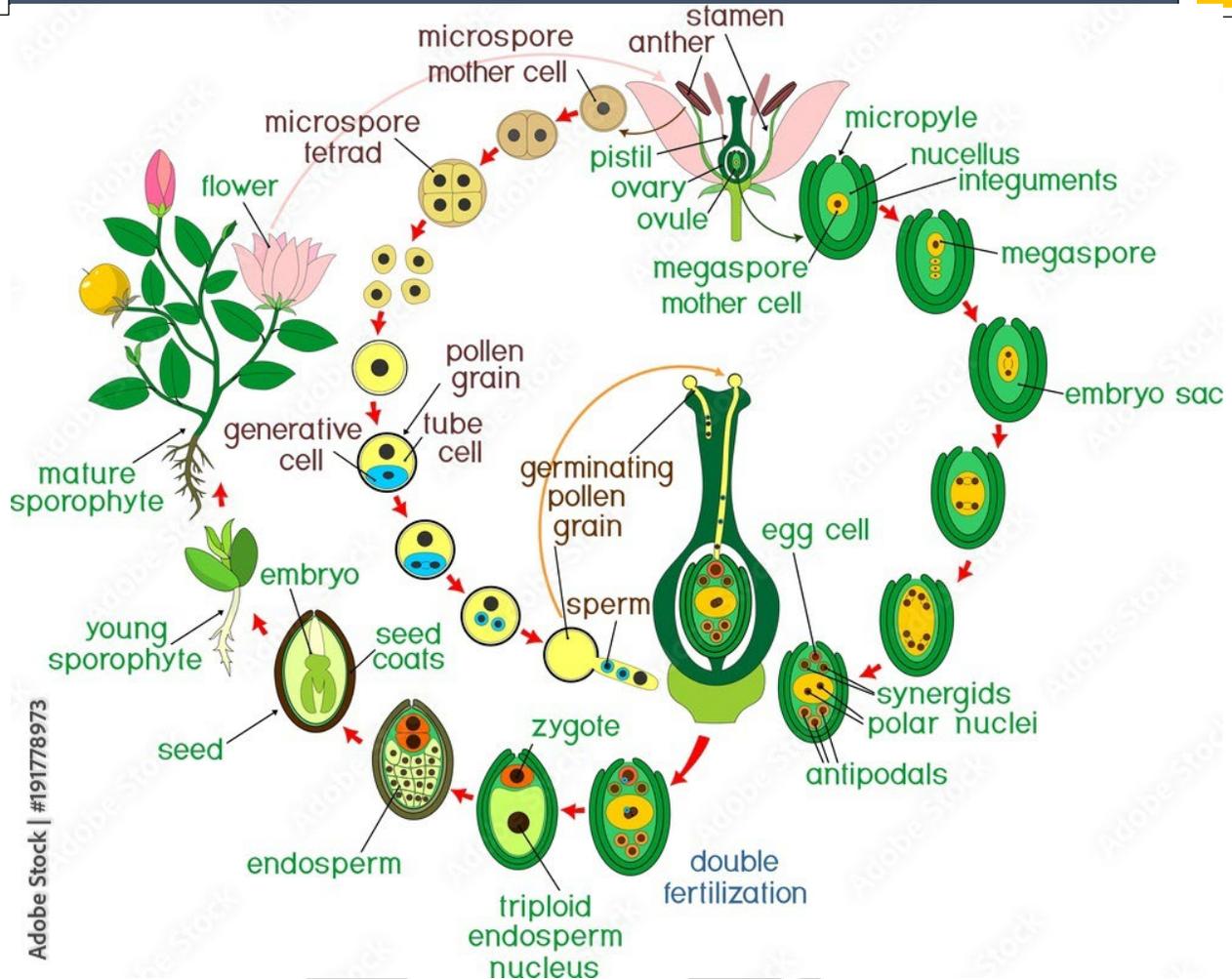
- **Hydration Phase (5-10 minutes):**
 - Pollen absorbs water from stigmatic exudate
 - Intine expands through apertures
- **Germination (20-30 minutes):**
 - Pollen tube emerges
 - **Calcium gradient** established at tip (1000X higher than base)
- **Pollen Tube Growth (1-100 mm/hour):**
 - **Tip Growth Mechanism:**
 - Vesicle fusion at apex (exocytosis)
 - **Actin cytoskeleton** directs vesicle transport
 - **Oscillatory growth** (pulsatile)
 - **Tube Cytoplasm:**
 - **Vegetative nucleus** and sperm cells in **cytoplasmic band**
 - **Callose plugs** seal off older portions

Pollen Tube Entry and Discharge

- **Synergid Reception:**
 - Pollen tube enters one synergid (usually degenerating)
 - **Fusion of pollen tube and synergid membranes**
- **Discharge:**
 - **Explosive release** of contents
 - **Sperm cells released** with associated cytoplasm (male germ unit)
- **Sperm Cell Movement:**

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III. ENDOSPERM DEVELOPMENT

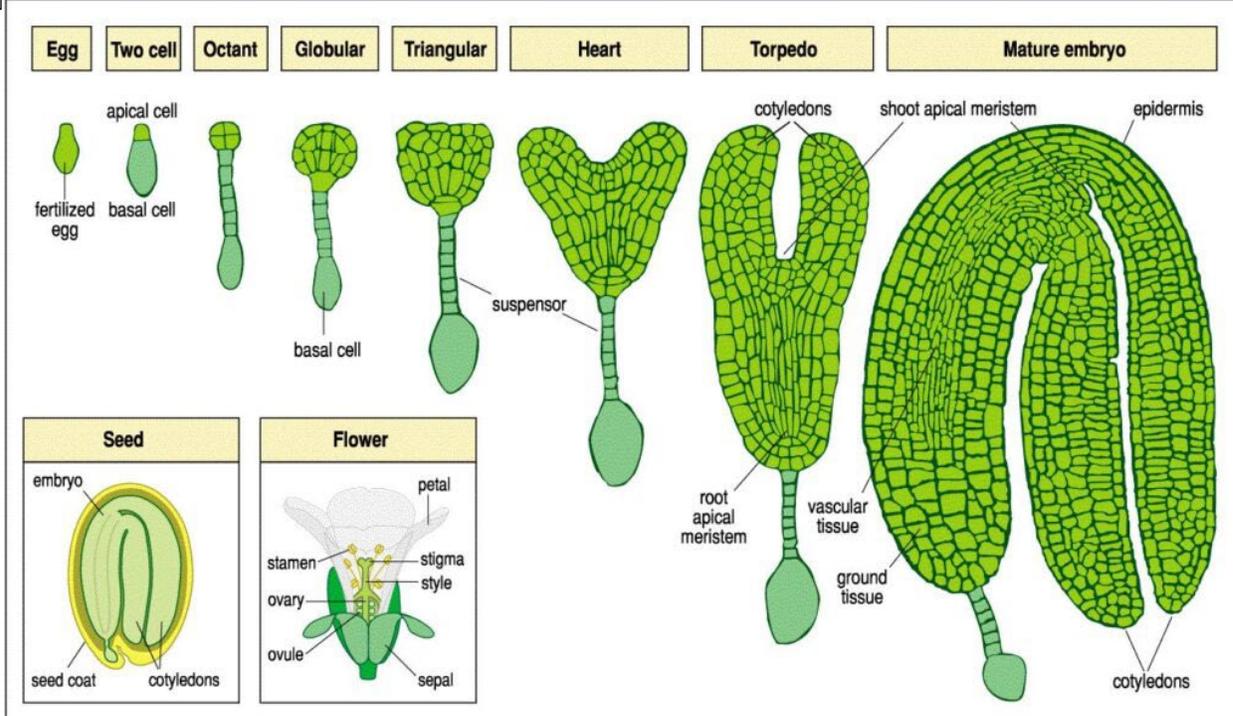
A. Types of Endosperm Development

1. Nuclear (Free Nuclear) Endosperm

- Most common type (≈56% of angiosperms)
- Phases:
 - Syncytial Phase:
 - Repeated mitotic divisions without cytokinesis
 - Nuclei arranged in **cytoplasmic domains** with radiating microtubules
 - **Peripheral organization:** Nuclei migrate to periphery, central vacuole forms
 - **Nuclei may be:** Diploid, polyploid, or mixoploid
 - Cellularization Phase:
 - Begins at micropylar end, progresses chalazally
 - **Process:**
 1. **Anticlinal walls** form between nuclei at periphery
 2. **Periclinal walls** form, creating alveoli
 3. **Inner walls** form, completing cellularization
 - **Timing:** Days to weeks after fertilization

2. Cellular Endosperm

- ≈25% of angiosperms (mostly dicots: Acanthaceae, Rubiaceae)
- First division followed by cell wall formation



V. SEED DEVELOPMENT

A. Integument Transformation to Seed Coat

- **Outer Integument:**
 - **Epidermis:** Becomes **macrosclereids** (palisade cells)
 - **Mesophyll:** Becomes **osteosclereids** (bone-shaped) or **spongy parenchyma**
- **Inner Integument:**
 - Often crushed or forms **pigmented layer**
- **Specialized Structures:**
 - **Hilum:** Scar from funicle detachment
 - **Raphe:** Vascular trace along seed
 - **Caruncle/Strophiole:** Elaiosome for ant dispersal

B. Physiological Changes During Seed Maturation

- **Phase I: Morphogenesis**
 - Cell division and differentiation
- **Phase II: Maturation**
 - Storage product accumulation
 - **Desiccation tolerance** acquisition:
 - **LEA proteins** (Late Embryogenesis Abundant)
 - **Oligosaccharides** (raffinose, stachyose)
 - **Antioxidants** (glutathione, tocopherols)
- **Phase III: Desiccation and Dormancy**
 - Water content drops to 5-15%
 - Metabolic quiescence
 - **ABA-mediated** dormancy induction

C. Seed Structure Variations

- **Albuminous (Endospermic):** Endosperm persistent (castor, coconut)
- **Exalbuminous (Non-endospermic):** Endosperm absorbed (pea, bean)
- **Perispermic:** Nucellus persists as perisperm (beet, black pepper)

Practice MCQs

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1. The most distinctive feature of angiosperms is:

- A. Vascular tissue
- B. **Production of flowers and fruits**
- C. Dominant sporophyte generation
- D. Presence of seeds

Answer: B

2. Double fertilization in angiosperms results in the formation of:

- A. Zygote and fruit
- B. **Zygote and endosperm**
- C. Embryo and seed coat
- D. Endosperm and fruit wall

Answer: B

3. The nutritive tissue in an angiosperm seed is:

- A. Haploid female gametophyte
- B. **Triploid endosperm**
- C. Diploid perisperm
- D. Haploid nucellus

Answer: B

4. The male gametophyte in angiosperms is represented by:

- A. Anther
- B. Pollen sac
- C. **Mature pollen grain**
- D. Microsporocyte

Answer: C

5. Which part of the flower develops into the fruit?

- A. Ovule
- B. Stigma
- C. **Ovary**
- D. Placenta

Answer: C

6. The typical embryo sac of angiosperms is:

- A. Monosporic, 8-nucleate, 7-celled
- B. **Monosporic, 8-nucleate, 7-celled (Polygonum type)**
- C. Bisporic, 4-nucleate, 4-celled
- D. Tetrasporic, 16-nucleate, 9-celled

Answer: B

7. Vessels in the xylem are a characteristic feature of:

- A. Pteridophytes and Gymnosperms
- B. Gymnosperms only
- C. **Angiosperms**

D. All vascular plants

Answer: C

8. Angiosperms are divided into two main classes based on:

- A. Root type
- B. **Number of cotyledons**
- C. Venation pattern
- D. Both B and C

Answer: D

9. Parallel venation is a characteristic feature of:

- A. Dicot leaves
- B. **Monocot leaves**
- C. Gymnosperm leaves
- D. Fern fronds

Answer: B

10. A plant with a taproot system, net-veined leaves, and floral parts in multiples of four or five is most likely a:

- A. **Dicot**
- B. Monocot
- C. Gymnosperm
- D. Pteridophyte

Answer: A

11. The androecium refers to the:

- A. Female part of the flower
- B. **Collective male parts (stamens)**
- C. Collection of petals
- D. Collection of sepals

Answer: B

12. The gynoecium is made up of:

- A. Stamens
- B. **Carpels**
- C. Sepals
- D. Petals

Answer: B

13. The transfer of pollen from the anther to the stigma of the same flower is called:

- A. Cross-pollination
- B. **Self-pollination**
- C. Allogamy
- D. Xenogamy

Answer: B

14. Which pollinating agent is associated with brightly colored, scented flowers with nectar?

- A. Wind
- B. Water



Chapter 13

Kingdom Animalia

Kingdom Animalia comprises multicellular, eukaryotic, heterotrophic organisms that lack cell walls. They are **ingestive feeders**, deriving nutrients by consuming other organisms. Animals typically develop from a **blastula** during embryonic development and have a dominant diploid stage. This kingdom is distinct from Protozoa, which are placed in Kingdom Protocista.

Characteristics:

- **Multicellular Eukaryotes:** Composed of eukaryotic cells without rigid cell walls. Structural support is provided by an extracellular matrix containing proteins like **collagen**.
- **Heterotrophic Nutrition:** Obligate heterotrophs that ingest and internally digest food.
- **Specialized Tissues:** Possess true tissues (except in sponges). The evolution of **nervous** and **muscle tissue** is a key innovation.
- **Blastula Formation:** A hollow ball of cells formed after zygote cleavage.
- **Sexual Reproduction:** Most reproduce sexually with haploid gametes (sperm and egg). Fertilization produces a diploid zygote.
- **Motility:** Most are motile at some life stage, aided by muscle tissues.
- **Regulative Development:** Cell fate is determined relatively late, allowing for high developmental plasticity.

Habitat & Adaptations:

- **Marine (Original):** Buoyancy, stable temperature. Adaptations include sessile attachment, burrowing, or planktonic forms.
- **Freshwater:** Challenges include osmoregulation (hypoosmotic environment) and variable conditions.
- **Terrestrial:** Major challenges are desiccation, gravity, and temperature extremes. Key adaptations include impermeable body coverings, internal respiratory surfaces, internal fertilization, amniotic eggs/vivipary, and supportive skeletons.

Animal Body Plans & Classification Criteria

A **body plan** is an integrated set of morphological and developmental traits. Key aspects are used to classify animals and infer evolutionary relationships.

1. Levels of Organization & Tissue Complexity

- **Cellular Level (Parazoa):** Cells are loosely associated; no true tissues or organs. Example: **Phylum Porifera (sponges)**.
- **Tissue Level:** Cells organized into tissues. Example: **Phylum Cnidaria**.
- **Organ & Organ System Level:** Tissues form organs and complex systems. Example: All higher phyla (**Eumetazoa**).

2. Germ Layers (Embryonic Tissue Layers)

Formed during gastrulation.

Feature	Diploblastic	Triploblastic
Germ Layers	Two: Ectoderm & Endoderm	Three: Ectoderm, Mesoderm & Endoderm
Intermediate Layer	Non-cellular Mesoglea	Cellular Mesoderm
Complexity	Limited tissue complexity.	Allows development of complex organs and systems (muscular, circulatory, skeletal).
Examples	Cnidaria, Ctenophora	All Bilateria (Platyhelminthes to Chordata)

13. Kingdom Animalia

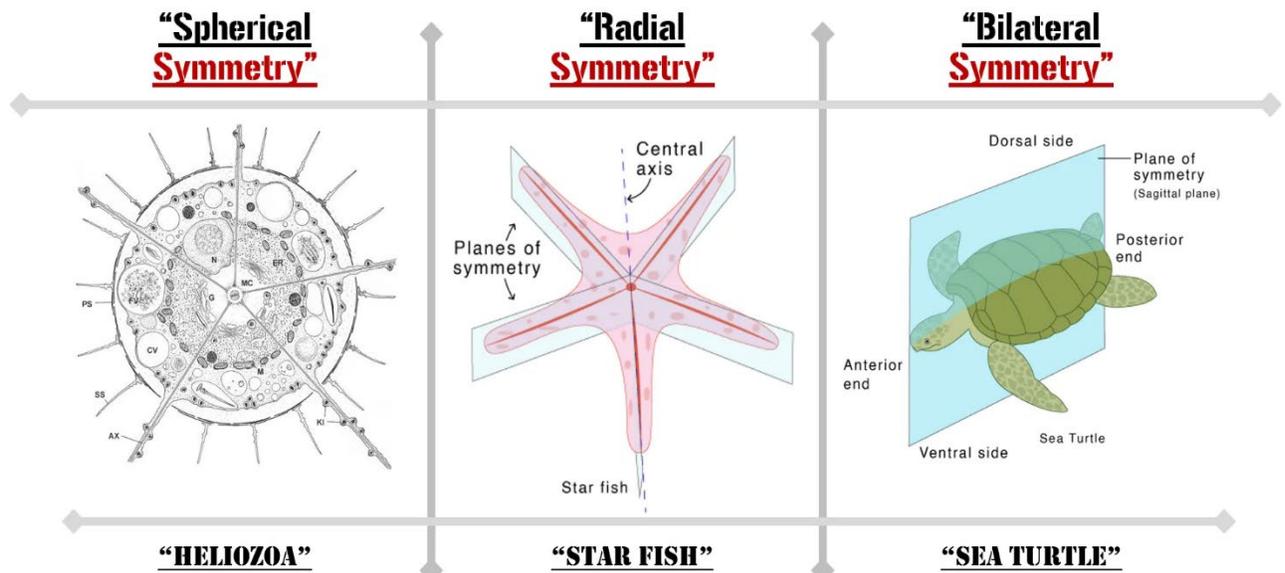
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3. Body Symmetry

Refers to the arrangement of body parts around a central axis.

Feature	Asymmetry	Radial Symmetry	Bilateral Symmetry
Definition	No plane of symmetry.	Body parts arranged around a central axis; multiple planes yield mirror images.	Body divisible into mirror-image halves by only one sagittal plane .
Germ Layers	-	Primarily diploblastic.	Triploblastic.
Body Surfaces	No distinct ends.	Oral (mouth) and aboral surfaces.	Distinct anterior/posterior, dorsal/ventral, and left/right sides.
Mobility & Sensing	Sessile.	Often sessile or floating; sensory structures surround body.	Associated with directed movement and cephalization (concentration of sensory organs/nervous tissue at anterior end).
Examples	Most sponges (Porifera).	Adult cnidarians, adult echinoderms.	Platyhelminthes, Annelida, Arthropoda, Chordata.

Biradial symmetry (a variant of radial symmetry where only two planes yield mirror images) is found in Ctenophora.

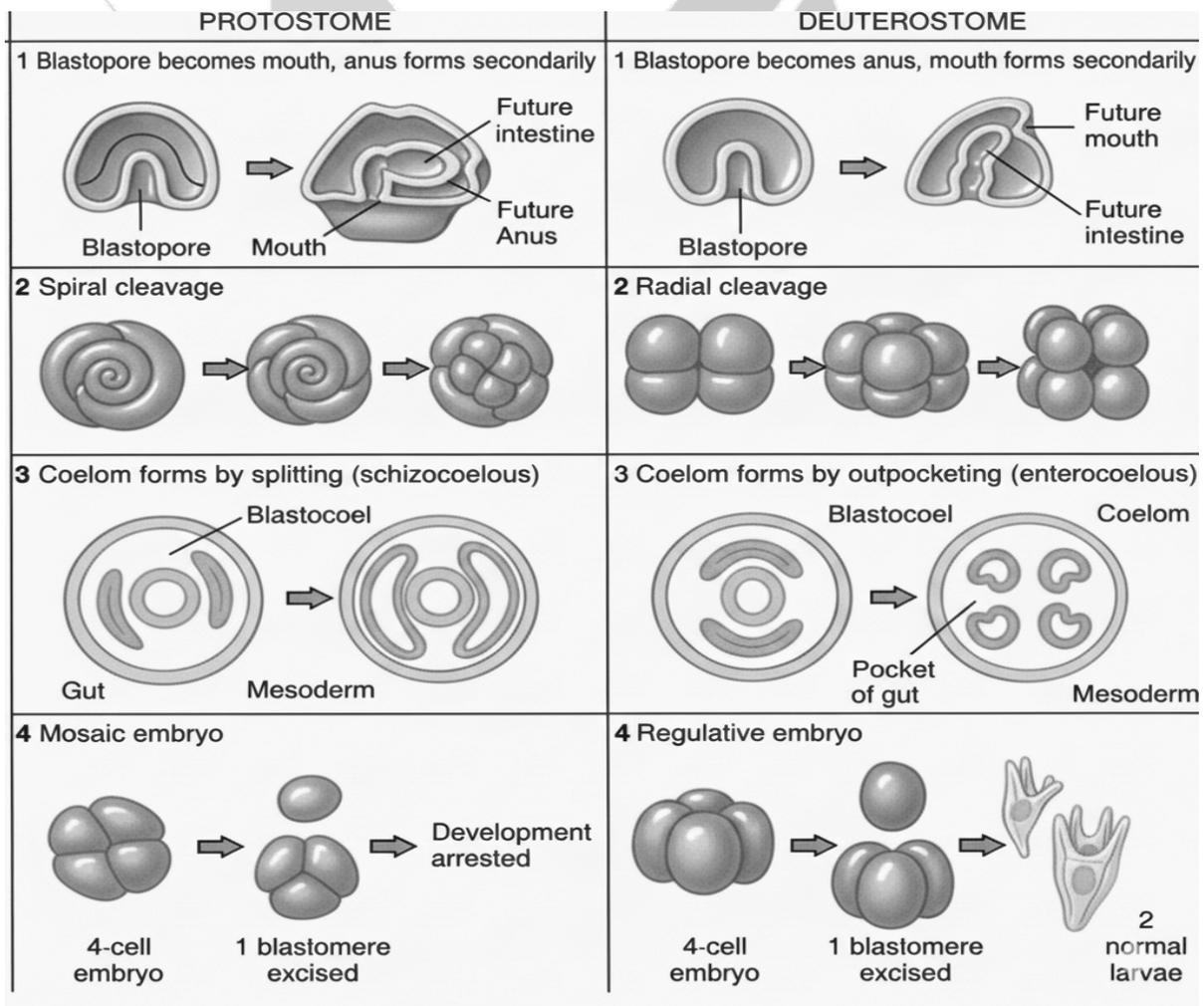


4. Body Cavity (Coelom)

A fluid-filled space between the gut (digestive tract) and the body wall.

Feature	Acoelomate	Pseudocoelomate	Coelomate (Eucoelomate)
Body Cavity	Absent. Space filled with mesenchyme/parenchyma .	Present (Pseudocoelom). Not fully lined by mesoderm. Derived from the blastocoel .	Present (True Coelom). Fully lined by mesoderm-derived peritoneum .

Characteristic	Protostomes ("mouth first")	Deuterostomes ("mouth second")
Cleavage Pattern	Spiral and determinate. Cells divide diagonally; fate of each cell is fixed early.	Radial and indeterminate. Cells divide parallel/perpendicular; cells remain totipotent (can form a complete embryo if separated).
Fate of Blastopore	Develops into the mouth .	Develops into the anus ; mouth forms secondarily.
Coelom Formation	Schizocoely: Coelom forms from splits within solid mesoderm.	Enterocoely: Coelom forms from outpouchings of the archenteron.
Mesoderm Origin	From cells near the blastopore lip.	From the wall of the archenteron.
Example Phyla	Platyhelminthes, Nematoda, Mollusca, Annelida, Arthropoda.	Echinodermata, Hemichordata, Chordata .



6. Segmentation (Metamerism)

The body is divided into a series of repeated segments (metameres).

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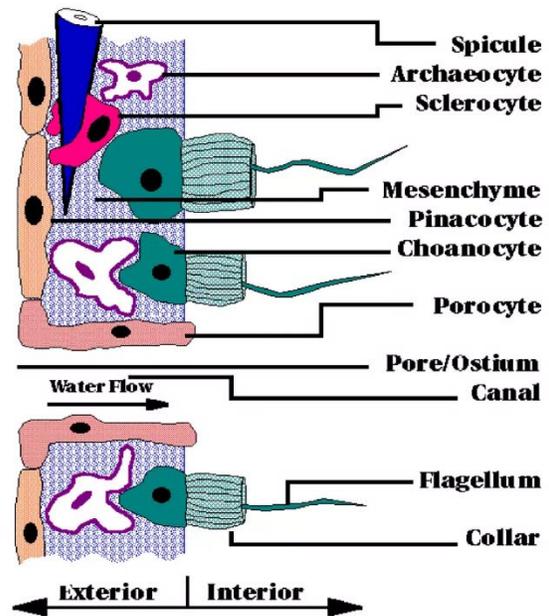
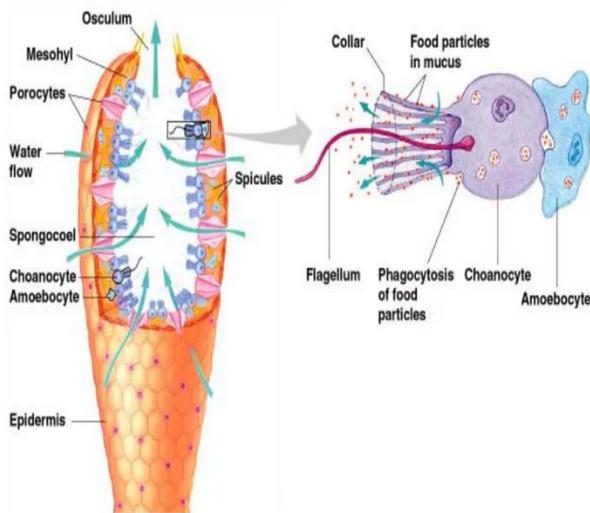
- Contains **porocytes** (tubular cells) in some sponges (e.g., *Leucosolenia*), which form the **ostia** (incurrent pores).

B. Mesohyl (Gelatinous Matrix):

- The non-living, gelatinous, proteinaceous layer between pinacoderm and choanoderm.
- Functions as a **hydrostatic skeleton** and connective tissue.
- Contains **mobile amoeboid cells**:
 - **Amoebocytes/Archaeocytes**: Totipotent cells; phagocytose food, transport nutrients, secrete **skeletal elements**, and differentiate into gametes. **The most important cell for regeneration.**
 - **Sclerocytes**: Secrete **calcareous or siliceous spicules**.
 - **Spongocytes**: Secrete **spongin fibers** (collagenous protein).
 - **Collencytes**: Secrete collagen.
 - **Lophocytes**: Produce collagen; may have a contractile role.
 - **Myocytes**: Modified pinacocytes around oscula; regulate water flow by contraction.

C. Choanoderm (Inner Layer):

- Composed of **choanocytes (collar cells)**. These are the **defining characteristic** of the phylum.
- **Structure**: Each has a **flagellum** surrounded by a **collar of microvilli**.
- **Critical Functions**:
 1. **Create Water Current**: Flagellar beating drives the entire water canal system.
 2. **Capture Food**: Particles (bacteria, detritus) are trapped on the collar and phagocytosed. **Intracellular digestion** occurs within choanocytes.
 3. **Role in Reproduction**: Often transform into sperm cells (spermatocytes).



Water Canal Systems

Complexity increases from simple to complex, affecting sponge size and efficiency.

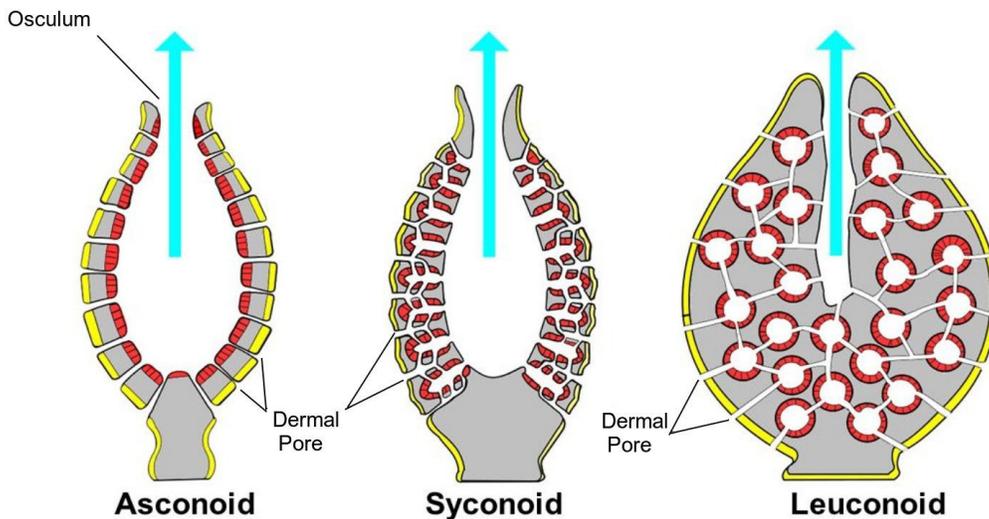
System Type	Structure	Flow Pathway	Example & Notes
Asconoid	Simplest. Vase-shaped. Spongocoel	Ostia → Spongocoel → Osculum	<i>Leucosolenia</i> . Size limited. Rare.

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	lined with choanocytes.		
Syconoid	Folded Walls. Choanocytes line radial canals, not the spongocoel.	Ostia → Incurrent Canals → Prosopyles → Radial Canals (lined with choanocytes) → Apopyles → Spongocoel → Osculum	<i>Scypha (Grantia)</i> . Spongocoel is a non-flagellated excurrent chamber.
Leuconoid	Most Complex & Common. Massive folding. Flagellated chambers only.	Ostia → Incurrent Canals → Prosopyles → Flagellated Chambers (lined with choanocytes) → Apopyles → Excurrent Canals → Osculum	Most Demospongiae & all large sponges. No true spongocoel. Allows for greater size & efficiency.

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■ Choanocytes ■ Mesohyl ■ Pinacocytes ■ Water flow

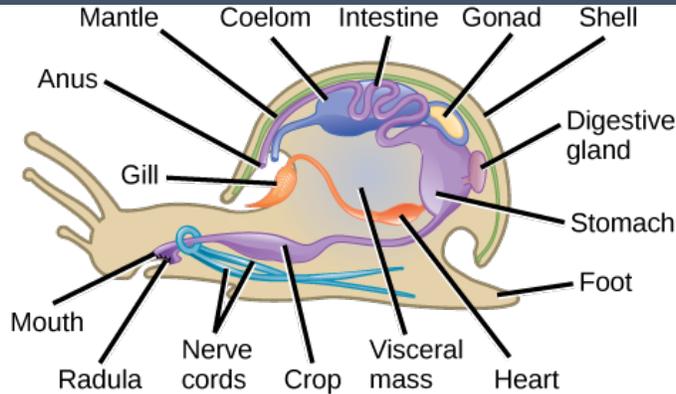
Skeleton

Provides support and defense.

- **Spicules:** Needle-like structures.
 - **Calcareous:** Made of Calcium Carbonate (CaCO_3). Found only in Class **Calcarea**. Shapes: monoaxon, triaxon, tetraaxon.
 - **Siliceous:** Made of Hydrated Silicon Dioxide (SiO_2). Found in Hexactinellida & Demospongiae. Shapes: monoaxon, tetraaxon, or **complex (e.g., amphidiscs, hexasters)**.
- **Spongin:** Flexible, fibrous protein (a form of collagen). Found in **Demospongiae** (e.g., bath sponges). May be sole skeleton or bind siliceous spicules.

Physiology

- **Feeding & Digestion:** Filter feeders (suspension feeders). Entire process is **intracellular** (within choanocytes & amoebocytes). No digestive tract.
- **Respiration, Excretion, Circulation:** Via **diffusion** directly into/out of cells. No systems. Amoebocytes aid in distribution.
- **Nervous/Sensory System:** **Absent**. Localized responses via cell signaling.



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Adaptations & Systems

A. Radula: The **unique molluscan feeding organ**. A ribbon-like membrane with rows of **chitinous teeth**. Used for scraping, drilling, or tearing food. **Absent in Bivalvia.**

B. Circulatory System:

- **Mostly Open:** Heart (1 ventricle, 2 atria) pumps blood into hemocoel, where it bathes tissues directly before returning via gills. Slower, low-pressure.
- **Cephalopods: Closed circulatory system** (blood confined to vessels). Allows for higher metabolic rate and active predation.

C. Respiratory System:

- **Ctenidia:** The characteristic gills in the mantle cavity. Filament structure varies.
- **Secondary Gills/Lungs:** Nudibranchs (skin), terrestrial snails (vascularized mantle cavity = lung).

D. Excretory System: Metanephridia (kidneys). Typically one or two, collecting wastes from the coelom (pericardial cavity) and releasing them into the mantle cavity.

E. Nervous System: Varies from simple (Bivalvia) to highly complex (Cephalopoda). Generally, paired ganglia (cerebral, pedal, visceral) connected by nerve cords.

Development & Larval Stages

- **Trochophore Larva:** A free-swimming, planktonic, ciliated larva **shared with Annelida**, indicating an evolutionary link.
- **Veliger Larva:** (In most marine gastropods & bivalves). A later larval stage with the beginnings of a **foot, shell, and mantle**. The **velum** (ciliated lobe) is used for swimming and feeding. A key dispersive stage.
- **Direct Development:** Common in terrestrial and freshwater species.

Classification

(Mnemonic: Please Give Breakfast Carefully = Polyplacophora, Gastropoda, Bivalvia, Cephalopoda)

Class	Key Distinguishing Features	Shell	Foot & Locomotion	Feeding & Radula	Examples
Polyplacophora	"Many plate bearers." Dors oventrally flattened.	8 overlapping dorsal plates (valves).	Broad, flat foot for adhesion & creeping.	Radula present. Herbivorous grazers on rocks.	Chitons. Primitive features: multiple gills, simple nervous system, no cephalic eyes. Mantle cavity runs as lateral grooves.

13. Kingdom Animalia



3. **Complex Life Cycles:** Often involve **intermediate hosts** and **migration** within the definitive host.
4. **High Reproductive Output:** Millions of eggs.
5. **Dormant/Infective Stages:** Thick-shelled eggs or encysted larvae that survive harsh external conditions.

Major Groups & Parasites Of Medical/Veterinary Importance
 (Mnemonic: Nematodes Are Very Wiggly Parasites
 = *Ascaris*, *Wuchereria*, *Enterobius*, *Ancylostoma*, *Trichinella*)

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Parasite & Disease	Primary Host & Site	Transmission Route	Key Features & Life Cycle Points
<i>Ascaris lumbricoides</i> (Giant Intestinal Roundworm)	Humans (Small Intestine).	Fecal-oral. Ingestion of embryonated eggs from contaminated soil/food.	Largest nematode parasite. Complex migration: Hatched larva → intestinal wall → bloodstream → lungs → coughed & swallowed → adult in intestine. Causes malnutrition, blockage.
<i>Wuchereria bancrofti</i> (Filarial Worm)	Humans (Lymphatic vessels).	Biological vector: Mosquito (e.g., <i>Culex</i> , <i>Anopheles</i>).	Causes Lymphatic Filariasis (Elephantiasis) . Adults block lymphatics → severe edema. Microfilariae circulate in blood with nocturnal periodicity .
<i>Ancylostoma duodenale</i> / <i>Necator americanus</i> (Hookworms)	Humans (Small Intestine).	Skin penetration by filariform larva from contaminated soil.	Pathology: Blood-feeding → iron-deficiency anemia, protein loss. Larval migration: skin → lungs → intestine. Ground itch.
<i>Enterobius vermicularis</i> (Pinworm)	Humans (Large Intestine, cecum).	Fecal-oral & autoinfection. Inhalation of airborne eggs.	Most common helminth in temperate zones. No tissue migration. Female migrates to perianal region at night to lay eggs → causes intense itching (pruritus ani). Diagnosis: Cellophane tape test.

13. Kingdom Animalia

symmetry, likely an adaptation to a sessile or slow-moving lifestyle, allowing interaction with the environment from all sides.

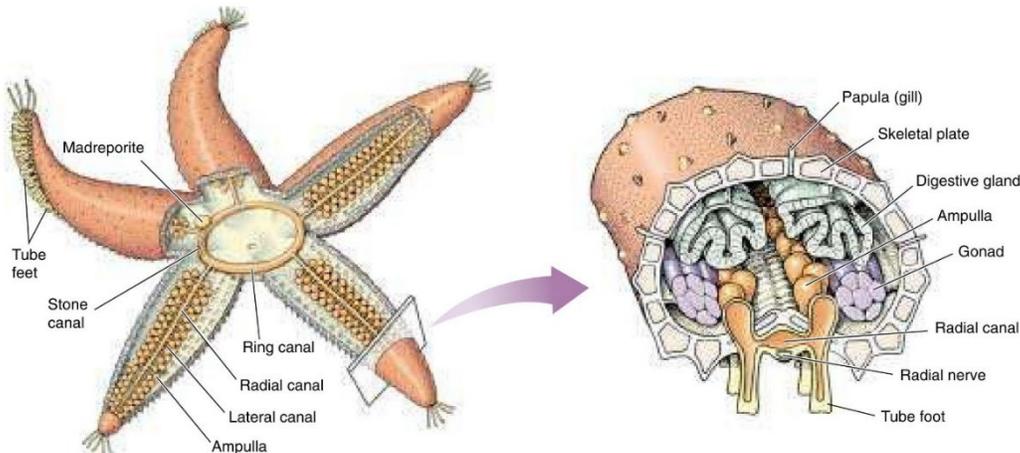
- **Habitat: Exclusively marine.**
- **Body Plan: Triploblastic, coelomate.** The coelom is well-developed and gives rise to unique systems.

Unique Features & Adaptations

A. The Water Vascular System (WVS) - A Hydraulic Marvel

This is the **defining system** of echinoderms.

- **Function: Locomotion, feeding, gas exchange, and attachment.**
- **Pathway & Components:**
 1. **Madreporite:** A sieved, calcareous plate on the aboral surface; the entry point for seawater.
 2. **Stone Canal:** Leads from madreporite to...
 3. **Ring Canal:** Circulates around the esophagus.
 4. **Radial Canals:** Extend from the ring canal into each arm/ray.
 5. **Lateral Canals & Tube Feet (Podia):** Each lateral canal connects to a **tube foot** and a muscular **ampulla**. Contraction of the ampulla forces fluid into the podium, extending it. **Suction is created by adhesive secretion, not pressure.**



B. Endoskeleton

- Composed of **calcareous ossicles** (plates) embedded in the dermis. May be loosely articulated (sea stars) or fused into a rigid **test** (sea urchins).
- Often bears **spines** (modified ossicles) for protection.
- **Pedicellariae: Tiny, pincer-like appendages** on the body surface (especially in Asteroidea & Echinoidea). Function: keep the surface clean, capture small prey, and defense.

C. Mutable Collagenous Tissue (Catch Connective Tissue)

- A unique physiological adaptation. They can rapidly change the stiffness of their connective tissue (from rigid to fluid) **under neural control**.
- **Functions:** Allows for **posture maintenance without muscle fatigue** (e.g., holding arms up), **autotomy** (shedding arms to escape predators), and **reduction of energy cost**.

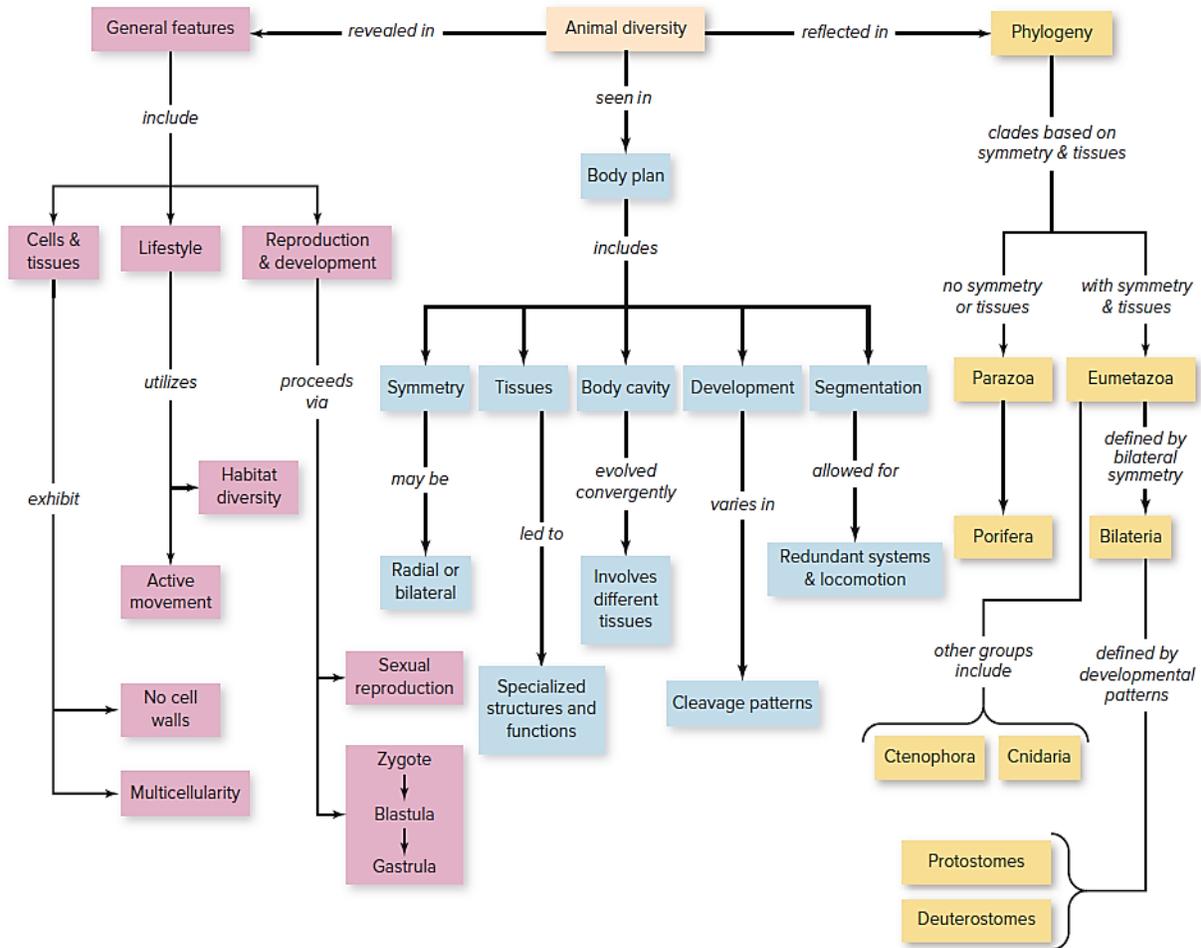
Internal Anatomy & Physiology

- **Digestive System:** Varies widely. Complete gut (mouth → anus). Includes adaptations like the **cardiac stomach** (eversible in sea stars) and **pyloric stomach**.
 - **Aristotle's Lantern:** The complex, **jaw-like chewing apparatus** of sea urchins, operated by specialized muscles.

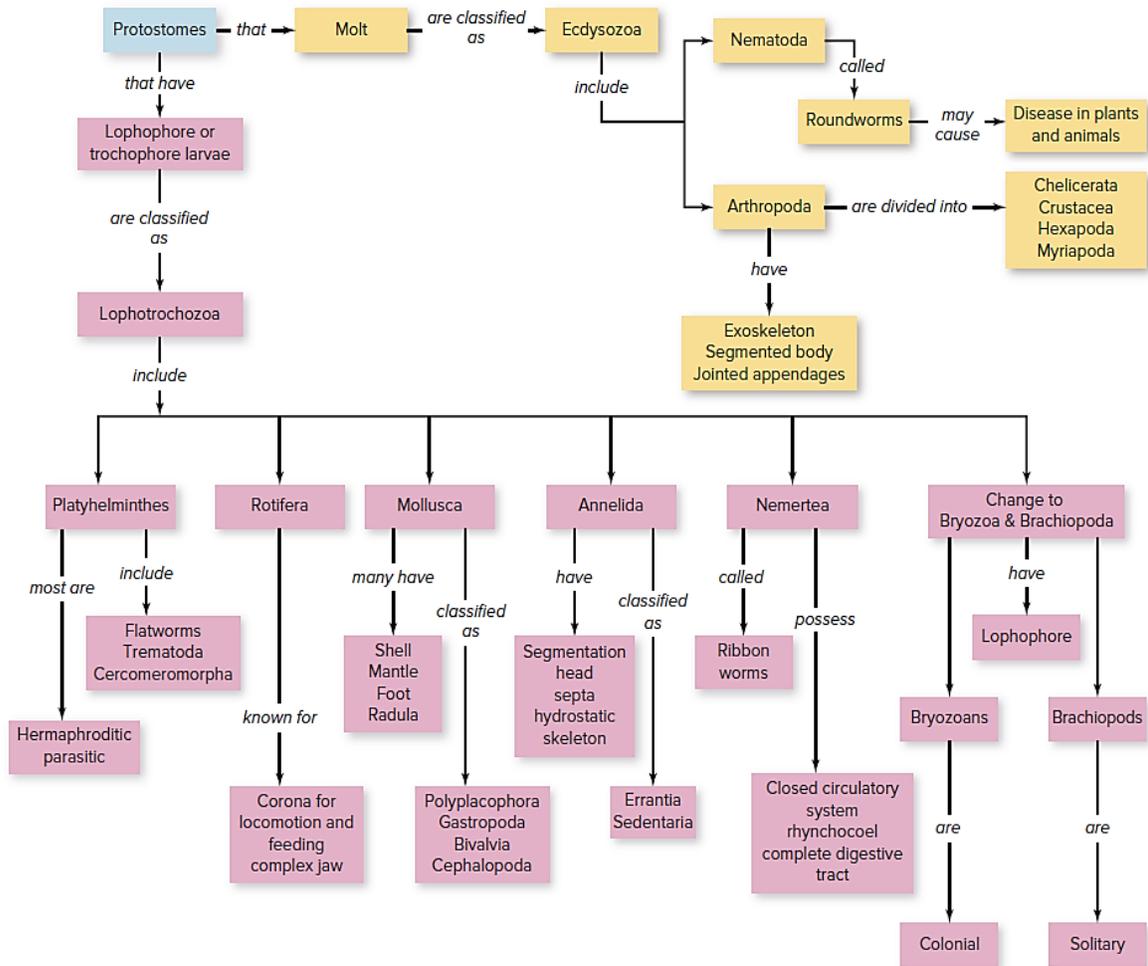
<p><i>Synapsida (Mammalia)</i></p>	<p>Hair/fur, mammary glands, three middle ear bones, muscular diaphragm, neocortex, heterodont dentition, endothermic.</p>	<p>Monotremes: Egg-laying (platypus, echidna). Marsupials: Pouched, short gestation (kangaroo, opossum). Eutherians (Placental Mammals): Long gestation, complex placenta (humans, whales, bats, rodents).</p>
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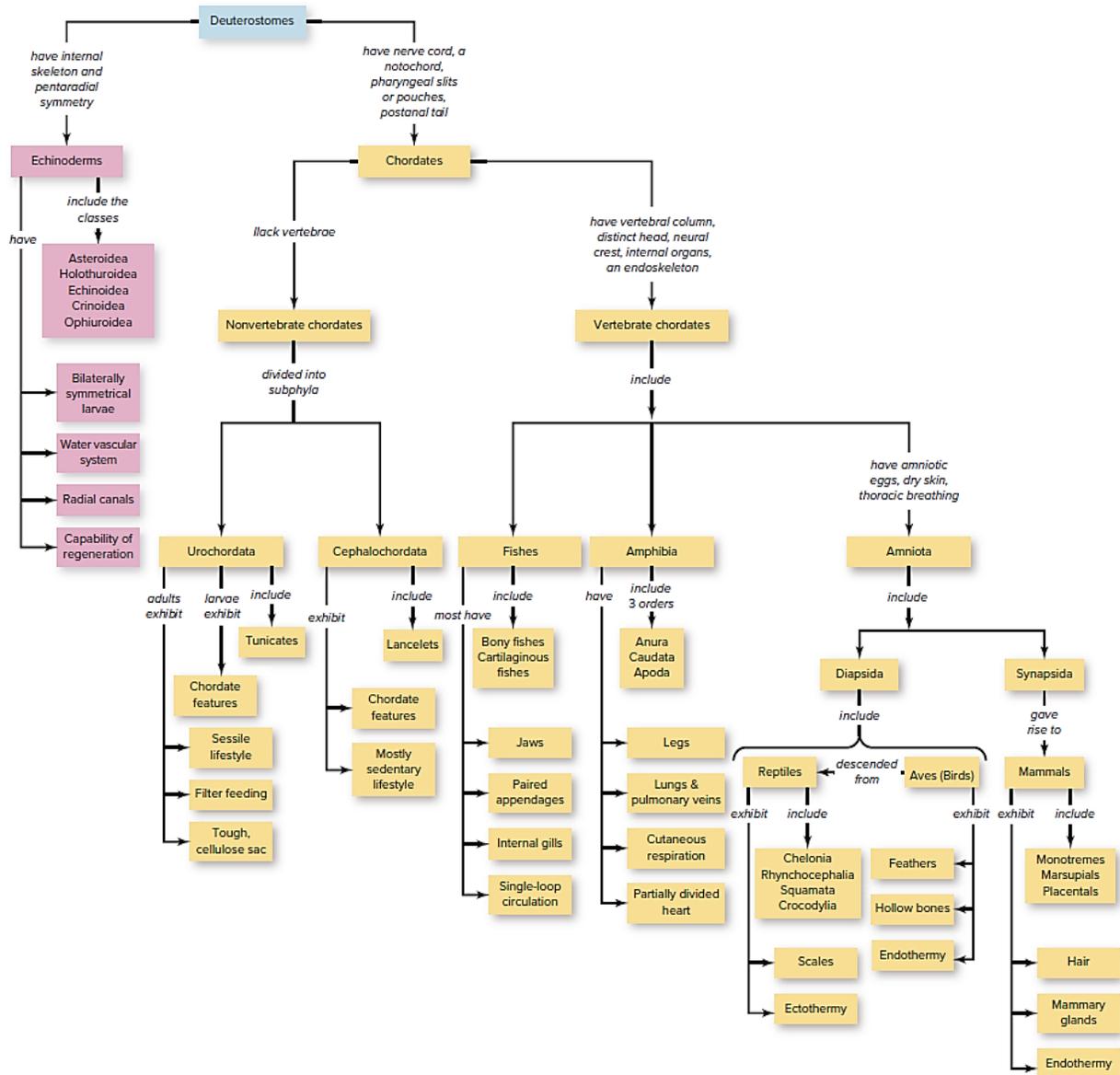
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13. Kingdom Animalia



13. Kingdom Animalia



Kingdom Animalia: One Liners

- Kingdom Animalia comprises multicellular, eukaryotic, heterotrophic organisms that lack cell walls.
- Animals are **ingestive feeders**, deriving nutrients by **consuming other organisms**.
- They develop from a **blastula** during embryonic development and have a **dominant diploid** stage.
- The kingdom is **monophyletic** and also called **Metazoa**.
- Animals, fungi, and **choanoflagellates** form the **Opisthokonta** clade.
- Their structural support comes from an **extracellular matrix** containing the protein **collagen**.
- Most possess **true tissues** (except sponges); the evolution of **nervous and muscle tissue** is a key innovation.
- They exhibit **regulative development** where **cell fate is determined relatively late**.
- The **original animal habitat** is **marine**, offering buoyancy and stable temperature.



- **Cryptic speciation** is the existence of **morphologically identical but reproductively isolated species**.
- **Pheromones** are **chemical signals** used for communication within a species.
- **Altricial young** are born **helpless and require extensive parental care**.
- **Precocial young** are born **relatively mature and mobile**.
- **Poikilotherms (ectotherms)** rely on **external environmental heat** to regulate body temperature.
- **Homeotherms (endotherms)** generate **internal metabolic heat** to maintain a constant body temperature.
- **Convergent evolution** explains the **independent evolution of similar traits** in unrelated lineages.
- **Adaptive radiation** is the **rapid diversification of a lineage into a variety of ecological niches**.

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Practice MCQs

1. Which of the following is NOT a defining characteristic of Kingdom Animalia?

- A) Multicellularity
- B) Presence of cell walls
- C) Heterotrophic nutrition
- D) Blastula formation during development

Answer: Presence of cell walls

2. Animals are distinguished from protozoans by being:

- A) Unicellular
- B) Placed in Kingdom Protocista
- C) Multicellular and ingestive feeders
- D) Autotrophic

Answer: Multicellular and ingestive feeders

3. The structural protein found in the extracellular matrix of animals is:

- A) Keratin
- B) Chitin
- C) Cellulose
- D) Collagen

Answer: Collagen

4. The hollow ball of cells formed after zygote cleavage is called:

- A) Gastrula
- B) Blastula
- C) Morula
- D) Neurula

Answer: Blastula

5. Which of the following is an autapomorphy of animals?

- A) Photosynthesis
- B) Regulative development
- C) Presence of cell walls
- D) Haploid dominant life cycle

Answer: Regulative development

6. The original habitat of animals is considered to be:

- A) Freshwater
- B) Terrestrial
- C) Marine
- D) Aerial

Answer: Marine

7. A major challenge for freshwater animals is:

- A) Buoyancy
- B) Osmoregulation
- C) Stable temperature
- D) High salinity

Answer: Osmoregulation

8. Which adaptation is NOT crucial for terrestrial life?

- A) Impermeable body covering
- B) External fertilization
- C) Amniotic egg
- D) Internal respiratory surfaces

Answer: External fertilization

9. Animals with loosely associated cells and no true tissues are at which level of organization?

- A) Tissue level
- B) Organ system level
- C) Cellular level (Parazoa)
- D) Organ level

Answer: Cellular level (Parazoa)

10. True tissues are first observed in which group?

- A) Porifera
- B) Eumetazoa
- C) Parazoa
- D) Protozoa

Answer: Eumetazoa

11. Diploblastic animals possess how many germ layers?

- A) One

13. Kingdom Animalia

Chapter 14

Phylum Mollusca

Phylum Mollusca is a highly successful, species-rich phylum with nearly 100,000 described living species—more than twice the number of vertebrate species. Its success is attributed to **extensive adaptive radiation**, resulting in adaptation to nearly every habitat on Earth: marine, freshwater, and terrestrial. Molluscs are **triploblastic, coelomate, protostomate** organisms exhibiting **cleavage** and **schizocoelous coelom formation**. They are placed within the **Lophotrochozoa**, a major protostome clade, though their precise relationships with groups like Annelida, Brachiopoda, and Entoprocta remain a subject of ongoing phylogenetic research.

- The vast majority of species belong to **Gastropoda** (snails, slugs) and **Bivalvia** (clams, mussels).
- Class **Cephalopoda** (octopuses, squid) has dramatically declined from an estimated 9,000 fossil species to about 700 living species. Hypotheses for this decline include **competition with evolving vertebrate predators** (bony fishes) and random evolutionary events.
- The phylum is ancient, with fossils over 550 million years old. Some evidence suggests the Ediacaran fossil *Kimberella* may be an early mollusc.

Theories on Coelom Origin

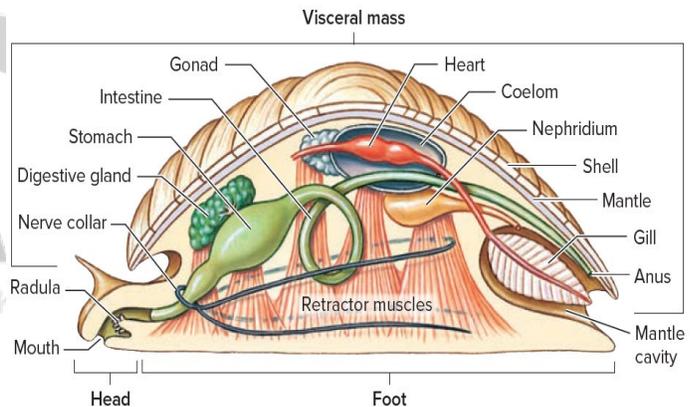
1. **Schizocoel Hypothesis:** The coelom arose from a splitting of mesodermal bands (as in protostomes), implying triploblastic acoelomates (e.g., flatworms) as forerunners.
2. **Enterocoel Hypothesis:** The coelom arose as outpocketings from the primitive gut (as in deuterostomes), implying formation from a diploblastic ancestor. Current understanding suggests the true origin may involve multiple independent evolutionary events.

General Molluscan Body Plan and Characteristics

Despite incredible diversity in size (from microscopic snails to the 18m giant squid) and form, all molluscs share a fundamental body plan.

Defining Morphological Features:

1. **Body Regions:**
 - **Head-Foot:** Anterior, muscular region containing the head (with mouth, sensory organs) and the foot (for locomotion/attachment).
 - **Visceral Mass:** Dorsal region containing most internal organs (digestive, circulatory, reproductive, excretory).
2. **Mantle and Shell:**
 - **Mantle:** A specialized epidermal tissue sheet that enfolds the visceral mass and secretes the shell.
 - **Shell:** Typically calcareous, secreted by the mantle. It is often **tri-layered**:
 - **Periostracum:** Outer organic layer (protein, conchiolin).
 - **Prismatic Layer:** Middle thick layer (calcium carbonate & organic matrix).
 - **Nacreous Layer (Mother-of-Pearl):** Inner iridescent layer (thin sheets of calcium carbonate).
3. **Mantle Cavity:** A water- or air-filled space between the mantle and body wall. It is central to biology, functioning in **respiration, excretion, waste elimination, and release of gametes**.



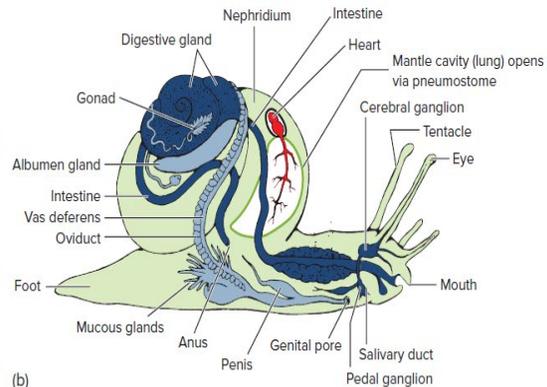
- **Statocysts:** For balance and orientation.
- **Touch:** Sensitive skin and tentacles.

F. Reproduction & Life History

- **Sexuality:** Highly variable.
 - **Diocious:** Separate sexes (common in marine prosobranchs). Some, like limpets, are **protandric hermaphrodites** (male first, then female).
 - **Monoecious (Hermaphroditic):** Common in pulmonates and opisthobranchs. Pulmonates engage in elaborate courtship and often exchange **spermatophores**. Many can self-fertilize if needed.
- **Development:**
 - **Marine:** Typically have **planktotrophic** development: small eggs hatch into free-swimming **trochophore** larvae, which develop into **veliger** larvae (characterized by the velum, a ciliated feeding and swimming organ). The veliger undergoes torsion.
 - **Terrestrial/Freshwater:** Typically **direct developers** with no free larval stage. Eggs are laid in protective clutches and young emerge as miniature adults. This eliminates the need for a vulnerable aquatic larval stage on land.



(a)



(b)

4. Major Groups

The traditional three-subclass system (Prosobranchia, Opisthobranchia, Pulmonata) is still useful for organization but is not strictly monophyletic according to modern phylogenetics. A more current classification uses major clades:

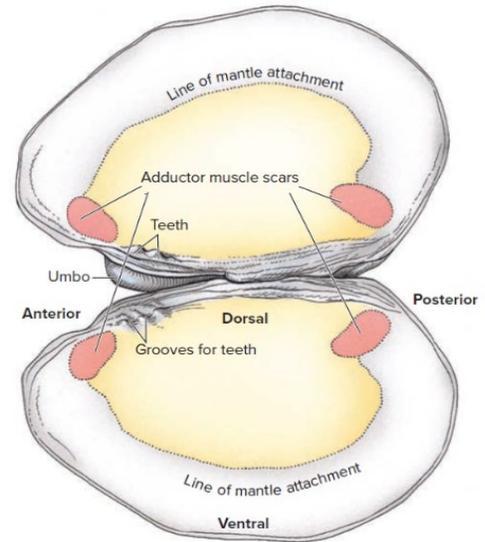
- **Patellogastropoda (True Limpets):** Primarily marine, with a simple, conical cap-like shell. Possess paired gills (a primitive trait). **E.g.**, Common limpets.
- **Vetigastropoda:** An ancient, diverse marine group. Often have shell slits, holes, or a mother-of-pearl interior. **E.g.**, Abalones, top shells, keyhole limpets.
- **Neritimorpha:** A small group in marine, freshwater, and terrestrial habitats. Have a distinctive, often brightly colored, semi-globular shell with a calcareous operculum. **E.g.**, Nerites.
- **Caenogastropoda:** A massive, diverse group that includes most former "prosobranchs." Mostly marine and freshwater. Highly specialized feeders. **E.g.**, Whelks, cone snails, periwinkles, cowries, moon snails, freshwater snails like *Viviparus*.
- **Heterobranchia:** A large clade encompassing the traditional **Opisthobranchia** and **Pulmonata**, plus others.
 - **Opisthobranchs:** Marine. Includes sea hares, sea butterflies, and **nudibranchs**. Characterized by detorsion, shell reduction/loss, and often bright warning (**aposematic**) coloration.
 - **Pulmonates:** Terrestrial and freshwater. Defined by the lung and pneumostome. **E.g.**, Garden snails and slugs, pond snails, ramshorn snails.

3. **Nacreous Layer:** Inner "mother-of-pearl" layer, secreted continuously by the entire mantle surface. In some species, it forms pearls in response to irritants.

B. Mantle & Mantle Cavity

The mantle is a thin sheet of tissue that lines each valve. Its edges may fuse to form **siphons**.

- **Mantle Cavity:** The space between the mantle and the visceral mass. It houses the gills and foot and is the chamber where water flow and filtration occur.
- **Siphons:** In many burrowing bivalves (e.g., clams), the posterior edges of the mantle fuse to form two tubular siphons.
 - **Incurrent Siphon:** Draws in oxygen- and food-rich water.
 - **Excurrent Siphon:** Expels filtered water, waste, and gametes.



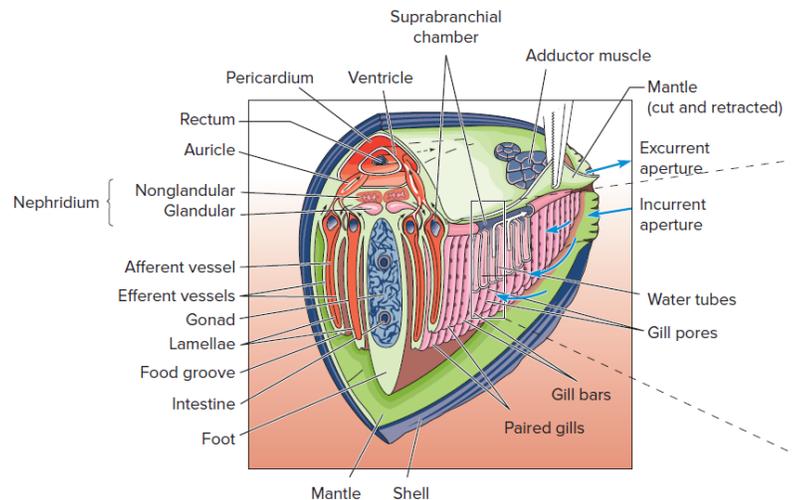
3. Feeding & Digestion: The Filter-Feeding Apparatus

Bivalves are masterful filter feeders. Their system is a highly efficient, cilia-driven conveyor belt.

- **1. Water Flow:** Cilia on the gills and mantle create a constant current. Water enters the **ventral** incurrent siphon or aperture, flows over the gills, and exits dorsally through the excurrent siphon.
- **2. Particle Capture:** The **ctenidia** (gills) are greatly enlarged and folded. Their surfaces are covered in **latero-frontal cilia** that act like a microscopic mesh, trapping suspended particles (algae, detritus, bacteria) as small as 1-2 μm .
- **3. Sorting & Transport:** Captured particles are entangled in mucus and moved by **frontal cilia** to food grooves along the gill margins. These grooves carry the particle-laden mucus to the **labial palps** near the mouth.
- **4. Pre-ingestive Sorting:** The labial palps are ridged, sensory organs that meticulously sort the collected material. Edible particles are directed to the mouth, while unwanted material (e.g., silt, large particles) is rolled into **pseudofeces** and rejected by the palps, to be carried away by the excurrent flow.
- **5. Digestion:** The stomach contains a unique organ, the **crystalline style**. This gelatinous, rotating rod, projected from the **style sac**, is loaded with digestive enzymes (e.g., amylase). Its rotation against a hardened gastric shield stirs the stomach contents and slowly releases enzymes to begin extracellular digestion.

4. Locomotion & Life Habits

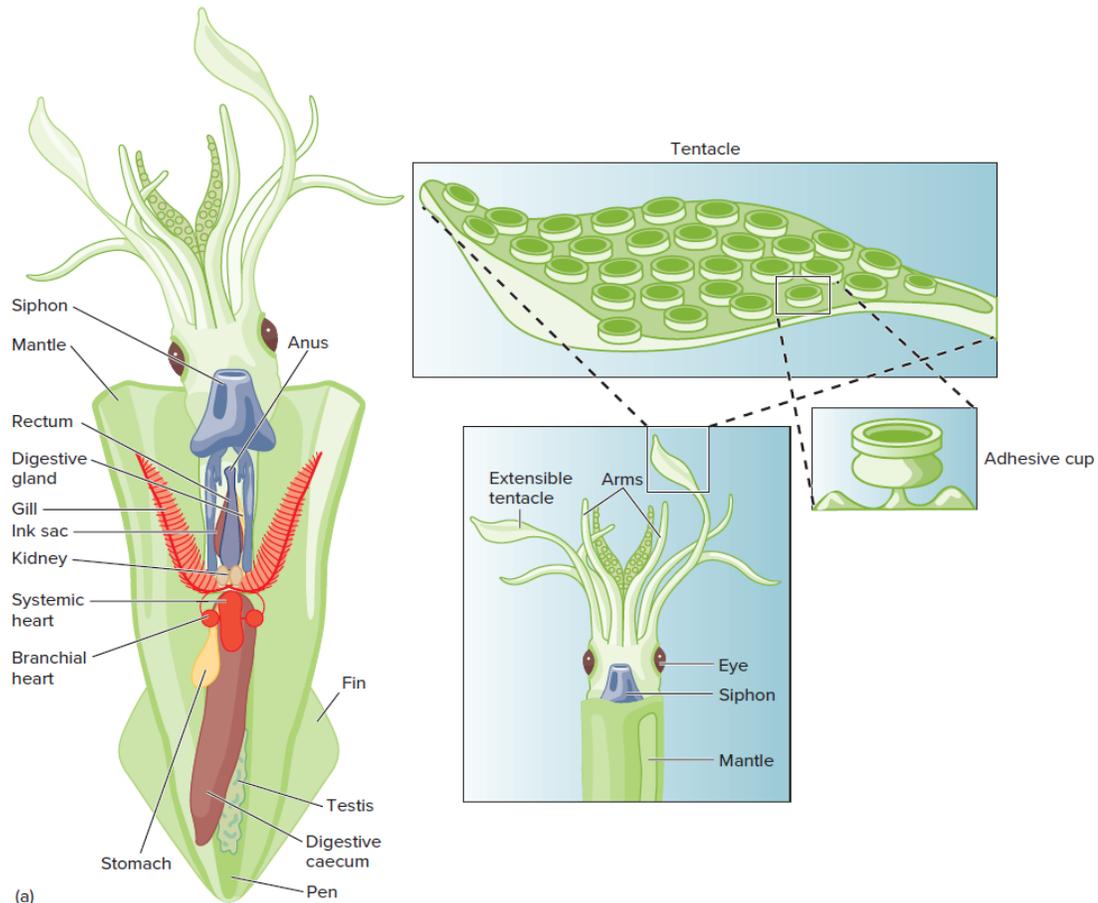
- **Burrowers (e.g., clams):** Use a muscular, hatchet-shaped foot in a repetitive cycle: extend, inflate with blood to form an anchor, then contract to pull the animal down into the sediment.



Cephalopoda ("head-foot") represents the most morphologically complex and neurologically advanced class of mollusks, and indeed, of all invertebrates. They are exclusively marine, active, and intelligent predators whose evolution marks a dramatic departure from the sedentary, shell-bound molluscan archetype. Their key innovations—advanced vision, jet propulsion, and complex brains—have enabled them to occupy an ecological niche similar to that of fish, demonstrating a remarkable case of convergent evolution.

The class is divided into two main subclasses:

- **Nautiloidea:** Represented only by the few species of **Nautilus**, which retain an external, chambered shell and many primitive traits.
- **Coleoidea:** Includes all other living cephalopods (squid, cuttlefish, octopuses). They are characterized by an internalized or absent shell, advanced chromatophores, and a complex nervous system.



2. Shell: From External Buoyancy to Internal Support

The evolutionary story of cephalopods is vividly told through the modification and reduction of the shell.

- **Nautilus (External Shell):** Possesses a planispirally coiled, **chambered shell**. The animal lives only in the outermost, largest chamber. The inner chambers are filled with gas (**cameral gas**) and fluid, regulated by the **siphuncle** (a strand of tissue penetrating the chambers), to achieve precise neutral buoyancy. The shell provides significant protection but limits mobility and flexibility.
- **Coleoid Evolution (Internalized Shell):**
 - **Cuttlefish:** Have a porous, calcareous internal shell called the **cuttlebone**. It serves as a rigid buoyancy device (by regulating gas-to-liquid ratio) and as an internal skeleton for muscle attachment.

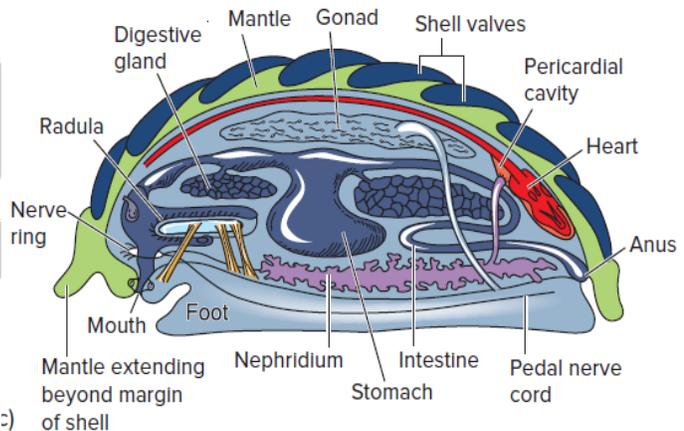
Class Polyplacophora, commonly known as **chitons**, represents a small but evolutionarily significant and ancient lineage of mollusks. Often described as "living fossils," they retain several primitive molluscan characteristics, providing a window into the early evolution of the phylum. Their most distinctive feature is the **eight-part dorsal shell**, which gives the class its name ("many plate-bearers"). They are exclusively marine, benthic grazers, supremely adapted to life in the wave-slammed intertidal zone.

2. Morphology & The Unique Shell System

A. The Eight-Valved Shell

The chiton shell is a composite structure, fundamentally different from the single or bivalved shells of other mollusks.

- **Structure:** It consists of eight separate, overlapping calcareous plates (**valves**) arranged in a longitudinal row. The valves are articulated, allowing a significant degree of upward flexure.
- **Girdle (Perinotum):** The valves are embedded in and surrounded by a thick, muscular, leathery mantle tissue called the **girdle**. The girdle can be smooth, scaly, or bristly with **chaetae** (chitinous spines).
- **Function:**
 - **Flexibility & Protection:** The articulating design allows the animal to conform tightly to irregular rocky surfaces. When dislodged, it can **convexly flex** (curl into a ball), protecting its vulnerable ventral side—a trait reminiscent of armadillos or pill bugs.
 - **Self-Righting:** The broad, flat foot and strong girdle musculature allow a curled chiton to unroll and reattach swiftly.



B. Body Plan & Anatomy

- **Head:** Greatly reduced, lacking tentacles and eyes. This reflects their non-selective grazing lifestyle.
- **Foot:** A large, broad, and powerfully muscular ventral foot. It acts as a suction cup, generating tremendous adhesive force, enabling chitons to withstand extreme wave action. The foot is also used for slow, creeping locomotion via muscular waves.
- **Mantle Cavity & Gills:** The mantle forms two long grooves, or **pallial grooves**, running along the sides of the body between the foot and the girdle.
 - **Multiple Gills:** Unlike most mollusks, chitons possess numerous (6 to 80+ pairs) of **bipectinate gills** (resembling feathers) suspended in these pallial grooves. Water flows into the grooves anteriorly, passes over the gills for respiration, and exits posteriorly, carrying away waste.
 - This multiple-gill condition is considered a primitive trait within mollusks.

3. Feeding & Digestion

Chitons are almost exclusively **herbivorous grazers**.

- **The Radula:** They possess a long, robust, and mineralized **radula** (tongue). The rachidian teeth at the center of the radular ribbon are often capped with **magnetite** (an iron mineral) or other hard materials, making them exceptionally tough.
- **Feeding Process:** Using their powerful foot to cling tightly, they rasp the radula back and forth over rocky substrates, scraping off microalgae, diatoms, and other microbial films. The constant wear on the iron-tipped teeth is counteracted by continuous production at the rear of the radular ribbon.



- **Ecosystem Roles:** Grazers, predators, filter-feeders, bioturbators, prey items.

Ocean Acidification: A Major Threat

- Increased atmospheric CO₂ lowers ocean pH, reducing available **calcium carbonate**.
- **Impact:** Leads to thinner, weaker shells in bivalves and gastropods, and impaired larval development, threatening fisheries.
- **Exception:** Cephalopods are less affected due to reduced/absent shells.

Other Anthropogenic Threats

1. **Habitat Destruction:** Coastal development, deforestation, mining.
2. **Pollution:** Eutrophication, chemical contaminants, plastics.
3. **Climate Change:** Warming, acidification, sea-level rise.
4. **Overexploitation:** Unsustainable harvesting for food and ornaments.
5. **Invasive Species:** e.g., Rosy wolf snail (*Euglandina rosea*), Zebra mussel (*Dreissena polymorpha*).

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Practice MCQs

1. What is the approximate number of described living species in Phylum Mollusca?

- A) 50,000
- B) 75,000
- C) 100,000
- D) 125,000

Answer: 100,000

2. Molluscs are classified within which major protostome clade?

- A) Ecdysozoa
- B) Deuterostomia
- C) Lophotrochozoa
- D) Radiata

Answer: Lophotrochozoa

3. Which class contains the largest number of molluscan species?

- A) Bivalvia
- B) Cephalopoda
- C) Gastropoda
- D) Polyplacophora

Answer: Gastropoda

4. What hypothesis proposes that the coelom arose from splitting of mesodermal bands?

- A) Enterocoel hypothesis
- B) Schizocoel hypothesis
- C) Pseudocoel hypothesis
- D) Hydrostatic hypothesis

Answer: Schizocoel hypothesis

5. Which structure is secreted by the mantle and typically tri-layered?

- A) Radula
- B) Shell
- C) Odontophore
- D) Operculum

Answer: Shell

6. In molluscs, the space between the mantle and body wall that functions in respiration and excretion is called the:

- A) Coelom
- B) Mantle cavity
- C) Visceral mass
- D) Hemocoel

Answer: Mantle cavity

7. The unique rasping feeding organ found in most molluscs is the:

- A) Ctenidium
- B) Radula
- C) Siphon
- D) Captacula

Answer: Radula

8. Which layer of the molluscan shell is the outer organic layer?

- A) Prismatic layer
- B) Nacreous layer
- C) Periostracum
- D) Conchiolin layer

Answer: Periostracum

9. Most molluscs possess which type of circulatory system?

- A) Closed
- B) Open
- C) Lacunar
- D) Vascular

Answer: Open

10. Which class of molluscs has a closed circulatory system?

- A) Gastropoda
- B) Bivalvia
- C) Cephalopoda



Chapter 15

Phylum Echinodermata

Echinodermata is a wholly marine phylum of triploblastic, coelomate deuterostomes. The name derives from Greek: *echinos* (spiny) + *derma* (skin), referring to their characteristic calcareous endoskeleton often bearing spines. They are a classic "noble group especially designed to puzzle the zoologist" due to their unique combination of features not found in any other animal group. Adults exhibit pentaradial symmetry, a derived condition from a bilateral ancestor, as confirmed by their bilateral larval stages and fossil record. They occupy diverse benthic habitats, from intertidal zones to abyssal depths, and play crucial ecological roles.

General Diagnostic Characteristics

The phylum is defined by a suite of unique characteristics:

- Pentaradial Symmetry:** The adult body is organized in five parts (or multiples thereof) around a central oral-aboral axis.
- Water-Vascular System (Ambulacral System):** A unique, coelom-derived hydraulic system used for locomotion, feeding, attachment, and respiration. It terminates externally in tube feet (podia).
- Endoskeleton:** Composed of calcareous ossicles (plates or spicules) of calcium carbonate (calcite) with a distinctive mesh-like stereom structure. The ossicles may be articulated or fused to form a rigid test.
- Mutable Collagenous Tissue (Catch Collagen):** Specialized connective tissue under neural control that can rapidly change stiffness, allowing energy-efficient posture maintenance, autotomy (self-amputation), and protection.
- Dermal Branchiae (Papulae):** Thin-walled, finger-like extensions of the body wall (skin gills) used for respiration in some classes.
- Pedicellariae:** Minute, pincer-like structures on the body surface, often stalked, used for defense and cleaning.

Characteristics of Phylum Echinodermata

- Unique water-vascular system of coelomic origin extends from body surface as series of tentacle-like projections (podia, or tube feet) protracted by increase of fluid pressure within them; opening to exterior (madrepore or hydropore) usually present
- Living in marine habitats
- Free-living taxa
- Body unsegmented (nonmetameric) with pentaradial symmetry; body rounded, cylindrical, or star-shaped, with five or more radiating areas, or ambulacra, alternating with interambulacral areas; no head
- Triploblastic body
- Coelom extensive, forming perivisceral cavity and cavity of water-vascular system; coelom of enterocoelous type; coelomic fluid with amebocytes
- Endoskeleton of dermal calcareous ossicles with spines or of calcareous spicules in dermis; covered by epidermis (ciliated in most); pedicellariae (in some)
- Digestive system usually complete; axial or coiled; anus absent in ophiuroids
- Skeletal elements connected by ligaments of mutable collagenous tissue under neural control, ligaments can be "locked" into rigid posture or relaxed to allow free movement at will; locomotion by tube feet, which project from ambulacral areas, by movement of spines, or by movement of arms, which project from central disc of body
- Nervous system with circumoral ring and radial nerves; usually two or three systems of networks located at different levels in the body, varying in degree of development according to group
- No brain; few specialized sensory organs; sensory system of tactile and chemoreceptors, podia, terminal tentacles, photoreceptors, and statocysts



- **The Holdfast:** For attachment. This is a **long, jointed stalk** in sea lilies and a set of **prehensile cirri** in feather stars.
- **Calyx Structure:** The cup-shaped **calyx** is the main body, composed of calcified plates. It houses the viscera.
 - **Dorsal Cup (Aboral):** The base of the calyx attached to the stalk or cirri.
 - **Oral Disc (Ventral):** The upper surface, bearing both the **mouth** (central or slightly off-center) and the **anus** (typically on a raised anal cone).
- **Arm & Pinnule Structure:**
 - **Arms:** Typically 5, but often branch once or multiple times at the **axillae**, giving 10, 20, or more arms. This increases the filtering surface area.
 - **Pinnules:** Small, lateral, finger-like appendages arranged alternately along the length of the arms. They are soft, highly flexible, and bear the **tube feet (podia)**. They give the arms a delicate, feathery appearance.
- **Cirri & Stalk:**
 - **Stalk (Sea Lilies):** Composed of numerous disc-shaped ossicles (**columnals**) stacked like vertebrae and connected by ligaments. May bear whorls of **cirri** along its length for additional stability. The stalk lifts the crown into water currents.
 - **Cirri (Feather Stars):** A whorl of jointed, claw-like appendages at the aboral end of the calyx. Used for **temporary attachment** to the substrate, algae, or coral. Feather stars can actively crawl and even swim by rhythmic arm movements.

Phylum Echinodermata (i-ki"na-dur'ma-tah)
 The phylum of triploblastic, coelomate animals whose members are pentaradially symmetrical as adults and possess a water-vascular system and an endoskeleton covered by epithelium. Pedicellaria often present.

Class Crinoidea (krin-oi'de-ah)
 Free living or attached by an aboral stalk of ossicles; flourished in the Paleozoic era. Sea lilies; feather stars. Approximately 630 living species.

Class Asteroidea (as"te-roi'de-ah)
 Rays not sharply set off from central disk; ambulacral grooves with tube feet; suction disks on tube feet; pedicellariae present. Sea stars. Approximately 1,800 species.

Class Ophiuroidea (o-fe-u-roi'de-ah)
 Arms sharply marked off from the central disk; tube feet without suction disks. Brittle stars. More than 2,000 species.

Class Echinoidea (ek"i-noi'de-ah)
 Globular or disk shaped; no rays; movable spines; skeleton (test) of closely fitting plates. Sea urchins, sand dollars. Approximately 1,000 species.

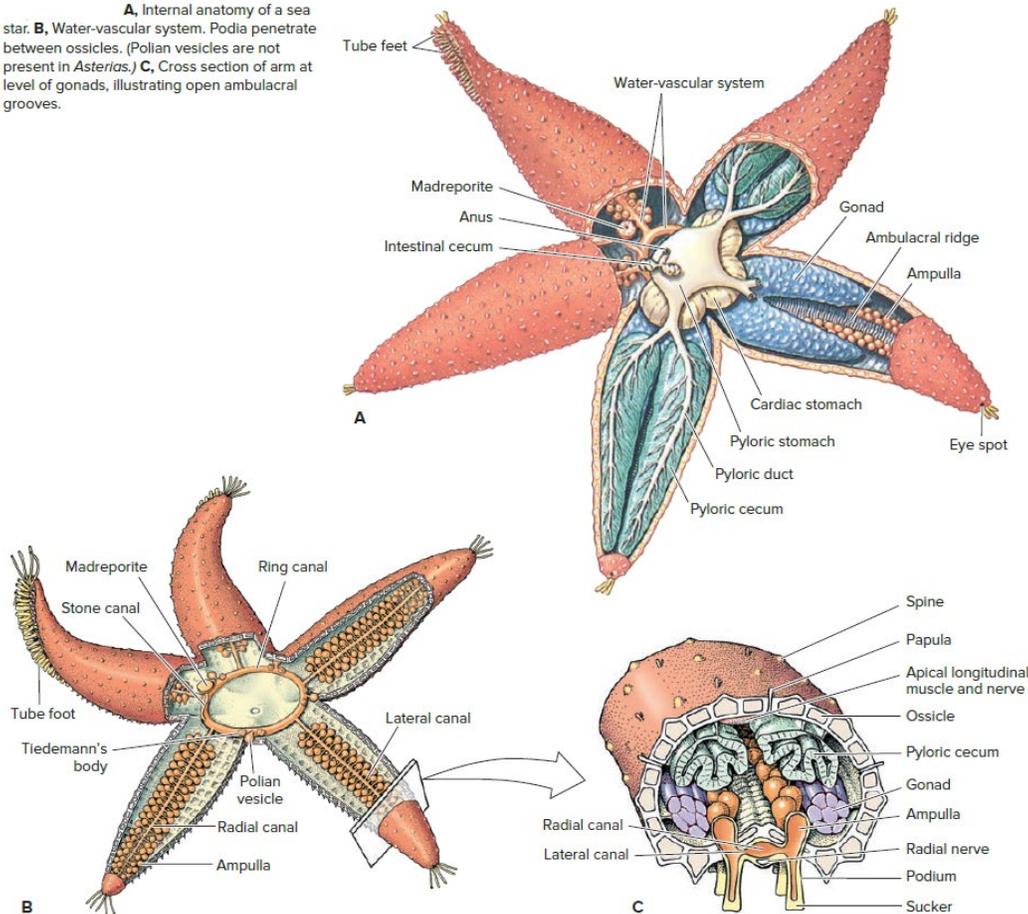
Class Holothuroidea (hol"o-thu-roi'de-ah)
 No rays; elongate along the oral-aboral axis; microscopic ossicles embedded in a muscular body wall; circumoral tentacles. Sea cucumbers. Approximately 1,700 species.

15. Phylum Echinodermata

Water-Vascular System: Specialization for Feeding

- **Open Ambulacral System:** Unlike in other eleutherozoans, the **ambulacral grooves are open and conspicuous**, running along the oral surface of the arms and pinnules. They are lined with **ciliated epithelium**.

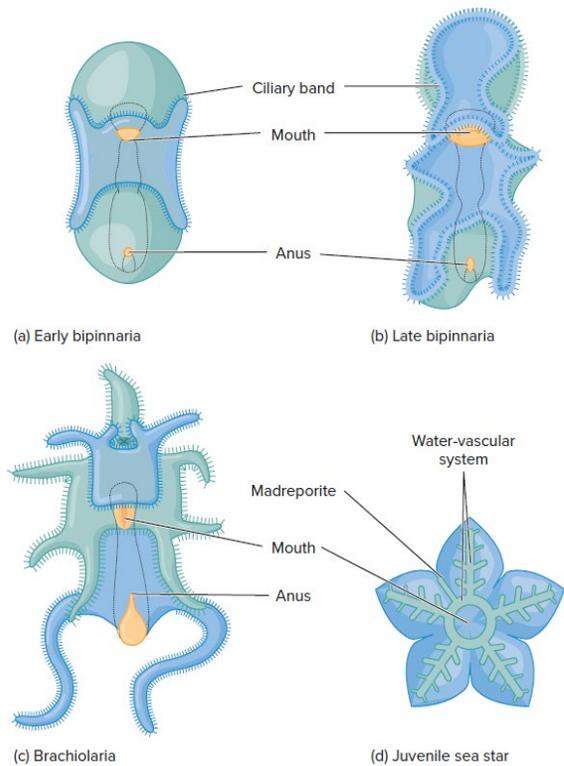
A, Internal anatomy of a sea star. **B**, Water-vascular system. Podia penetrate between ossicles. (Pollan vesicles are not present in *Asterias*.) **C**, Cross section of arm at level of gonads, illustrating open ambulacral grooves.



Feeding Biology & Digestive System

- **Diet:** Carnivorous predators dominating benthic communities. Prey includes bivalves (mussels, clams), gastropods, barnacles, crustaceans, other echinoderms, and even fish.
- **Bivalve Predation - A Detailed Sequence:**
 1. **Detection & Mounting:** The sea star locates prey chemotactically and mounts it, arching its disc.
 2. **Attachment:** Hundreds of tube feet attach to both valves of the shell.
 3. **Steady Pull:** The sea star adopts a **hunched posture**, applying constant tension via its tube feet and body wall muscles. This utilizes **catch connective tissue** in its ligaments to maintain force with minimal energy expenditure.
 4. **Fatigue & Gaping:** The bivalve's adductor muscles fatigue, causing a microscopic gap (as little as 0.1 mm).
 5. **Stomach Eversion:** The sea star increases coelomic pressure, **everts its cardiac stomach** through its mouth and into the gap.
 6. **External Digestion:** Digestive enzymes (proteases, lipases) are secreted directly onto the bivalve's soft tissues, liquefying them.
 7. **Ingestion:** The partially digested soup, along with the now-retracted stomach, is drawn into the **pyloric stomach**.
- **Internal Digestion:** Digestion continues within the **paired pyloric ceca** in each arm, which are major sites of enzyme secretion, absorption, and nutrient storage (glycogen, lipids).
- **Adaptations:** Some species are specialized feeders (e.g., *Acanthaster planci*, the crown-of-thorns starfish, feeds on coral polyps; *Pteraster* feeds on sponges).

- **Larval Development:** The **bipinnaria** larva is a feeding, bilaterally symmetrical planktotroph. It may metamorphose into a **brachiolaria** larva, which uses adhesive arms to settle before metamorphosis. Some species have non-feeding (lecithotrophic) larvae.
- **Asexual Reproduction:** Common via **fission** (splitting of the central disc) or **autotomy** of arms, followed by regeneration.
- **Regeneration:** An extreme adaptive trait.
 - **Process:** Involves wound healing, formation of a **blastema** (mass of undifferentiated cells), and re-differentiation of tissues. The **water-vascular system** is key in patterning the regenerate.
 - **Capability:** Most species can regenerate arms provided part of the central disc remains. A few (e.g., *Linckia*) can regenerate a complete individual from a single arm segment—a process called **comet formation**.



Ecology & Keystone Role

- **Keystone Predation:** By preying on dominant space-competitors (like mussels), sea stars maintain high species diversity in intertidal and subtidal communities. The classic example is *Pisaster ochraceus* in Pacific Northwest tide pools.
- **Population Outbreaks:** Some species, like the crown-of-thorns starfish (*Acanthaster planci*), undergo population explosions that can devastate coral reef ecosystems.
- **Trophic Cascades:** Their removal (e.g., due to disease, climate change, or human activity) can trigger **trophy cascades**, leading to ecosystem collapse (e.g., conversion of kelp forests to urchin barrens).

Types of Pedicellariae in Asterozoa

Type	Morphology	Function
Forceps (Straight)	Two straight, broad valves that meet directly.	Primarily cleaners . Remove debris and settling organisms from the body surface.
Crossed (Scissor)	Two curved, crossed valves with basal plates.	Often venomous . Defensive; can snap at and deter small predators or parasites.

Asteroids and Their Ecological Roles

Species	Common Name	Key Ecological Role / Trait
<i>Pisaster ochraceus</i>	Ochre Sea Star	Classic keystone predator in rocky intertidal zones.
<i>Acanthaster planci</i>	Crown-of-Thorns Starfish	Corallivore ; population outbreaks cause severe coral reef degradation.
<i>Asterias rubens</i>	Common European Sea Star	Generalist predator, model organism for development and regeneration studies.
<i>Pycnopodia helianthoides</i>	Sunflower Sea Star	Fast-moving, multi-armed predator; major controller of urchin populations in the NE Pacific.

Linckia guildingi

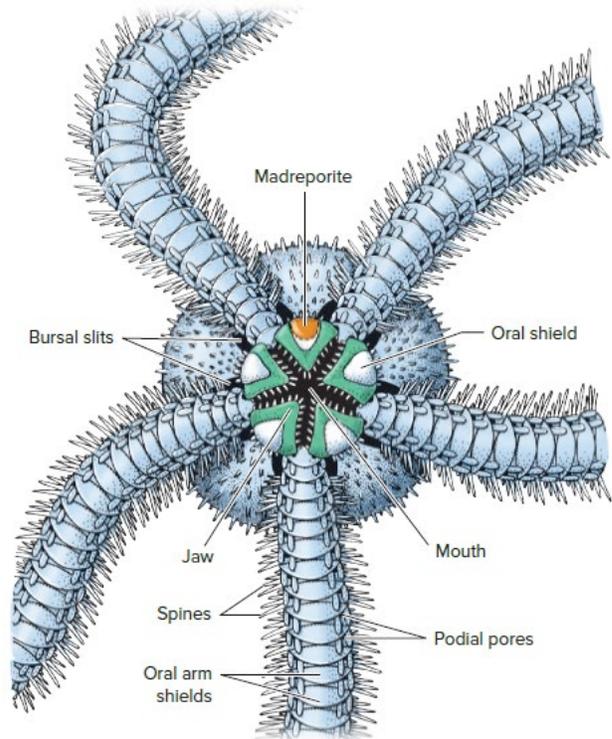
Comet Star

Exhibits exceptional **regeneration** from severed arms (comet formation).

Class Ophiuroidea (Brittle Stars & Basket Stars)

External Morphology & Distinguishing Features

- **Central Disc:** Highly compact, pentagonal or circular, and sharply demarcated from the arms. Contains all major organs. The oral surface is flat, bearing the mouth and **bursal slits**.
- **Arm Architecture:** Arms are long, slender, whip-like, and highly flexible. They are used for locomotion, feeding, and sensory perception.
 - **Brittle Stars:** Arms are unbranched, typically used for rapid crawling and burrowing.
 - **Basket Stars:** Arms undergo **repeated, dichotomous branching**, creating a complex, bush-like structure specialized for passive suspension feeding in currents.
- **Surface Features:** Generally lack pedicellariae and dermal branchiae (papulae). The skin is often smooth or granular.



Endoskeleton & Arm Structure: The Vertebral Column

- **Arm Ossicles (Vertebrae):** The key innovation of ophiuroids. The arm contains a central series of large, articulated ossicles called **vertebrae**. These are hourglass-shaped and join via ball-and-socket joints, forming a flexible, internal "**vertebral column**."
- **Closed Ambulacral Groove:** The ambulacral groove is not open as in asteroids. It is covered over and converted into an **internal epineural canal** by large lateral arm plates that arch over it. The radial water-vascular canal and nerve cord run protected within this canal.
- **Muscular Control:** Four pairs of intervertebral muscles connect successive vertebrae. Their coordinated contraction produces the rapid, **sinuous (snake-like) arm movements** characteristic of the class.

Water-Vascular System & Locomotion

- **Non-Locomotor Tube Feet:** Tube feet are slender, pointed, and lack both suckers and ampullae. They are extended by contraction of muscles at their base within the arm, not by a hydraulic ampulla. Their primary roles are **sensory perception, feeding, and burrowing**, not adhesion or locomotion.
- **Locomotion Mechanics:** Movement is **arm-powered**. Two primary methods:
 1. **Rowing/Rowing:** One or two arms lead, pulling the disc while others trail or push. This allows for surprisingly **fast, directional movement**.
 2. **Sinuous Crawling:** Coordinated, snake-like undulations of the arms propel the animal.
- **Burrowing:** Many species live infaunally in soft sediments. They use their pointed arms to dig and wedge themselves into the substrate.

Feeding Strategies:

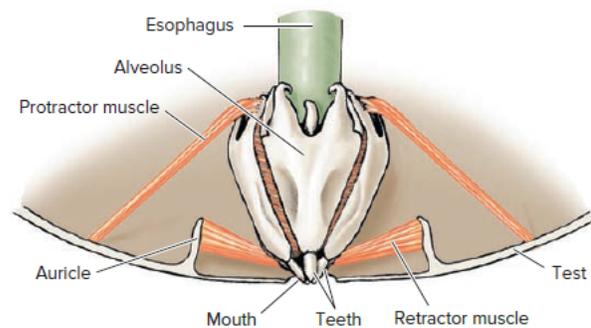
Ophiuroids exhibit the most varied feeding modes of any echinoderm class.

- **Brittle Star Strategies:**

- **Spines:**
 - **Structure:** Long, movable, and articulate with the **tubercles** on the test via a **ball-and-socket joint** controlled by both muscles and catch connective tissue. They are extensions of the stereom (the porous calcareous structure of the ossicle).
 - **Function: Primary defense and locomotion** (used like stilts). In some species (e.g., *Diadema*), spines are long, hollow, and venomous.
- **Pedicellariae:** Highly specialized and diverse in echinoids, serving critical defensive and cleaning roles. Three main types:
 - **Tridentate (Triphyllous):** The most common. Three small, straight jaws. Used for cleaning the test and removing debris.
 - **Globiferous (Globular):** Highly specialized for defense. The jaw ends in a venom sac, and the tips are often hollow for venom injection. Used against predators and settling larvae.
 - **Ophicephalous (Snake-headed):** Jaw valves are elongated and serrated, mounted on a long, flexible stalk. Function is primarily cleaning.

Aristotle's Lantern: A Masterful Jaw Apparatus

- **Location & Structure:** A complex, intricate chewing apparatus located internally but can be partially extruded through the mouth (peristome). It consists of **35 separate ossicles** and associated muscles. The five main, radially arranged components are:
 1. **Pyramids:** Five wedge-shaped pieces, each bearing a long, protruding **tooth**. The teeth are self-sharpening and grow continuously.
 2. **Rotulae & Compasses:** Ossicles that act as braces and supports, holding the lantern together and allowing for complex movements.
 3. **Epiphyses:** Ossicles that bridge adjacent pyramids.
- **Musculature & Function:** A set of **protractor and retractor muscles** allow the lantern to be extended from the test and retracted. **Adductor muscles** move the pyramids and teeth together in a scraping or biting motion.
- **Feeding in Regular Urchins:** Herbivores that graze on algae, seagrasses, and biofilms. They scrape the substrate clean with their teeth, a process so effective it can shape entire benthic communities.



Aristotle's lantern, a complex mechanism used by sea urchins for masticating their food. Five pairs of retractor muscles draw the lantern and teeth up into the test; five pairs of protractors push the lantern down and expose the teeth. Other muscles produce a variety of movements. Only major skeletal parts and muscles are shown in this diagram.

Water-Vascular System & Locomotion

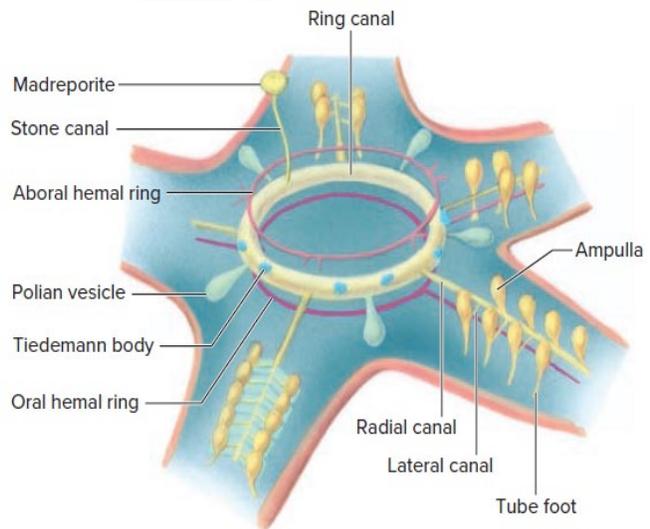
- **Internal Ambulacral System:** The radial canals run internally beneath the test, within the epineural sinus. Tube feet extend through the **pore pairs** in the ambulacral plates.
- **Tube Feet:** Equipped with **suckers and internal ampullae**. They serve multiple functions:
 - **Locomotion:** Work in coordination with spines. Tube feet provide adhesion and fine movement, while spines provide the main pushing force.
 - **Attachment:** Powerful suction allows urchins to withstand strong wave action.
 - **Feeding (Irregular Urchins):** In sand dollars and heart urchins, tube feet on the oral surface are modified into **phyllopodia** – delicate, flower-like structures used for collecting and transporting food particles.
- **Madreporite:** Located aborally on one of the **genital plates** (usually the one designated plate 2), often within the **apical system**.

Body Form	Cup-like calyx, branched arms, stalk/cirri	Star-shaped, arms continuous with disc	Arms slender, sharply distinct from disc	Globular/flat, no arms (rigid test)	Elongate, cylindrical, worm-like
Orientation	Oral surface up	Oral surface down	Oral surface down	Oral surface down	On side
Ambulacral Grooves	Open, ciliated	Open	Closed	Closed	Closed
Tube Feet (Suckers)	No suckers (feeding)	With suckers (locomotion)	No suckers (feeding)	With suckers (locomotion/feeding)	With suckers (oral tentacles)
Madreporite	Absent	Aboral	Oral	Aboral	Internal
Pedicellariae	Absent	Present	Absent	Present (some venomous)	Absent
Feeding Mode	Suspension feeder	Predator/Scavenger	Various (Scavenger/Predator/Filter)	Herbivore/Deposit feeder	Suspension/Deposit feeder
Endoskeleton	Plates in calyx/stalk	Ossicles, flexible	Articulated arm ossicles	Rigid test	Microscopic ossicles
Unique Structures	Pinnules, stalk/cirri	Papulae, pyloric ceca, eversible stomach	Bursae, closed grooves	Aristotle's lantern, spines, test	Respiratory trees, cloaca, Cuvierian tubules
Larval Form	Doliolaria	Bipinnaria/Brachiolaria	Ophiopluteus	Echinopluteus	Auricularia

The Water-Vascular System (WVS)

This is the most distinctive feature of echinoderms, a **coelom-derived hydraulic system** unique to the phylum. It is a closed network of canals and reservoirs that functions as a combined muscular and hydraulic organ system.

- **Function: Locomotion, feeding, attachment, respiration, and sensory perception.** Its primary function differs by class (e.g., feeding in Crinoids, locomotion in Asteroids).
- **Pathway & Components:**
 1. **Madreporite:** A sieve-like, calcified plate for filtered seawater entry. Its **position varies by class** (aboral in Asteroids/Echinoids, internal in Holothuroids, absent in Crinoids, on the oral surface in many Ophiuroids).
 2. **Stone Canal:** A calcareous, often spirally-grooved tube connecting the madreporite to the ring canal. In some species, it contains **calciferous glands** that may regulate ionic balance of the fluid.





Economic and Ecological Importance

- **Food Source:** Sea urchin gonads (**uni**) and sea cucumber body wall (**trepang** or **bêche-de-mer**) are commercially harvested, requiring sustainable management.
- **Ecological Roles:**
 - **Keystone Predators:** Some sea stars (e.g., *Pisaster*) control prey populations, maintaining biodiversity.
 - **Grazers:** Sea urchins prevent algal overgrowth on coral reefs; their overpopulation creates destructive barrens.
 - **Bioindicators:** Sensitive to pollution, temperature change, and **ocean acidification** (which dissolves calcareous skeletons).
- **Scientific Research:** Sea urchin eggs and embryos are classic models for **embryology, developmental biology, and fertilization studies.**

Threats and Conservation

Echinoderms face significant natural and anthropogenic threats:

- **Natural Threats:** Predation, parasitism, and diseases like **Sea Star Wasting Disease (SSWD)**, linked to a densovirus and environmental stress.
- **Anthropogenic Threats:** **Habitat destruction** (trawling, coastal development), **pollution** (heavy metals, plastics), **climate change** (ocean warming, acidification), and **overexploitation** for food and trade.
- **Survey Methods:** Monitoring employs techniques ranging from traditional **quadrat/transect surveys** (SCUBA) and **trawling** to modern **Baited Remote Underwater Video (BRUV)**, **Environmental DNA (eDNA)** analysis, and **ROV/AUV** deployments for deep-sea studies.

Practice MCQs

1. Which of the following is a wholly marine phylum?

- A) Mollusca
- B) Arthropoda
- C) Echinodermata
- D) Annelida

Answer: Echinodermata

2. Adult echinoderms exhibit which type of symmetry?

- A) Bilateral
- B) Spherical
- C) Pentaradial
- D) Asymmetrical

Answer: Pentaradial

3. The name Echinodermata is derived from Greek words meaning what?

- A) Star form
- B) Spiny skin
- C) Five arms
- D) Water tube

Answer: Spiny skin

4. What is the most distinctive feature of the phylum Echinodermata?

- A) Notochord

- B) Water-vascular system
- C) Mantle
- D) Radula

Answer: Water-vascular system

5. Echinoderm larvae are characteristically what?

- A) Pentaradial
- B) Asymmetrical
- C) Bilaterally symmetrical
- D) Radially symmetrical

Answer: Bilaterally symmetrical

6. The calcareous endoskeleton of echinoderms is composed of what?

- A) Chitin
- B) Silica
- C) Calcite ossicles
- D) Cartilage

Answer: Calcite ossicles

7. Which system in echinoderms is used for locomotion and feeding?

- A) Hemal system
- B) Ambulacral system
- C) Nervous system

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15. Phylum Echinodermata



Chapter 16

Fishes: Vertebrate Success In Water

16. Fishes

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In common usage, the term "fish" is often applied incorrectly to aquatic invertebrates such as jellyfish, cuttlefish, or starfish. Biologically, a **fish** is defined as an **aquatic, gill-breathing vertebrate with appendages (if present) in the form of fins, and usually skin covered in scales of dermal origin**. This is a **convenient descriptive term, not a valid taxonomic unit**, because fishes as traditionally defined do **not** form a **monophyletic group**. The ancestor of all land vertebrates (tetrapods) is found within a lineage of fishes (the Sarcopterygians). A more precise, cladistic definition is therefore: **all vertebrates that are not tetrapods**.

Fishes are the oldest and most diverse group of vertebrates. With **over 34,000 described species** (and thousands more likely undiscovered), they represent about half of all vertebrate species. They have successfully radiated into virtually every aquatic habitat on Earth, from high-altitude streams and desert springs to the abyssal depths of the ocean, demonstrating exquisite adaptations to life in water.

EVOLUTIONARY PERSPECTIVE AND PHYLOGENY

Water covers **73% of Earth's surface**. It is a dense, buoyant, and thermally stable medium that presents unique physiological challenges related to locomotion, respiration, and osmoregulation. Fishes represent the **ancestral vertebrate group** from which all other vertebrates (tetrapods) evolved. Their evolutionary history spans over 500 million years, beginning in the early Paleozoic era.

Milestones in Early Vertebrate Evolution:

- **Mylokunmingiids (~530-520 mya):** Among the earliest known craniates. Small, lancelet-shaped animals with a protective, non-bony braincase, large eyes, and fish-like muscle blocks (myomeres), suggesting they were active, visual predators.
- **Conodonts (~510 mya):** Eel-like vertebrates known primarily from their tooth-like feeding elements called **denticles**, made of **hydroxyapatite**. This represents one of the first appearances of mineralized tissue (bone) in the vertebrate lineage.
- **Ostracoderms (Extinct):** A paraphyletic assemblage of early, jawless vertebrates. They were bottom-dwelling, heavily armored with **bony dermal plates**, and mostly lacked paired fins. Most were filter-feeders or detritivores.
- **Placoderms (Extinct):** The first major group of **jawed vertebrates (Gnathostomes)**, characterized by heavy bony armor on the head and thorax. They possessed **paired pectoral and pelvic fins**.
- **Key Innovations:** The evolution of the **braincase, mineralized tissues (bone/dentine), hinged jaws** (from modified anterior pharyngeal arches), and **paired appendages** were transformative events that enabled vertebrate diversification.

Phylogenetic Relationships:

Modern cladistic analysis, supported by molecular data, clarifies the relationships of living fishes. The traditional group "Agnatha" (jawless fishes) is **paraphyletic**.

- **Cyclostomata** is a **monophyletic clade** containing the living jawless fishes: **Myxini (hagfishes)** and **Petromyzontida (lampreys)**.
- **Gnathostomata** is a **monophyletic clade** containing all jawed vertebrates, including cartilaginous fishes, bony fishes, and tetrapods.
- Hagfishes are the most basal living craniates. Lampreys are more closely related to jawed vertebrates than to hagfishes.

Marine vs. Freshwater Origins: Evidence suggests the first vertebrates were **marine**. However, vertebrates invaded freshwater very early in their history. Remarkably, **over 41% of all fish species are now restricted to freshwater habitats**, which constitute less than 0.01% of Earth's water volume, indicating a massive evolutionary radiation in continental waters.

SURVEY AND CLASSIFICATION OF LIVING FISHES

CYCLOSTOMATA: THE LIVING JAWLESS FISHES

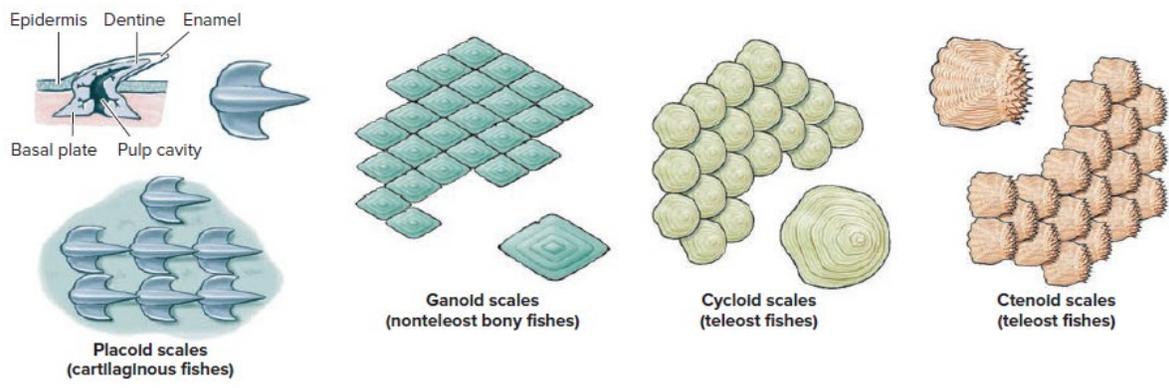
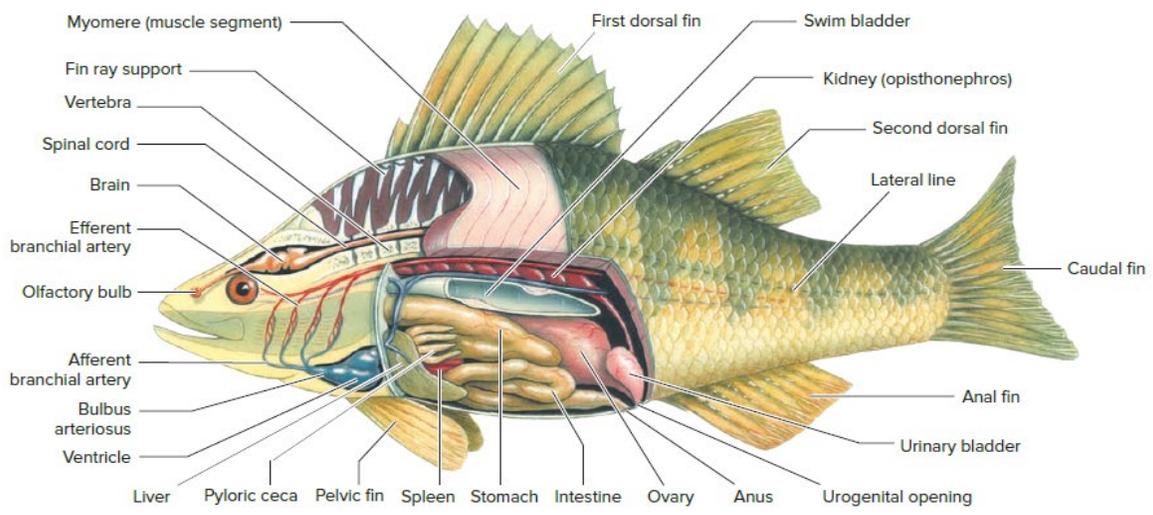
MK PREPARATIONS: Let's Make It Happen

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Characteristics of Fish Groups

Cyclostomata (Myxini and Petromyzontida)	Chondrichthyes	Actinopterygii	Sarcopterygii (fish members only)
1. Body slender, eel-like; no paired appendages	Body fusiform or dorsoventrally compressed; caudal fin heterocercal (sharks and rays) or diphycercal (chimaeras) (see Figure 24.15); paired pectoral and pelvic fins supported by cartilaginous rays	Caudal fin heterocercal (ancestral condition) or homocercal ; paired pectoral and pelvic fins usually present, supported by bony rays ; muscles controlling fin movements within trunk	Caudal fin heterocercal (fossil forms) or diphycercal ; paired pectoral and pelvic fins usually present, supported by stout bones and bony rays ; muscles controlling fin movements within fin
2. Skin naked (no scales)	Skin with placoid scales (see Figure 24.16) of dermal origin or naked	Skin with ganoid (ancestral condition), cycloid , or ctenoid scales of dermal origin or naked	Skin with elasmoid scales (in living species) with dense bone and some dentine
3. Fibrous and cartilaginous skeleton ; notochord persistent; vertebrae reduced or absent	Skeleton cartilaginous ; notochord persistent but reduced; vertebrae distinct	Skeleton of bone ; notochord usually absent; vertebrae distinct	Skeleton of bone ; notochord absent or nearly so; vertebrae distinct
4. Jaws absent ; mouth with keratinized plates (hagfishes) or teeth (lampreys); no distinctive stomach	Jaws present with polyphyodont teeth ; stomach large (absent in chimaeras); intestine with spiral valve (see Figure 24.10); liver often large and oil filled	Jaws present , usually with enameloid, polyphyodont teeth ; spiral valve present (ancestral condition) or absent	Jaws present ; teeth as enamel-covered crushing plates in lungfishes; intestine with spiral valve
5. Brain small, but distinct; 10 pairs of cranial nerves	Brain well developed; 10 pairs of cranial nerves	Brain well developed, but relatively small; 10 pairs of cranial nerves	Brain well developed, but relatively small; 10 pairs of cranial nerves
6. Eyes poorly developed (hagfishes) or moderately developed (lampreys); one pair (hagfishes) or two pairs (lampreys) of semicircular canals in inner ear	Senses of smell, vibration reception (lateral line), vision and electroreception well developed; three pairs of semicircular canals in inner ear	Senses of vision, hearing, smell, and vibration reception usually well developed, but highly variable; three pairs of semicircular canals in inner ear	Senses of vision, hearing, and smell usually well developed; three pairs of semicircular canals in inner ear

7. Sexes separate; external fertilization	Sexes separate; internal fertilization with claspers	Sexes usually separate; some hermaphroditic; some reproduce asexually by parthenogenesis; fertilization usually external, but internal in some	Sexes separate; many hermaphroditic; fertilization external (lungfishes) or internal (coelacanth)
8. Large yolkly eggs and no larval stage in hagfishes; small eggs and long larval stage (ammocoete) in lampreys	Oviparous or viviparous; embryos of viviparous species nourished by placenta, yolk sac (ovoviviparity), or cannibalism ; no larval stage	Oviparous or viviparous; embryos of viviparous species nourished by placenta or yolk sac (ovoviviparity); larval stage often greatly different from adult	Oviparous (lungfishes) or ovoviviparous (coelacanth)
9. Excretory system of pronephric and mesonephric (hagfishes) or opisthonephric (lampreys) kidneys (see Figure 30.9); kidneys drain via archinephric duct to cloaca; ammonia main nitrogenous waste	Excretory system of opisthonephric kidneys , which drain via archinephric duct to cloaca; high concentration of urea and trimethylamine oxide in blood ; rectal gland present	Excretory system of opisthonephric kidneys , which drain via archinephric duct to cloaca; ammonia usually main nitrogenous waste	Excretory system of opisthonephric kidneys , which drain via archinephric duct to cloaca; ammonia and urea usually main nitrogenous wastes
10. Hagfishes with 5-16 pairs of gills; lampreys with 7 pairs of gills	Five to seven pairs of gills leading to gill slits in rays and sharks or covered by operculum in chimaeras; no swim bladder or lung	Gills covered by bony operculum ; swim bladder present , usually functioning for buoyancy, sometimes used for respiration	Gills covered by bony operculum ; swim bladder present , used primarily in respiration (fat filled in coelacanth)
11. Heart with a sinus venosus, atrium, and ventricle; single circulation ; accessory hearts in hagfishes; nucleated red blood cells	Heart with a sinus venosus, atrium, ventricle, and conus arteriosus; single circulation ; nucleated red blood cells	Heart with a sinus venosus, atrium, and ventricle; single circulation ; nucleated red blood cells	Heart with a sinus venosus, atrium, and partly divided ventricle; pulmonary and systemic circuits incompletely separated ; nucleated red blood cells



- Changes in **Hox gene** expression patterns (particularly *HoxD*) were crucial in patterning the tetrapod limb (stylopod, zeugopod, autopod).

Practice MCQs

1. In bony fishes, the finger-like outgrowths from the intestine that increase absorptive surface area are called:

- A) Villi
- B) Pyloric ceca
- C) Mesenteries
- D) Hepatic caeca

Answer: Pyloric ceca

2. The spiral valve, which increases digestive surface area, is found in the intestine of:

- A) Teleost fishes
- B) Lampreys
- C) Elasmobranchs (sharks and rays)
- D) Lungfishes

Answer: Elasmobranchs (sharks and rays)

3. The primary site of enzymatic digestion and nutrient absorption in most fishes is the:

- A) Stomach
- B) Esophagus
- C) Small intestine
- D) Pharynx

Answer: Small intestine

4. Most modern bony fishes have teeth that are generally:

- A) Heterodont and thecodont
- B) Homodont and acrodont
- C) Diphyodont and bunodont
- D) Acrodont and pleurodont

Answer: Homodont and acrodont

5. Hagfishes feed by entering carcasses using body knots and a specialized:

- A) Muscular stomach
- B) Pharyngeal jaw
- C) Rasping tongue
- D) Suction disc

Answer: Rasping tongue

6. The feeding mode of adult lampreys is best described as:

- A) Filter feeding
- B) Herbivorous grazing
- C) Parasitic/predatory (blood and fluids)
- D) Detritivory

Answer: Parasitic/predatory (blood and fluids)

7. Paddlefishes and basking sharks are examples of fishes that are:

- A) Suction feeders

- B) Filter feeders
- C) Parasitic feeders
- D) Shell crushers

Answer: Filter feeders

8. The rapid expansion of the oral cavity to create negative pressure for prey capture is called:

- A) Ram ventilation
- B) Suction feeding
- C) Filter pumping
- D) Pharyngeal expansion

Answer: Suction feeding

9. The expandable region of the teleost digestive tract used for food storage is the:

- A) Crop
- B) Gizzard
- C) Stomach
- D) Rumen

Answer: Stomach

10. Which fish is known for a specialized scale-eating behavior?

- A) Electric eel
- B) Scale-eating cichlid (*Perissodus microlepis*)
- C) Piranha
- D) Archerfish

Answer: Scale-eating cichlid (*Perissodus microlepis*)

11. The bonnethead shark is unique among sharks for digesting significant amounts of:

- A) Coral
- B) Seagrass
- C) Mammalian bone
- D) Inorganic sediment

Answer: Seagrass

12. Ancient ostracoderms are believed to have been primarily:

- A) Apex predators
- B) Filter feeders or bottom detritus feeders
- C) Air-breathing omnivores
- D) Fast-swimming piscivores

Answer: Filter feeders or bottom detritus feeders

13. The primary nitrogenous waste excreted by most aquatic fishes is:

- A) Urea
- B) Uric acid
- C) Ammonia

Chapter 17

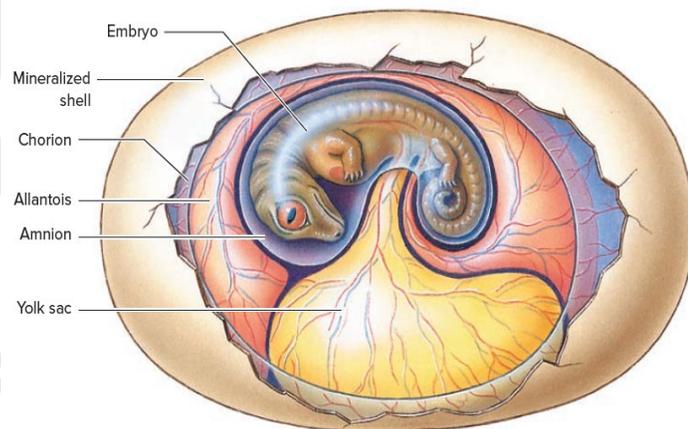
Reptiles

The **Amniota** is a **monophyletic lineage** of vertebrates whose defining, key evolutionary innovation is the **amniotic (cleidoic) egg**. This adaptation freed vertebrates from aquatic reproduction, enabling the full colonization of terrestrial habitats.

- **Evolutionary Significance:**
 - Severed the last reproductive tie to water.
 - Enabled exploitation of arid inland habitats.
 - Triggered a major adaptive radiation in the late Carboniferous and Permian periods (~312 MYA).
- **Structure of the Amniotic Egg:** It contains unique **extraembryonic membranes:**
 - **Amnion:** Forms a fluid-filled cavity (amniotic fluid), providing an aqueous microenvironment and hydraulic cushion.
 - **Chorion:** Outer membrane for gas exchange. Fuses with the allantois to form the **chorioallantois**, a highly vascularized respiratory surface.
 - **Allantois:** Stores nitrogenous waste (as uric acid) and is vascularized for respiration.
 - **Yolk Sac:** Nutrient reservoir (present in some anamniotes but fully integrated into the amniote system).
 - **Shell:** Leathery or calcified; provides mechanical support, limits water loss, and allows for gas exchange via pores.

Ancestry and Early Diversification

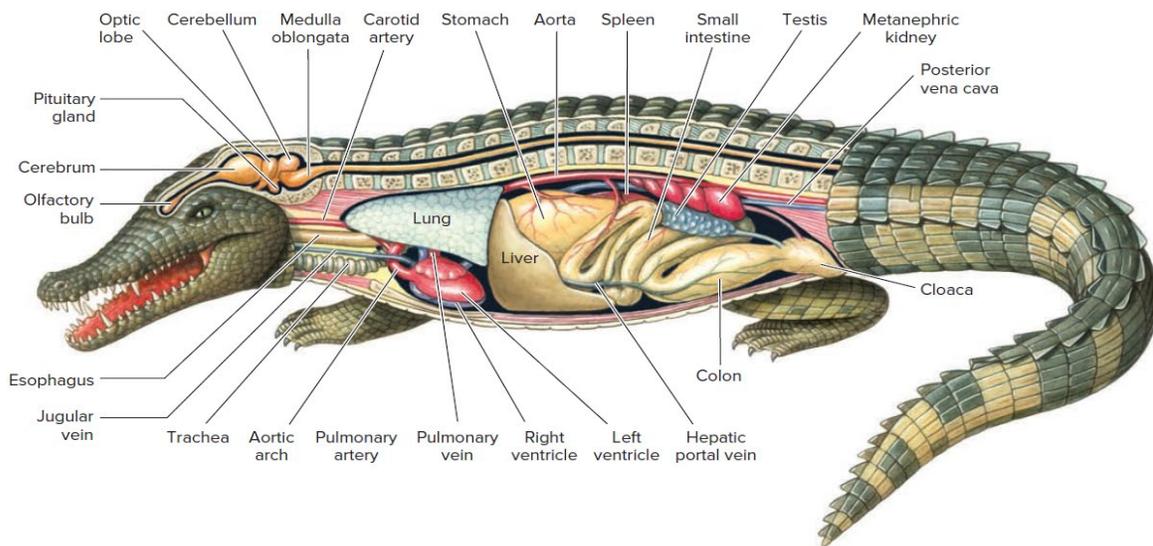
- **Ancestors:** Evolved from small, **lizard-like anthracosaur tetrapods** in the Late Carboniferous.
- **Basal Condition:** Possessed an **anapsid skull** (no temporal openings), were ectothermic, and had keratinous scales.
- **Major Divergence:** The amniote lineage split into two major branches:
 1. **Synapsida:** Characterized by a **single temporal fenestra**. This lineage gave rise to **mammals**.
 2. **Sauropsida (Reptilian Lineage):** This lineage includes all reptiles. Its earliest members had a **diapsid skull** (two pairs of temporal openings).



CLADISTICS & MODERN CLASSIFICATION OF REPTILES

Traditional Linnaean taxonomy classifies Class **Reptilia** as including turtles, lizards, snakes, tuataras, and crocodylians, but excludes birds. This makes **Reptilia a paraphyletic group** because it does not include all descendants of their most recent common ancestor (birds).

- **Process:** A new epidermal layer forms beneath the old. **Lymph** and specific enzymes are secreted between the layers, loosening the outer "stratum corneum." The animal then rubs against surfaces to shed it.
- **Patterns of Shedding:**
 - **Synchronous (Complete):** Seen in **snakes** and some lizards (e.g., geckos). The entire outer layer, including the eye **spectacle**, is shed in one inverted piece. Frequency depends on growth rate and health.
 - **Asynchronous (Patchy):** Seen in most **lizards**. The skin is shed in large, irregular patches or segments.
 - **Continuous/Piecemeal:** Seen in **crocodilians** and **turtles**. Individual scales or small patches are worn off and replaced gradually throughout life.



2. Feeding Adaptations

Dental Systems: Modes of Tooth Attachment

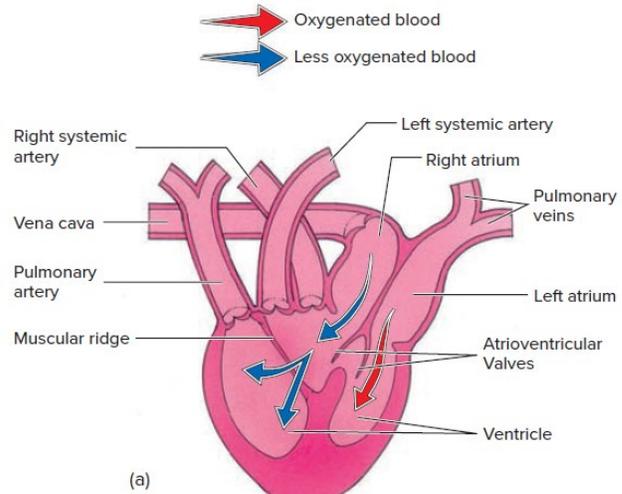
Tooth morphology and attachment are critical taxonomic traits, reflecting diet and evolutionary history.

REPTILIAN DENTITION TYPES

Type	Attachment	Replacement	Mechanical Advantage	Examples
Acrodont	Fused to the apex (top) of the jaw bone.	Limited or none. Teeth are not replaced, leading to wear over time.	Weaker attachment; suited for gripping soft prey.	Tuatara, chameleons, agamid lizards.
Pleurodont	Attached to the inner side (lingual) of the jaw bone, often in a shelf.	Continuous (polyphyodonty) from a dental lamina at the tooth base.	Stronger attachment than acrodont; allows for a broader tooth base.	Iguanids, anguid lizards, many colubrid snakes.
Thecodont	Set in deep individual sockets (alveoli) in the jaw bone.	Continuous (polyphyodonty) from a dedicated dental lamina.	The strongest and most stable	Archosaurs: Crocodilians, dinosaurs (including birds).

- **Structure:** This creates **fully independent pulmonary and systemic circuits**, allowing for higher blood pressure and more efficient oxygen delivery—critical for their active, predatory lifestyle.
- **The Foramen of Panizza:** A unique anatomical feature: a small opening connecting the **left and right aortic arches** at their base, just as they exit the heart. Its function is debated but may allow:

1. **Pressure Equalization:** Balancing blood pressure between the two systemic arches during diving when pulmonary flow is reduced.
2. **Shunting During Diving:** Enabling some oxygenated blood from the left ventricle to enter the right aortic arch, which primarily supplies the digestive system, potentially prioritizing oxygen delivery to the heart and brain via the left arch.



4. Respiratory System

Lung Morphology: From Simple to Complex

Reptilian lungs show significant advancement over the simple sac-like lungs of amphibians.

- **Progressive Complexity:**
 - **Simple Sac-like:** Found in some small lizards (e.g., anoles). Have smooth walls or minimal folding, offering limited surface area.
 - **Faveolar Lungs:** Found in more advanced lizards and the tuatara. The inner walls are divided into numerous small, vascularized chambers called **faveoli**, resembling a honeycomb, which dramatically increases the respiratory surface area.
 - **Multichambered (Edicular) Lungs:** Found in crocodylians and varanid lizards (monitors). Characterized by extensive **bronchial branching** leading to numerous **parenchymal chambers**, approaching the complexity of mammalian lungs.
 - **Snake Lungs:** A striking adaptation to their elongate body. Typically, only the **right lung is functional** and may extend for much of the body length. The **left lung is vestigial or absent**. In aquatic snakes, the lung may function as a buoyancy organ.

Mechanics of Breathing

- **Costal Aspiration (Primary Method):** Most reptiles ventilate their lungs using **intercostal muscles** to expand and contract the rib cage, creating negative pressure to draw air in (**inspiration**) and positive pressure to expel it (**expiration**). This is more efficient than the buccal pumping of amphibians.
- **Specialized Ventilation in Turtles:** The rigid shell immobilizes the ribs. Turtles have evolved two specialized muscle groups:
 1. **Diaphragmatic Muscle:** Not homologous to the mammalian diaphragm. It attaches the liver to the pelvic girdle and/or shell. Contraction pulls the liver posteriorly, increasing coelomic volume and drawing air into the lungs.
 2. **Abdominal and Limb Muscles:** Movements of the limbs and contractions of other muscles also alter internal pressure to aid ventilation.
- **Supplemental Respiration:** Some aquatic turtles can perform **cloacal respiration** (gas exchange across vascularized bursae in the cloaca) and **pharyngeal respiration** (across the mouth lining).

5. Nervous and Sensory Systems

Brain Structure



- **Overexploitation:** For the pet trade, traditional medicine, leather, and bushmeat.
- **Disease:** Emerging pathogens like ranaviruses and ophidian paramyxovirus.

REPTILE SURVEY AND MONITORING METHODS

- **Visual Encounter Surveys (VES):** Simple, for diurnal, visible species.
- **Pitfall Trapping (with drift fences):** For sampling ground-dwelling communities.
- **Funnel/Basking Trapping:** For semi-aquatic turtles and snakes.
- **Indirect Surveys:** Using signs like shed skin (slough), nests, or tracks.
- **Environmental DNA (eDNA):** Non-invasive detection of cryptic/aquatic species via DNA in water/soil.
- **Radio Telemetry:** Detailed data on individual movement and habitat use (invasive, expensive).
- **Camera Trapping:** Non-invasive method for nocturnal or cryptic species.
- Effective conservation requires a **multi-method approach**.

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Practice MCQs

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1. The amniotic egg, a key adaptation for terrestrial life, contains an extraembryonic membrane that encloses the embryo in fluid.

This membrane is the:

- A) Chorion
- B) Allantois
- C) Amnion
- D) Yolk sac

Answer: Amnion

2. Which of the following is a unique, hard form of keratin found in the epidermis of clade Reptilia (including birds and nonavian reptiles)?

- A) Alpha-keratin
- B) Beta-keratin
- C) Gamma-keratin
- D) Collagen

Answer: Beta-keratin

3. A skull with two pairs of temporal fenestrae (upper and lower openings) is characteristic of which amniote group?

- A) Anapsida
- B) Synapsida
- C) Diapsida
- D) Euryapsida

Answer: Diapsida

4. The traditional class "Reptilia" is considered paraphyletic because it excludes which of the following descendant groups?

- A) Amphibians
- B) Mammals
- C) Birds
- D) Fish

Answer: Birds

5. In turtles, the dorsal part of the shell, formed from fused vertebrae, ribs, and dermal bone, is called the:

- A) Plastron
- B) Carapace
- C) Scute
- D) Bridge

Answer: Carapace

6. The only surviving member of the order Sphenodontia, often called a "living fossil," is the:

- A) Komodo dragon
- B) Gila monster
- C) Tuatara
- D) Glass lizard

Answer: Tuatara

7. The movable quadrate bone, a key feature allowing for a kinetic skull, is a defining characteristic of the order:

- A) Testudines
- B) Crocodylia
- C) Squamata
- D) Sphenodonta

Answer: Squamata

8. The closest living relatives of birds are:

- A) Turtles
- B) Lizards and snakes
- C) Tuataras
- D) Crocodylians

Answer: Crocodylians

9. Most reptiles excrete their primary nitrogenous waste as a semi-solid paste to conserve water. This waste product is:

- A) Ammonia
- B) Urea
- C) Uric acid
- D) Allantoin

Answer: Uric acid

10. Which of the following reptiles possesses a complete, four-chambered heart similar to

Chapter 18

Mammals

Mammals (Class **Mammalia**) represent one of the most biologically differentiated of **endothermic, amniotic vertebrates**. They are uniquely characterized by the presence of **hair** and **mammary glands**, occupying nearly every terrestrial, aquatic, and aerial habitat on Earth.

- **Species Diversity:** Approximately 5,700 described species.
- **Size Range:** From the 2-gram bumblebee bat (*Craseonycteris thonglongyai*) to the 170-ton blue whale (*Balaenoptera musculus*).

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18. Mammals

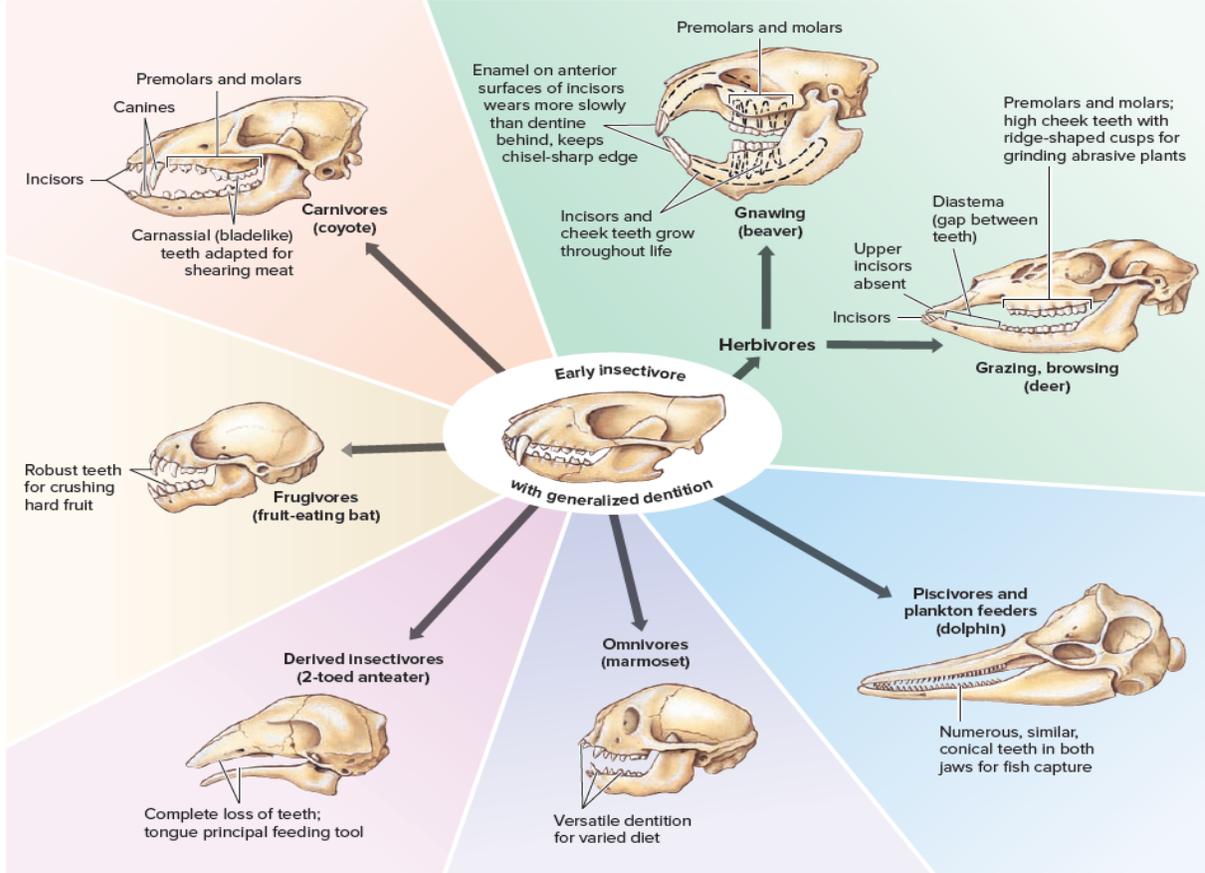
Characteristic	Description & Components	Functional Significance
Hair/Fur	Composed of keratin ; present at some life stage in all species. Layers: medulla, cortex, cuticle. Types: underhair (insulation) and guard hair (protection).	Insulation, camouflage, sensory perception (vibrissae), protection, communication.
Mammary Glands	Modified apocrine (sweat) glands that secrete milk for nourishing offspring.	Defines the class; enables extended parental care .
Single Dentary Bone	Lower jaw composed of a single dentary bone, articulating directly with the squamosal bone of the skull.	Increased jaw strength and efficiency; part of evolutionary transition from reptilian jaw.
Three Middle Ear Ossicles	Malleus (from articular bone), Incus (from quadrate bone), Stapes (homologous to amphibian/reptilian columella).	Amplifies sound vibrations; enhances hearing acuity, especially in higher frequencies.
Diphyodont Dentition	Two sets of teeth: deciduous ("milk teeth") and permanent set.	Balanced wear and replacement; specialization for varied diets.
Muscular Diaphragm	Sheet of muscle separating thoracic and abdominal cavities.	Enables efficient negative-pressure lung ventilation , supporting high metabolic rates.
Four-Chambered Heart	Complete separation of pulmonary and systemic circuits.	Supports endothermy and high metabolic rates; prevents mixing of oxygenated/deoxygenated blood.
Highly Developed Neocortex	Enlarged, often convoluted outer layer of cerebral cortex .	Responsible for higher cognitive functions: sensory integration, voluntary motor control, learning, memory, reasoning, complex social behavior.
Endothermy & Homeothermy	Internal heat generation via metabolism (endothermy); maintenance of constant high body temperature (homeothermy).	Enables activity in varied climates; supports high-energy lifestyles.
Other Notable Features	Epiphyses on long bones, enucleated red blood cells , metanephric kidneys with loop of Henle, urea as primary nitrogenous waste.	Growth regulation, efficient gas transport, water conservation, waste excretion.

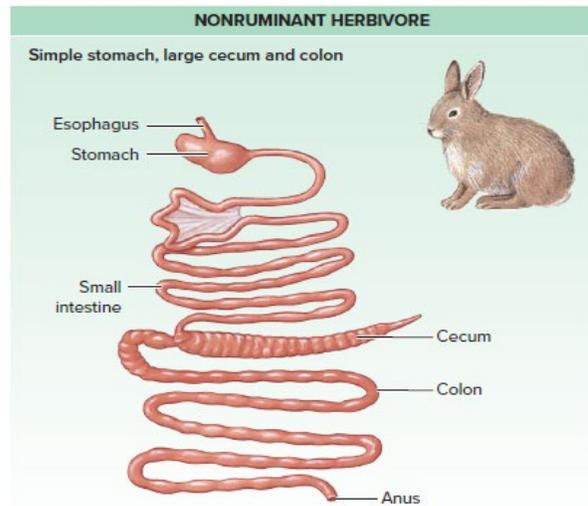
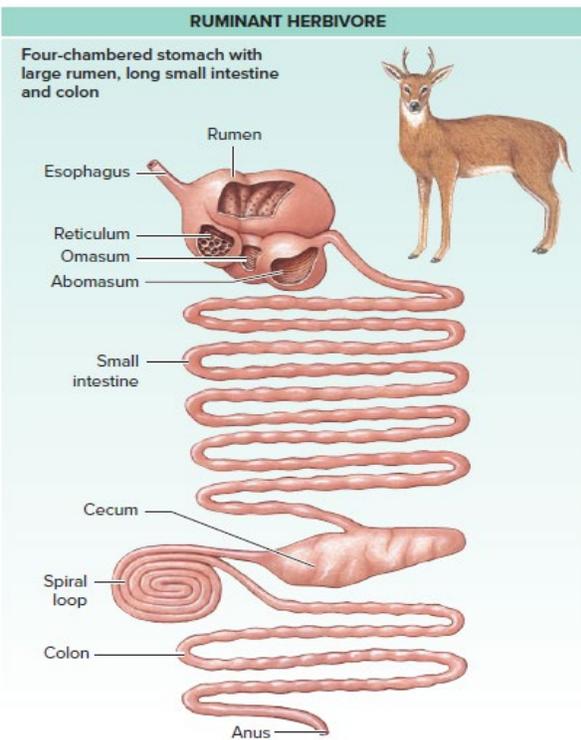
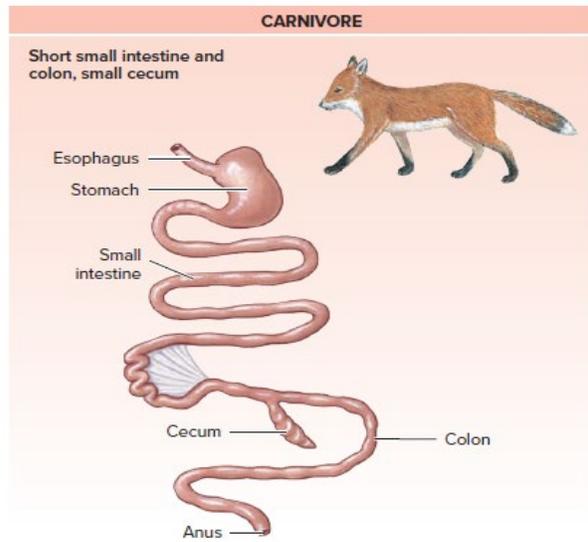
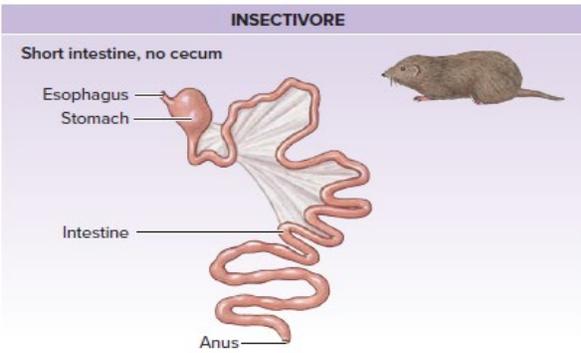
ORIGIN AND EVOLUTION OF MAMMALS

Mammals evolved from **synapsid amniotes**, a lineage distinct from diapsid reptiles (dinosaurs, lizards, birds).

Synapsid Lineage

Characterized by a skull with a **single pair of temporal fenestrae**.





Type	Adaptations	Examples
Cursorial	Elongated limbs; digitigrade/unguligrade posture.	Horses, deer, antelope.
Fossorial	Powerful forelimbs; reduced eyes/pinnae.	Moles, armadillos, marsupial moles.
Scansorial/Arboreal	Grasping limbs; claws; prehensile tails.	Squirrels, primates, possums.
Aerial	True powered flight via patagium over elongated digits.	Bats (Chiroptera) – only mammals capable.
Gliding	Patagial membranes for controlled descent.	Flying squirrels, colugos.
Aquatic	Streamlined body; limbs modified into flippers; blubber.	Whales (Cetacea), seals, manatees (Sirenia).
Saltatorial	Adapted for leaping; powerful hindlimbs.	Kangaroos, kangaroo rats.
Bipedalism	Obligate in humans: S-shaped spine, short broad pelvis, angled femur, anterior foramen magnum.	Humans (exclusive among living mammals).



SIGNIFICANT EVENTS IN HOMININ EVOLUTION

SPECIES (YEARS BEFORE PRESENT)	CRANIAL CAPACITY (BRAIN SIZE)* AND STATURE	SIGNIFICANT EVENTS	EXTENT OF FOSSIL RECORD
<i>Sahelanthropus tchadensis</i> (7-6 million)	350 cm ³ ? cm Possibly bipedal	Oldest known hominin fossil	Single skull
<i>Ardipithecus ramidus</i> (5.8-4 million)	? cm ³ 122 cm Possibly bipedal		Three fossil sites include partial jaw, teeth, and partial arm bones.
<i>Australopithecus anamensis</i> (4.2-3.9 million)	? cm ³ ? cm Probably bipedal		Three fossil sites include partial jaw, humerus, and tibia.
<i>Australopithecus afarensis</i> (3.9-3 million)	375-550 cm ³ 107-152 cm Bipedal	Possible divergence point to <i>Homo</i> lineage	Multiple fossil sites and numerous individuals, including the 40% complete "Lucy" and another 70% complete specimen.
<i>Australopithecus africanus</i> (3-2 million)	420-500 cm ³ ? cm Bipedal		Multiple fossil sites and numerous individuals. Skull, pelvis, vertebrae, and leg bones. Includes a nearly complete skull of a child about three years old.
<i>Homo habilis</i> (2.4-1.5 million)	500-800 cm ³ 127 cm Bipedal	Possibly rudimentary speech. Primitive stone tool use.	Multiple fossil sites with many skeletal remains, including skulls and arm and leg bones.
<i>Homo erectus</i> (1.8 million-300,000)	750-1,225 cm ³ 160-180 cm Bipedal	More sophisticated stone tools and fire. Migrated widely out of Africa into Europe and Asia	Multiple fossil sites with many skeletal remains, including skulls and a nearly complete skeleton of "Turkana boy," a 10- or 11-year-old individual discovered near Lake Turkana in Kenya.
<i>Homo heidelbergensis</i> (500,000-200,000)	1,200 cm ³ ? cm Bipedal		Multiple fossil sites with skulls and teeth.
<i>Homo neanderthalensis</i> (230,000-30,000)	1,450 cm ³ 170 cm Bipedal	More advanced tools and weapons. Burial rituals. Construction of shelters.	Many fossil sites with nearly complete skeletons.
<i>Homo sapiens</i> (300,000-present)	1,350 cm ³ 180 cm Bipedal	More advanced tools and weapons. Developed fine artwork.	Many fossil sites with nearly complete skeletons.

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18. Mammals

TAXONOMIC CLASSIFICATION OF LIVING MAMMALS

29 orders grouped into three major lineages.

Subclass Prototheria (Monotremes)

- **Order Monotremata:** Oviparous; cloaca; no nipples (milk patch); adults toothless; lower variable body temperature (~31°C); retain reptilian bones (interclavicle, coracoids). *Examples:* Platypus, echidnas. *Distribution:* Australia, New Guinea.

Infraclass Metatheria (Marsupials)

Short gestation; choriovitelline placenta; altricial young; prolonged pouch development; epipubic bones; lack corpus callosum.

Order	Common Name(s)	Key Characteristics	Distribution	Examples
Didelphimorphia	American Opossums	Prehensile tail; well-developed pouch; omnivorous.	The Americas	Virginia opossum



- **Advanced methods:** camera trapping (SECR), genetic census, aerial/drone surveys, acoustic monitoring.
- Key considerations: objective, species biology, habitat, logistics, sampling design, pilot study.

MISCELLANEOUS EXAM-ORIENTED FACTS

- **Largest mammalian order:** Rodentia.
- **Second largest order:** Chiroptera (bats).
- **Only flying mammals:** bats (Chiroptera).
- **Only poisonous mammal:** male platypus (ankle spur).
- **Largest land mammal:** African elephant.
- **Largest animal ever:** blue whale.
- **Only mammal with true horns in both sexes:** Bovidae.
- **Only mammals that shed antlers annually:** Cervidae (except caribou females).
- **Mammals with the longest gestation:** elephants (~19 months).
- **Mammals with the shortest gestation:** marsupials (e.g., opossum: 12–13 days).
- **Monotremes lack nipples;** milk is secreted onto a **mammary patch**.
- **Marsupials have a bifurcated (double) vagina.**
- **Eutherians have a single vagina and a well-developed placenta.**
- **Baleen whales are filter-feeders with keratin plates.**
- **Toothed whales use echolocation.**
- **Human dental formula (permanent):** I2/2, C1/1, P2/2, M3/3 = 32 total.
- **Human vertebral formula:** C7 T12 L5 S5 Co4.

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18. Mammals

Practice MCQs

1. Which of the following is a diagnostic characteristic unique to all mammals at some stage of their life cycle?

- A) Feathers
- B) Scales
- C) Hair
- D) Antlers

Answer: Hair

2. What is the primary component of mammalian hair?

- A) Chitin
- B) Cellulose
- C) Keratin
- D) Collagen

Answer: Keratin

3. From which lineage of amniotes did mammals evolve?

- A) Diapsids
- B) Synapsids
- C) Anapsids
- D) Sauropsids

Answer: Synapsids

4. Which early synapsid group is often incorrectly called "mammal-like reptiles"?

- A) Cynodonts
- B) Pelycosaur
- C) Therapsids

D) Dinosaurs

Answer: Pelycosaur

5. What key adaptation in therapsids allowed for more efficient locomotion?

- A) Sprawling limbs
- B) Erect gait
- C) Fins
- D) Wings

Answer: Erect gait

6. Which advanced therapsid subgroup is considered the direct ancestor of mammals?

- A) Pelycosaur
- B) Cynodont
- C) Dicyodont
- D) Gorgonopsid

Answer: Cynodont

7. The evolution of which structure in cynodonts allowed breathing while eating?

- A) Gizzard
- B) Secondary palate
- C) Syrinx
- D) Pharyngeal slit

Answer: Secondary palate

8. Which bones in mammals evolved from the articular and quadrate bones of reptilian ancestors?

- A) Stapes and incus
- B) Malleus and incus



Chapter 19

Nutrition and Digestion

Nutrition is the sum of all processes involved in the procurement, intake, digestion, absorption, and utilization of substances necessary for growth, maintenance, repair, and metabolic functions. Nutrients are substances that supply the body with elements essential for metabolism.

Importance of Nutrition

Aspect	Physiological & Molecular Role
Growth (Hyperplasia & Hypertrophy)	Provides substrates (amino acids, fatty acids, minerals) for the synthesis of new tissues (e.g., bone matrix, muscle protein). Critical during developmental windows (prenatal, adolescent). Hormones (GH, IGF-1) are nutrient-sensitive.
Repair & Maintenance (Homeostasis)	Enables continuous tissue turnover (e.g., intestinal epithelium renewal every 3-5 days). Nutrients act as cofactors (Zn in DNA polymerase) and antioxidants (Vitamins C & E) to mitigate oxidative damage and support apoptosis/autophagy of damaged cells.
Energy (ATP Production)	Macronutrients undergo catabolism to yield ATP: <ul style="list-style-type: none"> • Carbohydrates: Primary fuel via glycolysis & oxidative phosphorylation. • Lipids: High-yield energy reserve via β-oxidation. • Proteins: Emergency fuel via gluconeogenesis (catabolic states).

Nutrition Vs Digestion

Feature	NUTRITION	DIGESTION
Definition	Holistic process of obtaining & utilizing nutrients.	Specific breakdown of food into absorbable units.
Scope	Extremely broad (behavior, physiology, ecology).	Narrow (focused on GI tract processes).
Primary Goal	Acquire matter & energy for life functions.	Convert food into absorbable form.
Key Processes	Ingestion, Digestion, Absorption, Transport, Assimilation, Catabolism, Egestion.	Ingestion, Mechanical/Chemical Breakdown, Propulsion.
Systems Involved	Digestive, Circulatory, Lymphatic, Endocrine, Excretory, Nervous.	Primarily Digestive System & exocrine glands.
End Point	Cellular metabolism (ATP, biosynthesis).	Lumen of small intestine (simple molecules ready for absorption).
Regulation	Systemic (e.g., insulin, leptin).	Largely local (e.g., gastrin, secretin, enteric nervous system).

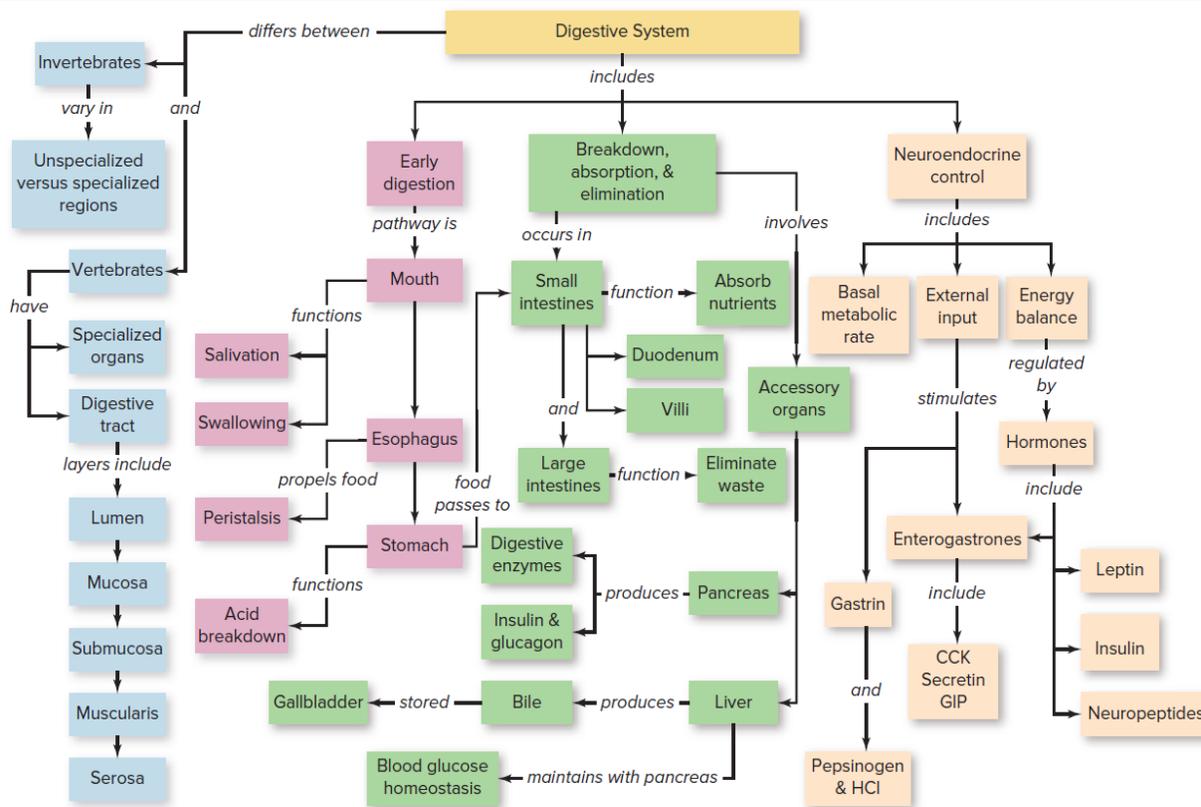
Fundamental Nutritional Dichotomy:

- **Autotrophy:** Organisms synthesize their own complex organic molecules from simple inorganic substances.

			expandable stomachs (snakes).
Omnivores	Consume both plant and animal matter.	Humans, bears, rats, cockroaches.	Generalized dentition and digestive system.
Filter Feeders	Strain suspended particles from water.	Baleen whales, clams, barnacles, flamingos.	Specialized structures (baleen plates, cilia, gill rakers).
Fluid Feeders	Suck nutrient-rich fluids.	Mosquitoes, ticks, aphids, leeches, butterflies.	Piercing-sucking mouthparts (stylets, proboscis); anticoagulant saliva.
Substrate/Deposit Feeders	Live in/on or ingest food source (e.g., soil, leaf tissue).	Earthworms, leaf-miner caterpillars, maggots.	Burrowing/mining through food; simple guts.
Detritivores	Consume decomposing organic matter.	Dung beetles, millipedes, some crabs.	Often host symbiotic microbes for breakdown.

MK PREPARATIONS

19. Nutrition and Digestion



Evolutionary Perspective of Heterotrophy: Heterotrophy is ancient, originating with early heterotrophic bacteria. The loss of certain biosynthetic pathways in animals provided a **selective advantage**, allowing energy to be redirected toward growth and reproduction.

Diversity in Digestive System Plans

The structure of the digestive system correlates with complexity and diet.

- **Intracellular Digestion:** Food particles are engulfed by phagocytosis and digested within **food vacuoles** that fuse with lysosomes.



- o **Iodine:** Thyroid hormone production. Sources: Iodized salt, seafood, dairy.

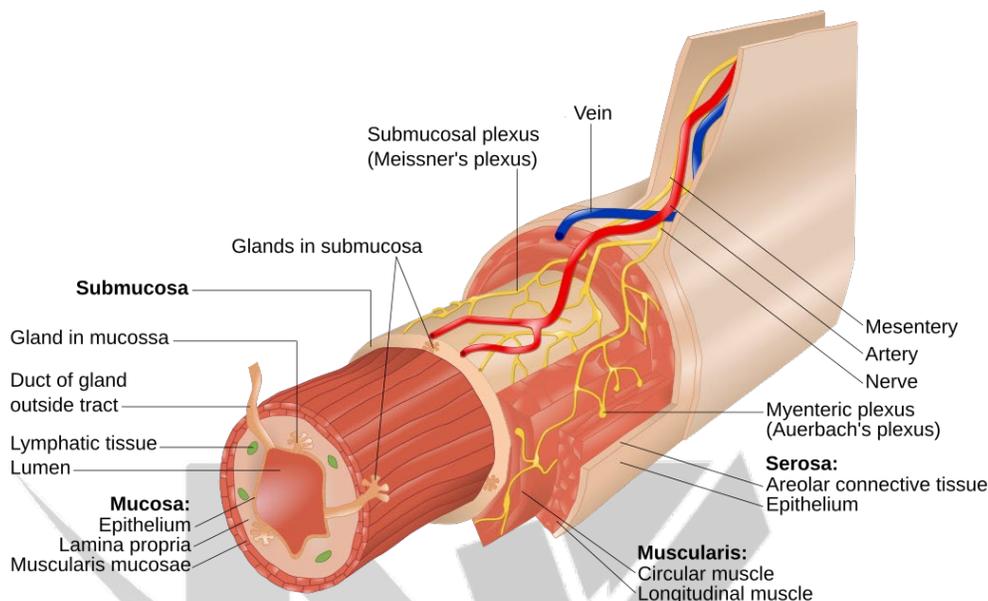
Mineral	Category	Key Functions	Major Dietary Sources	Deficiency Symptoms / Disorders
Calcium (Ca)	Macro	Bone/teeth structure , muscle contraction, nerve transmission, blood clotting.	Dairy, fortified plant milks, tofu (set with calcium), sardines with bones, leafy greens.	Osteoporosis, osteopenia, muscle cramps, rickets.
Magnesium (Mg)	Macro	300+ enzyme reactions , muscle/nerve function, blood glucose control, blood pressure regulation.	Spinach, nuts, seeds, legumes, whole grains, dark chocolate.	Muscle cramps, arrhythmia, fatigue, migraines.
Potassium (K)	Macro	Fluid balance , nerve impulses, muscle contraction, counteracts sodium to lower BP.	Bananas, potatoes, beans, lentils, avocado, spinach, coconut water.	Weakness, fatigue, muscle cramps, arrhythmia, hypertension.
Sodium (Na)	Macro	Fluid balance , nerve impulse conduction, muscle contraction.	Table salt, processed foods, canned soups, savory snacks.	Excess is common: Hypertension, cardiovascular strain. Deficiency (hyponatremia) is rare.
Iron (Fe)	Trace	Oxygen transport (hemoglobin), energy production, immune function.	Heme Iron (better absorbed): Red meat, organ meat, shellfish. Non-heme: Lentils, spinach, tofu, fortified cereals.	Iron-deficiency anemia: Fatigue, pallor, shortness of breath, weakness.
Zinc (Zn)	Trace	Immune function , wound healing, DNA synthesis, taste/smell perception, growth.	Oysters, red meat, poultry, beans, nuts, seeds, dairy.	Impaired immunity, hair loss, diarrhea, delayed wound healing, loss of taste/smell.
Iodine (I)	Trace	Synthesis of thyroid hormones (regulate metabolism, growth, development).	Iodized salt, seafood, dairy products, seaweed.	Goiter (enlarged thyroid), hypothyroidism, congenital issues.
Selenium (Se)	Trace	Antioxidant (part of glutathione peroxidase), thyroid hormone metabolism, immune function.	Brazil nuts, seafood, meat, eggs, whole grains.	Keshan disease (heart muscle disorder), Kashin-Beck disease (joint/bone disorder).
Copper (Cu)	Trace	Iron metabolism, connective tissue formation, antioxidant enzyme function.	Shellfish, liver, nuts, seeds, whole grains, dark chocolate.	Rare; anemia, bone abnormalities, neurological issues.

OTHER COMPONENTS

MK PREPARATIONS: Let's Make It Happen

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Serosa/Adventitia a	Outer connective tissue layer; serosa is covered by visceral peritoneum.	Protection and lubrication.
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ORGANS OF THE DIGESTIVE SYSTEM AND THEIR FUNCTIONS

1. MOUTH (ORAL CAVITY)

- **Functions:** Ingestion, mechanical breakdown (mastication), initiation of chemical digestion.
- **Structures:**
 - **Teeth: Heterodont dentition** (Incisors, Canines, Premolars, Molars) for cutting, tearing, and grinding.
 - **Tongue:** Muscular organ for manipulation, taste, and swallowing.
 - **Salivary Glands:** Three pairs - Parotid, Submandibular, Sublingual.
- **Secretion - Saliva** (~1-1.5 L/day):
 - **Composition:** Water, mucus, electrolytes, **salivary amylase (ptyalin)**, lingual lipase, lysozyme, IgA.
 - **Functions:**
 - Moistens and lubricates food (mucin).
 - Initiates starch digestion (**amylase**).
 - **Bolus formation.**
 - Antimicrobial action (lysozyme).
 - **Regulation:** Primarily under parasympathetic nervous control (CN VII, IX).

Functions: Selection, Grinding (Mastication), Lubrication, Digestion.

A. Selection of Food

- Involves senses of **taste, smell, sight, and touch**.
- **Tongue** (with taste buds) and sensory receptors detect undesirable substances (bad taste, smell, hard objects).

B. Mastication

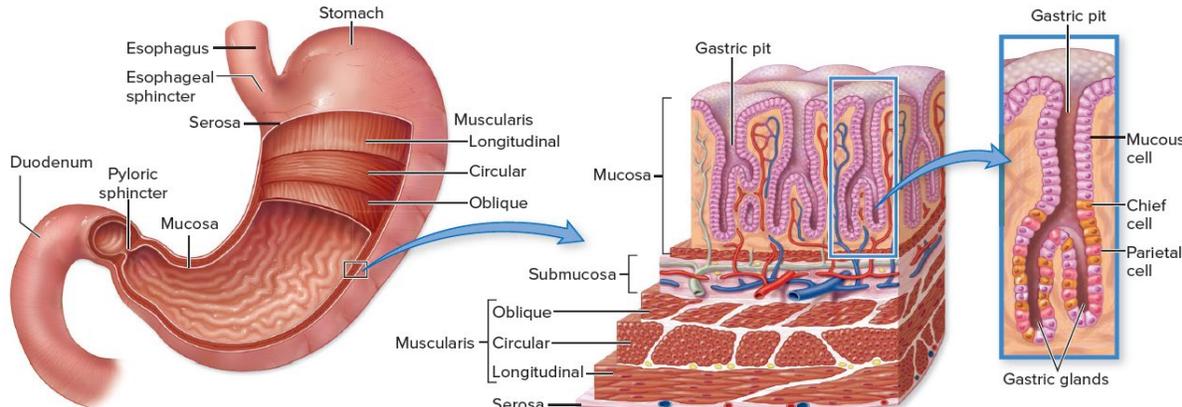
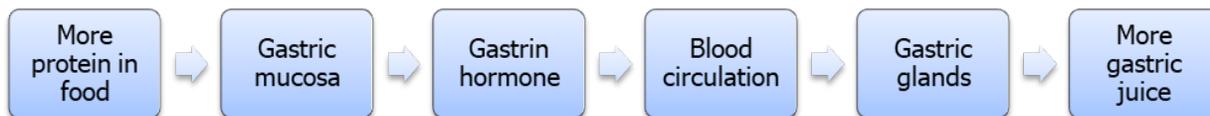
- Chewing by **molars** breaks food into smaller pieces.
- **Importance:**
 1. Allows passage through the esophagus.
 2. Increases surface area for enzyme action.

G-Cells

Gastrin (hormone)

Stimulates parietal and chief cells.

- **Chyme:** Semi-fluid, partially digested food mass leaving the stomach.
- **Regulation of Gastric Secretion**
- **Cephalic Phase:** Stimulated by sight, smell, taste of food (via vagus nerve).
- **Gastric Phase:** Food distension stimulates gastrin hormone release → increases secretion.
- **Intestinal Phase:** Inhibitory signals from duodenum slow gastric emptying.
- **Functions:** Temporary storage, mechanical churning, chemical digestion of proteins.
- **Gastric Glands & Secretions:**
- **Process:** Food mixes with gastric juice to form semi-liquid **chyme**.
- **Protection Against Self-Digestion:** Mucous-bicarbonate barrier, rapid epithelial turnover, tight junctions.
- **Exit:** **Pyloric sphincter** regulates chyme release into duodenum.



5. The Small Intestine

The small intestine is the primary site for the **chemical digestion of macromolecules** and the **absorption of over 90% of nutrients, water, and electrolytes**. Its considerable length (~6 meters in vivo, longer post-mortem) and specialized architecture provide an immense surface area and ample transit time for efficient processing.

Anatomical Regions & Specialized Functions

The small intestine is divided into three sequential regions, each with distinct roles.

A. Duodenum (First ~25 cm)

The "**mixing bowl**" and initial site of major chemical digestion.

- **Receives Inputs:**
 - Acidic **chyme** from the stomach.
 - **Bile** from the liver and gallbladder (via the bile duct).
 - **Bicarbonate-rich pancreatic juice** from the pancreas (via the pancreatic duct).
- **Key Structural Feature: Brunner's glands** in the submucosa secrete an **alkaline mucus** to neutralize acid, protect the duodenal wall, and optimize pH for pancreatic enzymes.
- **Hormonal Control (Enteroendocrine Secretions):**
 - **Secretin:** Released by **S-cells** in response to acidic chyme. Stimulates the pancreas to secrete bicarbonate-rich fluid.
 - **Cholecystinin (CCK):** Released by **I-cells** in response to fats and proteins. Stimulates pancreatic enzyme secretion and gallbladder contraction.

B. Jejunum (~2.5 meters)

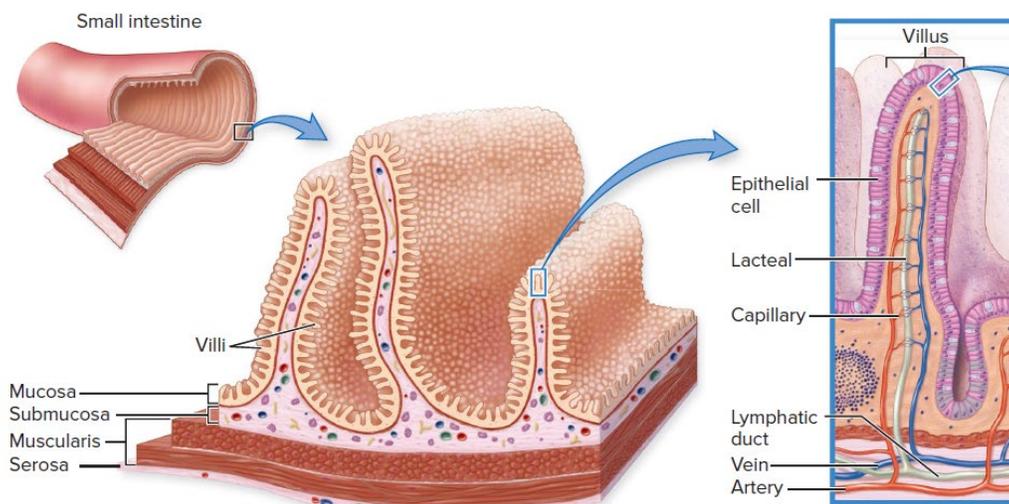
The **primary site of nutrient absorption**.

- Characterized by the tallest and most numerous **plicae circulares** and **villi**, maximizing surface area.
- Major site for absorption of:
 - **Carbohydrates:** Monosaccharides (glucose, galactose, fructose).
 - **Proteins:** Amino acids and small peptides.
 - **Lipids:** Fatty acids and monoglycerides.
 - **Vitamins & Minerals.**
- Possesses an extensive vascular and lymphatic network for rapid nutrient transport.

C. Ileum (~3.5 meters)

The "**completion and defense**" segment.

- Completes absorption of remaining nutrients, specifically:
 - **Vitamin B₁₂ (cobalamin).**
 - **Bile salts** (initially absorbed here for **enterohepatic circulation**).
- **Mucosal Immunity:** Rich in **Peyer's patches**—large aggregates of lymphoid tissue in the submucosa that sample gut antigens and initiate immune responses.
- Terminates at the **ileocecal valve**, a sphincter regulating entry into the large intestine and preventing bacterial backflow.



Structural Adaptations for Absorption

The intestinal wall is engineered to create a cumulative surface area increase of ~600x. From macroscopic to microscopic:

1. **Plicae Circulares:** Large, permanent circular folds of the mucosa and submucosa. They slow chyme transit, creating turbulence for better mixing.
2. **Villi:** Finger-like projections of the mucosa (0.5-1.5 mm tall). Each villus contains:
 - A dense **capillary network** (absorbs water-soluble nutrients).
 - A central **lacteal**, a lymphatic capillary (absorbs fat-soluble nutrients packaged into **chylomicrons**).
 - Strands of **muscularis mucosae** allowing gentle swaying to enhance contact.
3. **Microvilli (Brush Border):** Form a dense "fuzzy" border on the apical surface of absorptive **enterocytes**. This final layer houses **brush border enzymes** for terminal digestion and maximizes surface area.

Chemical Digestion: The Enzyme Cascade

Digestion is a sequential process involving secretions from the pancreas, liver, and intestine itself.

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Water & Electrolyte Reabsorption: Reabsorbs ~1.5 liters of water daily, along with Na⁺, Cl⁻, and other ions, concentrating the luminal contents.

1. **Microbial Fermentation:** The **gut microbiota** (mostly in the proximal colon) ferments undigested carbohydrates (fiber) into **short-chain fatty acids (SCFAs)** like butyrate (a primary energy source for colonocytes), acetate, and propionate. This also produces gases (flatus).
2. **Vitamin Synthesis:** Bacteria synthesize **Vitamin K** (essential for clotting) and some **B vitamins** (biotin, B5, folate), which are then absorbed.
3. **Feces Formation & Storage:** Compacts indigestible residue, bacteria, sloughed cells, and bile pigments (which give color) into **feces**. Storage occurs primarily in the descending and sigmoid colon.

Defecation Reflex:

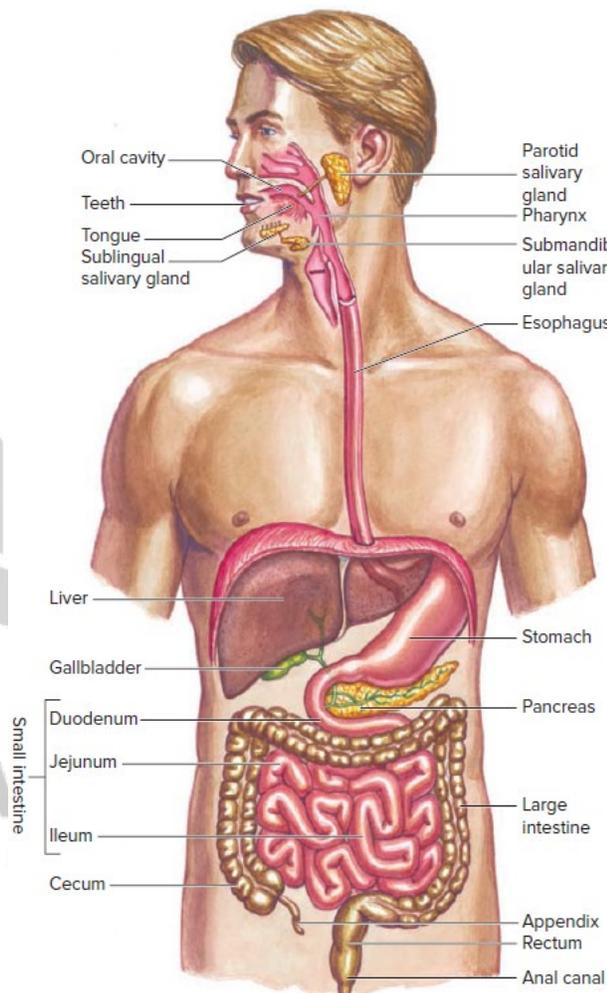
1. **Filling:** Feces move into the rectum by mass movements, causing **rectal distension**.
2. **Spinal Reflex:** Stretch receptors signal via pelvic nerves to the **defecation center** in the sacral spinal cord (S2-S4).
3. **Involuntary Response:** The reflex causes peristalsis in the sigmoid colon/rectum and **relaxes the internal anal sphincter** (smooth muscle, involuntary).
4. **Voluntary Control:** Conscious awareness allows the **external anal sphincter** (skeletal muscle, voluntary) to be contracted to delay defecation. When appropriate, voluntary relaxation of this sphincter, combined with increased abdominal pressure (Valsalva maneuver), allows expulsion.

ACCESSORY DIGESTIVE ORGANS

A. LIVER

- **Largest gland;** multifunctional metabolic powerhouse.
- **Functions:**
 - **Bile Production:** 600-1000 mL/day. Bile contains bile salts (emulsify fats), cholesterol, phospholipids, bile pigments (bilirubin).
 - **Metabolic Regulation:**
 - Carbohydrates: Glycogenesis, glycogenolysis, gluconeogenesis.
 - Proteins: Deamination of amino acids; urea synthesis.
 - Lipids: Synthesis of cholesterol, lipoproteins (HDL, LDL).
 - **Detoxification:** Processes drugs, alcohol, metabolic wastes.
 - **Storage:** Glycogen, vitamins (A, D, B12), iron.
 - **Synthesis:** Plasma proteins (albumin, clotting factors).
- **Hepatic Portal System:** Veins from GI tract carry nutrient-rich, toxin-laden blood to liver for processing **before** it enters systemic circulation.

B. GALLBLADDER





Examples	Cats, snakes.	Cows (ruminant), horses (hindgut fermenter).	Humans, bears, pigs.	Eagles, sparrows.
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Specific Adaptations:

- **Foregut Fermentation (Ruminants):** Multi-chambered stomach (rumen, reticulum, omasum, abomasum). Microbes digest cellulose; animal regurgitates **cud** for re-chewing (rumination).
- **Hindgut Fermentation:** Enlarged **cecum** and/or colon (e.g., horses, rabbits). **Coprophagy** in some allows re-ingestion of microbially processed feces.
- **Molecular Adaptations:** Convergent evolution of stomach **lysozyme** in ruminants and leaf-eating monkeys for digesting bacteria.

The Gut Microbiome: A Vital Symbiotic Organ

The community of microorganisms (bacteria, archaea, fungi, viruses) in the alimentary tract.

Functions:

1. **Digestion:** Ferments indigestible fibers into **Short-Chain Fatty Acids (SCFAs)** like acetate, propionate, butyrate.
2. **Synthesis:** Produces vitamins (K, B12, Biotin, Folate).
3. **Immunological:** Trains and modulates the host immune system; supports gut-barrier integrity.
4. **Protective:** Outcompetes pathogens via colonization resistance.

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Practice MCQs

1. Which of the following is the correct sequence of the digestive tract from proximal to distal?

- A) Esophagus, Stomach, Duodenum, Jejunum, Ileum
- B) Stomach, Esophagus, Ileum, Jejunum, Duodenum
- C) Duodenum, Jejunum, Ileum, Stomach, Esophagus
- D) Jejunum, Ileum, Duodenum, Stomach, Esophagus

Answer: Esophagus, Stomach, Duodenum, Jejunum, Ileum

2. Which hormone is responsible for stimulating the release of bicarbonate-rich pancreatic juice?

- A) Gastrin
- B) Secretin
- C) Cholecystokinin
- D) Gastric Inhibitory Peptide

Answer: Secretin

3. Which of the following cells secrete pepsinogen in the stomach?

- A) Parietal Cells
- B) G Cells
- C) Chief Cells

D) Mucous Neck Cells

Answer: Chief Cells

4. The majority of nutrient absorption occurs in which part of the small intestine?

- A) Duodenum
- B) Jejunum
- C) Ileum
- D) All parts equally

Answer: Jejunum

5. Which vitamin requires intrinsic factor for its absorption in the ileum?

- A) Vitamin C
- B) Vitamin B12
- C) Vitamin D
- D) Vitamin K

Answer: Vitamin B12

6. The process of breaking down large fat globules into smaller droplets is primarily the function of:

- A) Pancreatic Lipase
- B) Bile Salts
- C) Gastric Lipase
- D) Colipase

Answer: Bile Salts

7. Which of the following is NOT a primary function of the liver?

- A) Gluconeogenesis

Chapter 20

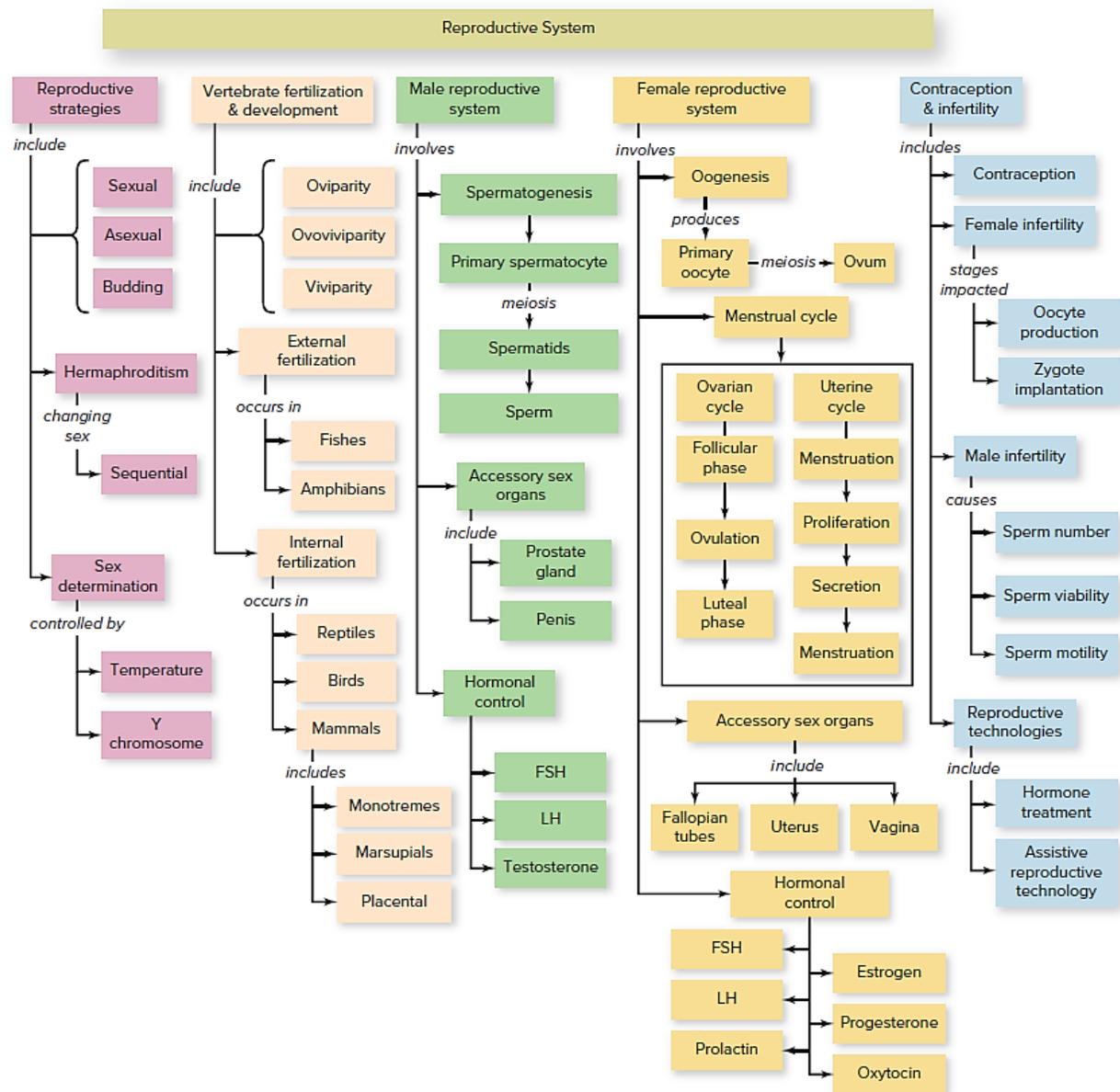
Reproduction and Development

Developmental biology represents one of the most integrative fields in biological science, seeking to explain how **genetic information** is translated into **three-dimensional form and function**. At its core lies a profound paradox: unlike human-engineered machines that are built first and then function, organisms must **maintain physiological function** while simultaneously **constructing themselves** through embryonic development, growth, and repair. This field transcends traditional **embryology** (development from fertilization to birth) to encompass the entire lifespan, including:

- **Metamorphosis:** Radical post-embryonic transformation (e.g., caterpillar to butterfly)
- **Regeneration:** Replacement of lost body parts (e.g., salamander limbs, zebrafish heart)
- **Tissue Turnover:** Continuous renewal of cells in skin, gut, and blood
- **Aging:** Progressive changes in structure and function over time

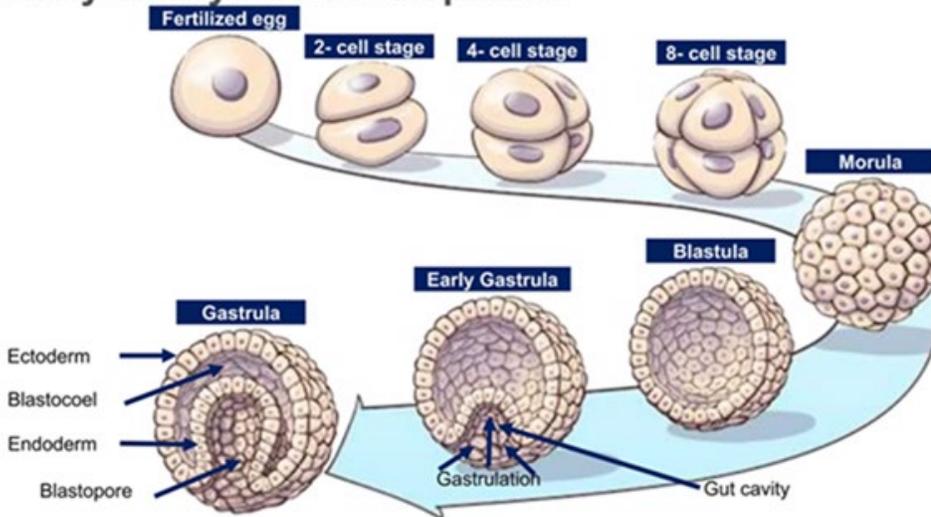
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20. Reproduction and Development



		layer formation; body plan establishment		
Organogenesis	Formation of organs from germ layers	Tissue interactions, morphogenesis, cell differentiation	Weeks 4-8	Builds organ systems; highly sensitive to teratogens
Fetal Period	Growth and maturation of organs	Histogenesis (tissue specialization), functional maturation, growth	Week 9 to birth	Organs become functional; massive growth
Metamorphosis	Radical transformation to adult form	Tissue remodeling, apoptosis, new growth	Variable (e.g., ~12 weeks in frogs)	Adapts organism to different ecological niches
Gametogenesis	Production of next generation's gametes	Meiosis, gamete differentiation, maturation	Puberty to reproductive senescence	Completes life cycle; enables reproduction

Early embryonic development



Comparative Embryology and Germ Layer Theory:

The Germ Layer Concept:

The discovery that most animals develop from three primary germ layers represents one of the most profound unifying principles in biology.

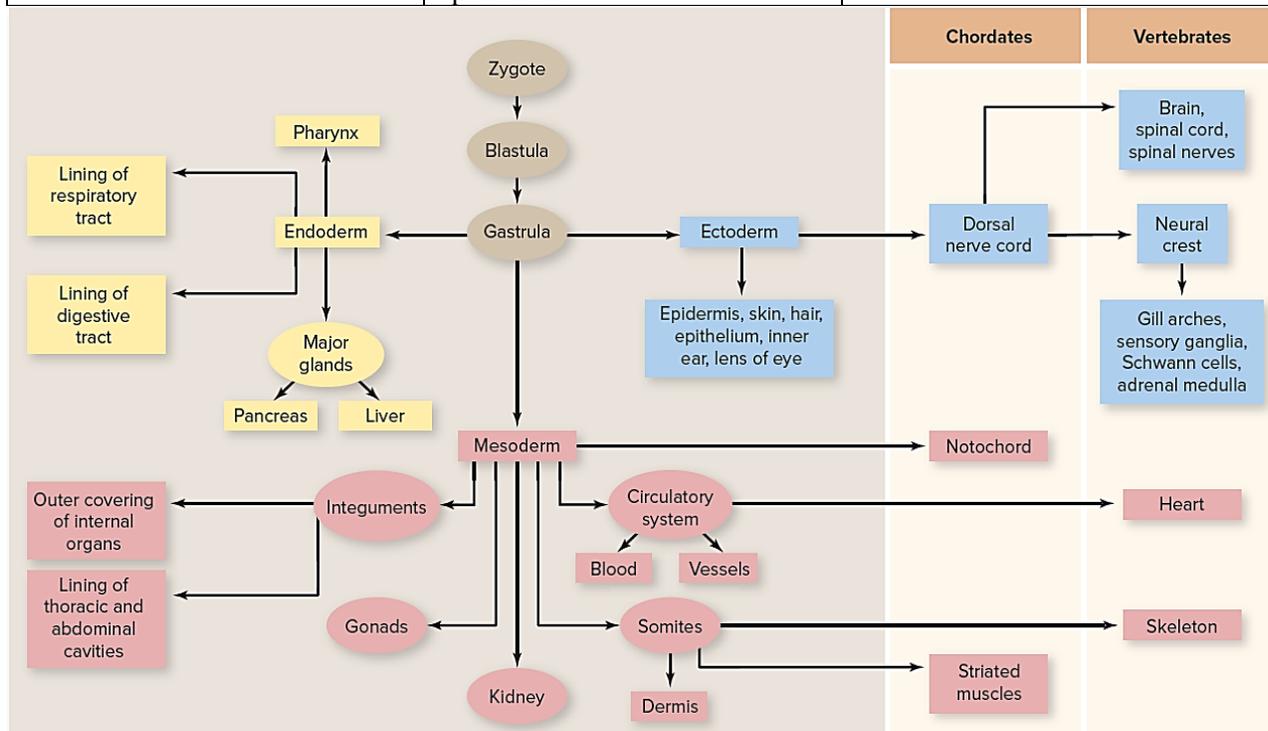
Germ Layer Derivatives with Specific Examples

Germ Layer	Major Derivatives	Specific Tissues/Organs
Ectoderm (Outer Layer)	Surface Ectoderm: Epidermis, hair, nails, lens, inner ear, enamel	Keratinocytes, melanocytes, Merkel cells
	Neuroectoderm: CNS (brain, spinal cord), retina, posterior pituitary	Neurons, astrocytes, oligodendrocytes, ependymal cells
	Neural Crest: PNS, facial bones, adrenal medulla, melanocytes	Schwann cells, dorsal root ganglia, odontoblasts
Mesoderm (Middle Layer)	Axial Mesoderm: Notochord	Nucleus pulposus of intervertebral discs

	Paraxial Mesoderm: Somites → vertebrae, skeletal muscle, dermis	Myoblasts, sclerotome, dermatome
	Intermediate Mesoderm: Urogenital system	Nephrotomes, gonads, ducts
	Lateral Plate Mesoderm: Heart, blood vessels, limbs, body wall	Cardiomyocytes, endothelial cells, limb bud mesenchyme
Endoderm (Inner Layer)	Foregut Derivatives: Pharynx, lungs, thyroid, liver, pancreas	Hepatocytes, pancreatic β -cells, pneumocytes
	Midgut Derivatives: Small intestine, proximal colon	Enterocytes, goblet cells, Paneth cells
	Hindgut Derivatives: Distal colon, rectum, bladder epithelium	Colonocytes, urothelial cells

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20. Reproduction and Development

Induction: The Dialogue Between Tissues

- **Definition:** The process by which one group of cells (**inducer**) influences the developmental fate of adjacent cells (**responder**)
- **Historical Example: Spemann-Mangold Organizer (1924)** - Transplantation of dorsal lip of blastopore induced secondary axis
- **Molecular Mechanism:** Inducer cells secrete **morphogens** (signaling molecules) that form concentration gradients
- **Types of Induction:**
 1. **Instructive:** Inducer is necessary AND sufficient to change responder fate
 2. **Permissive:** Responder already determined; inducer provides environment for expression

Von Baer's Laws: The Embryological Basis of Evolution

Karl Ernst von Baer's observations (1828) laid groundwork for evolutionary embryology:

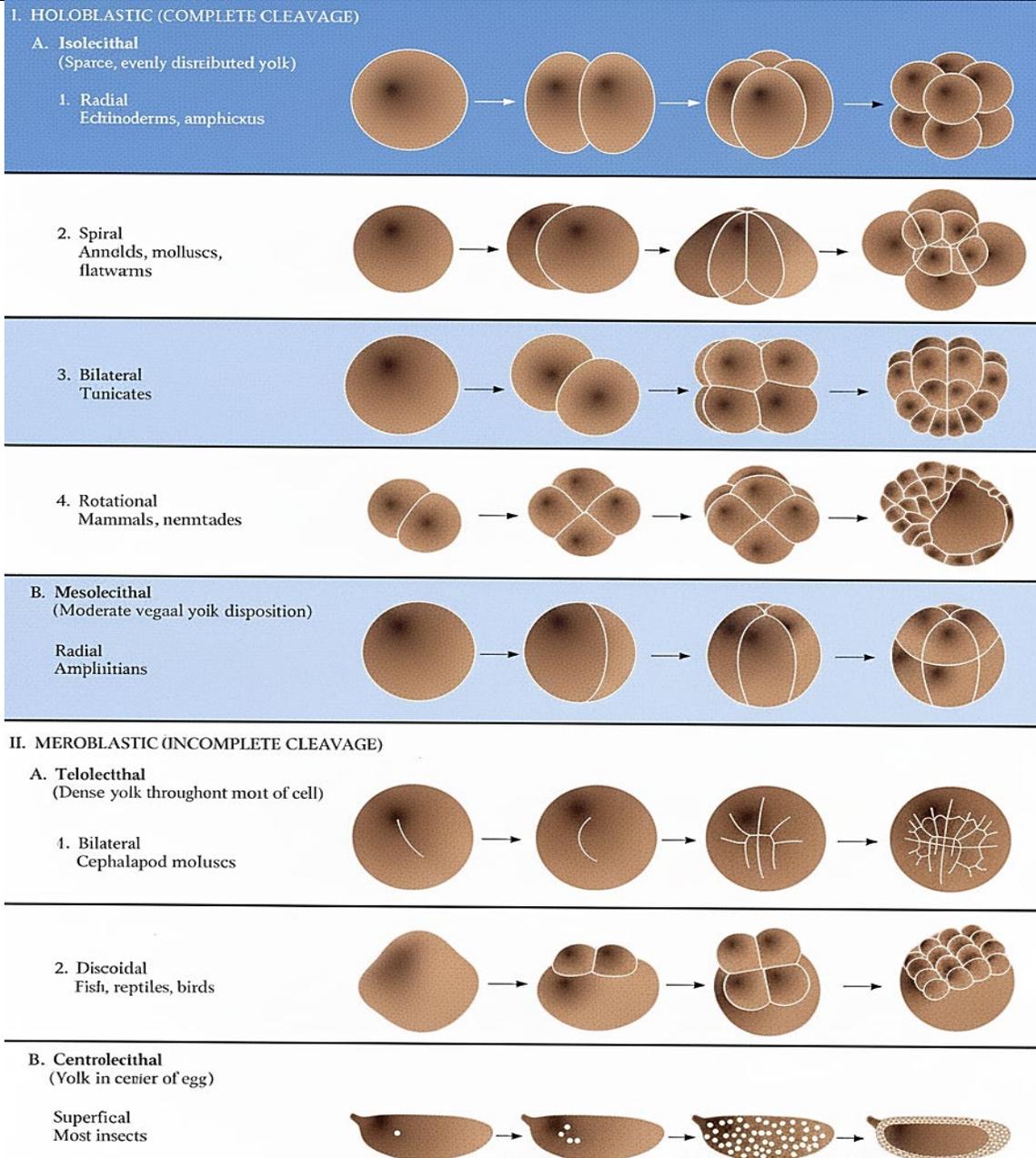
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Meroblastic: Superficial	Centrolecithal (central yolk)	Early nuclear divisions without cytokinesis → syncytium ; nuclei migrate to periphery before cellularization	Controlled by centrosom e cycles ; cellularization occurs simultaneously	Most insects (Drosophila), some crustaceans	Syncytial specification - morphogen gradients in common cytoplasm pattern nuclei before cellularization
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20. Reproduction and Development

Molecular Regulators of Cleavage:

- **Cyclin-CDK Complexes:** Control cell cycle progression; modified to eliminate G1/G2 phases
- **Aurora Kinases & Polo-like Kinases:** Regulate spindle assembly and cytokinesis

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- Convergent Extension:** Cells intercalate mediolaterally, narrowing tissue in one dimension while lengthening in another
 - Mediation:* **Planar cell polarity (PCP)** pathway (Frizzled, Dishevelled, Van Gogh)
 - Example:* Elongation of archenteron in sea urchin; neural plate in vertebrates
- Epiboly:** Spreading of cell sheets to cover embryo
 - Mechanisms:* Cell division, cell shape change (radial intercalation), directed migration
- Cell Migration:** Individual cells move through extracellular matrix
 - Guidance:* Chemotaxis, haptotaxis, contact inhibition
 - Example:* Primordial germ cells, neural crest cells

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Invagination: Infolding of cell sheet into embryo	Involution: Inturning of cell sheet over the basal surface of an outer layer	Ingression: Migration of individual cells into the embryo	Delamination: Splitting of one sheet into two	Epiboly: Expansion of one cell sheet over other cells
<i>Example:</i> Sea urchin endoderm	<i>Example:</i> Amphibian mesoderm	<i>Example:</i> Drosophila neuroblasts	<i>Example:</i> Mammalian hypoblast	<i>Example:</i> Amphibian ectoderm

Sex Determination

Introduction to Sexual Reproduction

Sexual reproduction generates genetic variation through fusion of haploid gametes. Sex is often determined chromosomally at fertilization, but other mechanisms exist.

Primary Sex Determination

Refers to the development of gonads (testes or ovaries) from a bipotential precursor.

Chromosomal Sex Determination Mechanisms:

TAXON	SYSTEM	KEY FEATURE
Mammals	XX = female, XY = male	SRY gene on Y chromosome triggers testes.
Birds	ZZ = male, ZW = female	System reversed compared to mammals.
Drosophila	XX = female, XY = male	X:A ratio determines sex; Y chromosome only for spermatogenesis.
Hymenopterans	Haplodiploidy	Fertilized (diploid) eggs → females; unfertilized (haploid) eggs → males.

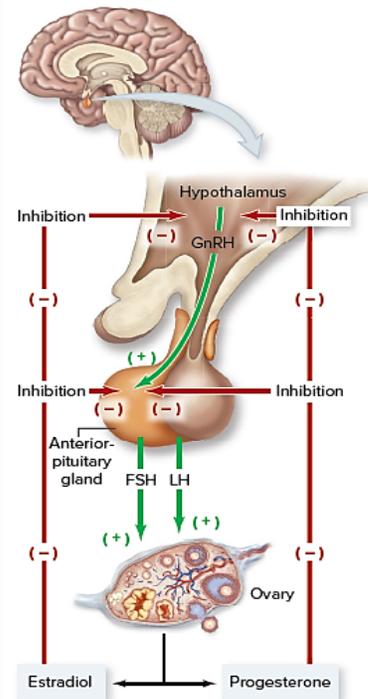
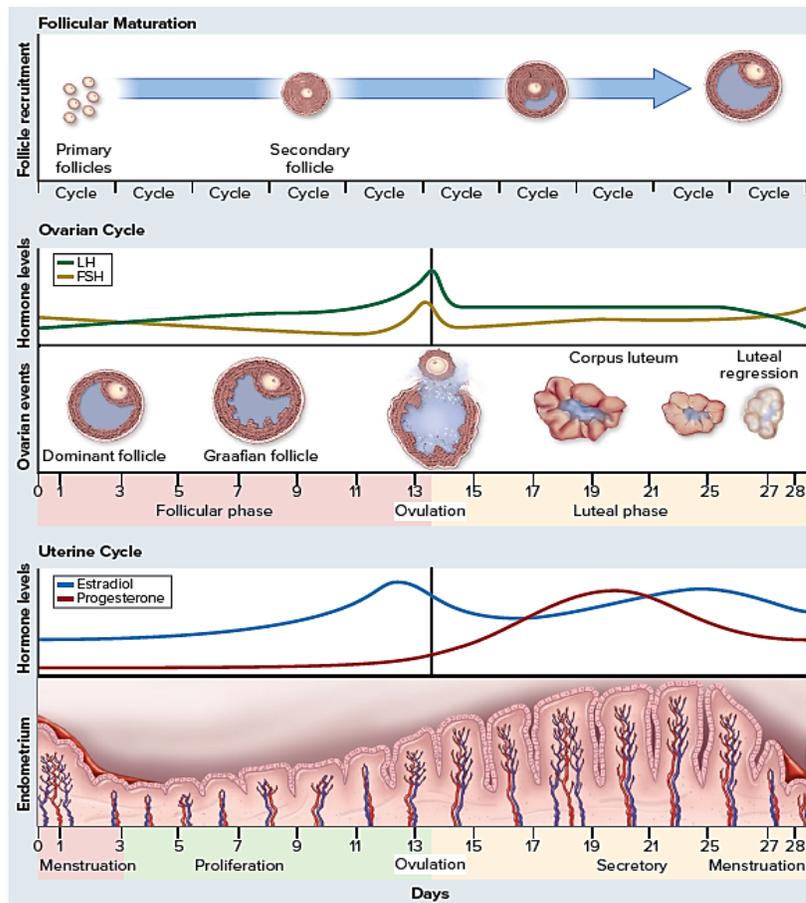
The Mammalian Pathway:

- Testis-Determining (XY):** **SRY** → activates **SOX9** → Sertoli cell differentiation → testes form → produce **Testosterone** and **Anti-Müllerian Hormone (AMH)**.
- Ovary-Determining (XX):** Absence of SRY → **WNT4/RSPO1** stabilize **β-catenin** → ovary formation → **FOXL2** maintains ovarian identity.

Key Genes in Mammalian Sex Determination

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Gametogenesis

Gametogenesis is the process by which diploid **primordial germ cells (PGCs)** undergo meiotic division and differentiation to form haploid, functional gametes: **spermatozoa** in males and **oocytes/ova** in females. While both processes share the goal of producing haploid cells through meiosis, they differ profoundly in timing, pattern, and outcome, reflecting the distinct biological roles of sperm (motile, numerous) and eggs (large, nutrient-rich). The fundamental difference is encapsulated in the concept of **anisogamy** – the production of two dissimilar gametes.

Primordial Germ Cell (PGC) Specification and Migration

- **Origin:** PGCs are specified very early in embryonic development, outside the gonads (e.g., in the epiblast of mice, yolk-sac endoderm in other vertebrates). They are transcriptionally repressed to maintain pluripotency.
- **Migration:** Guided by chemotactic signals like **SDF1/CXCR4**, PGCs migrate via the hindgut and dorsal mesentery to colonize the developing **bipotential (indifferent) gonadal ridges**. This migration is supported by a niche of cells secreting **Stem Cell Factor (SCF)**.
- **Sexual Differentiation:** Upon reaching the genital ridge, the developmental pathway diverges based on genetic sex. In an XY gonad, PGCs become enclosed within **testis cords** to become **spermatogonia**. In an XX gonad, PGCs undergo mitosis to form clusters of **oogonia**.

SPERMATOGENESIS

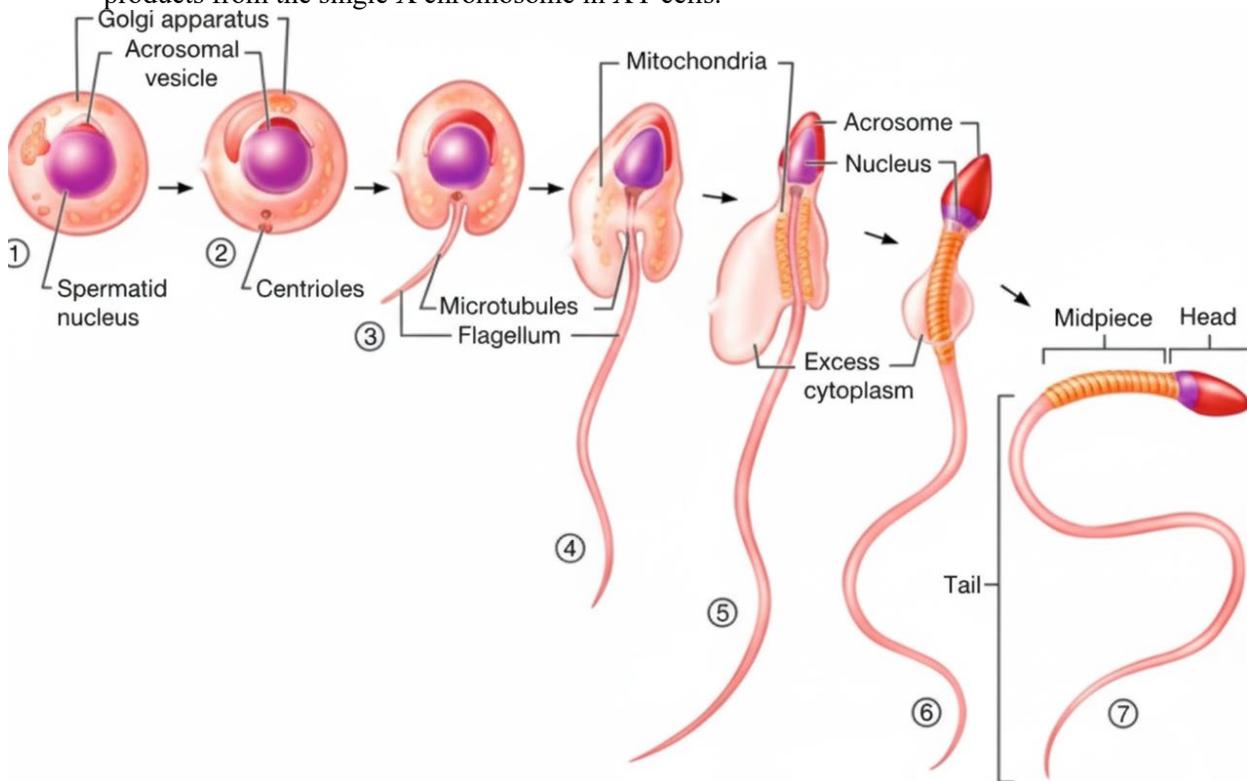
Spermatogenesis is the continuous, high-yield production of motile spermatozoa within the **seminiferous tubules** of the testes, beginning at puberty and continuing throughout life. It occurs in a highly organized, wave-like pattern along the tubule length.

Stages of Spermatogenesis

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- **Nuclear Condensation & Repackaging:** Histones are replaced by smaller, positively charged **protamines**, enabling extreme DNA compaction and inactivation of transcription.
- **Acrosome Formation:** The Golgi apparatus forms a cap-like **acrosome** over the nucleus, filled with hydrolytic enzymes (hyaluronidase, acrosin) for egg penetration.
- **Flagellum Assembly:** One centriole elongates to form the axoneme (9+2 microtubule arrangement) of the tail. The motor protein **dynein** generates motility.
- **Mitochondrial Sheath Formation:** Mitochondria spiral around the proximal part of the flagellum (midpiece) to provide ATP.
- **Cytoplasmic Shedding:** Excess cytoplasm is extruded as a **residual body**, which is phagocytosed by Sertoli cells.
- **Cytoplasmic Bridges:** Throughout meiosis and spermiogenesis, descendant cells remain connected by intercellular bridges, allowing synchronous development and sharing of gene products from the single X chromosome in XY cells.



4. Spermiation and Release:

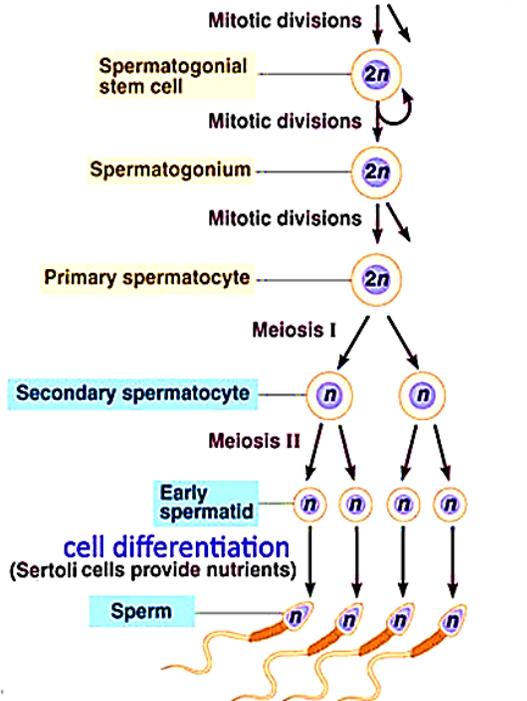
Mature **spermatozoa** are released into the tubule lumen. They are still non-motile and undergo further functional maturation in the **epididymis** (gaining motility and fertilizing capacity) and final **capacitation** in the female reproductive tract.

Hormonal Regulation of Spermatogenesis

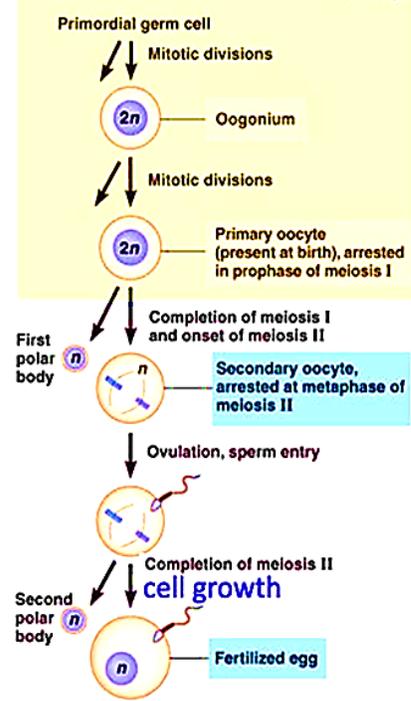
The **Hypothalamic-Pituitary-Gonadal (HPG) Axis** provides precise control:

- **Hypothalamus:** Secretes **Gonadotropin-Releasing Hormone (GnRH)** in pulses.
- **Anterior Pituitary:** GnRH stimulates release of:
 - **Follicle-Stimulating Hormone (FSH):** Binds to Sertoli cells, stimulating production of **Androgen-Binding Protein (ABP)** and other factors crucial for supporting meiosis and spermiogenesis.
 - **Luteinizing Hormone (LH):** Stimulates **Leydig cells** in the interstitium to produce **testosterone**.

Spermatogenesis



Oogenesis



Clinical and Biological Significance

- **Male Infertility:** Can result from defects at any spermatogenic stage (e.g., **azoospermia**, **oligospermia**), hormonal imbalances, or genetic issues like Y-chromosome microdeletions.
- **Female Fertility & Maternal Age:** The **ovarian reserve** declines with age. More critically, the prolonged dictyate arrest makes oocytes susceptible to age-related damage, particularly to the **cohesin** complexes that hold homologous chromosomes together. This is the primary reason for the dramatic increase in **aneuploidy** (e.g., Trisomy 21/Down syndrome) with advanced maternal age.
- **Conservation of Resources:** Oogenesis invests heavily in one gamete to support early development, while spermatogenesis prioritizes quantity and motility to ensure fertilization success. This anisogamy is a fundamental aspect of sexual reproduction.
- **Epigenetic Reprogramming:** Both processes involve extensive epigenetic remodeling (DNA methylation, histone modification) that is crucial for genomic imprinting and normal embryonic development. Errors here can lead to transgenerational epigenetic disorders.

FERTILIZATION

Fertilization is the fundamental biological process involving the fusion of two highly specialized **haploid gametes**—the **spermatozoon** (male) and the **oocyte/ovum** (female)—to form a single **diploid zygote**.

This event accomplishes two primary, interconnected functions:

1. **Sexual Reproduction:** It combines genetic material from two parents, generating a genetically unique individual and promoting genetic diversity within a population.
2. **Activation of Development:** It triggers the resumption of the arrested metabolism and cell cycle of the mature oocyte, initiating the complex program of embryogenesis.

The process is a tightly coordinated sequence of molecular and cellular events designed to ensure **species specificity** and prevent lethal **polyspermy** (entry of multiple sperm). Mechanisms vary between **external fertilizers** (e.g., sea urchins, many fish) and **internal fertilizers** (e.g., mammals, birds), but core principles are conserved.

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Structural Preparation: The Specialized Gametes

A. The Spermatozoon: A Cell Designed for Delivery

The sperm is a minimalist, motile cell optimized for transporting the paternal genome to the egg.

Anatomy and Functional Compartments:

1. Head:

- **Nucleus:** Contains a tightly compacted, transcriptionally inactive haploid genome. **Protamines** replace histones for extreme DNA condensation.
- **Acrosome:** A Golgi-derived, membrane-bound vesicle capping the nucleus. It contains a cocktail of **hydrolytic enzymes** (e.g., **hyaluronidase**, **acrosin**, proteases) essential for penetrating the egg's outer investments.

2. Midpiece (Neck):

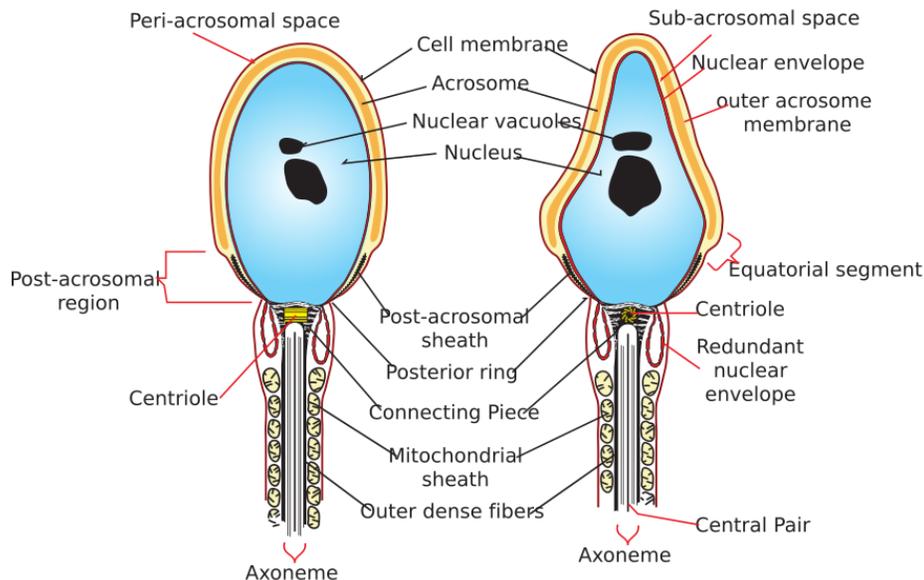
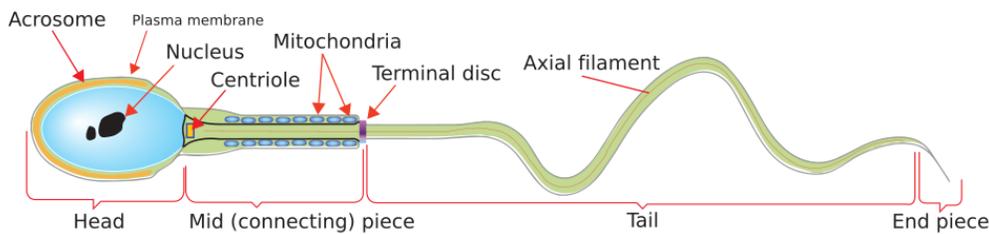
- Packed with **spirally arranged mitochondria** that generate ATP via oxidative phosphorylation to power flagellar motility.
- Contains the **centriole(s)** that will nucleate microtubules for pronuclear migration and first cleavage spindle.

3. Tail (Flagellum):

- The propulsive apparatus with a canonical "**9+2**" **axoneme** of microtubules.
- Motility is generated by the motor protein **dynein**, which hydrolyzes ATP to create sliding forces between microtubule doublets.

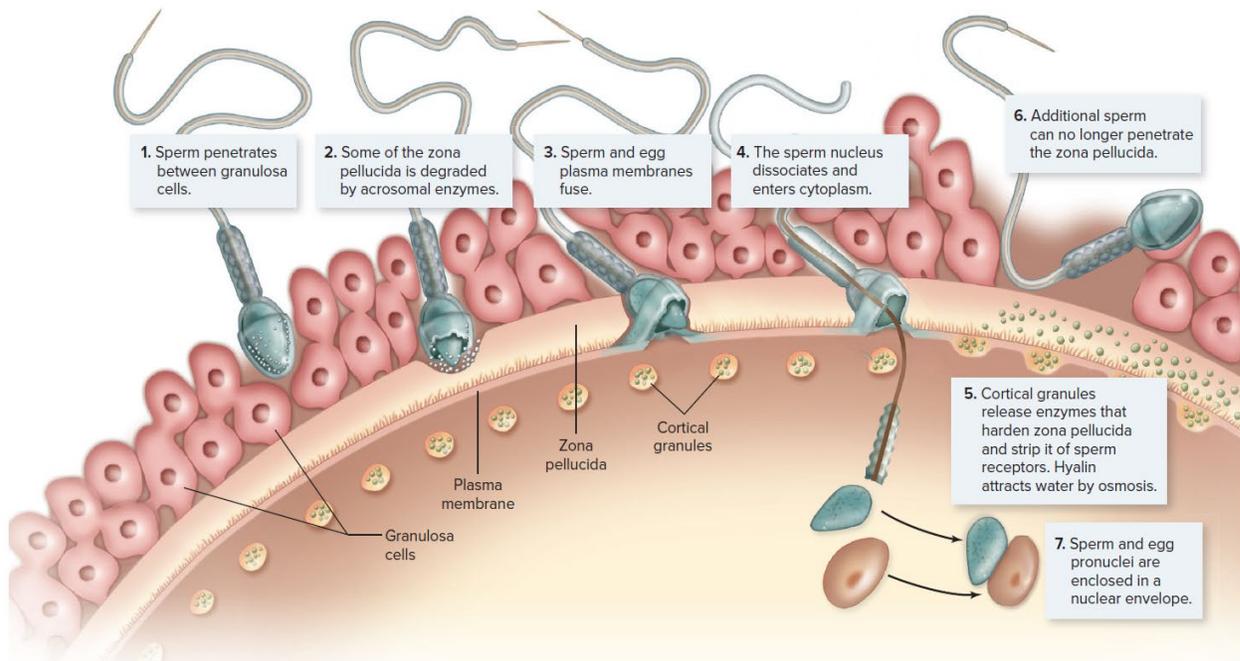
Maturation Events Post-Testis:

- **Epididymal Maturation:** Sperm gain forward motility and fertilizing capacity.
- **Capacitation (in mammals):** A final maturation step occurring in the female reproductive tract. It involves cholesterol efflux from the sperm plasma membrane, leading to increased membrane fluidity, hyperactivated motility, and preparation for the **acrosome reaction**.



Stage 2: The Acrosome Reaction

- **Purpose:** A triggered exocytosis that releases acrosomal enzymes and exposes proteins necessary for binding to and penetrating the egg's outer layers.
- **Induction:**
 - **Sea Urchin:** Sulfated polysaccharides (fucose sulfate) in the egg jelly bind to sperm receptors, causing membrane depolarization and an influx of Ca^{2+} and Na^+ , which triggers the reaction.
 - **Mammals:** Binding of sperm to the **Zona Pellucida (ZP)**, specifically to glycoproteins like **ZP3** (in the classical model) or **ZP2** (in newer models), induces the reaction.
- **Events:**
 1. Fusion of the outer acrosomal membrane with the sperm plasma membrane.
 2. Formation of hybrid vesicles and release of soluble enzymes to create a path.
 3. In many species (e.g., sea urchin), polymerization of globular actin forms a finger-like **acrosomal process**, which extends and presents **bindin** (or equivalent) for species-specific adhesion.



Stage 3: Species-Specific Binding

- **Purpose:** To ensure only conspecific sperm can fertilize the egg, a key mechanism of **reproductive isolation**.
- **Mechanism:** A molecular "lock-and-key" interaction between sperm surface proteins and receptors on the egg coat.
 - **Sea Urchin:** **Bindin** on the acrosomal process binds to **bindin receptors** (glycoprotein complexes like EBR1) on the vitelline envelope.
 - **Mammals:** Acrosome-reacted sperm bind to the ZP. Current evidence points to binding of sperm proteins to a cleaved form of **ZP2** as the primary interaction for maintaining sperm binding post-acrosome reaction.

Stage 4: Sperm-Egg Membrane Fusion

- **Purpose:** To allow the sperm nucleus, centriole, and activating factors to enter the egg cytoplasm.
- **Fusogenic Proteins:** Specific proteins mediate the merger of the two plasma membranes.

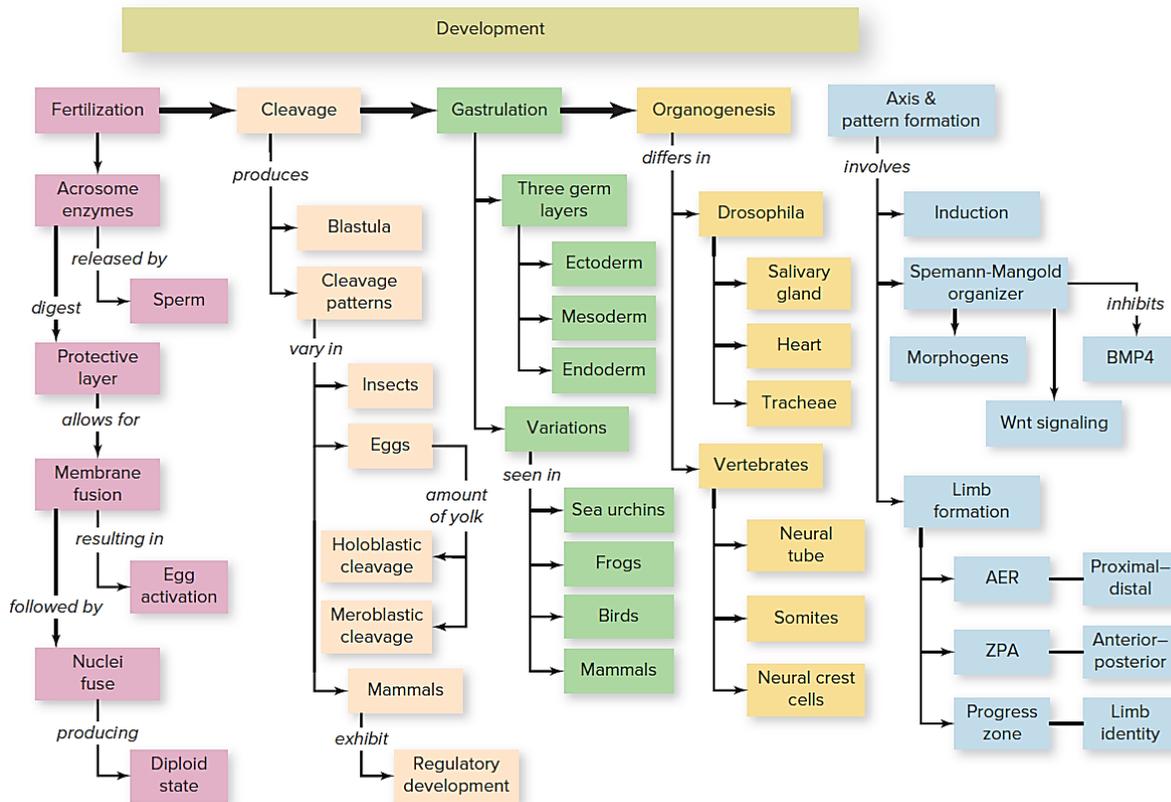
Centrosome Inheritance	Derived from sperm centriole .	Derived from sperm centriole (in most).
Mitochondrial Inheritance	Exclusively maternal.	Exclusively maternal.

Clinical and Applied Significance

- **Infertility:** Defects in any step (sperm motility, acrosome reaction, sperm-egg binding, fusion, egg activation) can cause infertility. Understanding these steps underpins **Assisted Reproductive Technologies (ART)** like **ICSI**.
- **Contraception:** Targeting key steps (e.g., sperm capacitation, acrosome reaction, zona pellucida binding) is a strategy for developing non-hormonal contraceptives.
- **Prevention of Polyspermy:** In IVF, ensuring monospermic fertilization is critical. Techniques like **intracytoplasmic sperm injection (ICSI)** bypass all natural barriers but must be performed with precision.
- **Pronuclear Transfer:** For preventing mitochondrial diseases, techniques involve transferring the pronuclei from a fertilized egg with defective mitochondria into an enucleated donor egg with healthy mitochondria.

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20. Reproduction and Development



Pregnancy and Human Development

Fertilization

Fertilization is the process by which a sperm fuses with an oocyte (secondary oocyte) to form a **zygote**. This typically occurs in the **ampulla of the oviduct** (fallopian tube), the widest section near the ovary.

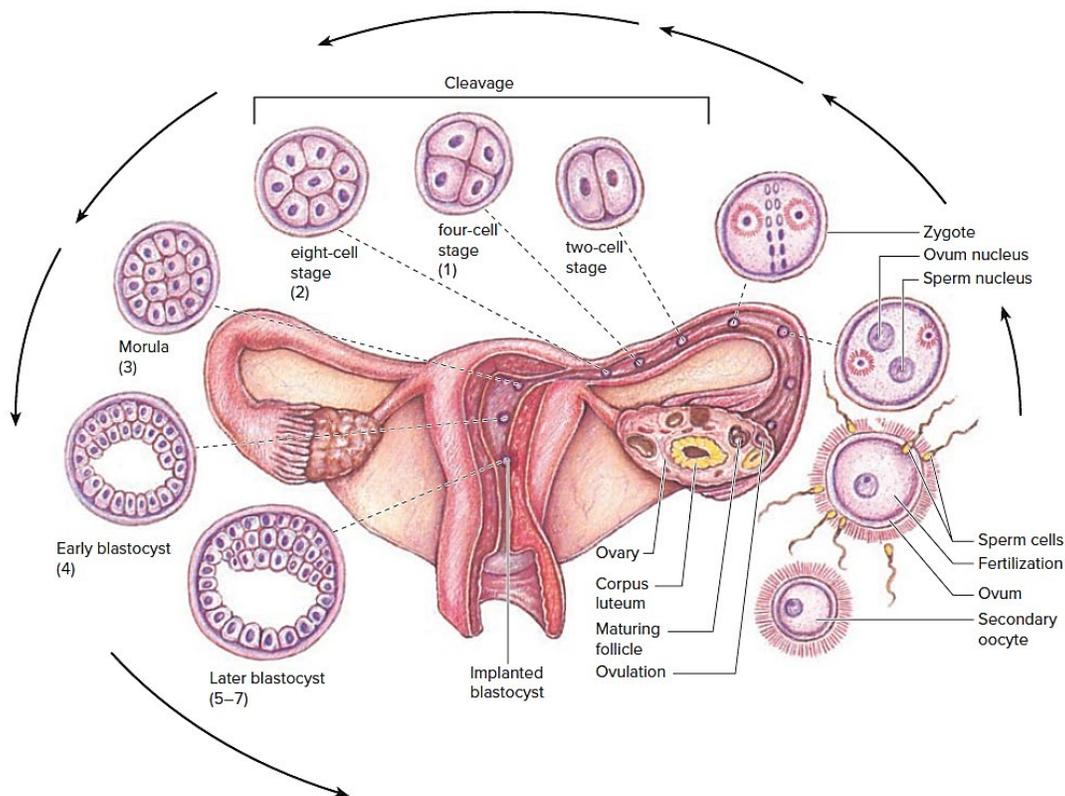
Key Steps in Fertilization:

1. **Sperm Capacitation:** Sperm undergo final maturation within the female reproductive tract, gaining the ability to fertilize the egg.

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2. **Acrosomal Reaction:** Upon contact with the **zona pellucida** (glycoprotein layer surrounding the oocyte), the sperm's **acrosome** releases hydrolytic enzymes (hyaluronidase, acrosin) that digest the zona pellucida.
3. **Sperm Penetration:** A single sperm penetrates the zona pellucida and fuses with the oocyte's plasma membrane.
4. **Cortical Reaction:** Fusion triggers the **cortical reaction** – cortical granules in the oocyte cytoplasm release enzymes that modify the zona pellucida, making it impenetrable to other sperm. This **blocks polyspermy** (fertilization by multiple sperm).
5. **Completion of Meiosis II:** The sperm entry activates the oocyte to complete **meiosis II**, forming the mature **ovum** and a second polar body.
6. **Pronuclei Formation:** The sperm nucleus swells to form the **male pronucleus**; the ovum nucleus becomes the **female pronucleus**.
7. **Syngamy:** The pronuclei fuse, combining their chromosomes to form a diploid **zygote**.



Cleavage

Cleavage is a series of rapid **mitotic divisions** of the zygote without overall growth. The cells produced are called **blastomeres**.

Stages:

- **Day 1-3:** Zygote divides into 2, then 4, then 8 cells, forming a **morula** (solid ball of 16+ cells) by day 4.
- **Day 4-5:** The morula develops into a **blastocyst** as it enters the uterus. The blastocyst has:
 - **Trophoblast:** Outer cell layer that will form the placenta and extra-embryonic membranes.
 - **Inner Cell Mass (Embryoblast):** Cluster of cells that will develop into the embryo.
 - **Blastocoel:** Fluid-filled cavity.

Implantation

Implantation is the attachment and embedding of the blastocyst into the **endometrium** (uterine lining), occurring approximately **6–7 days after fertilization**.

Process:

1. **Hatching:** The blastocyst "hatches" from the zona pellucida.
2. **Attachment:** The **trophoblast** adheres to the endometrium.
3. **Invasion:** Trophoblast cells proliferate and invade the endometrium, forming two layers:
 - **Cytotrophoblast** (inner cellular layer).
 - **Syncytiotrophoblast** (outer multinucleated layer that erodes maternal tissues to establish nutrient exchange).
4. **Decidual Reaction:** The endometrium undergoes changes (increased vascularity, edema) to form the **decidua**, which supports implantation.

By day 7–10, the blastocyst is fully embedded. The **inner cell mass** differentiates into the **bilaminar germ disc** (epiblast and hypoblast), the precursor to the embryo.

Placenta Formation and Function

Placental Structure

The **placenta** is a temporary organ formed from both fetal and maternal tissues.

Fetal Components:

- **Chorionic villi:** Finger-like projections of the **chorion** (derived from trophoblast) containing fetal capillaries.
- **Chorionic plate:** Fetal side of the placenta.
- **Umbilical cord:** Connects fetus to placenta; contains **two umbilical arteries** (carry deoxygenated blood from fetus) and **one umbilical vein** (carries oxygenated blood to fetus).

Maternal Components:

- **Decidua basalis:** The portion of the endometrium underlying the implantation site.
- **Maternal blood pools (lacunae):** Spaces where maternal blood bathes the chorionic villi.

Important: Maternal and fetal blood **do not mix**; exchange occurs across the **placental barrier** (syncytiotrophoblast, connective tissue, and fetal capillary endothelium).

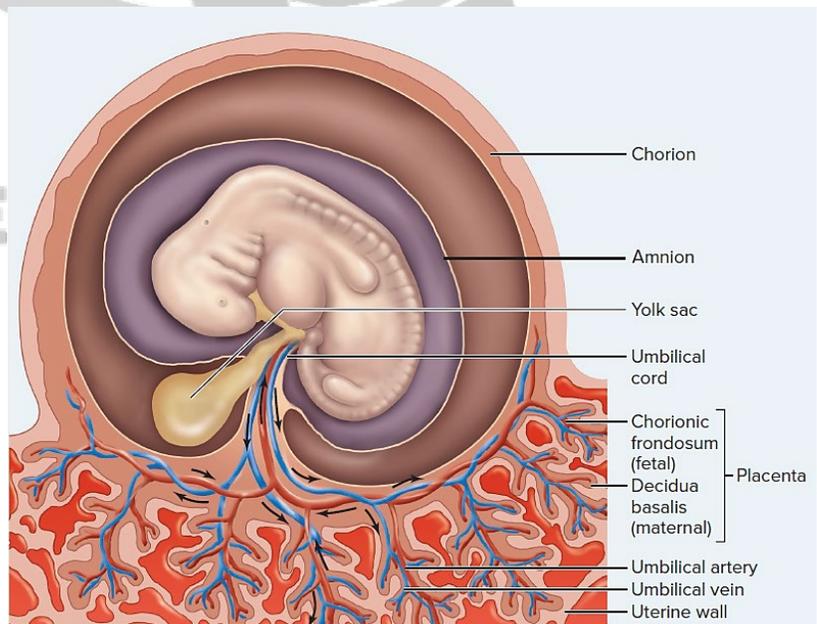
Placental Functions

A. Exchange & Transport:

- **Passive Diffusion:** Oxygen, carbon dioxide, water, electrolytes.
- **Facilitated Diffusion:** Glucose (via GLUT1 transporters).
- **Active Transport:** Amino acids, ions (e.g., Ca^{2+} , Fe^{2+}).
- **Pinocytosis:** Maternal antibodies (IgG) for passive immunity.
- **Waste Removal:** Urea, creatinine, bilirubin transferred to maternal blood.

B. Endocrine Secretion:

- **hCG (Human Chorionic Gonadotropin):** Produced by syncytiotrophoblast; maintains the **corpus luteum** for progesterone secretion until the placenta takes over (~week 8–10). Basis for pregnancy tests.
- **Progesterone:** Maintains endometrium, suppresses uterine contractions, prevents menstruation, prepares mammary glands.



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20. Reproduction and Development

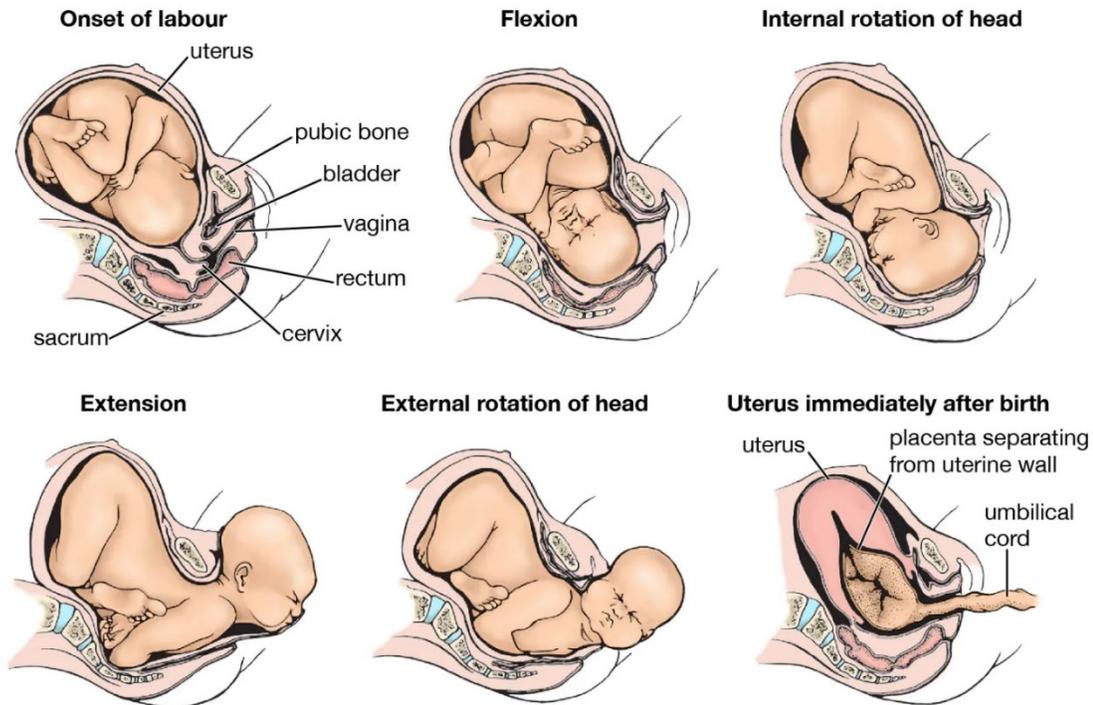
- Typically lasts up to a few hours.

Stage 3 – Placental Delivery:

- Uterine contractions detach and expel the placenta and membranes ("afterbirth") within 30 minutes.
- Important to ensure complete expulsion to prevent hemorrhage.

Positive Feedback Mechanism:

Contractions → Cervical stretching → Oxytocin release → Stronger contractions → More stretching → Continued until delivery.



Lactation

Mammary Gland Preparation:

- During pregnancy, **estrogen** and **progesterone** stimulate duct and alveolar growth.
- **Prolactin** levels rise but milk production is inhibited by high progesterone.

Postpartum Lactation:

- After delivery, progesterone drops, allowing **prolactin** to initiate **lactogenesis** (milk production).
- **Colostrum** is produced first (days 1–3): yellowish fluid rich in **antibodies (IgA)**, proteins, and vitamins, but lower in fat and lactose. Provides passive immunity and laxative effect to clear meconium.
- **Mature milk** appears by ~day 4: higher in lactose and fat.

Milk Ejection Reflex (Let-down):

- Stimulated by **oxytocin** released in response to suckling (neuroendocrine reflex).
- Oxytocin causes myoepithelial cells around alveoli to contract, ejecting milk into ducts.

Maintenance of Lactation:

- **Suckling** stimulates prolactin secretion (maintains milk production) and oxytocin release (ejection).
- Emotional stress can inhibit oxytocin release, hindering milk let-down.

Benefits of Breastfeeding:

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20. Reproduction and Development

- A) Epigenesis
- B) Homunculus theory
- C) Modern synthesis
- D) Germ layer theory

Answer: Homunculus theory

3. Which of the following is the correct sequence of early developmental stages in animals?

- A) Gastrulation, Cleavage, Fertilization, Organogenesis
- B) Fertilization, Cleavage, Gastrulation, Organogenesis
- C) Cleavage, Fertilization, Organogenesis, Gastrulation
- D) Organogenesis, Gastrulation, Cleavage, Fertilization

Answer: Fertilization, Cleavage, Gastrulation, Organogenesis

4. During gastrulation, which germ layer gives rise to the nervous system and epidermis?

- A) Mesoderm
- B) Endoderm
- C) Ectoderm
- D) Trophoblast

Answer: Ectoderm

5. Von Baer's laws of embryology state that:

- A) Embryos of higher animals pass through adult stages of lower animals
- B) General features appear before specialized features
- C) Embryonic development is identical across all species
- D) All embryos look the same at birth

Answer: General features appear before specialized features

6. Cleavage pattern in mammals is typically:

- A) Meroblastic and discoidal
- B) Holoblastic and isolecithal
- C) Superficial
- D) Meroblastic and superficial

Answer: Holoblastic and isolecithal

7. Which gastrulation movement involves the infolding of a cell sheet?

- A) Involution
- B) Ingression
- C) Delamination
- D) Invagination

Answer: Invagination

8. Programmed cell death that sculpts structures like digits is known as:

- A) Necrosis
- B) Mitosis
- C) Apoptosis
- D) Metastasis

Answer: Apoptosis

9. A fate map is used to:

- A) Determine the genetic sequence of an embryo
- B) Trace which embryonic cells give rise to which adult structures
- C) Map the migration of birds
- D) Identify teratogenic agents

Answer: Trace which embryonic cells give rise to which adult structures

10. The study of how changes in developmental genes drive evolution is called:

- A) Teratology
- B) Evo-Devo
- C) Phylogenetics
- D) Ontogeny

Answer: Evo-Devo

11. An external agent that causes birth defects during critical periods is a:

- A) Mutagen
- B) Carcinogen
- C) Teratogen
- D) Pathogen

Answer: Teratogen

12. In mammals, primary sex determination is triggered by which gene on the Y chromosome?

- A) SOX9
- B) WNT4
- C) SRY
- D) FOXL2

Answer: SRY

13. Which hormone causes the regression of the Müllerian ducts in male fetal development?

- A) Testosterone
- B) Estrogen
- C) Anti-Müllerian Hormone
- D) Follicle-Stimulating Hormone

Answer: Anti-Müllerian Hormone

14. Androgen Insensitivity Syndrome (AIS) results from a mutation in the:

- A) SRY gene
- B) Androgen receptor gene
- C) 5 α -reductase enzyme

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Most Important and Repeated MCQs from Past Papers

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1. Ornithology is the study of:

- A. Insects
- B. Bee keeping
- C. Birds
- D. Fossils

Answer: C

2. Study of life in outer space is called:

- A. Exobiology
- B. Eugenics
- C. Ethology
- D. Anthropology

Answer: A

3. Chlorophyll is a/an molecule:

- A. Inorganic
- B. Cationic
- C. Anionic
- D. Organic

Answer: D

4. Taking in of liquid material into the cells is known as:

- A. Phagocytosis
- B. Pinocytosis
- C. Exocytosis
- D. None of these

Answer: B

5. The type of plastids which help in pollination is:

- A. Chromoplasts
- B. Leukoplasts
- C. Chloroplasts
- D. All of these

Answer: A

6. Cycas & Adiantum resemble each other in having:

- A. Cambium
- B. Vessels
- C. Seeds
- D. Motile sperms

Answer: D

7. In chlorophyceae, the mode of sexual reproduction is:

- A. Isogamy
- B. Anisogamy
- C. Oogamy
- D. All of these

Answer: D

8. Which of the following is known as resurrection plant?

- A. Rafflesia
- B. Selaginella
- C. Chlorella
- D. Welwitschia

Answer: B

9. Meiosis in Dryopteris takes place during:

- A. Spore formation
- B. Gamete formation
- C. Sperm formation
- D. Spore germination

Answer: A

10. Ectophloic siphonostele is found in:

- A. Adiantum
- B. Marsilea
- C. Osmunda
- D. All of these

Answer: C

11. Cuscuta is:

- A. Partial stem parasite
- B. Total stem parasite
- C. Epiphyte
- D. Total root parasite

Answer: B

12. Fibrous roots develop in maize from:

- A. Lower nodes
- B. Upper nodes
- C. Lower internodes
- D. Upper internodes

Answer: A

13. Roots of Dahlia are:

- A. Naphthol
- B. Fasciulated
- C. Fibrous
- D. Assimilatory

Answer: B

14. Vegetative reproduction in Colocasia takes place through:

- A. Sucker
- B. Rhizome
- C. Offset
- D. Corm

Answer: D



15. Zigzag development of inflorescence axis is an example of:

- A. Helicarpus
- B. Verticillaster
- C. Scorpidium
- D. Spadix

Answer: B

16. Smallest flower is of:

- A. Wolfia microscopic
- B. Rafflesia arnoldii
- C. Carica Papaya
- D. Colocasia antiquorum

Answer: A

17. In Bougainvillea, the large coloured structures are:

- A. Epidermis
- B. Coloured Sepals
- C. Coloured petals
- D. Petaloid bracts

Answer: D

18. Gynobasic style is found in:

- A. Ranunculus
- B. Ocimum
- C. Coleus
- D. Centella

Answer: B

19. In Ruellia tuberosa seeds are dispersed by:

- A. Parachute mechanism
- B. Censor mechanism
- C. Jaculator mechanism
- D. None of these

Answer: C

20. Pappus helps in seed dispersal in:

- A. Brassicaceae
- B. Asteraceae
- C. Malvaceae
- D. Solanaceae

Answer: B

21. Plants capable of growing in nitrogen deficient soil is:

- A. Orchids
- B. Ferns
- C. Insectivorous plants
- D. None of these

Answer: C

22. Gray spots of oat are caused by deficiency of:

- A. Cu
- B. Fe
- C. Zn
- D. Mn

Answer: D

23. Which of the following is correct set of micronutrient for plants?

- A. Mg, Si, Fe, Cu, Ca
- B. Cu, Fe, Zn, B, Mn
- C. Mg, Fe, Zn, B, Mn
- D. Mn, Zn, Cl, Mg, Ca

Answer: B

24. The assimilatory power in photosynthesis is:

- A. ATP
- B. NADPH
- C. ATP & NADPH
- D. ATP, NADPH & CO₂

Answer: C

25. Photosynthesis will proceed upto:

- A. Limit of temperature
- B. Limit of wind
- C. Limit of light
- D. Limit of moisture

Answer: C

26. Kranz type of anatomy is found in:

- A. C₂ plants
- B. C₃ plants
- C. C₄ plants
- D. CAM plants

Answer: C

27. Munch mass flow hypothesis explains:

- A. Transcription
- B. Translocation
- C. Transpiration
- D. Translation

Answer: B

28. A plant requires magnesium for:

- A. Chlorophyll synthesis
- B. Protein synthesis
- C. Cell development
- D. Holding cells together

Answer: A

29. The CO₂ fixation during C₄ pathway occurs in the chloroplast of:

- A. Guard cells

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Answer: B

445. The tracking method which include predetermined walking pathway & recording of birds observation is:

- A. Line transect Method
- B. Point count method
- C. Mark and recapture
- D. Radio telemetry

Answer: A

446. The tracking method which includes aerial tracking & ground truthing is:

- A. Direct observation
- B. Camera tap
- C. Multi-method observation
- D. None of these

Answer: C

447. Crossing over of chromosomes in meiosis-1 occurs in:

- A. Leptotene
- B. Zygotene
- C. Pachytene
- D. Diplotene

Answer: C

448. Trains leaves at 21.30 and reached at 7.30 how much time it takes:

- A. 9 Hours
- B. 10 Hours
- C. 11 Hours
- D. 8 Hours

Answer: B

449. Weight of a standard cricket ball is:

- A. 155.9 g to 163 g
- B. 140 g to 150 g
- C. 165 g to 170 g
- D. 170 g to 175 g

Answer: A

450. The physical parts of a computer are:

- A. Software
- B. Hardware
- C. File
- D. Data

Answer: B

451. حروف کا مجموعہ جو کسی بامعنی لفظ کے شروع میں لگے اور اس کا معنی تبدیل کر دے اسے کہتے ہیں:

- A. سابقہ

B. لاحقہ

C. مضاف

D. مضاف الیہ

Answer: A

452. Goblet cells produce:

- A. Mucous
- B. Base
- C. Acid
- D. Water

Answer: A

453. The substances which produce H⁺ ions when dissolve in water:

- A. Acid
- B. Base
- C. Buffer solutions
- D. Salt

Answer: A

454. Which of the following are paired fins in fishes:

- A. Pectoral & pelvic fins
- B. Caudal fins
- C. Dorsal fin
- D. All of these

Answer: A

455. Bilateral symmetry important for:

- A. Active Life Style For efficient movement & sensory perception
- B. Sedentary lifestyle
- C. Passive drifting
- D. None of these

Answer: A

456. The best tracking method for data analysis of non invasive species of animals:

- A. Genetic Sampling
- B. Direct observation
- C. Camera trapping
- D. Radio telemetry

Answer: A

457. The key limitations of direct observation methods for mammals tracking is:

- A. Ineffective for nocturnal species
- B. Too expensive
- C. Harmful to animals
- D. Requires a large team

Answer: A



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D. None of these

Answer: C

1097. Oxygen transport from the lungs to tissues occurs primarily through:

- A. Difference in pressure
- B. Solubility in plasma
- C. Attachment to hemoglobin in RBCs
- D. None of these

Answer: C

1098. Lipase is an enzyme responsible for:

- A. Carbohydrate metabolism
- B. Lipid breakdown
- C. Protein breakdown
- D. None of these

Answer: B

1099. The law of segregation is applicable to:

- A. Homozygous individual
- B. Heterozygous individual
- C. Both homozygous and heterozygous (in gamete formation)
- D. None of these

Answer: C

1100. Sex-linked genes concern:

- A. Sex characters
- B. Somatic characters
- C. Mostly somatic characters located on sex chromosomes
- D. None of these

Answer: C

1101. An XXY individual in humans is a phenotypic male because:

- A. Two X chromosomes are present
- B. A Y-chromosome is present
- C. Both X and Y chromosomes are present
- D. None of these

Answer: B

1102. A trisomic condition can be produced through:

- A. Primary Non-disjunction
- B. Secondary non-disjunction
- C. Both a and b
- D. None of these

Answer: A

1103. Lamarck's theory of inheritance of acquired characters states that:

- A. Environment forces a character (creates need)

B. Environment selects a character

C. Environment has no effect

D. None of these

Answer: A

1104. Orthoselection means:

- A. Selection occurring at different times
- B. Selection occurring at different rates
- C. Selection occurring in one direction (directional selection)
- D. None of these

Answer: C

1105. Haeckel's biogenetic law states:

- A. Ontogeny repeats phylogeny
- B. Phylogeny repeats ontogeny
- C. None of these
- D. Both a and b together

Answer: A

1106. An ecosystem is a system involving biotic and abiotic components which:

- A. Interact
- B. Interact for energy flow and nutrient cycling
- C. Do not interact
- D. None of these

Answer: B

1107. The nitrogen biogeochemical cycle is regarded as a gaseous cycle because:

- A. Nitrogen is a gas
- B. Recycling is almost complete
- C. The major part of the cycle is in the gaseous state (atmospheric nitrogen)
- D. None of these

Answer: C

1108. Raw materials for evolution are variations, which are produced through:

- A. Gene mutation
- B. Chromosomal aberration
- C. Recombination
- D. All of these

Answer: D