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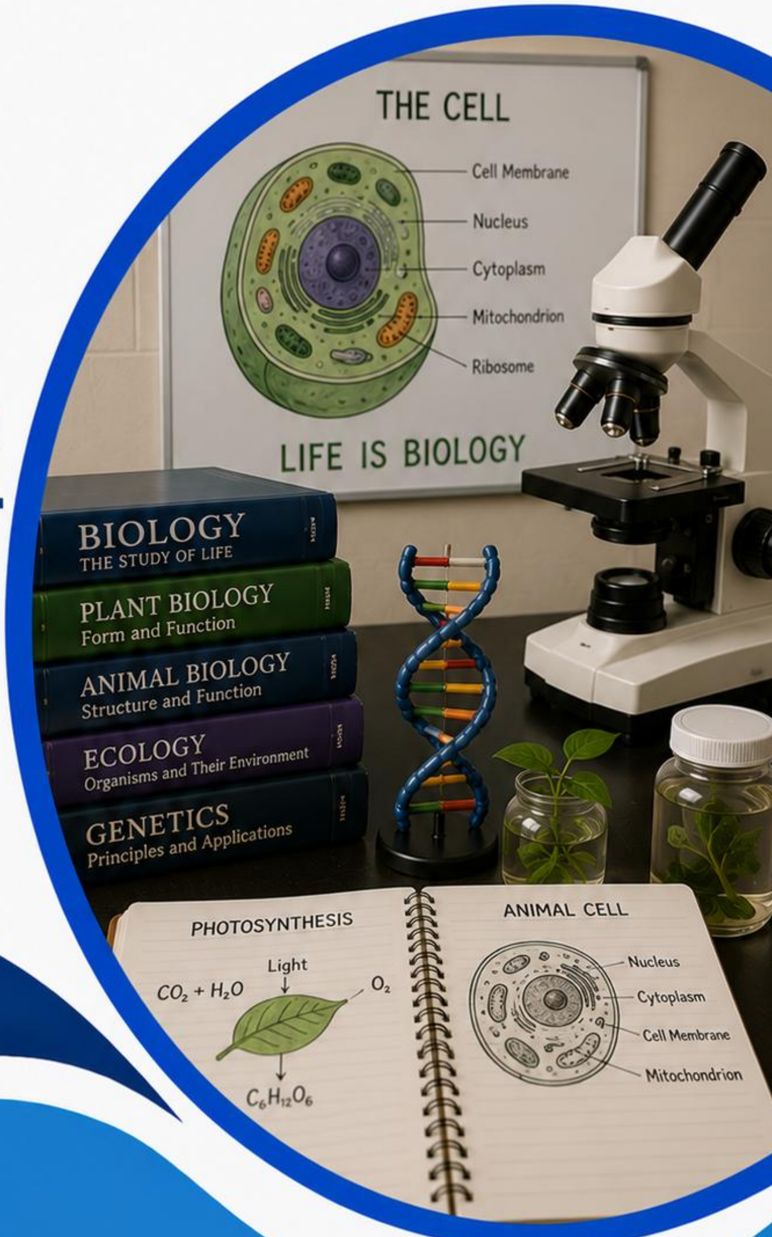
BIO 102

GENERAL BIOLOGY II



Course code: BIO 102

Course title: General Biology II

Course credit load: 2 Units

Series 1: Characteristics of Plant and Animal Kingdoms

- **Part 1.1: The Plant Kingdom**
    - Sub Part 1.1.1: General characteristics of plants
    - Sub Part 1.1.2: Major divisions of the plant kingdom
    - Sub Part 1.1.3: External features of representative plants
- **Part 1.2: The Animal Kingdom**
    - Sub Part 1.2.1: General characteristics of animals
    - Sub Part 1.2.2: Major phyla of the animal kingdom
    - Sub Part 1.2.3: External features of representative animals
- **Part 1.3: Similarities and Differences Between Plants and Animals**
    - Sub Part 1.3.1: Shared characteristics of living organisms
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    - Sub Part 1.3.3: Comparison of cell structure
- **Part 1.4: Classification and Taxonomy**
    - Sub Part 1.4.1: Principles of biological classification
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    - Sub Part 1.4.3: Importance of classification in biology

Introduction

Biology is the scientific study of living organisms. The two largest kingdoms of multicellular organisms are the Plant Kingdom (Plantae) and the Animal Kingdom (Animalia). Understanding their defining characteristics, internal organisation, and shared properties provides the foundation for all further study in ecology, physiology, and evolutionary biology.

This Series surveys the unique features of plants and animals, the major groups within each kingdom, the similarities they share as living organisms, key structural differences, and the principles of biological classification and taxonomy. This knowledge is essential for interpreting everything that follows in General Biology II.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 1.1** state the general characteristics of the Plant Kingdom and describe the major divisions (Linked to Part 1.1),
- **SLO 1.2** describe the external features of representative plants from different divisions (Linked to Part 1.1),
- **SLO 1.3** state the general characteristics of the Animal Kingdom and describe the major phyla (Linked to Part 1.2),
- **SLO 1.4** describe the external features of representative animals from different phyla (Linked to Part 1.2),
- **SLO 1.5** list the characteristics shared by all living organisms and state the key differences between plants and animals (Linked to Part 1.3),
- **SLO 1.6** compare plant and animal cell structure (Linked to Part 1.3), and
- **SLO 1.7** explain the principles of biological classification and the binomial nomenclature system (Linked to Part 1.4).

1.1 The Plant Kingdom

1.1.1 General characteristics of plants

Plants are multicellular, eukaryotic organisms with cell walls made of cellulose. They are autotrophs, producing their own food through photosynthesis using chlorophyll pigments in specialised organelles called chloroplasts. Most plants are sessile (fixed in place) and show indeterminate growth throughout their life. They reproduce both sexually and asexually and are adapted to terrestrial and aquatic environments.

Key plant characteristics: presence of cellulose cell walls; chloroplasts containing chlorophyll a and b; food stored as starch; large central vacuole in mature cells; absence of centrioles in most higher plants; and reproduction involving alternation of generations (a haploid gametophyte and diploid sporophyte phase). Most plants obtain water and mineral salts from the soil through roots and transport these upward through specialised vascular tissue.

Fill in the blank: Plants are ________ organisms that produce their own food through photosynthesis using chlorophyll pigments in chloroplasts; their cell walls are composed of cellulose.

1.1.2 Major divisions of the plant kingdom

The Plant Kingdom is divided into four major groups. Bryophytes (mosses, liverworts, hornworts): non-vascular; no true roots, stems, or leaves; depend on water for sexual reproduction; found in moist habitats. Pteridophytes (ferns, horsetails): vascular; true roots, stems, and leaves; reproduce by spores; no seeds. Gymnosperms (conifers, cycads, ginkgo): vascular; seeds borne naked on cones (not enclosed in fruit); produce pollen.

Angiosperms (flowering plants): the largest and most diverse plant group; vascular; seeds enclosed in fruit; reproduce by flowers; divided into monocots (one seed leaf, parallel veins, fibrous root system) and dicots (two seed leaves, net veins, tap root system). Angiosperms dominate most terrestrial ecosystems and include virtually all crop plants of agricultural importance such as maize, cassava, yam, rice, tomato, and citrus.

Fill in the blank: Angiosperms are divided into ________ (one seed leaf, parallel veins) and dicots (two seed leaves, net veins); they are the most diverse and dominant plant group on Earth.

1.1.3 External features of representative plants

A typical dicot plant (e.g. Hibiscus or tomato) has: root (primary tap root with lateral roots; anchors the plant; absorbs water and minerals); stem (erect or climbing; supports leaves and flowers; transports water upward and food downward); leaves (flat blade called the lamina; petiole attaches to stem; veins carry vascular tissue; site of photosynthesis and gas exchange through stomata); and reproductive organs (flowers contain sepals, petals, stamens, and carpel).

A typical monocot (e.g. maize) has: fibrous roots; hollow jointed stem called a culm; long narrow leaves with parallel veins and no petiole; and flowers grouped into inflorescences. Bryophytes such as mosses have rhizoids (root-like anchors), a flattened thallus or upright leafy shoot, and a sporophyte (spore-bearing structure) attached to the gametophyte. Ferns have fronds (leaves), rhizomes (horizontal underground stems), and sori (clusters of sporangia on the underside of fronds).

Fill in the blank: The flat blade of a leaf is called the ________; it is connected to the stem by the petiole and contains veins that carry vascular tissue to and from the leaf.

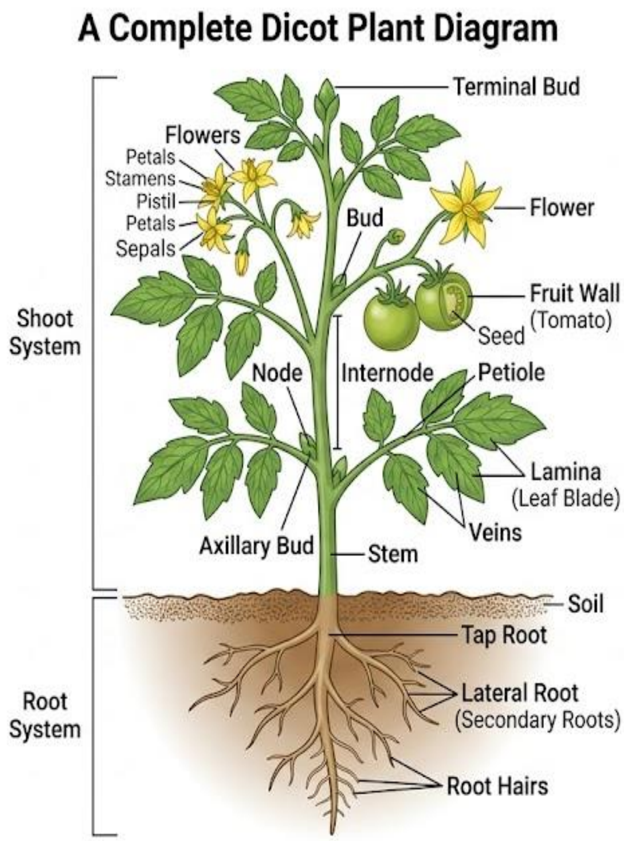

Figure 1.1: Labelled diagram of a typical dicot plant showing external features

Pilot questions 1.1

1. State five general characteristics of the Plant Kingdom.
2. Distinguish between bryophytes and pteridophytes.
3. Distinguish between monocots and dicots with two examples each.
4. Name and describe the external features of a typical dicot plant.
5. Explain why angiosperms are more successful than gymnosperms.

1.2 The Animal Kingdom

1.2.1 General characteristics of animals

Animals are multicellular, eukaryotic organisms that lack cell walls and chloroplasts. They are heterotrophs, obtaining energy by ingesting and digesting organic matter. Most animals can move and respond rapidly to stimuli through a nervous system. Animal cells contain centrioles, which are absent from most plant cells. Food is stored as glycogen rather than starch. Growth in most animals is determinate (stops at maturity).

Key animal characteristics: no cell walls (only a flexible plasma membrane); no chloroplasts; heterotrophic nutrition; food stored as glycogen; presence of nervous tissue; ability to move (in most animals); and reproduction that is predominantly sexual with internal or external fertilisation. Animals occupy virtually every habitat on Earth, from deep ocean trenches to high-altitude mountain peaks, and show extraordinary diversity in body plans, size, and lifestyle.

Fill in the blank: Animals store food as ________ rather than starch; they lack cell walls and chloroplasts, and most obtain energy by ingesting and digesting organic matter from other organisms.

1.2.2 Major phyla of the animal kingdom

Major invertebrate phyla: Porifera (sponges; no true tissues; filter feeders); Cnidaria (jellyfish, coral, hydra; radial symmetry; stinging cells called nematocysts); Platyhelminthes (flatworms, tapeworms; acoelomate; dorsoventrally flattened); Nematoda (roundworms; pseudocoelomate; cylindrical; many are parasites); Annelida (earthworms, leeches; true coelom; segmented body); Mollusca (snails, clams, squids; soft body; many have shells); Arthropoda (insects, spiders, crabs; jointed legs; exoskeleton; largest animal phylum).

Phylum Echinodermata (sea stars, sea urchins): spiny skin; radial symmetry in adults; water vascular system. Phylum Chordata contains all vertebrates: Class Chondrichthyes (sharks; cartilaginous skeleton); Class Osteichthyes (bony fish); Class Amphibia (frogs, salamanders; moist skin; semi-aquatic); Class Reptilia (lizards, snakes; dry scaly skin; amniote egg); Class

Aves (birds; feathers; endothermic); Class Mammalia (hair; mammary glands; endothermic; most viviparous).

Fill in the blank: Arthropoda is the largest animal phylum; its members have ________ legs, an exoskeleton, and a segmented body; it includes insects, spiders, centipedes, and crustaceans.

1.2.3 External features of representative animals

An earthworm (Lumbricus terrestris) shows: segmented cylindrical body; mouth at anterior end; anus at posterior end; clitellum (swollen saddle-shaped segment for reproduction); setae (small bristles on each segment for movement). A grasshopper (Arthropoda, Insecta) shows: head (antennae, compound eyes, mouthparts); thorax (three pairs of jointed legs, two pairs of wings); abdomen (digestive and reproductive organs); tough exoskeleton of chitin.

A frog (Amphibia) shows: moist smooth skin; two bulging eyes; tympanic membrane (ear drum) behind the eye; nostrils; webbed hind feet adapted for swimming; no tail in adults. A mammal such as a rabbit shows: body covered in fur; external pinnae (ears); vibrissae (whiskers); four limbs with claws; tail; and visible nostrils. External features reflect ecological adaptations to the animal's mode of life and habitat.

Fill in the blank: The ________ is the swollen saddle-shaped segment of an earthworm that secretes mucus during reproduction; it is used to identify sexually mature earthworms.

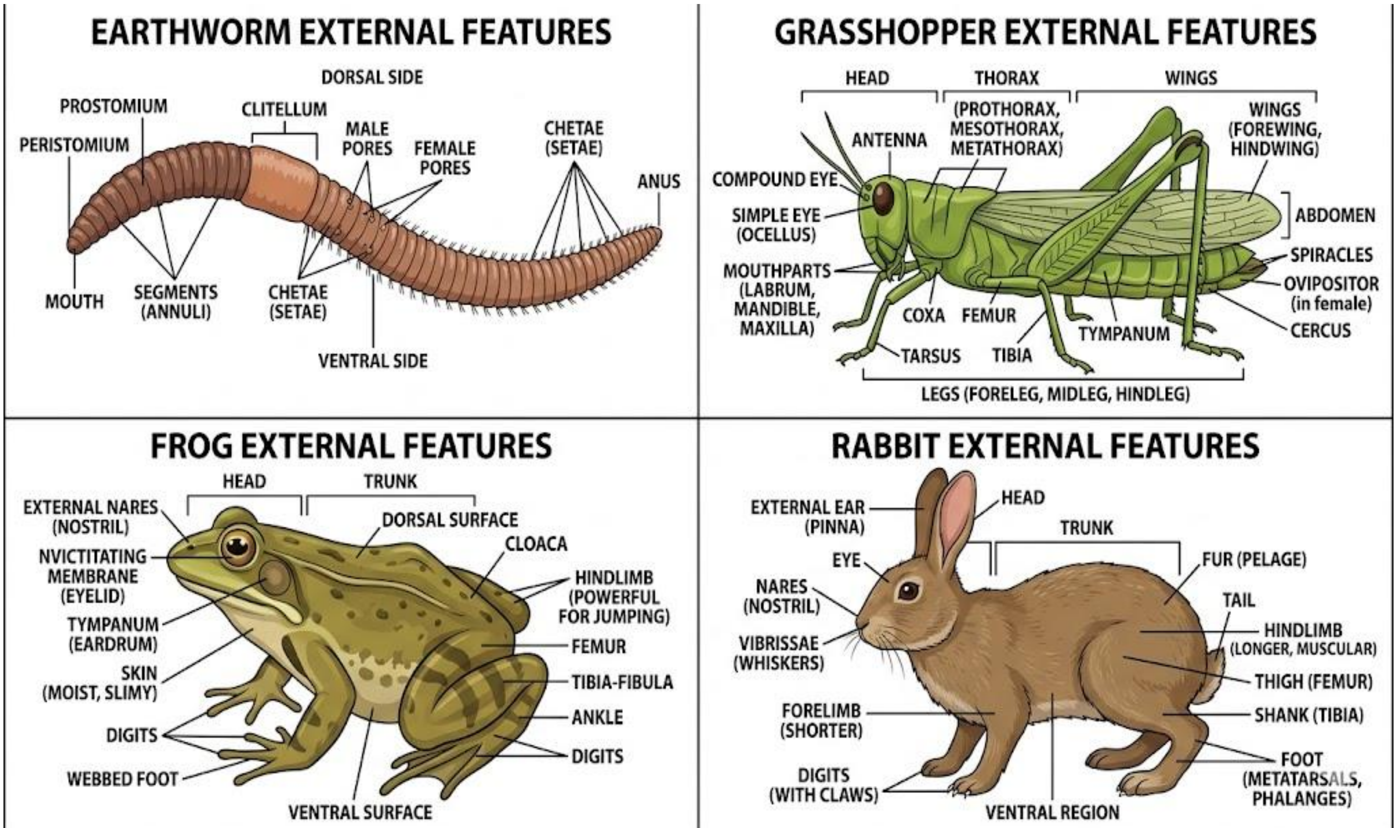

Figure 1.2: Labelled diagrams of representative animals from different phyla

Pilot questions 1.2

1. State five general characteristics of animals.
2. Name six major phyla of the animal kingdom and give one example of each.
3. Describe the external features of a grasshopper.
4. Distinguish between amphibians and reptiles.
5. State three features that distinguish mammals from other vertebrates.

1.3 Similarities and Differences Between Plants and Animals

1.3.1 Shared characteristics of living organisms

All living organisms, including both plants and animals, share seven fundamental characteristics: movement (all organisms exhibit some form of movement, even if only at the cellular level);

respiration (release of energy from organic molecules); sensitivity (response to stimuli in the environment); growth (increase in size and complexity); reproduction (production of offspring); excretion (removal of metabolic waste products); and nutrition (obtaining energy and raw materials).

These seven characteristics are summarised by the acronym MRS GREN (Movement, Respiration, Sensitivity, Growth, Reproduction, Excretion, Nutrition). Both plants and animals are composed of cells, carry out metabolism, maintain homeostasis, and are subject to evolution by natural selection. Understanding these shared properties is essential for understanding the unity of life that underlies the diversity of living forms on Earth.

Fill in the blank: The seven characteristics of living organisms can be remembered using the acronym MRS GREN: Movement, Respiration, Sensitivity, Growth, Reproduction, ________, and Nutrition.

1.3.2 Key differences between plants and animals

Key differences: cell wall (plants have cellulose cell walls; animals have none); chloroplasts (present in plant cells; absent in animal cells); mode of nutrition (plants are autotrophic via photosynthesis; animals are heterotrophic); food storage (plants store starch; animals store glycogen); movement (plants are generally sessile; animals are motile); growth (plants show indeterminate growth; most animals show determinate growth); and nervous system (absent in plants; present in animals).

Additional differences: vacuoles (plants have one large central vacuole; animal vacuoles are small and temporary); centrioles (absent in most plants; present in animal cells for cell division); external features (plants have roots, stems, leaves, and flowers; animals have specialised organs such as limbs, sense organs, and mouth parts). These differences reflect fundamentally different evolutionary strategies for obtaining energy and responding to the environment.

Fill in the blank: Plants store food as ________ while animals store food as glycogen; plants are autotrophic while animals are heterotrophic; plants are generally sessile while animals are motile.

Feature	Plants	Animals
1. Cell Wall	Present; primarily composed of **cellulose** which provides rigid structural support.	Absent; cells are enclosed only by a flexible plasma membrane.
2. Chloroplasts	Present in green plant cells; contains chlorophyll to harvest sunlight.	Absent; cannot perform photosynthesis.
3. Mode of Nutrition	**Autotrophic**; they manufacture their own food via photosynthesis.	**Heterotrophic**; they must ingest or consume other organisms for energy.
4. Food Storage	Excess glucose is stored primarily as **starch**.	Excess glucose is stored primarily as **glycogen** (in liver and muscle cells) and fat.
5. Movement / Locomotion	Generally **sessile** (fixed in one place); movement is limited to growth directions or tropisms (e.g., bending toward light).	Generally **motile**; capable of active locomotion from one place to another using muscles and specialized appendages.
6. Growth Pattern	Indeterminate growth; they continue to grow throughout their lifespan, primarily localized at meristems (tips of roots and shoots).	Determinate growth; they reach a defined adult size, and growth occurs uniformly across all body parts.
7. Cellularity & Structure	Multicellular with tissue systems, but lack complex organ systems	Multicellular with highly specialized tissues, organs, and complex organ systems.

Feature	Plants	Animals
	(e.g., no nervous or circulatory systems).	
8. Response to Stimuli	Slow response; primarily coordinated via plant hormones (phytohormones) since they lack a nervous system.	Rapid response; coordinated through a well-developed **nervous system** and endocrine system.
9. Respiration (Gas Exchange)	Take in carbon dioxide and release oxygen during the day (photosynthesis); take in oxygen and release carbon dioxide during respiration.	Constantly take in oxygen and release carbon dioxide through specialized respiratory organs (e.g., lungs, gills).
10. Reproduction	Can reproduce both asexually (vegetative propagation) and sexually (often involving alternation of generations).	Primarily reproduce sexually, though some lower animals can reproduce asexually (e.g., budding, regeneration).

Box 1.1: Comparison of key characteristics of plants and animals

1.3.3 Comparison of cell structure

Both plant and animal cells are eukaryotic and share: a nucleus (with nuclear envelope and nucleolus); cell membrane (plasma membrane); cytoplasm; mitochondria (for aerobic respiration); ribosomes (for protein synthesis); endoplasmic reticulum (rough and smooth); Golgi apparatus (for secretion); and lysosomes (in animal cells; rare in plants).

Plant cells additionally have: cellulose cell wall (rigid support outside the plasma membrane); chloroplasts (containing grana and thylakoids for photosynthesis); large central vacuole (containing cell sap; provides turgor pressure); and plasmodesmata (cytoplasmic connections through cell walls). Animal cells have: centrioles (involved in spindle formation during cell division); and are surrounded only by the flexible plasma membrane with no rigid wall.

Fill in the blank: Plant cells have a large central ________ containing cell sap that provides turgor pressure; animal cells lack this structure and are not bounded by a rigid cell wall.

Pilot questions 1.3

1. State the seven characteristics shared by all living organisms and explain each briefly.
2. State five differences between plants and animals.
3. State four structures found in plant cells but not in animal cells.
4. State two structures found in animal cells but not in most plant cells.
5. Explain what turgor pressure is and why it is important in plant cells.

1.4 Classification and Taxonomy

1.4.1 Principles of biological classification

Biological classification (taxonomy) is the science of naming, describing, and grouping organisms based on shared characteristics. The hierarchical classification system organises organisms into progressively broader groups. From most specific to most general, the ranks are: Species, Genus, Family, Order, Class, Phylum (or Division in plants), and Kingdom. A useful mnemonic is: "Kings Play Chess On Fine Glass Surfaces" (Kingdom, Phylum, Class, Order, Family, Genus, Species).

The modern classification of living organisms recognises five kingdoms: Monera (bacteria; prokaryotes); Protista (unicellular eukaryotes such as amoeba, paramecium, algae); Fungi (multicellular decomposers with chitin cell walls); Plantae; and Animalia. More recent systems recognise three Domains (Bacteria, Archaea, Eukarya) above the Kingdom level. Classification reflects evolutionary relationships and allows scientists to communicate precisely about organisms.

Fill in the blank: The hierarchical ranks of biological classification from most specific to broadest are: Species, Genus, Family, Order, Class, Phylum, and ________; the mnemonic is "Kings Play Chess On Fine Glass Surfaces".

1.4.2 The binomial nomenclature system

The binomial nomenclature system was developed by Carl Linnaeus in the 18th century. Each organism is given a unique two-part scientific name: the first part is the Genus name (capitalised) and the second is the species epithet (lower case). Both parts are written in italics (or underlined when handwritten). Examples: Homo sapiens (human); Zea mays (maize); Canis lupus familiaris (domestic dog); Mangifera indica (mango); Rana temporaria (common frog).

The binomial system ensures each species has one universally recognised name regardless of language or country. It avoids confusion caused by the same organism having different common names in different languages (e.g. Lycopersicon esculentum is unambiguously tomato in any scientific context, unlike the local names which vary). Scientific names are written in Latin or latinised Greek, making them internationally neutral.

Fill in the blank: In binomial nomenclature, the first part of the scientific name is the ________ (capitalised) and the second part is the species epithet (lower case); both are written in italics.

1.4.3 Importance of classification in biology

Classification is important for several reasons: it organises the enormous diversity of life into manageable, meaningful groups; it reveals evolutionary relationships between organisms; it provides a standardised universal language for communication between scientists worldwide; it helps predict the properties of newly discovered species based on their relatives; and it is essential for the study of ecology, conservation, medicine, and agriculture.

In Nigeria, correct biological classification is critical for accurate pest identification in agriculture (e.g. distinguishing between harmful and beneficial insects); for medical diagnosis of parasitic diseases (identifying the correct Plasmodium species causing malaria determines the drug treatment); and for conservation (correctly identifying endangered species to design appropriate protection measures). Classification is therefore not merely academic; it has direct practical applications.

Fill in the blank: Correct biological classification is essential for ________ diagnosis (e.g. identifying Plasmodium species to determine the appropriate malaria drug treatment) and for pest management in agriculture.

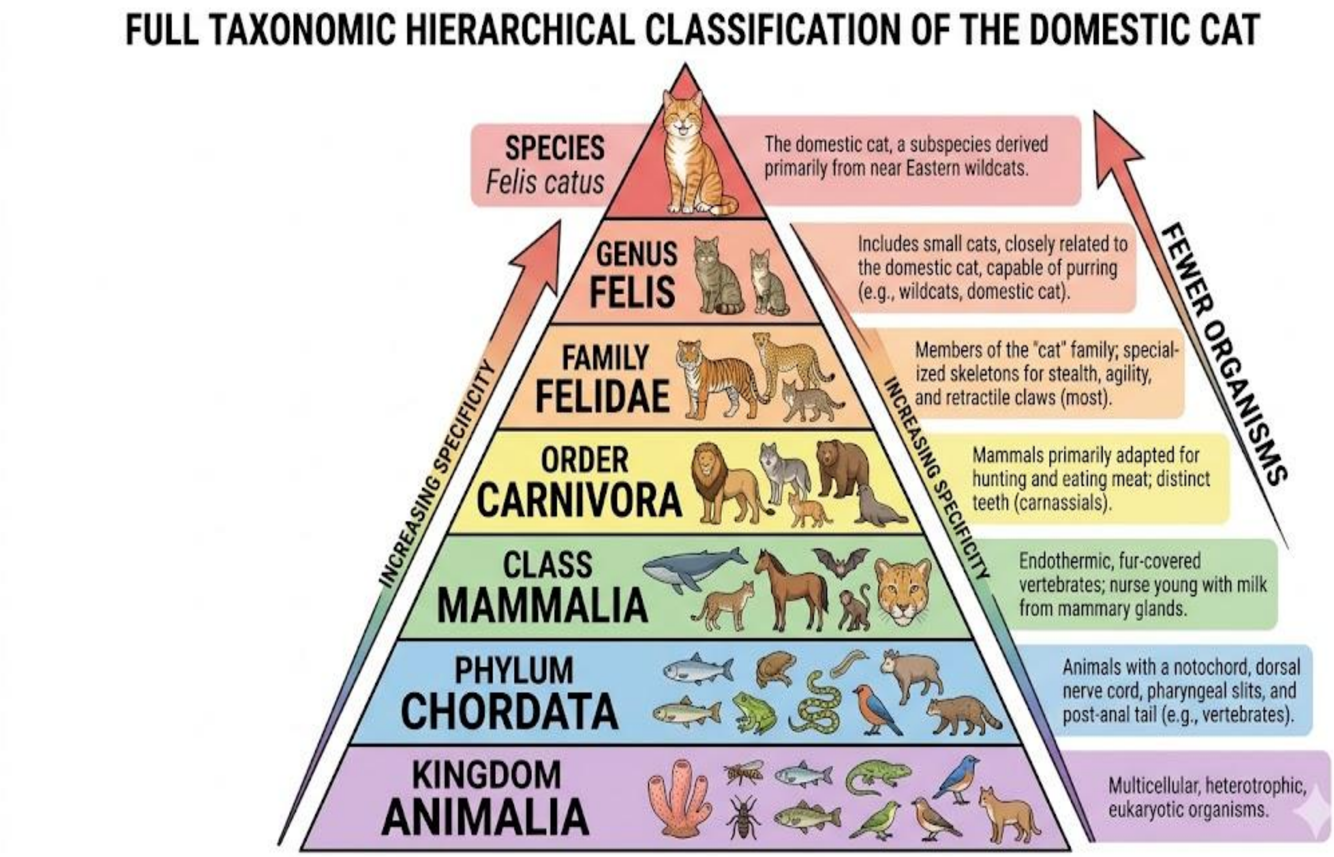

Figure 1.3: Diagram showing the hierarchical classification of the domestic cat

Pilot questions 1.4

1. State the seven levels of biological classification from most specific to broadest.
2. Write the binomial names of four organisms and state the rules of binomial nomenclature.
3. State three advantages of the binomial nomenclature system.
4. Name the five kingdoms of organisms and give one example of each.
5. Explain two practical applications of biological classification in Nigeria.

Series Summary

This Series introduced the characteristics of the Plant and Animal Kingdoms. Plants are autotrophic, multicellular eukaryotes with cellulose cell walls, chloroplasts, and indeterminate growth, divided into Bryophytes, Pteridophytes, Gymnosperms, and Angiosperms (monocots and dicots). Animals are heterotrophic, multicellular eukaryotes without cell walls, with determinate growth and a nervous system, organised into major phyla including Porifera, Cnidaria, Platyhelminthes, Annelida, Mollusca, Arthropoda, and Chordata.

All living organisms share seven characteristics (MRS GREN). Key plant-animal differences include cell wall, chloroplasts, food storage (starch vs glycogen), movement, and nervous system. Plant cells additionally contain chloroplasts, large central vacuoles, and cellulose walls; animal cells have centrioles. Biological classification uses seven hierarchical levels (Species to Kingdom); binomial nomenclature gives each organism a unique two-part Latin name. By completing this Series, you should achieve all seven SLOs (1.1 to 1.7).

Glossary of Terms

- **Angiosperm:** a flowering plant with seeds enclosed in a fruit; the most diverse plant group; includes monocots (one seed leaf) and dicots (two seed leaves).
- **Autotroph:** an organism that produces its own food from inorganic materials using light (photosynthesis) or chemical energy (chemosynthesis); plants are autotrophs.
- **Binomial nomenclature:** the scientific naming system giving each organism a unique two-part Latin name: Genus (capitalised) followed by species epithet (lower case), both in italics.
- **Bryophyte:** a non-vascular plant lacking true roots, stems, and leaves; includes mosses, liverworts, and hornworts; requires water for sexual reproduction.
- **Cellulose:** a polysaccharide forming the structural component of plant cell walls; provides rigidity and support.
- **Chloroplast:** a membrane-bound organelle in plant cells containing chlorophyll; the site of photosynthesis; absent from animal cells.

- **Chordata:** the phylum containing all vertebrates (fish, amphibians, reptiles, birds, mammals) plus some invertebrate chordates; defined by presence of a notochord at some life stage.
- **Centriole:** a cylindrical organelle involved in forming the spindle fibres during cell division; present in animal cells; absent from most plant cells.
- **Determinate growth:** growth that stops when the organism reaches maturity; characteristic of most animals.
- **Dicot:** an angiosperm with two seed leaves (cotyledons), net-veined leaves, and a tap root system; examples include tomato, mango, and Hibiscus.
- **Eukaryote:** an organism with cells containing a membrane-bound nucleus and other membrane-bound organelles; includes plants, animals, fungi, and protists.
- **Genus:** a taxonomic rank above species; the first part of the binomial scientific name; written with a capital letter and in italics.
- **Gymnosperm:** a vascular plant with seeds borne naked on cones, not enclosed in fruit; includes conifers, cycads, and ginkgo.
- **Heterotroph:** an organism that obtains energy by ingesting and digesting organic molecules produced by other organisms; animals are heterotrophs.
- **Indeterminate growth:** growth that continues throughout the life of the organism; characteristic of most plants.
- **Kingdom:** the broadest taxonomic rank in classical classification; the five kingdoms are Monera, Protista, Fungi, Plantae, and Animalia.
- **Monocot:** an angiosperm with one seed leaf (cotyledon), parallel-veined leaves, and a fibrous root system; examples include maize, rice, and grasses.
- **MRS GREN:** the acronym for the seven characteristics of living organisms: Movement, Respiration, Sensitivity, Growth, Reproduction, Excretion, Nutrition.
- **Phylum:** a major taxonomic rank below Kingdom used in the Animal Kingdom (Division is used in the Plant Kingdom).
- **Pteridophyte:** a vascular plant that reproduces by spores, has no seeds, and has true roots, stems, and leaves; includes ferns and horsetails.

- **Sessile:** fixed in place; unable to move from one location to another; characteristic of most plants.
- **Taxonomy:** the science of naming, describing, and classifying organisms based on their shared characteristics and evolutionary relationships.
- **Turgor pressure:** the pressure exerted by the cell contents against the cell wall when the vacuole is full of water; provides structural support in plant cells.
- **Vacuole:** a membrane-bound sac in the cytoplasm; plants have one large central vacuole; animal vacuoles are small and temporary.

Concept Check Questions [Series 1]

Objective Questions

1. Plants are ________ organisms that produce food by photosynthesis; their cell walls are composed of cellulose. (Linked to SLO 1.1)
2. Animals store food as ________ rather than starch; they lack cell walls and chloroplasts. (Linked to SLO 1.3)
3. The seven characteristics of living organisms are summarised by the acronym MRS GREN: Movement, Respiration, Sensitivity, Growth, Reproduction, ________, and Nutrition. (Linked to SLO 1.5)
4. In binomial nomenclature, the first part of the scientific name is the ________ name (capitalised) and the second is the species epithet (lower case), both written in italics. (Linked to SLO 1.7)
5. The seven levels of biological classification from most specific to broadest are: Species, Genus, Family, Order, Class, Phylum, and ________. (Linked to SLO 1.7)

Short-Answer Questions

6. State five characteristics of the Plant Kingdom. (Linked to SLO 1.1)
7. Name the four major divisions of the Plant Kingdom and state one distinguishing feature of each. (Linked to SLO 1.1)
8. State five characteristics of the Animal Kingdom. (Linked to SLO 1.3)
9. State five differences between plant and animal cells. (Linked to SLO 1.6)
10. Write the binomial names of three organisms and state two rules of the system. (Linked to SLO 1.7)

Long-Answer Questions

11. Describe the Plant Kingdom: its general characteristics, major divisions, and external features of a typical dicot plant. (Linked to SLOs 1.1, 1.2)
12. Describe the Animal Kingdom: its general characteristics, major phyla, and external features of a grasshopper and an earthworm. (Linked to SLOs 1.3, 1.4)
13. Compare plants and animals in terms of shared characteristics and key differences; compare their cell structures; and explain the principles and importance of biological classification. (Linked to SLOs 1.5, 1.6, 1.7)

Answers to Concept Check Questions [Series 1]

Objective Questions

1. Autotrophic.
2. Glycogen.
3. Excretion.
4. Genus.
5. Kingdom.

Short-Answer Questions

6. Multicellular eukaryotes; autotrophic by photosynthesis; cellulose cell walls; chloroplasts containing chlorophyll; food stored as starch; large central vacuole; indeterminate growth.
7. Bryophytes (non-vascular; reproduce by spores; no seeds); Pteridophytes (vascular; reproduce by spores; no seeds); Gymnosperms (vascular; seeds on cones; no fruit); Angiosperms (vascular; seeds in fruit; flowering plants).
8. Multicellular eukaryotes; heterotrophic; no cell walls or chloroplasts; food stored as glycogen; nervous system present; motile; determinate growth; reproduction predominantly sexual.
9. Plant cells have cellulose cell wall, chloroplasts, large central vacuole, and plasmodesmata; animal cells have centrioles. Plant cells lack centrioles; animal cells lack cell walls, chloroplasts, and large vacuoles.
10. Homo sapiens (human); Zea mays (maize); Mangifera indica (mango). Two rules: the Genus name is capitalised; the species epithet is lower case; both are written in italics.

Long-Answer Questions

11. Plant Kingdom characteristics: autotrophic; multicellular eukaryotes; cellulose cell walls; chloroplasts; food as starch; large central vacuole; indeterminate growth; sessile. Divisions: Bryophytes (non-vascular; no true roots/stems/leaves; spores; moist habitats; e.g. mosses); Pteridophytes (vascular; true roots/stems/fronds; spores; no seeds; e.g. ferns); Gymnosperms (vascular; seeds on cones; no fruit; pollen; e.g. conifers); Angiosperms (vascular; seeds in fruit; flowers; monocots and dicots; e.g. maize, tomato). External features of a typical dicot: tap root (absorbs water and minerals; anchors plant); stem (supports and transports); leaves (lamina,

petiole, veins; photosynthesis and gas exchange through stomata); flower (sepals, petals, stamens, carpel; reproduction).

12. Animal Kingdom characteristics: heterotrophic; multicellular eukaryotes; no cell walls or chloroplasts; food as glycogen; nervous system; motile; determinate growth. Major phyla: Porifera (sponges; no true tissues); Cnidaria (jellyfish; nematocysts; radial symmetry); Platyhelminthes (flatworms; acoelomate); Annelida (earthworms; segmented; true coelom); Mollusca (snails; soft body); Arthropoda (insects; jointed legs; exoskeleton; largest phylum); Chordata (vertebrates; notochord). Grasshopper external features: head (antennae, compound eyes, mouthparts); thorax (three pairs of jointed legs, two pairs of wings); abdomen (digestive and reproductive organs); chitin exoskeleton. Earthworm external features: segmented cylindrical body; mouth anteriorly; anus posteriorly; clitellum (reproductive saddle); setae (bristles for movement).
13. Shared characteristics (MRS GREN): Movement, Respiration, Sensitivity, Growth, Reproduction, Excretion, Nutrition. Key differences: cell wall (plants have cellulose; animals none); chloroplasts (plants yes; animals no); nutrition (autotrophic vs heterotrophic); food storage (starch vs glycogen); movement (sessile vs motile); growth (indeterminate vs determinate); nervous system (absent vs present). Cell structure comparison: both have nucleus, mitochondria, ribosomes, endoplasmic reticulum, Golgi apparatus, cell membrane. Plant cells additionally: cellulose cell wall; chloroplasts; large central vacuole; plasmodesmata. Animal cells additionally: centrioles; no rigid wall. Classification principles: organisms grouped into seven hierarchical ranks (Species, Genus, Family, Order, Class, Phylum, Kingdom); binomial nomenclature gives each species a unique two-part Latin name (Genus capitalised, species epithet lower case, both italicised); five kingdoms: Monera, Protista, Fungi, Plantae, Animalia. Importance: organises diversity; reveals evolutionary relationships; universal language for scientists; essential for medicine (pathogen identification), agriculture (pest identification), and conservation.

Answers to Pilot Questions [Series 1]

Part 1.1

1. Multicellular eukaryotes with cellulose cell walls; autotrophic by photosynthesis; chloroplasts containing chlorophyll; food stored as starch; large central vacuole; indeterminate growth throughout life; sessile (fixed in place); reproduce sexually and asexually.

2. Bryophytes are non-vascular (no xylem or phloem), have no true roots, stems, or leaves, and reproduce by spores; they depend on water for fertilisation and are restricted to moist habitats. Pteridophytes are vascular, have true roots, stems, and leaves, reproduce by spores but not seeds, and can grow in drier habitats than bryophytes.
3. Monocots: one seed leaf (cotyledon); parallel-veined leaves; fibrous root system; examples: maize, rice. Dicots: two seed leaves; net-veined leaves; tap root system; examples: tomato, mango. Monocots also have flower parts in multiples of three; dicots in multiples of four or five.
4. Root: tap root with lateral roots; absorbs water and minerals; anchors plant. Stem: erect; supports leaves and flowers; transports water upward and food downward. Leaf: lamina (blade), petiole, and veins; site of photosynthesis; gas exchange through stomata on the lower epidermis. Flower: sepals, petals, stamens, and carpel; organ of sexual reproduction.
5. Angiosperms enclose their seeds within a fruit, which protects the seed and aids dispersal by animals, wind, or water. They produce flowers that attract pollinators, making fertilisation more reliable and efficient than wind pollination by gymnosperms. Their enclosed seeds and diverse pollination mechanisms make them better adapted to a wider range of terrestrial habitats.

Part 1.2

1. Multicellular eukaryotes; heterotrophic; no cell walls or chloroplasts; food stored as glycogen; nervous system for rapid response to stimuli; motile (most can move); determinate growth; predominantly sexual reproduction.
2. Porifera (sponges); Cnidaria (jellyfish); Platyhelminthes (tapeworm); Annelida (earthworm); Mollusca (snail); Arthropoda (grasshopper); Echinodermata (sea star); Chordata (tilapia fish).
3. Head: pair of antennae; two large compound eyes; mouthparts (for chewing). Thorax: three pairs of jointed legs; two pairs of wings (one leathery, one membranous). Abdomen: segmented; contains digestive and reproductive organs. Entire body covered by a hard exoskeleton of chitin.
4. Amphibians have moist smooth skin, lay unshelled eggs in water, and require water for reproduction; they undergo metamorphosis. Reptiles have dry scaly skin, lay shelled amniote eggs on land, and do not require water for reproduction; no metamorphosis.
5. Presence of hair or fur; mammary glands that produce milk to nourish young; endothermic (warm-blooded); most are viviparous (give birth to live young).

Part 1.3

1. The seven characteristics (MRS GREN): Movement (all organisms show movement at least at the cellular level); Respiration (release energy from organic molecules); Sensitivity (detect and respond to stimuli); Growth (increase in size and complexity); Reproduction (produce offspring); Excretion (remove metabolic waste); Nutrition (obtain energy and raw materials for life processes).
2. Plants have cellulose cell walls; animals do not. Plants have chloroplasts and are autotrophic; animals have no chloroplasts and are heterotrophic. Plants store food as starch; animals store food as glycogen. Plants are sessile; most animals are motile. Plants show indeterminate growth; most animals show determinate growth.
3. Cellulose cell wall; chloroplasts; large central vacuole; plasmodesmata (cytoplasmic channels through cell walls).
4. Centrioles (for spindle formation during cell division); absence of a rigid cell wall (only a flexible plasma membrane).
5. Turgor pressure is the outward pressure exerted by water-filled cell contents against the rigid cellulose cell wall. It is important because it provides structural support to non-woody plant tissues (making leaves and young stems firm); when cells lose water, turgor is lost and the plant wilts.

Part 1.4

1. Species, Genus, Family, Order, Class, Phylum (or Division in plants), Kingdom.
2. Homo sapiens (human); Zea mays (maize); Mangifera indica (mango); Canis lupus familiaris (dog). Two rules: the Genus name is capitalised and the species epithet is lower case; both are written in italics (or underlined in handwriting).
3. Each species has one universal scientific name recognised by scientists worldwide; it avoids confusion from multiple common names for the same organism; it reveals the evolutionary relationship between species in the same genus.
4. Monera (Escherichia coli); Protista (Amoeba); Fungi (Rhizopus); Plantae (Mangifera indica); Animalia (Homo sapiens).
5. Medical diagnosis: identifying the correct Plasmodium species (P. falciparum vs P. vivax) determines the appropriate anti-malarial drug treatment. Pest management in agriculture:

correctly classifying an insect pest (e.g. distinguishing stem-borer species) determines the appropriate control method.

References and Attributions [Series 1]

Textual References (Books and External Sources)

- Campbell, N. A., & Reece, J. B. (2008). Biology (8th ed.). Pearson Benjamin Cummings.
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- Odum, E. P. (1971). Fundamentals of ecology (3rd ed.). W.B. Saunders.
- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 1.1: Labelled diagram of a typical dicot plant Attribution: AI generated. Suggested OER search string: "dicot plant external features labelled diagram roots stem leaf flower OER".
- Figure 1.2: Labelled diagrams of representative animals Attribution: AI generated. Suggested OER search string: "representative animal external features earthworm grasshopper frog rabbit labelled diagram OER".
- Box 1.1: Comparison of key characteristics of plants and animals Attribution: AI generated. Suggested OER search string: "comparison plant animal characteristics table cell wall chloroplasts nutrition OER box".
- Figure 1.3: Hierarchical classification diagram for the domestic cat Attribution: AI generated. Suggested OER search string: "biological classification hierarchy domestic cat kingdom phylum class order family genus species OER".

Course code: BIO 102

Course title: General Biology II

Course credit load: 2 Units

Series 2: Ecological Adaptations in Plants and Animals

- **Part 2.1: Introduction to Ecological Adaptation**
    - Sub Part 2.1.1: Definition and significance of adaptation
    - Sub Part 2.1.2: Types of adaptation
    - Sub Part 2.1.3: Major terrestrial habitats and their challenges
- **Part 2.2: Adaptations of Plants to Different Habitats**
    - Sub Part 2.2.1: Hydrophytes (aquatic plants)
    - Sub Part 2.2.2: Xerophytes (desert and dry habitat plants)
    - Sub Part 2.2.3: Mesophytes, halophytes, and epiphytes
- **Part 2.3: Adaptations of Animals to Different Habitats**
    - Sub Part 2.3.1: Adaptations to aquatic environments
    - Sub Part 2.3.2: Adaptations to terrestrial environments
    - Sub Part 2.3.3: Adaptations to extreme environments
- **Part 2.4: Ecological Relationships and Interdependence**
    - Sub Part 2.4.1: Food chains and food webs
    - Sub Part 2.4.2: Symbiotic relationships
    - Sub Part 2.4.3: Population and community ecology

Introduction

An adaptation is any structural, physiological, or behavioural feature that increases an organism's survival and reproductive success in its environment. Adaptations are the result of natural selection acting over many generations. Understanding how plants and animals are adapted to their habitats is central to ecology and explains the extraordinary diversity of life on Earth.

This Series explores the major types of ecological adaptation, how plants are adapted to aquatic, arid, and other specialised habitats, how animals are adapted to aquatic and terrestrial environments, and the ecological relationships between organisms in communities. These concepts build directly on the kingdom characteristics studied in Series 1.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 2.1** define ecological adaptation and distinguish between structural, physiological, and behavioural adaptations (Linked to Part 2.1),
- **SLO 2.2** describe the major challenges of terrestrial habitats and explain how organisms respond to them (Linked to Part 2.1),
- **SLO 2.3** describe the adaptive features of hydrophytes, xerophytes, mesophytes, halophytes, and epiphytes (Linked to Part 2.2),
- **SLO 2.4** describe the adaptive features of aquatic and terrestrial animals (Linked to Part 2.3),
- **SLO 2.5** describe adaptations of animals to extreme environments (Linked to Part 2.3),
- **SLO 2.6** describe food chains, food webs, and energy flow in ecosystems (Linked to Part 2.4), and
- **SLO 2.7** describe symbiotic relationships and explain the concepts of population and community ecology (Linked to Part 2.4).

2.1 Introduction to Ecological Adaptation

2.1.1 Definition and significance of adaptation

An ecological adaptation is any heritable characteristic that increases an organism's fitness in its particular environment. Adaptations arise through the process of natural selection: individuals with beneficial traits survive and reproduce more successfully, passing those traits to offspring. Over many generations, the adaptive trait becomes more common in the population. Adaptations reduce competition, improve resource acquisition, and enhance survival.

Significance: adaptations allow organisms to exploit specific ecological niches that other organisms cannot, reducing direct competition. They explain why different species in the same habitat look and behave differently, and why similar habitats on different continents often contain similar-looking but unrelated organisms (convergent evolution). In Nigeria, the diversity of plant and animal life across the rainforest, savanna, mangrove, and semi-arid zones reflects different adaptive solutions to different environmental challenges.

Fill in the blank: An ecological adaptation is any heritable characteristic that increases an organism's ________ in its particular environment; adaptations arise through natural selection over many generations.

2.1.2 Types of adaptation

Structural adaptations: physical features of an organism's body that improve survival. Examples: the thick waxy cuticle of desert plants reduces water loss; the streamlined body of fish reduces drag in water; the hollow bones of birds reduce weight for flight; the flattened body of a flatworm allows absorption of nutrients without a gut. Structural adaptations are directly visible in the organism's external and internal anatomy.

Physiological adaptations: internal biochemical or metabolic features. Examples: camels produce highly concentrated urine to conserve water; desert plants use the CAM photosynthesis pathway, opening stomata only at night; some Antarctic fish produce antifreeze proteins. Behavioural adaptations: actions that improve survival. Examples: migration of birds to warmer regions in winter; hibernation of mammals in cold seasons; nocturnal activity of many desert animals to avoid daytime heat.

Fill in the blank: ________ adaptations are internal biochemical or metabolic features; examples include the production of antifreeze proteins in Antarctic fish and concentrated urine production in camels to conserve water.

2.1.3 Major terrestrial habitats and their challenges

Tropical rainforest: high rainfall and humidity; challenge is competition for light; plants grow tall or develop broad leaves to capture sunlight in the understorey. Savanna and grassland: seasonal rainfall; challenge is water stress during dry season and periodic fire; grasses have deep fibrous roots to regenerate quickly after burning. Desert: extreme heat and very low rainfall; challenge is water acquisition and conservation and extreme temperature fluctuation.

Mangrove: coastal wetland of tidal saltwater; challenges include salt stress, waterlogged anaerobic soil, and tidal flooding; mangrove trees have pneumatophores (aerial roots) for gas exchange and salt-excreting or salt-excluding mechanisms. Freshwater: challenge is osmotic regulation (fresh water diffuses into body tissues of aquatic animals by osmosis). Nigerian habitats span all of these zones: rainforest in the south, savanna in the Middle Belt and north, mangroves along the Delta, and semi-arid Sahel in the far north.

Fill in the blank: Mangrove trees have ________ (aerial roots that project above the waterlogged anaerobic soil) to enable gas exchange; they also have salt-excluding or salt-excreting mechanisms to deal with salt stress.

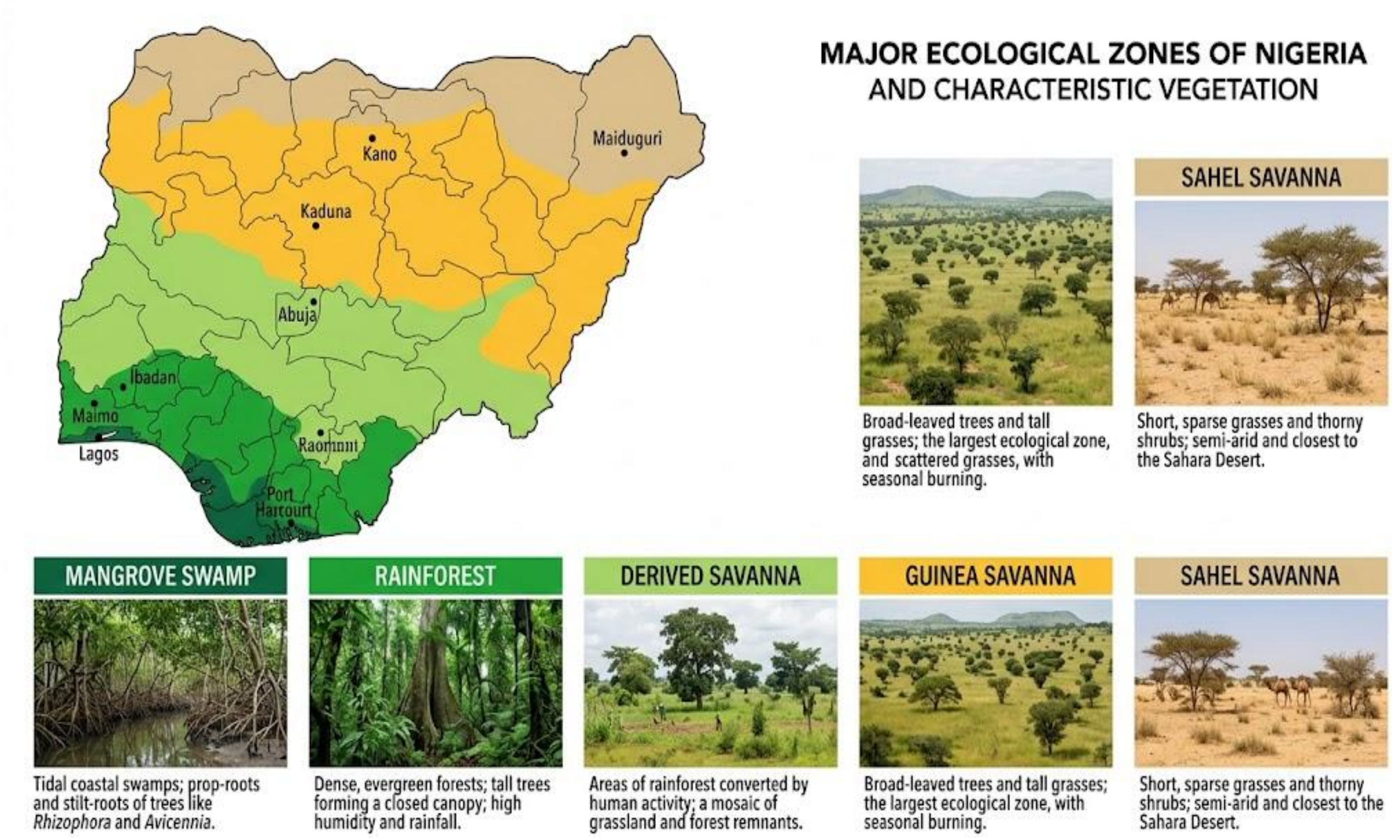

Figure 2.1: Map and photographs of Nigeria's major ecological zones

Pilot questions 2.1

1. Define ecological adaptation and explain how adaptations arise.
2. Distinguish between structural, physiological, and behavioural adaptations with one example each.
3. State the major ecological challenges of desert habitats.
4. Explain why mangrove trees have pneumatophores.
5. Name four ecological zones found in Nigeria.

2.2 Adaptations of Plants to Different Habitats

2.2.1 Hydrophytes (aquatic plants)

Hydrophytes are plants adapted to live in water or waterlogged soil. They are classified by position: submerged (e.g. Elodea, Ceratophyllum); floating-leaved (e.g. water lily Nymphaea, water hyacinth Eichhornia); emergent (e.g. bulrush Typha, papyrus Cyperus); and free-floating (e.g. duckweed Lemna, Azolla). Each has specific adaptations to its degree of submersion and light availability.

Key adaptive features of hydrophytes: large air spaces (aerenchyma) in stems, petioles, and leaves to provide buoyancy and supply oxygen to submerged parts; reduced or absent waxy cuticle (water loss not a problem); stomata on the upper surface of floating leaves (to access air); thin and flexible leaves that bend with water currents without breaking; reduced or absent xylem (water is absorbed directly through the surface); roots reduced or absent in some free-floating species.

Fill in the blank: Hydrophytes have large air spaces called ________ in their tissues that provide buoyancy and supply oxygen to submerged parts; their cuticle is thin or absent since water loss is not a concern.

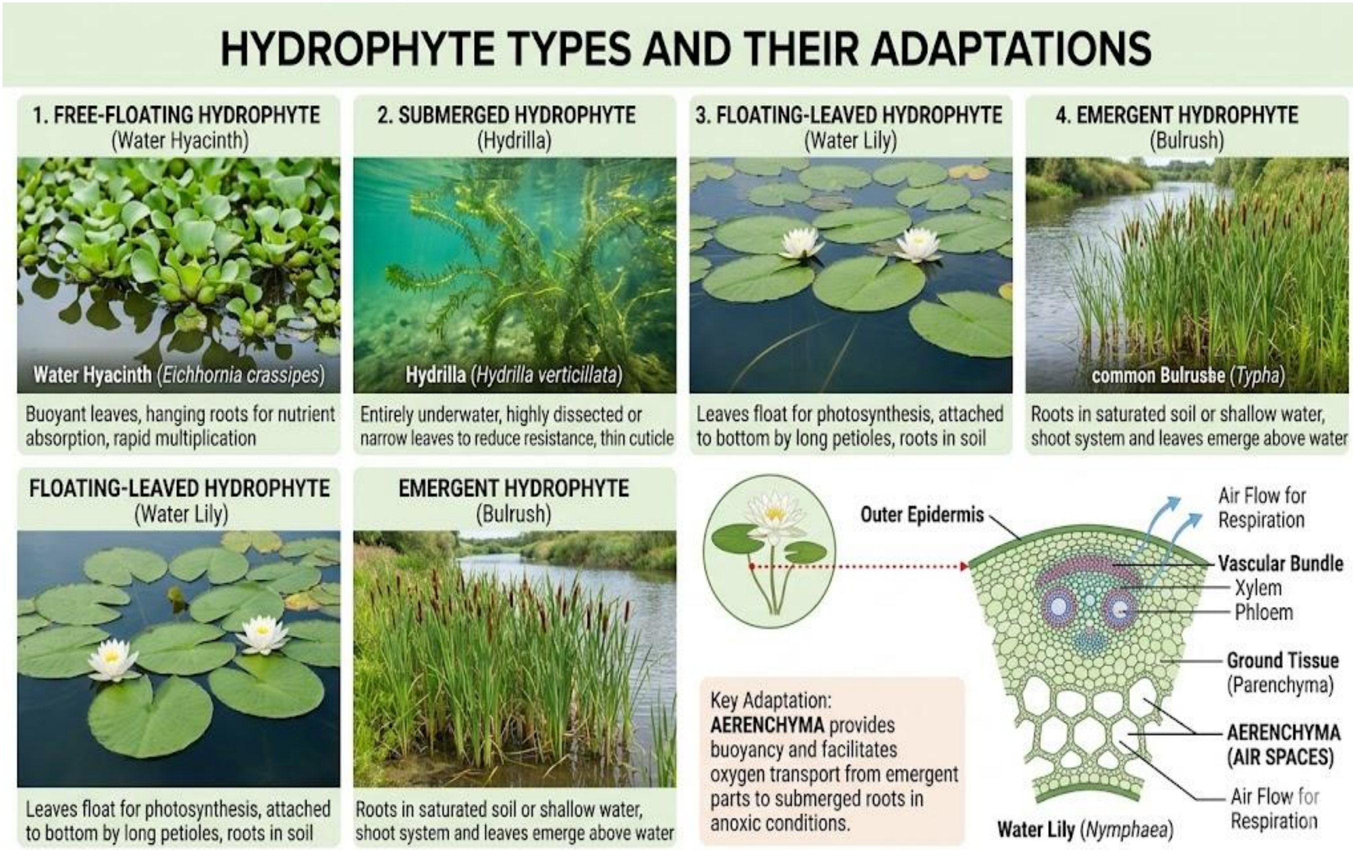

Figure 2.2: Photographs and diagram of hydrophyte types and their adaptive features

2.2.2 Xerophytes (desert and dry habitat plants)

Xerophytes are adapted to survive in habitats where water is scarce. Their adaptations fall into three strategies: drought avoidance (completing the life cycle during the brief wet season as ephemeral annuals; seeds survive the drought); drought endurance (storing water in specialised succulent tissues; e.g. cacti store water in their swollen stems); and drought resistance (deep or widespread root systems, reduced leaves, and physiological mechanisms that minimise water loss).

Structural adaptations of xerophytes: thick waxy cuticle on leaves to reduce evaporation; sunken stomata or stomata open only at night (CAM photosynthesis); leaves reduced to spines or scales (e.g. cactus); swollen stem or leaves for water storage; deep taproot or extensive shallow root network; rolled leaves (e.g. marram grass) to trap humid air; hairy leaf surface to reduce air movement and transpiration. Examples in Nigeria: Acacia, baobab (Adansonia), and Euphorbia species in the north.

Fill in the blank: Xerophytes reduce water loss through a thick waxy ________, sunken or few stomata, and leaves reduced to spines; some store water in succulent tissues such as the swollen stems of cacti.

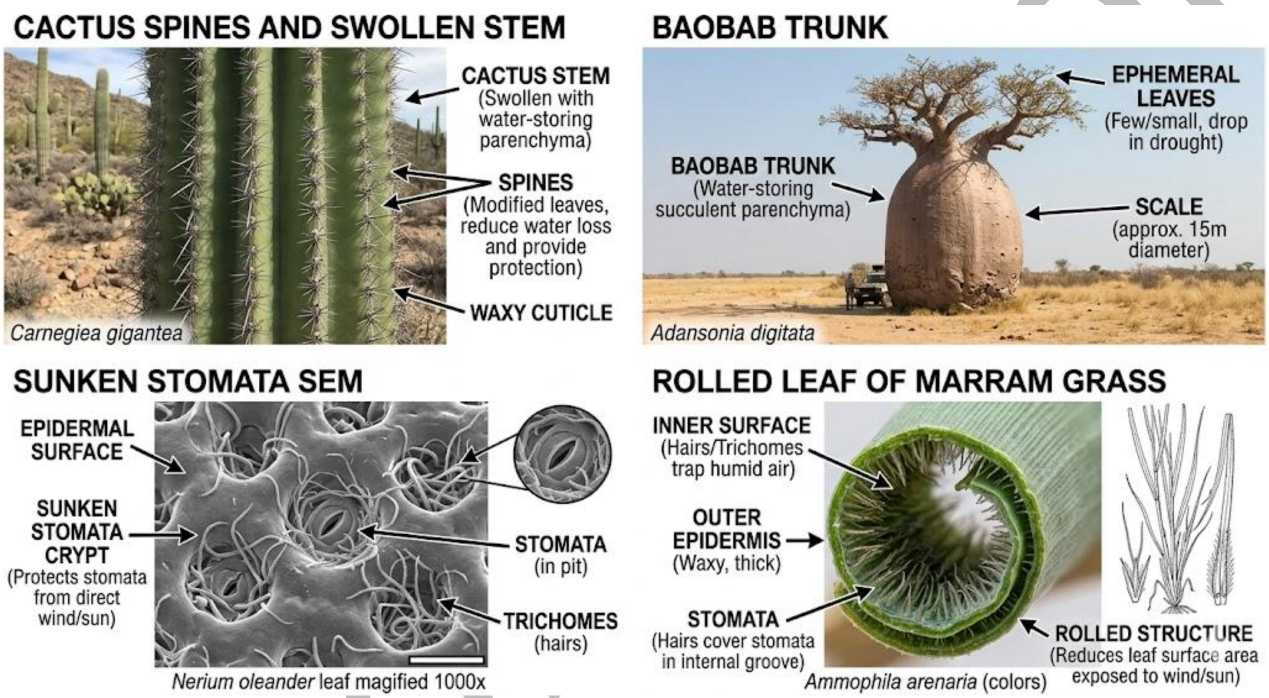

Figure 2.3: Photographs of xerophyte adaptations

2.2.3 Mesophytes, halophytes, and epiphytes

Mesophytes are adapted to habitats with moderate water availability, neither waterlogged nor arid. Most agricultural plants (maize, cassava, tomato) and rainforest understorey plants are mesophytes. Their leaves are typically broad and flat with a normal cuticle, stomata on the lower surface, and a well-developed vascular system. They cannot tolerate prolonged drought or waterlogging and wilt rapidly when water is insufficient.

Halophytes grow in saline habitats (coastal salt marshes, mangroves, inland salt flats). Adaptations include: salt glands on leaves that actively secrete excess salt; thick and succulent leaves to dilute salt concentrations; waxy cuticle to prevent salt damage to leaf cells;

pneumatophores (in mangroves) for gas exchange in anaerobic soil. Epiphytes (e.g. orchids, bromeliads, ferns) grow on other plants for support without being parasitic; they absorb water and nutrients from rain, dew, and organic debris trapped on their host.

Fill in the blank: ________ grow in saline habitats and tolerate salt through salt glands that actively secrete excess salt, thick succulent leaves, and waxy cuticles that protect cells from salt damage.

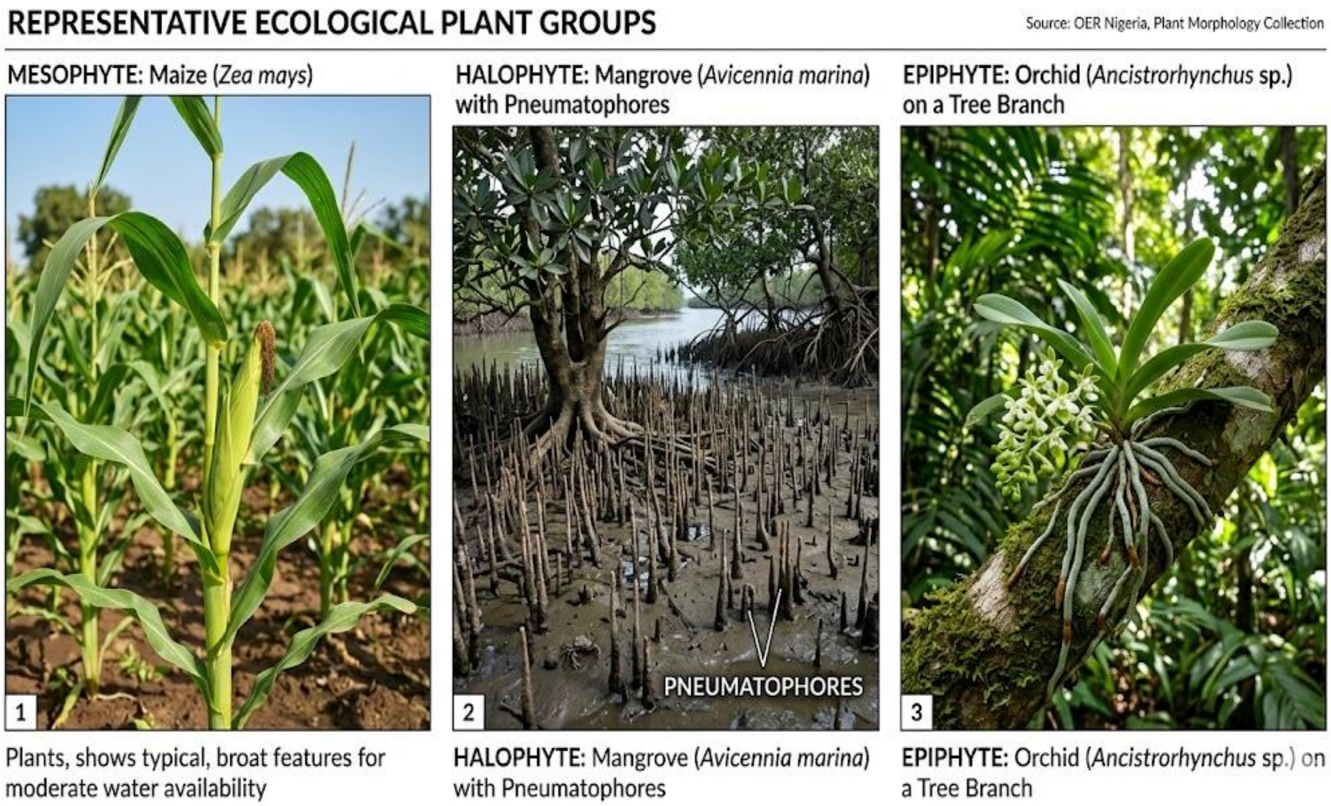

Figure 2.4: Photographs of mesophyte, halophyte, and epiphyte habitats

Pilot questions 2.2

1. Define hydrophytes and state four of their adaptive features.
2. Explain three strategies xerophytes use to survive drought.
3. State four structural adaptations of xerophytes.
4. Distinguish between halophytes and epiphytes.
5. Explain why most crop plants are classified as mesophytes.

2.3 Adaptations of Animals to Different Habitats

2.3.1 Adaptations to aquatic environments

Fish are the most fully adapted aquatic vertebrates. Key adaptations: streamlined (fusiform) body shape minimises water resistance; scales overlap to reduce friction; fins provide propulsion and steering (paired pectoral and pelvic fins; unpaired dorsal, caudal, and anal fins); lateral line system detects water vibrations; gills extract dissolved oxygen from water; swim bladder adjusts buoyancy. Cartilaginous fish (sharks) lack a swim bladder but have a large oil-rich liver for buoyancy.

Aquatic invertebrates show diverse adaptations: aquatic insects (e.g. water beetle Dytiscus) trap an air bubble under the elytra for respiration; mayfly and dragonfly larvae have gills for aquatic gas exchange; freshwater mussels have siphons to draw in water and extract oxygen and food particles. Aquatic mammals (whales, dolphins) have streamlined bodies, paddle-like flippers, no hind limbs, a horizontal tail fluke for propulsion, and a thick layer of blubber for insulation and energy storage.

Fill in the blank: Fish detect water vibrations through the ________ line system; they extract dissolved oxygen from water using gills; and they adjust buoyancy using a swim bladder.

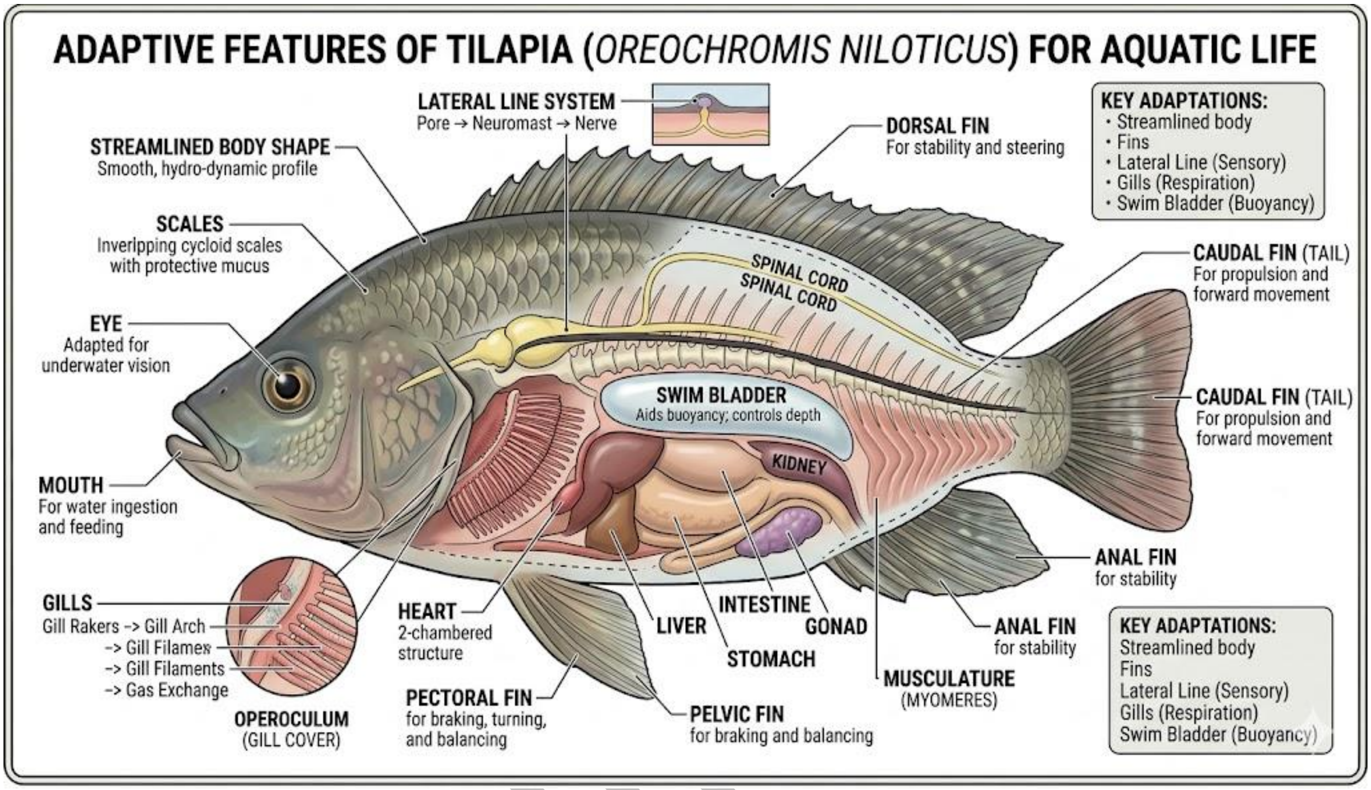

Figure 2.5: Labelled diagram of a fish showing aquatic adaptations

2.3.2 Adaptations to terrestrial environments

Terrestrial life presents challenges not faced in water: the need to support body weight against gravity; risk of desiccation (water loss); need for efficient gas exchange in air; and need for effective locomotion on land. Insects have a waterproof cuticle (chitin) to prevent desiccation; a tracheal system delivering oxygen directly to tissues; jointed legs for walking; and compound eyes sensitive to movement. Terrestrial vertebrates have limbs replacing fins, lungs replacing gills, and waterproof skin.

Reptiles are well-adapted to dry terrestrial environments: dry scaly skin (keratin) prevents water loss; amniote eggs with a leathery shell allow reproduction on land without water; they are ectothermic (body temperature regulated behaviourally). Birds and mammals are endothermic (maintain constant body temperature internally): birds have feathers for insulation and flight; mammals have fur or fat for insulation; both have efficient four-chambered hearts and a complete double circulation for sustained activity.

Fill in the blank: Reptiles have dry ________ skin (made of keratin) that prevents water loss; they lay amniote eggs with a leathery or calcareous shell, allowing reproduction on land without requiring water.

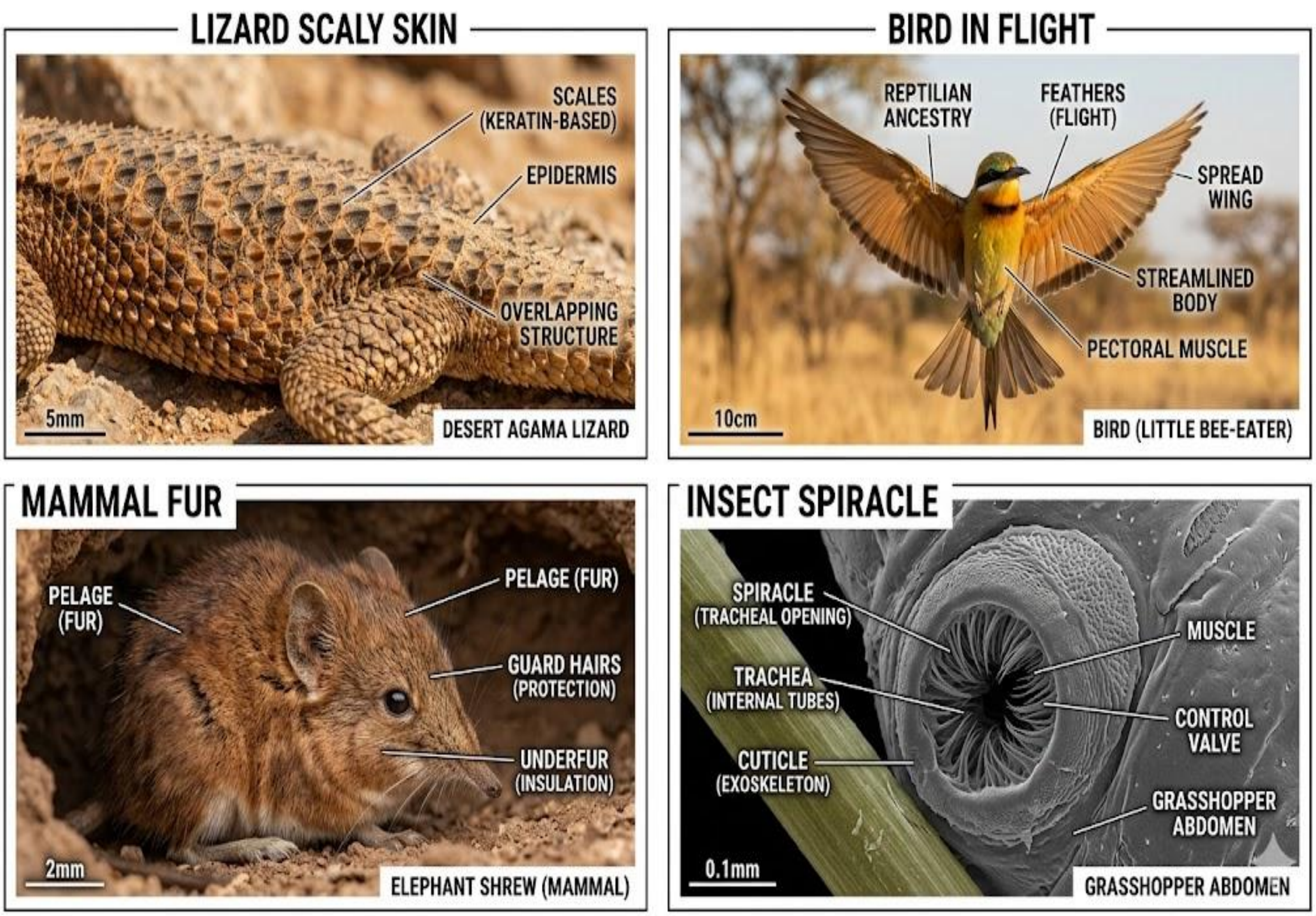

Figure 2.6: Comparison photographs of terrestrial animal adaptations

2.3.3 Adaptations to extreme environments

Desert animals face heat and water scarcity. The camel is the classic example: humps store fat (not water) as an energy reserve; the camel can tolerate 25% body weight water loss without harm; it produces very little urine and dry faeces to conserve water; its body temperature can fluctuate by 6 degrees Celsius during the day, reducing the need for sweating; long legs keep the body away from hot ground; and it can drink up to 200 litres of water at once when available.

Polar animals face extreme cold and food scarcity. The polar bear has a thick layer of subcutaneous fat (blubber) and dense white fur for insulation; white colouration provides camouflage in snow. Penguins huddle together for warmth; their wings are modified as flippers for swimming; their feet have a counter-current heat exchange system to prevent heat loss to cold ground. Hibernating mammals reduce metabolic rate to near zero during winter, surviving on stored fat. Deep-sea animals tolerate extreme pressure and near-total darkness.

Fill in the blank: A camel's hump stores ________ (not water) as an energy reserve; the camel conserves water by producing very concentrated urine, tolerating large fluctuations in body temperature, and absorbing moisture from exhaled breath.

Pilot questions 2.3

1. State five adaptive features of fish for aquatic life.
2. Explain how insects are adapted to terrestrial life.
3. Compare the adaptations of reptiles and mammals for life on land.
4. Describe four water-conserving adaptations of the camel.
5. Explain how polar bears are adapted to survive in Arctic conditions.

2.4 Ecological Relationships and Interdependence

2.4.1 Food chains and food webs

A food chain shows the linear transfer of energy from one organism to the next through feeding. The sequence is: Producer (plants; autotrophs) → Primary consumer (herbivore) → Secondary consumer (carnivore) → Tertiary consumer (top carnivore). Example: grass → grasshopper → frog → snake → eagle. Energy is lost at each trophic level (only 10% is transferred to the next level); this means food chains rarely exceed four or five links.

A food web is a network of interconnected food chains within an ecosystem. It more accurately represents feeding relationships because most organisms eat more than one type of food and are eaten by more than one predator. Producers (green plants and algae) capture solar energy by photosynthesis; decomposers (bacteria and fungi) break down dead organic matter and return minerals to the soil, completing the cycle of matter. Energy flows in one direction; matter cycles.

Fill in the blank: Energy transfer between trophic levels in a food chain is approximately ________ per cent efficient; the rest is lost as heat, which is why food chains rarely have more than four or five links.

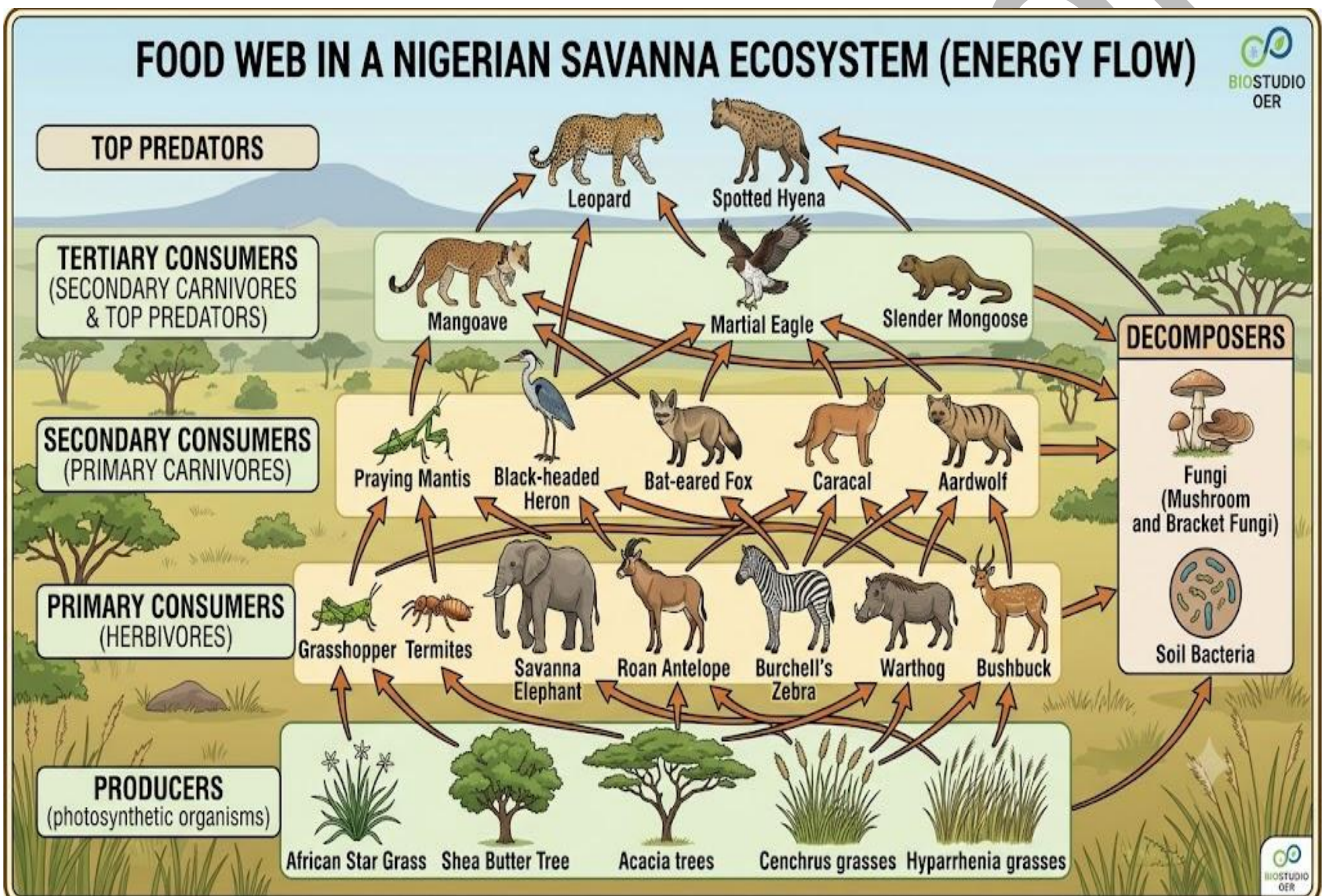

Figure 2.7: Diagram of a food web in a Nigerian savanna ecosystem

2.4.2 Symbiotic relationships

Symbiosis is a close and long-term biological interaction between two species. Three main types: Mutualism: both organisms benefit. Examples: nitrogen-fixing bacteria (Rhizobium) in root nodules of legumes benefit both the plant (fixed nitrogen) and the bacterium (carbohydrates from the plant); mycorrhizal fungi enhance mineral absorption by plant roots and receive sugars in return; cleaner fish remove parasites from larger fish.

Commensalism: one organism benefits; the other is neither helped nor harmed. Example: epiphytic orchids use a tree for physical support but do not harm the host tree; oxpecker birds on cattle eat ticks and parasites (some consider this mutualism). Parasitism: one organism (the parasite) benefits at the expense of the host, which is harmed but rarely killed quickly. Examples: Plasmodium (malaria parasite) in human blood; tapeworms in the intestine; mistletoe partially parasitising tree branches. Parasitism is the most common symbiotic relationship in nature.

Fill in the blank: In ________, both organisms benefit from the relationship; examples include Rhizobium bacteria fixing nitrogen in legume root nodules and mycorrhizal fungi improving mineral absorption by plant roots.

2.4.3 Population and community ecology

A population is a group of individuals of the same species living in the same area at the same time. Population size is affected by birth rate, death rate, immigration, and emigration. Populations grow exponentially when resources are unlimited (J-shaped growth curve) but growth is limited by carrying capacity (K), producing an S-shaped (logistic) growth curve when resources are restricted. Factors limiting population growth include food, water, space, disease, and predation.

A community is all the populations of different species living together in the same area. Ecosystems consist of the community plus its abiotic environment. Important community concepts: biodiversity (the number and variety of species in a community); ecological niche (the functional role of an organism in its community, including what it eats, where it lives, and when it is active); succession (the gradual change in community composition over time, from pioneer species to a stable climax community, e.g. bare rock to forest).

Fill in the blank: A ________ is all the populations of different species living together in the same area; together with the abiotic environment it forms an ecosystem; species diversity and ecological niches describe the organisation of a community.

Relationship	Effect on Partner A	Effect on Partner B	Nigerian Example
Mutualism	Benefits	Benefits	Rhizobium bacteria in root nodules of legumes (beans, groundnuts) – bacteria fix nitrogen, plants provide shelter and nutrients. Bees pollinating flowers in Nigerian farms – bees get nectar, plants achieve fertilization.
Commensalism	Benefits	Unaffected	Cattle egrets feeding on insects stirred up by cattle movement in Nigerian grazing fields – birds benefit, cattle unaffected. Skin bacteria feeding on dead skin cells without harming humans.
Parasitism	Benefits	Harmed	Malaria parasite (*Plasmodium*) in human red blood cells – parasite multiplies, human suffers fever and illness. Ticks on cattle in Nigerian farms – ticks feed on blood, cattle lose nutrients and may suffer disease. Tapeworms in intestines of humans/animals.

Box 2.1: Summary of symbiotic relationships with Nigerian examples

Pilot questions 2.4

1. Write a food chain with five links from a Nigerian ecosystem and label each trophic level.
2. Explain the difference between a food chain and a food web.
3. Distinguish between mutualism, commensalism, and parasitism with one example of each.
4. Define population and explain four factors that affect population size.
5. Explain what an ecological niche is and give one example.

Series Summary

This Series covered ecological adaptations in plants and animals. Adaptations are structural, physiological, or behavioural and arise through natural selection. Hydrophytes have aerenchyma, reduced cuticle, and surface stomata; xerophytes have thick cuticles, sunken stomata, reduced leaves, and water storage; mesophytes are adapted to moderate conditions; halophytes tolerate salt; epiphytes grow on hosts. Fish show streamlined bodies, fins, lateral lines, and gills; insects have a waterproof cuticle and tracheal system.

Reptiles have dry scaly skin and amniote eggs; birds and mammals are endothermic. Camels conserve water through multiple physiological and behavioural mechanisms; polar bears use blubber and fur. Ecologically, energy flows through food chains (10% efficiency at each level) and food webs; symbiotic relationships are mutualistic, commensal, or parasitic. Populations are regulated by biotic and abiotic factors, and communities progress through succession to a climax. By completing this Series, you should achieve all seven SLOs (2.1 to 2.7).

Glossary of Terms

- **Aerenchyma:** air-filled tissue in the stems, petioles, and leaves of hydrophytes that provides buoyancy and channels oxygen to submerged parts.
- **Amniote egg:** an egg with internal membranes (amnion, chorion, allantois) and a leathery or hard shell, allowing reproduction on land without water; characteristic of reptiles, birds, and monotreme mammals.
- **Behavioural adaptation:** an action or activity that increases an organism's survival or reproductive success; examples include migration, hibernation, and nocturnal activity.
- **CAM photosynthesis:** Crassulacean Acid Metabolism; a photosynthetic pathway in which stomata open only at night to absorb CO2, minimising water loss; common in succulents and many xerophytes.
- **Carrying capacity (K):** the maximum population size that a given environment can sustain indefinitely; sets the upper limit of logistic population growth.

- **Commensalism:** a symbiotic relationship in which one organism benefits and the other is neither harmed nor benefited; e.g. epiphytic orchids on forest trees.
- **Community:** all the populations of different species living together in the same area at the same time.
- **Convergent evolution:** the independent evolution of similar traits in unrelated organisms living in similar environments; e.g. streamlined body shapes in fish, dolphins, and ichthyosaurs.
- **Decomposer:** an organism (bacteria or fungi) that breaks down dead organic matter, releasing mineral nutrients back into the soil or water.
- **Ecological niche:** the functional role of an organism in its community, including its food sources, habitat, activity time, and interactions with other species.
- **Ecosystem:** a community of organisms and their abiotic environment, interacting as a functional system; includes biotic and abiotic components.
- **Epiphyte:** a plant that grows on another plant for physical support without being parasitic; absorbs water and nutrients from rain and organic debris.
- **Food chain:** a linear sequence showing the transfer of energy from producer to successive consumers; arrows indicate the direction of energy flow.
- **Food web:** a network of interconnected food chains in an ecosystem; more accurately represents the complexity of feeding relationships than a single food chain.
- **Halophyte:** a plant adapted to grow in saline habitats; tolerates high salt concentrations through salt glands, succulence, and waxy cuticles.
- **Hydrophyte:** a plant adapted to live in water or permanently waterlogged soil; has aerenchyma, thin cuticle, and stomata on the upper leaf surface.
- **Lateral line:** a sense organ in fish and some amphibians that detects vibrations and pressure changes in the surrounding water.
- **Mesophyte:** a plant adapted to habitats with moderate water availability; includes most agricultural plants and rainforest understorey species.
- **Mutualism:** a symbiotic relationship in which both species benefit; e.g. Rhizobium bacteria in legume root nodules.

- **Natural selection:** the process by which organisms with heritable traits that improve survival and reproduction leave more offspring, causing those traits to become more common over generations.
- **Parasitism:** a symbiotic relationship in which the parasite benefits at the expense of the host, which is harmed but rarely killed immediately.
- **Pneumatophore:** a specialised aerial root in mangrove trees that projects above waterlogged anaerobic soil to obtain oxygen for respiration.
- **Population:** a group of individuals of the same species living in the same area at the same time; size affected by birth, death, immigration, and emigration.
- **Structural adaptation:** a physical feature of an organism's body that improves survival in its environment; e.g. streamlined body of fish, waxy cuticle of xerophytes.
- **Succession:** the gradual, directional change in the species composition of a community over time; proceeds from pioneer species to a stable climax community.
- **Swim bladder:** a gas-filled organ in most bony fish that controls buoyancy by adjusting the volume of gas within it.
- **Xerophyte:** a plant adapted to survive in habitats with very low water availability; has thick cuticles, sunken stomata, reduced leaves, and often stores water in succulent tissues.

Concept Check Questions [Series 2]

Objective Questions

1. An ecological adaptation is any heritable characteristic that increases an organism's ________ in its particular environment. (Linked to SLO 2.1)
2. Hydrophytes have large air spaces called ________ in their tissues that provide buoyancy and channel oxygen to submerged parts. (Linked to SLO 2.3)
3. Xerophytes reduce water loss through a thick waxy ________, sunken stomata, and leaves reduced to spines or scales. (Linked to SLO 2.3)
4. Fish detect water vibrations through the ________ line system and adjust buoyancy using a swim bladder. (Linked to SLO 2.4)
5. Energy transfer between trophic levels in a food chain is approximately ________ per cent efficient; the rest is lost as heat. (Linked to SLO 2.6)

Short-Answer Questions

1. Define adaptation and distinguish between structural, physiological, and behavioural adaptations. (Linked to SLO 2.1)
2. State four adaptive features of hydrophytes. (Linked to SLO 2.3)
3. State four adaptive features of xerophytes. (Linked to SLO 2.3)
4. State five adaptive features of fish for aquatic life. (Linked to SLO 2.4)
5. Distinguish between mutualism, commensalism, and parasitism. (Linked to SLO 2.7)

Long-Answer Questions

1. Define adaptation, describe the three types of adaptation, and explain the major ecological challenges of desert and mangrove habitats. (Linked to SLOs 2.1, 2.2)
2. Describe the adaptive features of hydrophytes, xerophytes, and halophytes; compare their adaptations. (Linked to SLO 2.3)
3. Describe the adaptations of aquatic and terrestrial animals; explain food chains, food webs, and symbiotic relationships. (Linked to SLOs 2.4, 2.5, 2.6, 2.7)

Answers to Concept Check Questions [Series 2]

Objective Questions

1. Fitness.
2. Aerenchyma.
3. Cuticle.
4. Lateral.
5. 10.

Short-Answer Questions

1. An adaptation is a heritable feature that increases fitness. Structural: physical body feature (e.g. streamlined fish body). Physiological: internal biochemical feature (e.g. camel concentrated urine). Behavioural: action improving survival (e.g. bird migration).
2. Aerenchyma for buoyancy and oxygen transport; thin or absent cuticle (water loss not a problem); stomata on the upper leaf surface of floating leaves; reduced or absent xylem; roots reduced or absent in some free-floating species.
3. Thick waxy cuticle; sunken or night-opening stomata; leaves reduced to spines or scales; succulent tissues for water storage; deep taproot or extensive shallow root network.
4. Streamlined fusiform body; overlapping scales; fins for propulsion and steering; lateral line for detecting water vibrations; gills for extracting dissolved oxygen; swim bladder for buoyancy control.
5. Mutualism: both benefit (Rhizobium in legume root nodules). Commensalism: one benefits, other unaffected (epiphytic orchid on tree). Parasitism: parasite benefits, host harmed (Plasmodium in human blood).

Long-Answer Questions

1. Adaptation: heritable characteristic increasing fitness through natural selection. Types: structural (physical body features; e.g. waxy cuticle of desert plants); physiological (biochemical features; e.g. CAM photosynthesis, concentrated urine in camels); behavioural (survival actions; e.g. nocturnal activity, hibernation, migration). Desert challenges: very low rainfall; extreme heat and temperature fluctuation; water acquisition and conservation essential. Desert adaptations: succulent water storage; deep roots; reduced leaves; night

stomata. Mangrove challenges: salt stress; waterlogged anaerobic soil; tidal flooding. Mangrove adaptations: pneumatophores (aerial roots for gas exchange); salt-excreting glands; vivipary (seeds germinate on parent before dropping into mud).

2. Hydrophytes: live in water or waterlogged soil (Elodea, water lily, bulrush, duckweed); aerenchyma for buoyancy; thin cuticle; stomata on upper surface of floating leaves; reduced xylem; roots reduced or absent. Xerophytes: live in dry habitats (cactus, baobab, Acacia); thick waxy cuticle; sunken or night-opening stomata (CAM); leaves reduced to spines; succulent water-storing tissues; deep taproot. Halophytes: live in saline habitats (mangrove, salt marsh); salt glands; succulent leaves to dilute salt; waxy cuticle; pneumatophores. Comparison: hydrophytes reduce or eliminate water conservation structures; xerophytes maximise every possible water-saving mechanism; halophytes must manage both water and salt stress simultaneously.
3. Aquatic adaptations: fish have streamlined body, scales, fins, lateral line, gills, swim bladder; aquatic insects trap air bubbles; whales and dolphins have streamlined body, flippers, no hind limbs, and blubber for insulation. Terrestrial adaptations: insects have chitin cuticle, tracheal system, jointed legs; reptiles have dry scaly skin, amniote egg, ectothermic; birds have feathers, hollow bones, four-chambered heart, endothermic; mammals have fur or blubber, endothermic, efficient lungs. Camel extreme environment: fat-storing hump; concentrated urine; variable body temperature; drinks large volumes when available. Food chain: Grass → Grasshopper → Frog → Snake → Eagle; energy loss approximately 90% at each link so 10% transferred. Food web: network of interconnected food chains; decomposers return minerals to soil; energy flows one way, matter cycles. Symbiosis: mutualism (Rhizobium and legume); commensalism (orchid on tree); parasitism (Plasmodium in human red blood cells).

Answers to Pilot Questions [Series 2]

Part 2.1

1. An ecological adaptation is any heritable characteristic that increases an organism's fitness in its particular environment. Adaptations arise through natural selection: individuals with beneficial traits survive and reproduce more successfully, passing those traits to offspring over many generations until the trait becomes common in the population.

2. Structural: physical body feature; e.g. thick waxy cuticle on desert plant leaves reduces water loss. Physiological: internal biochemical or metabolic feature; e.g. camels produce very concentrated urine to conserve water. Behavioural: an action or activity improving survival; e.g. nocturnal activity in desert animals avoids daytime heat.
3. Very low and unpredictable rainfall; extreme daytime heat (up to 50 degrees Celsius) and cold nights; high rate of evaporation; nutrient-poor sandy or rocky soils; strong desiccating winds.
4. Mangrove trees grow in waterlogged anaerobic (oxygen-poor) soil where the roots cannot obtain oxygen by diffusion from the soil. Pneumatophores are specialised aerial roots that project upward above the waterlogged mud surface into the air, allowing gas exchange (oxygen absorption and CO2 release) for root respiration.
5. Mangrove and coastal zone; rainforest; guinea savanna; Sudan/Sahel savanna (and derived savanna as an intermediate zone).

Part 2.2

1. Hydrophytes are plants adapted to live in water or permanently waterlogged soil. Four adaptive features: (1) aerenchyma (air-filled tissue providing buoyancy and oxygen supply to submerged roots); (2) thin or absent cuticle (water loss not a problem in aquatic habitats); (3) stomata on the upper surface of floating leaves (to access atmospheric air); (4) reduced or absent xylem (water absorbed directly through all surfaces).
2. Drought avoidance: completing the life cycle during the brief wet season as ephemeral annuals (seeds survive the dry period). Drought endurance: storing water in succulent tissues (e.g. cactus swollen stems) for use during drought. Drought resistance: structural and physiological features that minimise water loss throughout the year (thick cuticle, sunken stomata, reduced leaves, deep roots).
3. Thick waxy cuticle on leaf surfaces; sunken stomata (stomata located in pits below the leaf surface to reduce air movement over them) or stomata that open only at night (CAM); leaves reduced to spines or scales to minimise the surface area for transpiration; swollen stems or leaves for water storage; deep taproot reaching underground water or extensive shallow roots capturing surface rainfall.
4. Halophytes grow in saline habitats (coastal salt marshes, mangroves) and tolerate high salt concentrations through salt glands, succulent leaves, and waxy cuticles; they actively manage excess salt. Epiphytes grow on other plants for physical support in habitats such as rainforest

canopies where competition for light is intense; they are not parasitic and obtain water and minerals from rain, dew, and organic debris on the host.

5. Crop plants (maize, cassava, tomato, yam, rice) grow in habitats with reliable rainfall or irrigation, moderate temperatures, and fertile soils; these are the conditions that mesophytes are adapted to. Mesophytes have broad flat leaves for maximum photosynthesis, a well-developed root system for water and mineral absorption, normal cuticle and stomata, and cannot tolerate prolonged drought, waterlogging, or high salt; exactly the conditions agricultural management attempts to maintain.

Part 2.3

1. Streamlined fusiform body shape to minimise water resistance; overlapping scales to reduce friction; paired and unpaired fins for propulsion, steering, and stability; lateral line system to detect water vibrations and pressure changes; gills to extract dissolved oxygen from water; swim bladder to control buoyancy without expending energy.
2. Insects have a waterproof chitin exoskeleton that prevents desiccation on land; a tracheal system delivers oxygen directly to tissues through a network of tubes opening at spiracles on the abdomen, avoiding the need for a moist respiratory surface; three pairs of jointed legs for walking; wings for flight and dispersal; compound eyes sensitive to movement for predator detection.
3. Reptiles: dry scaly skin (keratin) prevents water loss; amniote egg allows land reproduction; ectothermic (use sun to regulate temperature); cannot sustain prolonged high activity. Mammals: fur or subcutaneous fat for insulation; endothermic (internally generate heat); four-chambered heart for efficient oxygen delivery; viviparity (mostly); can sustain prolonged activity; adapted to wide range of climates including cold where ectotherms cannot survive.
4. Produces very concentrated urine to minimise water loss in urine; produces dry faeces with little water content; allows body temperature to vary by up to 6 degrees Celsius daily, reducing the need to sweat for cooling; can drink up to 200 litres at once to replenish water reserves rapidly when available.
5. Thick subcutaneous fat (blubber) provides thermal insulation against extreme cold; dense white fur traps warm air next to the skin and provides camouflage in snow; large body size reduces surface area to volume ratio, reducing heat loss relative to body mass; broad padded feet distribute weight on snow and ice; excellent swimmers for hunting seals in Arctic waters.

Part 2.4

1. Example: Grass (producer) → Locust (primary consumer/herbivore) → Agama lizard (secondary consumer/carnivore) → Cobra snake (tertiary consumer) → Martial eagle (quaternary consumer/top carnivore). Energy decreases at each link because approximately 90% is lost as heat at each trophic level.
2. A food chain is a single linear sequence showing energy transfer from one organism to the next: Producer → Herbivore → Carnivore. A food web is a network of interconnected food chains showing all the feeding relationships in an ecosystem; it is more realistic because most organisms eat multiple prey species and are eaten by multiple predators.
3. Mutualism: both benefit (Rhizobium bacteria fix nitrogen for the legume; the plant provides carbohydrates for the bacterium). Commensalism: one benefits, other is unaffected (epiphytic orchid uses tree for support without harming it). Parasitism: parasite benefits, host is harmed (Plasmodium falciparum causes malaria in the human host whose red blood cells are destroyed).
4. A population is a group of individuals of the same species in the same area at the same time. Four factors: (1) birth rate (natality; increases population); (2) death rate (mortality; decreases population); (3) immigration (individuals moving into the population; increases it); (4) emigration (individuals leaving; decreases it). Population also limited by carrying capacity set by food, water, space, and disease.
5. An ecological niche is the functional role of an organism in its community: what it eats, where it lives, when it is active, and how it interacts with other species. Example: the niche of the weaver bird includes nesting in tall grasses, feeding on seeds, being active during the day, serving as prey for raptors, and competing with other seed-eating birds for food resources.

References and Attributions [Series 2]

Textual References (Books and External Sources)

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Figures, Plates, Tables, and Boxes

- Figure 2.1: Nigeria's major ecological zones map and photographs Attribution: AI generated. Suggested OER search string: "Nigeria ecological zones map mangrove rainforest savanna Sahel vegetation OER".
- Figure 2.2: Hydrophyte types and aerenchyma cross-section Attribution: AI generated. Suggested OER search string: "hydrophyte types water lily bulrush duckweed aerenchyma adaptation aquatic plant OER photograph".
- Figure 2.3: Xerophyte adaptations photographs Attribution: AI generated. Suggested OER search string: "xerophyte adaptations cactus baobab sunken stomata rolled leaf marram grass OER photograph".
- Figure 2.4: Mesophyte, halophyte, and epiphyte photographs Attribution: AI generated. Suggested OER search string: "mesophyte halophyte epiphyte mangrove pneumatophore orchid aerial roots Nigeria OER photograph".
- Figure 2.5: Fish aquatic adaptations labelled diagram Attribution: AI generated. Suggested OER search string: "fish aquatic adaptations labelled diagram streamlined body fins lateral line gills swim bladder OER".
- Figure 2.6: Terrestrial animal adaptations comparison photographs Attribution: AI generated. Suggested OER search string: "terrestrial animal adaptations lizard scaly skin bird feathers mammal fur insect spiracle OER photograph".

- Figure 2.7: Nigerian savanna food web diagram Attribution: AI generated. Suggested OER search string: "food web Nigerian savanna ecosystem producers consumers decomposers energy flow OER diagram".
- Box 2.1: Symbiotic relationships comparison table Attribution: AI generated. Suggested OER search string: "symbiotic relationships mutualism commensalism parasitism Nigerian examples table OER box".

Course code: BIO 102

Course title: General Biology II

Course credit load: 2 Units

Series 3: Physiology of Plants and Animals

- **Part 3.1: Transport in Plants**
  - Sub Part 3.1.1: Water and mineral uptake by roots
  - Sub Part 3.1.2: Transpiration and stomatal control
  - Sub Part 3.1.3: Translocation of organic solutes
- **Part 3.2: Photosynthesis**
  - Sub Part 3.2.1: Overview and site of photosynthesis
  - Sub Part 3.2.2: The light-dependent reactions
  - Sub Part 3.2.3: The light-independent reactions (Calvin cycle)
- **Part 3.3: Circulatory Systems in Animals**
  - Sub Part 3.3.1: Open and closed circulatory systems
  - Sub Part 3.3.2: The human heart and double circulation
  - Sub Part 3.3.3: Blood composition and functions
- **Part 3.4: Nervous and Hormonal Coordination**
  - Sub Part 3.4.1: The nervous system in animals
  - Sub Part 3.4.2: Plant hormones and tropisms
  - Sub Part 3.4.3: Homeostasis

Introduction

Physiology is the study of how living organisms function at the cellular, tissue, organ, and whole-body level. Plants and animals have evolved fundamentally different physiological systems to carry out the same basic life processes: obtaining and distributing nutrients, producing energy, coordinating responses, and maintaining internal stability.

This Series covers transport in plants (water uptake, transpiration, and translocation), photosynthesis (light-dependent and light-independent reactions), circulatory systems in animals (open and closed, the human heart, and blood), and nervous and hormonal coordination in animals and plants, including homeostasis.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 3.1** describe how water and minerals are absorbed by roots and transported upward through the xylem (Linked to Part 3.1),
- **SLO 3.2** explain transpiration and describe how stomata control water loss (Linked to Part 3.1),
- **SLO 3.3** explain translocation of organic solutes in the phloem (Linked to Part 3.1),
- **SLO 3.4** describe the site and overview of photosynthesis and explain the light-dependent and light-independent reactions (Linked to Part 3.2),
- **SLO 3.5** distinguish between open and closed circulatory systems and describe the human heart and double circulation (Linked to Part 3.3),
- **SLO 3.6** describe the composition and functions of blood (Linked to Part 3.3),
- **SLO 3.7** describe the structure of the nervous system, explain plant hormones and tropisms, and define homeostasis (Linked to Part 3.4).

3.1 Transport in Plants

3.1.1 Water and mineral uptake by roots

Water enters the plant through root hair cells by osmosis. Root hair cells have a large surface area, thin cell walls, and a cell sap more concentrated than the surrounding soil water. Water moves from the soil into root hair cells (high water potential to low), then crosses the cortex by two pathways: the apoplast pathway (through cell walls, bypassing the cytoplasm) and the symplast pathway (through cytoplasm via plasmodesmata). At the endodermis, the Casparian strip forces all water through the symplast.

Mineral salts (nitrates, phosphates, potassium ions) enter root hair cells by active transport against a concentration gradient, using ATP. Once inside the xylem vessels at the stele, water is pulled upward through the stem by the transpiration pull (cohesion-tension mechanism): water evaporating from leaves at the top creates a tension that pulls the continuous water column upward through the narrow xylem vessels; cohesion between water molecules maintains the column.

Fill in the blank: Water moves from the soil into root hair cells by ________; mineral salts enter by active transport; both are then transported upward through the xylem by the cohesion-tension mechanism.

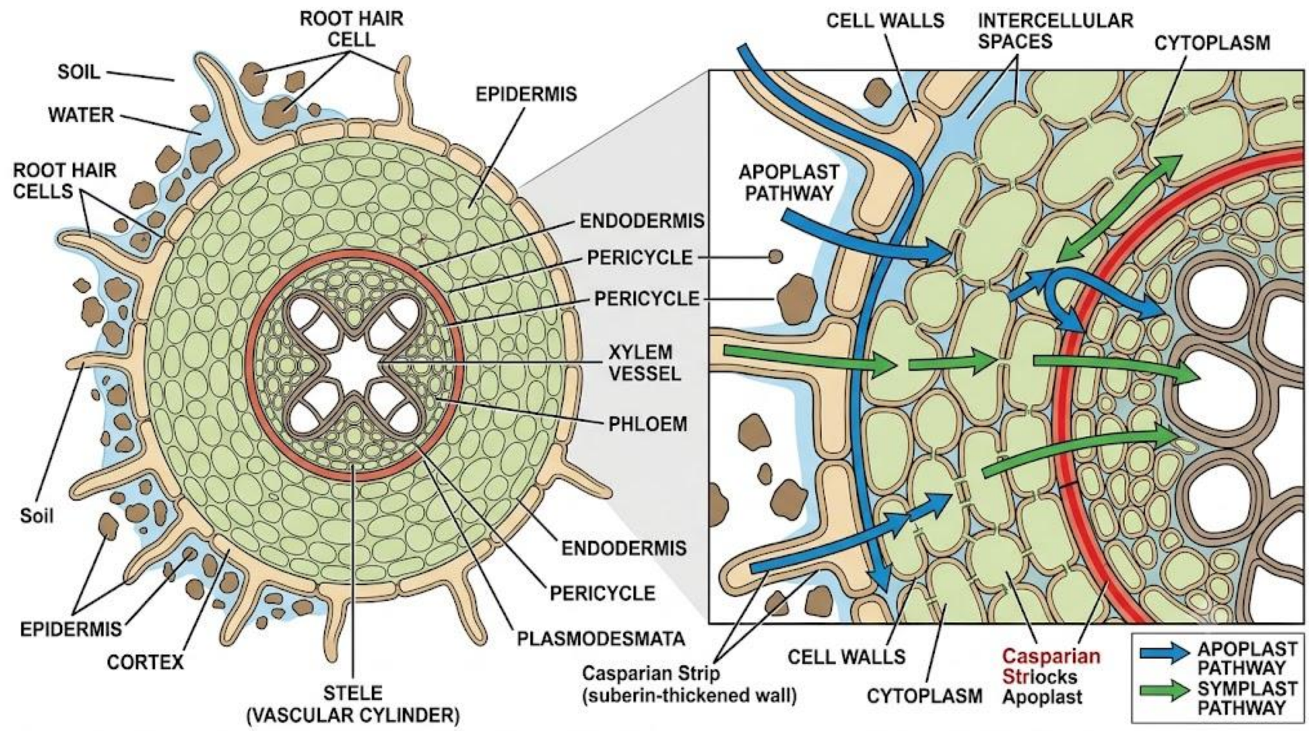

Figure 3.1: Diagram of water uptake by root hair cells and the apoplast and symplast pathways

3.1.2 Transpiration and stomatal control

Transpiration is the loss of water vapour from the aerial parts of a plant, mainly through stomata on the leaf surface. It is driven by the difference in water vapour concentration between the saturated air spaces inside the leaf and the drier outside air. Transpiration is essential: it drives the transpiration stream that carries water and minerals from roots to leaves, and it cools the leaf surface. However, excessive transpiration causes wilting.

Stomata are pores in the leaf epidermis, each surrounded by two guard cells. When guard cells absorb water and become turgid, they bow outward and the stoma opens. When they lose water and become flaccid, the stoma closes. Stomata open in light (when photosynthesis demands CO2) and close in darkness. Factors increasing transpiration rate: high temperature; low humidity; high light intensity; wind; large leaf area. Xerophytes reduce transpiration by sunken stomata, rolled leaves, and thick cuticles.

Fill in the blank: Stomata open when guard cells become ________ (swollen with water) and close when guard cells become flaccid (lose water); they open in light to allow CO_2 entry for photosynthesis.

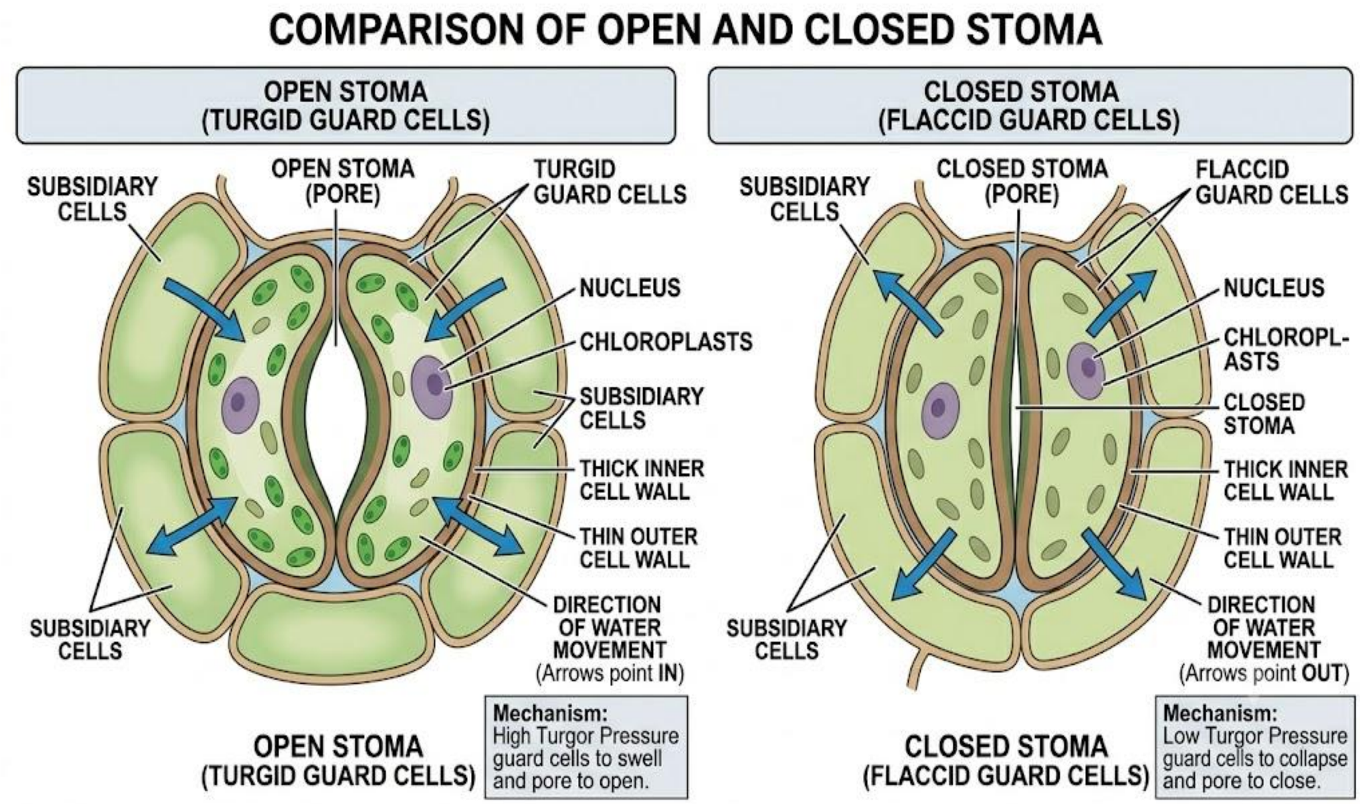

Figure 3.2: Diagram of a stoma showing open and closed states and guard cell mechanism

3.1.3 Translocation of organic solutes

Translocation is the transport of organic solutes (mainly sucrose produced by photosynthesis) from leaves (sources) to all other parts of the plant (sinks: roots, fruits, seeds, growing tips) through the phloem. Unlike xylem (which transports upward only), phloem can transport in both directions simultaneously. The pressure-flow hypothesis explains translocation: sucrose is actively loaded into phloem sieve tubes at source leaves, raising osmotic pressure; water enters by osmosis, creating a high-pressure region.

The high pressure at the source pushes the sucrose solution along the phloem to sink regions where sucrose is unloaded (used or stored), lowering the osmotic pressure and allowing water to leave. This creates a pressure gradient that drives continuous flow from source to sink. Sieve tube elements are the main conducting cells of the phloem; they are living cells with perforated end walls (sieve plates) and are assisted by companion cells that provide ATP for active loading of sucrose.

Fill in the blank: In the pressure-flow hypothesis of translocation, sucrose is actively loaded into phloem sieve tubes at ________ (leaves), creating high osmotic pressure; it is unloaded at sinks (roots, fruits), driving flow from source to sink.

Pilot questions 3.1

1. Explain how water moves from the soil into the xylem of the root.
2. What is the Casparian strip and why is it important?
3. Define transpiration and state three factors that increase the transpiration rate.
4. Explain how guard cells control the opening and closing of stomata.
5. Distinguish between xylem and phloem transport.

3.2 Photosynthesis

3.2.1 Overview and site of photosynthesis

Photosynthesis is the process by which green plants, algae, and some bacteria use light energy to convert carbon dioxide and water into glucose and oxygen. The overall equation is: $6CO_2$ + $6H_2O$ + light energy → $C_6H_{12}O_6$ + $6O_2$. Photosynthesis occurs in chloroplasts, which contain the pigment chlorophyll. Chlorophyll absorbs red and blue light most efficiently and reflects green light (hence the green colour of leaves).

Chloroplast structure: the outer and inner membranes enclose a fluid-filled stroma; within the stroma are stacks of membrane discs called thylakoids; each stack is called a granum. Chlorophyll and other pigments are embedded in the thylakoid membranes. The light-dependent reactions occur on the thylakoid membranes; the light-independent reactions (Calvin cycle) occur in the stroma. Leaves are the main organs of photosynthesis: broad flat lamina, thin (short diffusion distances), and abundant stomata for gas exchange.

Fill in the blank: Photosynthesis occurs in ________; the light-dependent reactions take place on the thylakoid membranes while the light-independent reactions (Calvin cycle) occur in the stroma.

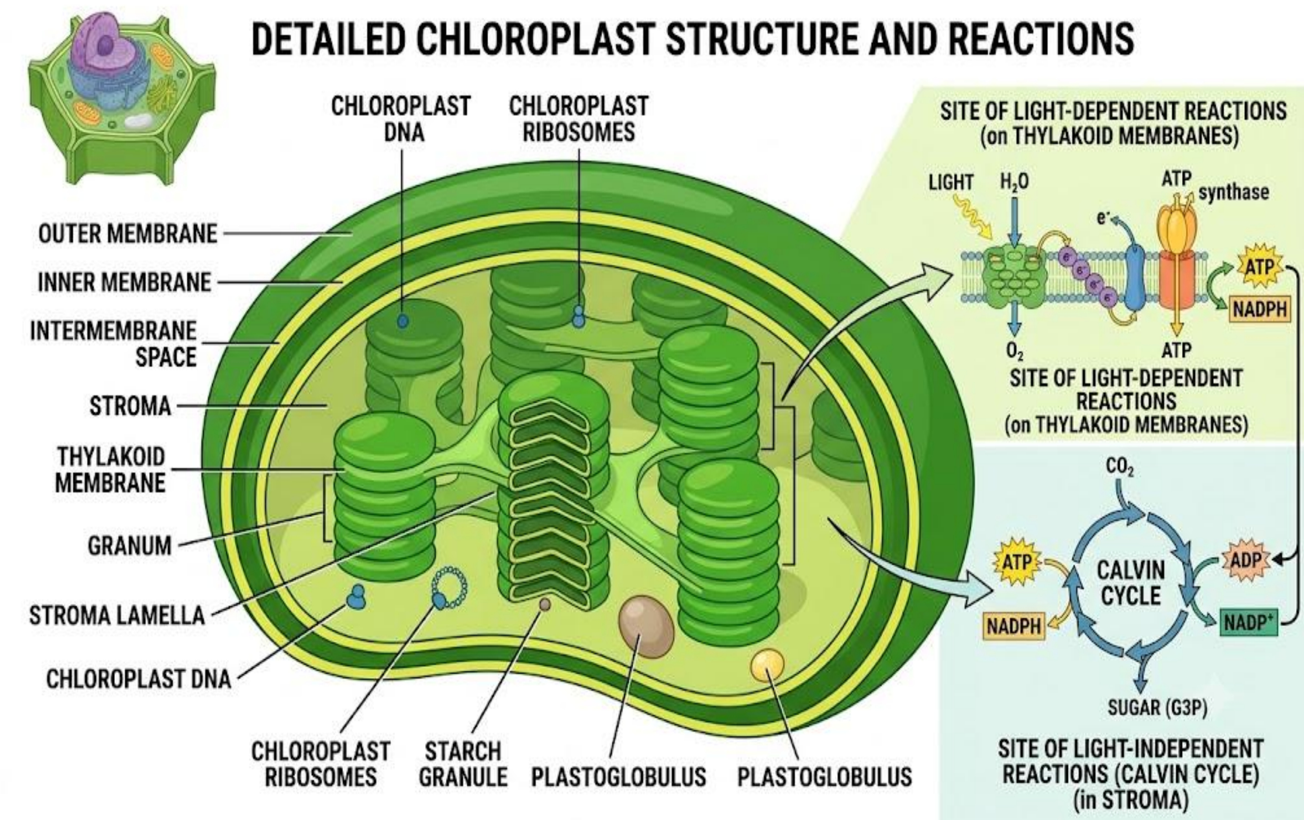

Figure 3.3: Diagram of chloroplast structure showing thylakoids, grana, and stroma

3.2.2 The light-dependent reactions

The light-dependent reactions occur in the thylakoid membranes and require direct light. Light energy is absorbed by chlorophyll in Photosystem II (PSII) and Photosystem I (PSI). In PSII, light energy splits water molecules (photolysis): 2H2O → 4H+ + 4e- + O2. The oxygen is released as a by-product. The electrons released pass along the electron transport chain in the thylakoid membrane, releasing energy used to pump hydrogen ions (H+) across the thylakoid membrane.

The flow of H^+ ions back through ATP synthase drives the synthesis of ATP from ADP and inorganic phosphate (photophosphorylation). Electrons then enter PSI where they are re-energised by another photon of light and used to reduce $NADP^+$ to NADPH. The products of the light-dependent reactions are: ATP, NADPH, and O_2. ATP and NADPH pass to the stroma for use in the Calvin cycle. O_2 diffuses out through stomata.

Fill in the blank: In the light-dependent reactions, water is split by ________ in Photosystem II, releasing oxygen; the electrons drive ATP synthesis and $NADP^+$ reduction, producing ATP, NADPH, and O_2.

3.2.3 The light-independent reactions (Calvin cycle)

The Calvin cycle occurs in the stroma of the chloroplast and does not directly require light but uses ATP and NADPH from the light-dependent reactions. Carbon dioxide from the air is fixed (combined) with a 5-carbon compound called ribulose bisphosphate (RuBP) by the enzyme RuBisCO, forming two molecules of a 3-carbon compound (glycerate-3-phosphate, G3P). G3P is reduced using ATP and NADPH to form glyceraldehyde-3-phosphate (G3P or GALP).

Some GALP molecules are used to synthesise glucose, starch, amino acids, and fatty acids. The majority are used to regenerate RuBP using ATP, so the cycle can continue. For every three CO_2 molecules fixed, one net molecule of GALP is produced (which can form half a glucose). The Calvin cycle requires 3 ATP and 2 NADPH per CO_2 fixed. Overall, photosynthesis converts light energy into chemical energy stored in organic molecules.

Fill in the blank: In the Calvin cycle, CO_2 is fixed by combining with ________ (RuBP) using the enzyme RuBisCO; the resulting 3-carbon compound is reduced using ATP and NADPH to eventually produce glucose.

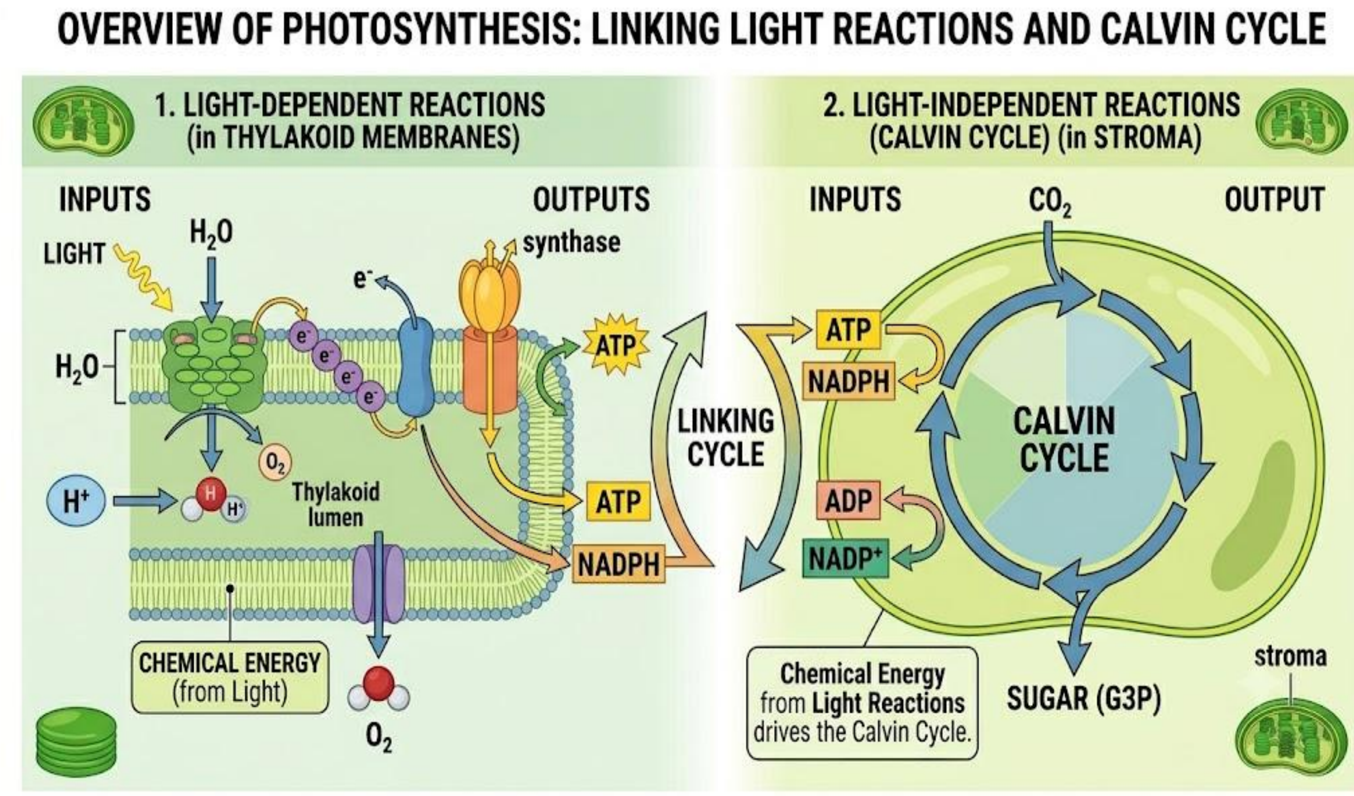

Figure 3.4: Summary diagram of photosynthesis showing light-dependent and Calvin cycle reactions

Pilot questions 3.2

1. Write the overall equation for photosynthesis and name the reactants and products.
2. State the site of the light-dependent reactions and name three products.
3. Explain what photolysis is and state why it is important.
4. Describe what happens in the Calvin cycle.
5. Explain the role of RuBisCO in photosynthesis.

3.3 Circulatory Systems in Animals

3.3.1 Open and closed circulatory systems

In an open circulatory system (found in insects, molluscs), blood (called haemolymph) is not always enclosed in vessels. The heart pumps haemolymph into a body cavity (haemocoel) where it bathes the organs directly; it returns to the heart through openings called ostia. Exchange of materials occurs by direct bathing of tissues. Open systems are less efficient for delivering oxygen to active tissues but are adequate for animals with a tracheal system (insects) or small body size.

In a closed circulatory system (found in annelids, vertebrates), blood is always enclosed in blood vessels (arteries, veins, capillaries) and pumped by a heart. Exchange of materials occurs across the thin walls of capillaries. Closed systems are more efficient: blood can be pumped at higher pressure, oxygen delivery can be precisely controlled, and blood moves faster. Vertebrates all have closed circulatory systems; fish have single circulation (one loop); amphibians, reptiles, birds, and mammals have double circulation (two loops).

Fill in the blank: In an ________ circulatory system, blood is enclosed in vessels at all times; exchange occurs across capillary walls; this is more efficient than an open system at delivering oxygen to active tissues.

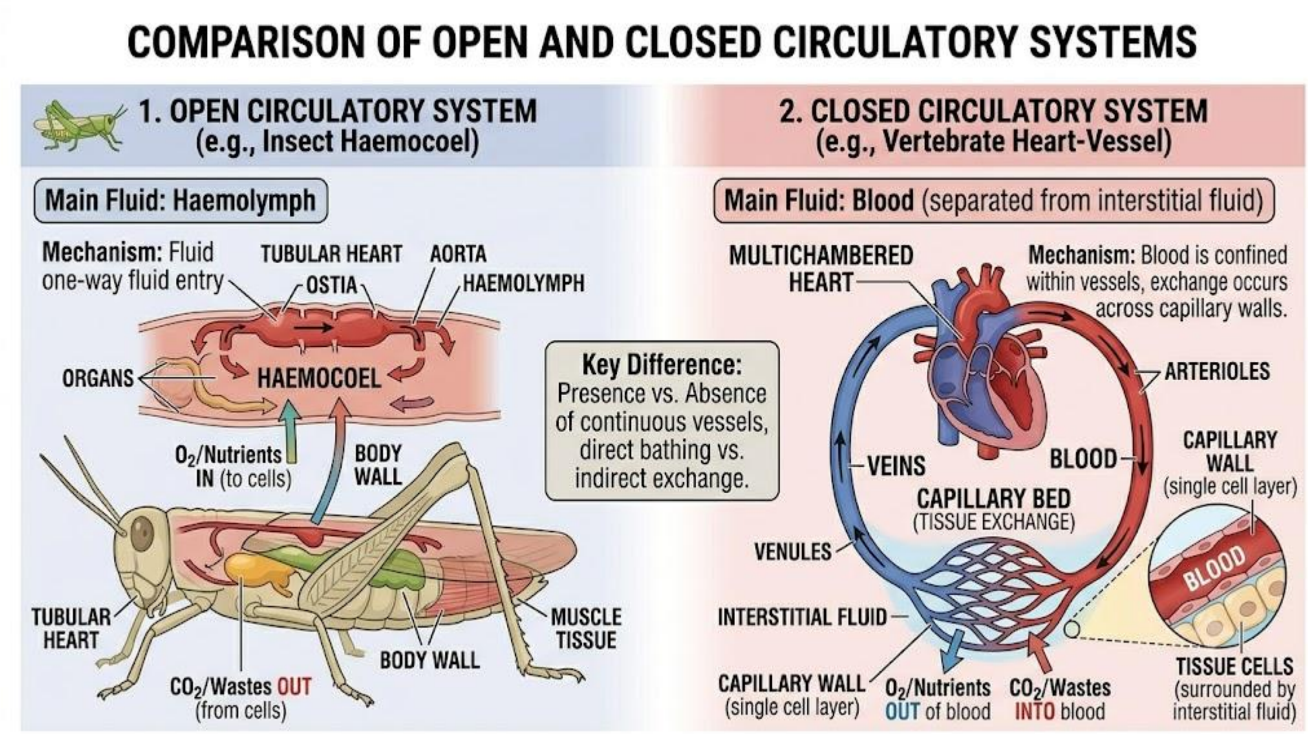

Figure 3.5: Diagram comparing open and closed circulatory systems

3.3.2 The human heart and double circulation

The human heart is a four-chambered muscular pump: two atria (upper; thin-walled; receive blood) and two ventricles (lower; thick-walled; pump blood out). The right side receives deoxygenated blood from the body (via vena cava) and pumps it to the lungs (pulmonary circulation). The left side receives oxygenated blood from the lungs (via pulmonary veins) and pumps it to the body (systemic circulation). This is double circulation: two separate loops.

Valves prevent backflow: the atrioventricular (mitral and tricuspid) valves prevent backflow from ventricles to atria; the semilunar valves prevent backflow from arteries to ventricles. The heart's own contraction is initiated by the sinoatrial node (SA node or pacemaker) in the right atrium, spreads to the atrioventricular node (AV node), and then down the Bundle of His and Purkinje fibres to the ventricle walls. The sequence generates a rhythmic heartbeat of approximately 70 beats per minute at rest.

Fill in the blank: The ________ node (SA node) in the right atrium initiates each heartbeat; it is called the pacemaker because it sets the rhythm of cardiac contraction at approximately 70 beats per minute at rest.

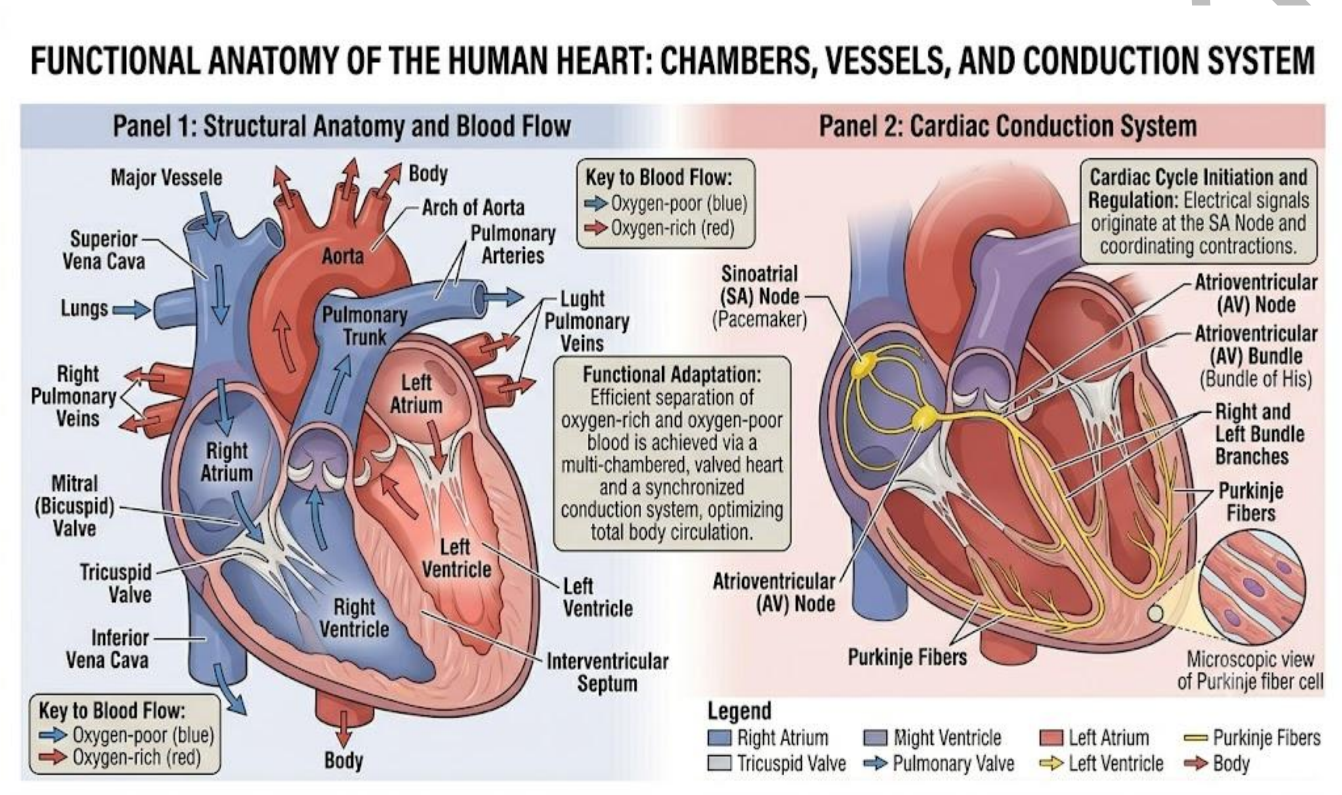

Figure 3.6: Labelled diagram of the human heart showing chambers, valves, and blood flow

3.3.3 Blood composition and functions

Blood consists of plasma (55% by volume; liquid matrix; 90% water; contains dissolved proteins, glucose, amino acids, hormones, CO_2, urea, and mineral ions) and cellular components (45% by volume). Red blood cells (erythrocytes): biconcave, no nucleus, contain haemoglobin which binds oxygen reversibly (forms oxyhaemoglobin in the lungs); carry oxygen from lungs to tissues; CO_2 is carried mainly as bicarbonate ions in the plasma.

White blood cells (leucocytes): nucleated; fewer than red cells; defend the body against disease; types include neutrophils (engulf bacteria by phagocytosis), lymphocytes (produce antibodies; involved in specific immunity), and monocytes (become macrophages). Platelets (thrombocytes): cell fragments; involved in blood clotting. Functions of blood: transport of O_2, CO_2, nutrients, hormones, and waste products; defence (white blood cells, antibodies); clotting (platelets and clotting factors); temperature regulation; and pH buffering.

Fill in the blank: Red blood cells transport oxygen by reversibly binding it to ________; carbon dioxide is transported mainly as bicarbonate ions dissolved in the blood plasma.

Pilot questions 3.3

1. Distinguish between open and closed circulatory systems.
2. Describe the pathway of blood through the human heart in one complete circuit.
3. Explain what double circulation means and state its advantage.
4. State the composition of blood and the function of each component.
5. Explain how oxygen is transported in the blood.

3.4 Nervous and Hormonal Coordination

3.4.1 The nervous system in animals

The nervous system coordinates rapid responses to stimuli. The basic functional unit is the neurone (nerve cell). A motor neurone has: a cell body (containing the nucleus); dendrites (receive impulses from other neurones); an axon (conducts impulses away from the cell body); a myelin sheath (fatty insulation that speeds impulse conduction in vertebrates); and synaptic terminals (where the impulse is passed to the next cell via a chemical neurotransmitter at a synapse).

In vertebrates, the nervous system has two main divisions: the central nervous system (CNS: brain and spinal cord) and the peripheral nervous system (PNS: all nerves outside the CNS). A reflex arc is the simplest neural pathway: stimulus → receptor → sensory neurone → relay neurone (in spinal cord) → motor neurone → effector (muscle or gland) → response. Reflex actions are rapid and automatic, not requiring conscious thought. Examples: withdrawal of hand from a hot object; knee-jerk reflex.

Fill in the blank: A reflex arc involves: stimulus → receptor → sensory neurone → ________ neurone → motor neurone → effector → response; it produces a rapid automatic response that does not require conscious thought.

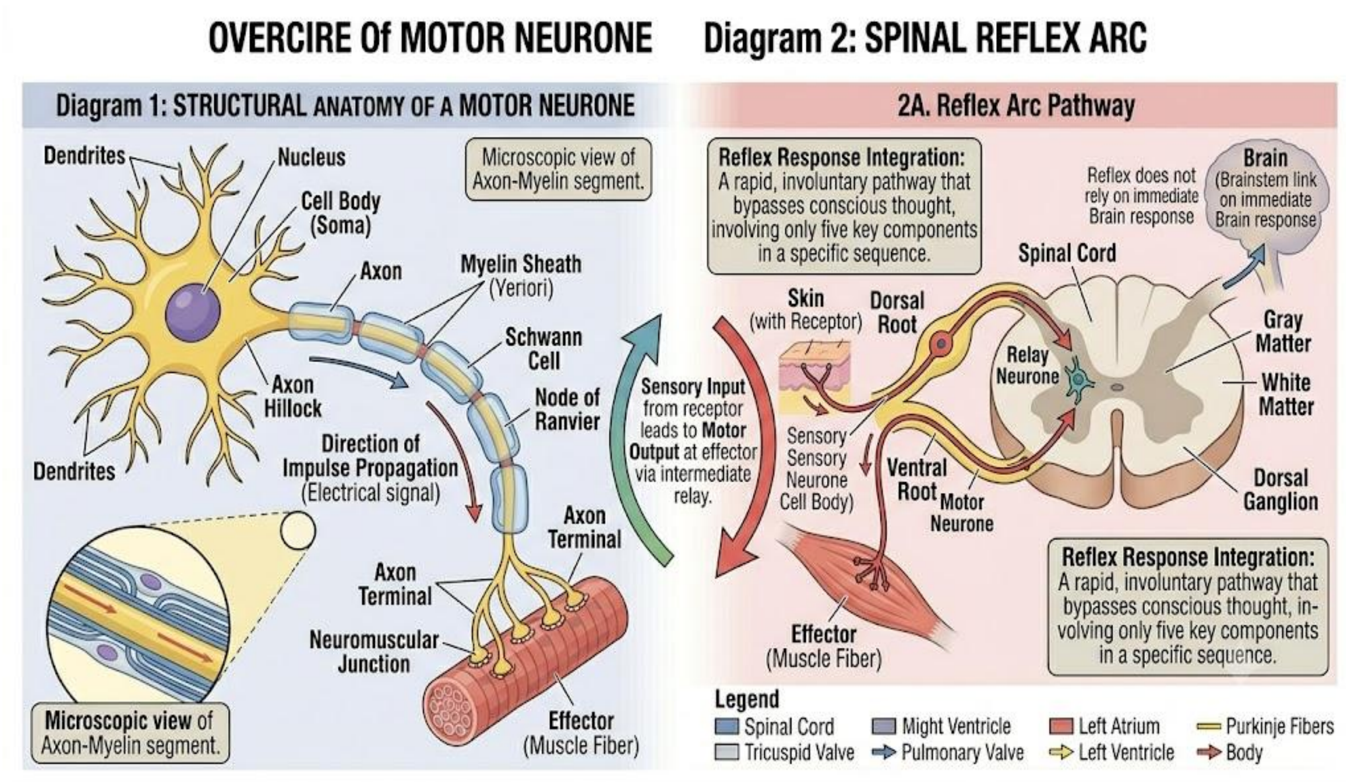

Figure 3.7: Diagram of a motor neurone and a spinal reflex arc

3.4.2 Plant hormones and tropisms

Plants lack a nervous system but coordinate responses using hormones (plant growth regulators). Auxins (principally indole-3-acetic acid, IAA) are produced in shoot tips and promote cell elongation on the shaded side, causing the shoot to bend toward light (phototropism). In roots, low concentrations of IAA promote growth; high concentrations inhibit it, causing roots to grow downward (gravitropism). Gibberellins promote stem elongation, seed germination, and breaking of dormancy.

Cytokinins promote cell division and delay leaf senescence. Abscisic acid (ABA) promotes stomatal closure during drought and maintains seed dormancy. Ethylene is a gaseous hormone that promotes fruit ripening and leaf abscission (leaf fall). A tropism is a directional growth response of a plant to a directional stimulus. Positive tropism: growth toward the stimulus (positive phototropism of shoots toward light). Negative tropism: growth away from the stimulus (negative phototropism of roots, growing away from light).

Fill in the blank: ________ (IAA) are plant hormones produced in shoot tips that promote cell elongation; they cause shoots to bend toward light (positive phototropism) and roots to grow downward (positive gravitropism).

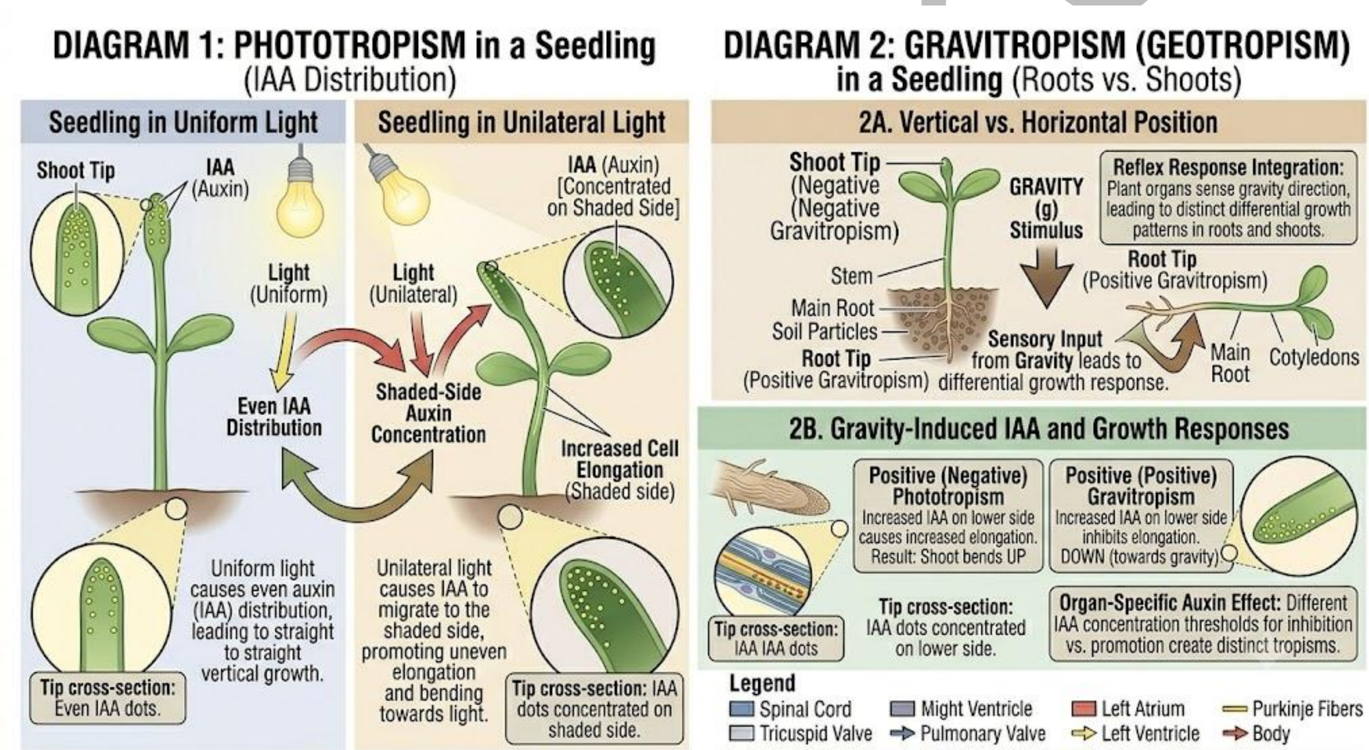

Figure 3.8: Diagram illustrating phototropism and gravitropism in plants

3.4.3 Homeostasis

Homeostasis is the maintenance of a constant internal environment despite changes in the external environment. It is essential for the efficient functioning of enzymes and cells. Key physiological variables maintained by homeostasis: body temperature (thermoregulation); blood glucose concentration; blood pH; blood water potential (osmoregulation); and CO2 concentration. Homeostasis operates through negative feedback: a deviation from the set point triggers a corrective response that returns the variable to normal.

Example: thermoregulation in humans. When body temperature rises above 37 degrees Celsius, the hypothalamus (the body's thermostat) triggers: vasodilation (widening of blood vessels near the skin to radiate heat); sweating (evaporation cools the skin); reduction in metabolic rate. When temperature falls, the hypothalamus triggers: vasoconstriction; shivering (muscular contractions generate heat); erection of body hair (traps insulating air in other mammals). Plants do not have homeostasis in the same sense; they regulate their internal environment mainly through stomatal control and osmotic adjustment.

Fill in the blank: Homeostasis maintains a constant internal environment through ________ feedback: a deviation from the set point triggers a response that corrects the deviation and returns the variable to normal.

High Body Temperature	Low Body Temperature
Sweating – sweat glands release fluid; evaporation cools the body.	**Shivering** – rapid muscle contractions generate heat.
Vasodilation – blood vessels widen, increasing blood flow to the skin for heat loss.	**Vasoconstriction** – blood vessels narrow, reducing blood flow to skin to conserve heat.
Reduced metabolic activity – lowers internal heat production.	**Increased metabolic activity** – boosts heat generation.
Behavioral responses – seeking shade, removing clothing.	**Behavioral responses** – wearing warm clothes, seeking shelter.

Box 3.1: Summary of homeostatic control of body temperature in humans

Pilot questions 3.4

1. Describe the structure of a motor neurone.
2. Describe a spinal reflex arc with a named example.
3. Explain how IAA (auxin) causes a shoot to bend toward light.

4. Name four plant hormones and state one function of each.
5. Define homeostasis and explain the role of negative feedback.

Series Summary

This Series covered plant and animal physiology. In plants, water enters by osmosis through root hairs and moves to the xylem via apoplast and symplast pathways; minerals enter by active transport; transpiration drives the water column upward by cohesion-tension; stomata open when guard cells are turgid. Translocation moves sucrose through phloem by pressure flow from source to sink. Photosynthesis: light-dependent reactions produce ATP, NADPH, and O_2 from water and light; the Calvin cycle fixes CO_2 into glucose using ATP and NADPH.

In animals, open circulatory systems bathe organs in haemolymph; closed systems use vessels and are more efficient. The human heart has four chambers, four valves, and a conduction system (SA node, AV node). Blood plasma, red blood cells (haemoglobin, O_2 transport), white blood cells (defence), and platelets (clotting) perform transport and defence functions. The nervous system coordinates rapid responses through neurones and reflex arcs. Plant hormones (IAA, gibberellins, cytokinins, ABA, ethylene) regulate growth; tropisms are directional growth responses. Homeostasis maintains a stable internal environment via negative feedback. By completing this Series, you should achieve all seven SLOs (3.1 to 3.7).

Glossary of Terms

- **Apoplast pathway:** the route by which water moves through plant cell walls and intercellular spaces, bypassing the cytoplasm.
- **ATP synthase:** an enzyme in the thylakoid membrane that synthesises ATP from ADP and inorganic phosphate using the energy of H^+ ions flowing down a concentration gradient.
- **Auxin (IAA):** indole-3-acetic acid; a plant hormone produced in shoot tips that promotes cell elongation; causes phototropism and gravitropism.
- **Calvin cycle:** the light-independent reactions of photosynthesis occurring in the stroma; CO_2 is fixed into G3P using ATP and NADPH from the light-dependent reactions.
- **Casparian strip:** a band of waxy suberin in the walls of endodermal cells that blocks the apoplast pathway, forcing all water to pass through the symplast before entering the xylem.

- **Closed circulatory system:** a system in which blood is always enclosed in blood vessels; found in annelids and all vertebrates; more efficient than an open system.
- **Cohesion-tension mechanism:** the process by which water is pulled upward through the xylem by tension created by transpiration at the leaf surface; sustained by cohesion between water molecules.
- **Double circulation:** a circulatory system with two separate loops: pulmonary circulation (heart to lungs and back) and systemic circulation (heart to body and back); found in birds and mammals.
- **Ethylene:** a gaseous plant hormone that promotes fruit ripening and leaf abscission; produced in large quantities by ripening fruit.
- **Gibberellin:** a plant hormone that promotes stem elongation, seed germination, and breaking of dormancy.
- **Guard cells:** specialised epidermal cells surrounding each stoma; control stomatal opening and closing by changes in turgor.
- **Haemoglobin:** the iron-containing protein in red blood cells that reversibly binds oxygen forming oxyhaemoglobin; enables efficient oxygen transport.
- **Haemolymph:** the blood-like fluid in animals with open circulatory systems; bathes the organs directly in the haemocoel.
- **Homeostasis:** the maintenance of a constant internal environment despite changes in the external environment; operates through negative feedback.
- **Myelin sheath:** a fatty insulating layer around the axon of some neurones; speeds up impulse conduction by saltatory conduction between nodes of Ranvier.
- **Negative feedback:** a control mechanism in which a deviation from a set point triggers a corrective response that returns the variable to normal.
- **Neurone:** the basic structural and functional unit of the nervous system; a specialised cell that transmits electrical impulses.
- **Osmosis:** the movement of water molecules through a selectively permeable membrane from a region of higher water potential to a region of lower water potential.

- **Phloem:** the vascular tissue that transports organic solutes (mainly sucrose) from source leaves to sink organs through sieve tube elements and companion cells.
- **Photolysis:** the splitting of water molecules using light energy in Photosystem II; releases oxygen as a by-product and provides electrons and protons for the electron transport chain.
- **Photosynthesis:** the process by which plants use light energy, water, and CO2 to produce glucose and oxygen; occurs in chloroplasts.
- **RuBisCO:** ribulose bisphosphate carboxylase/oxygenase; the enzyme that catalyses CO2 fixation in the Calvin cycle.
- **SA node (sinoatrial node):** the pacemaker of the heart; generates the electrical impulse that initiates each heartbeat; located in the wall of the right atrium.
- **Stomata:** pores in the leaf epidermis through which gas exchange (CO2 and O2) and transpiration (water vapour) occur; each stoma is flanked by two guard cells.
- **Symplast pathway:** the route by which water moves through the cytoplasm of plant cells via plasmodesmata.
- **Transpiration:** the loss of water vapour from plant surfaces, primarily through stomata; drives the transpiration stream that carries water and minerals from roots to leaves.
- **Translocation:** the transport of organic solutes (mainly sucrose) through the phloem from source (leaves) to sink (roots, fruits, growing tips) organs.
- **Tropism:** a directional growth response of a plant to a directional stimulus; positive if growth is toward the stimulus, negative if away.
- **Xylem:** the vascular tissue that transports water and mineral salts upward from roots to leaves through dead, hollow, lignified vessels.

Concept Check Questions [Series 3]

Objective Questions

1. Water moves from soil into root hair cells by ________; mineral salts enter by active transport. (Linked to SLO 3.1)
2. Stomata open when guard cells become ________ (turgid with water) and close when they become flaccid. (Linked to SLO 3.2)
3. The light-dependent reactions of photosynthesis occur on the ________ membranes; the Calvin cycle occurs in the stroma. (Linked to SLO 3.4)
4. The ________ node (SA node) in the right atrium is the pacemaker of the human heart. (Linked to SLO 3.5)
5. Homeostasis maintains a stable internal environment through ________ feedback: deviations trigger corrective responses. (Linked to SLO 3.7)

Short-Answer Questions

1. Explain the cohesion-tension mechanism of water transport in xylem. (Linked to SLO 3.1)
2. State three products of the light-dependent reactions and state where each goes next. (Linked to SLO 3.4)
3. Distinguish between open and closed circulatory systems. (Linked to SLO 3.5)
4. State the composition of blood and one function of each component. (Linked to SLO 3.6)
5. Name four plant hormones and state one function of each. (Linked to SLO 3.7)

Long-Answer Questions

1. Describe how water and minerals are absorbed and transported in plants, explain transpiration and stomatal control, and describe translocation. (Linked to SLOs 3.1, 3.2, 3.3)
2. Describe the site and reactions of photosynthesis, distinguishing between the light-dependent reactions and the Calvin cycle. (Linked to SLO 3.4)
3. Describe open and closed circulatory systems, the human heart and double circulation, the composition and functions of blood, and explain the nervous system, plant hormones, and homeostasis. (Linked to SLOs 3.5, 3.6, 3.7)

Answers to Concept Check Questions [Series 3]

Objective Questions

1. Osmosis.
2. Turgid.
3. Thylakoid.
4. Sinoatrial.
5. Negative.

Short-Answer Questions

1. Transpiration at the leaf surface removes water from the xylem, creating tension; this tension pulls the continuous water column upward through the xylem; cohesion between water molecules maintains the unbroken column from roots to leaves.
2. ATP (passes to the stroma for the Calvin cycle); NADPH (passes to the stroma for the Calvin cycle); O_2 (diffuses out through stomata as a waste product of photolysis).
3. Open system: blood (haemolymph) leaves vessels and bathes organs directly; found in insects; less efficient. Closed system: blood always enclosed in vessels; exchange across capillaries; found in vertebrates; more efficient at delivering O_2 to active tissues.
4. Plasma (liquid; transports dissolved nutrients, hormones, CO_2, urea); red blood cells (contain haemoglobin; transport O_2); white blood cells (defend against disease); platelets (involved in blood clotting).
5. Auxin/IAA (promotes cell elongation; phototropism); gibberellin (promotes stem elongation and seed germination); cytokinin (promotes cell division; delays leaf senescence); abscisic acid (promotes stomatal closure and seed dormancy).

Long-Answer Questions

1. Water uptake: water enters root hair cells by osmosis; moves across cortex by apoplast (cell walls) or symplast (cytoplasm/plasmodesmata); Casparian strip forces water through symplast at endodermis; enters xylem at stele. Minerals enter by active transport using ATP. Water transported upward by cohesion-tension: transpiration creates tension at leaves; cohesion between water molecules maintains the continuous column. Transpiration: loss of water vapour mainly through stomata; increases with temperature, wind, low humidity, high

light; essential for water transport but causes wilting if excessive. Stomata: open when guard cells are turgid (absorb water, bow outward); close when guard cells are flaccid (lose water); open in light (CO_2 needed for photosynthesis). Translocation: sucrose moves from source (leaves) to sinks (roots, fruits) through phloem by pressure flow; sucrose actively loaded at source raises osmotic pressure; water enters by osmosis creating high pressure; sucrose unloaded at sink lowers pressure; flow is from source to sink.

2. Photosynthesis overall equation: $6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$. Site: chloroplasts; thylakoid membranes for light-dependent; stroma for Calvin cycle. Light-dependent reactions: light absorbed by chlorophyll in PSII and PSI; photolysis splits water ($2H_2O \rightarrow 4H^+ + 4e^- + O_2$); electrons pass along electron transport chain; ATP synthesised by ATP synthase (photophosphorylation); PSI re-energises electrons to reduce $NADP^+$ to NADPH; products: ATP, NADPH, and O_2. Calvin cycle: CO_2 fixed by combining with RuBP (5-carbon) using RuBisCO; forms 3-carbon G3P; G3P reduced using ATP and NADPH from light-dependent reactions forming GALP; GALP used to synthesise glucose and other organic molecules, and to regenerate RuBP.
3. Circulatory systems: open (haemolymph bathes organs; found in insects; less efficient); closed (blood in vessels; capillary exchange; vertebrates; more efficient). Human heart: four chambers (right and left atria; right and left ventricles); right side pumps deoxygenated blood to lungs (pulmonary circulation); left side pumps oxygenated blood to body (systemic circulation); double circulation. Valves prevent backflow: atrioventricular and semilunar. SA node (pacemaker) initiates each beat; AV node, Bundle of His, and Purkinje fibres conduct impulse to ventricles. Blood: plasma (water, dissolved nutrients, hormones, waste); red blood cells (haemoglobin; O_2 transport); white blood cells (phagocytosis, antibody production; defence); platelets (clotting). Nervous system: neurone (dendrites, cell body, axon, myelin sheath, synaptic terminals); CNS and PNS; reflex arc (stimulus, receptor, sensory neurone, relay neurone, motor neurone, effector). Plant hormones: IAA (phototropism, gravitropism); gibberellin (elongation, germination); cytokinin (division); ABA (stomatal closure, dormancy); ethylene (ripening, abscission). Homeostasis: stable internal environment via negative feedback; hypothalamus controls thermoregulation; too hot: sweating and vasodilation; too cold: shivering and vasoconstriction.

Answers to Pilot Questions [Series 3]

Part 3.1

1. Water enters root hair cells by osmosis (high water potential in soil, lower in root hair cell sap). It crosses the root cortex by the apoplast pathway (through cell walls) or symplast pathway (through cytoplasm and plasmodesmata). At the endodermis, the Casparian strip forces all water into the symplast before it enters the xylem. Minerals enter by active transport using ATP, against a concentration gradient.
2. The Casparian strip is a band of waxy suberin deposited in the cell walls of endodermal cells surrounding the xylem. It blocks the apoplast pathway, forcing all water and dissolved minerals to pass through the cytoplasm (symplast) of endodermal cells before entering the xylem. This allows the plant to control what enters the xylem rather than allowing unrestricted movement of all soil solutes.
3. Transpiration is the loss of water vapour from aerial plant parts, mainly through stomata. Three factors that increase it: (1) high temperature (increases evaporation rate); (2) low humidity (increases the water vapour gradient between the leaf and air); (3) wind (removes water vapour from around the leaf, maintaining the gradient).
4. When guard cells absorb water (from surrounding epidermal cells) they become turgid; their unequally thickened walls cause them to bow outward, opening the stoma. When guard cells lose water and become flaccid, they collapse inward and the stoma closes. Guard cells open stomata in light (when photosynthesis requires CO_2) and close them in darkness or water stress.
5. Xylem: transports water and mineral salts upward only, from roots to leaves; composed of dead lignified hollow vessels; driven by cohesion-tension (transpiration pull). Phloem: transports organic solutes (mainly sucrose) in both directions, from source to sink; composed of living sieve tube elements and companion cells; driven by pressure flow.

Part 3.2

1. $6CO_2 + 6H_2O$ + light energy → $C_6H_{12}O_6 + 6O_2$. Reactants: carbon dioxide (from air through stomata) and water (from soil through xylem). Products: glucose (stored as starch or used for energy and building materials) and oxygen (released as a by-product of photolysis).

2. Site: thylakoid membranes of the chloroplast. Three products: (1) ATP (synthesised by ATP synthase during photophosphorylation); (2) NADPH (formed when $NADP^+$ is reduced by electrons from PSI); (3) oxygen (released by photolysis of water in PSII).
3. Photolysis is the splitting of water molecules ($2H_2O \rightarrow 4H^+ + 4e^- + O_2$) using light energy absorbed by chlorophyll in Photosystem II. It is important because: (1) it provides the electrons that replace those lost from chlorophyll in PSII and drive the electron transport chain; (2) it produces the oxygen released as a by-product of photosynthesis, which is essential for aerobic respiration of most living organisms.
4. CO_2 from the air is fixed by combining with the 5-carbon compound RuBP, catalysed by RuBisCO, forming two 3-carbon G3P molecules. G3P is reduced using ATP and NADPH (from the light-dependent reactions) to form GALP. Some GALP is used to synthesise glucose, starch, and other organic molecules; most is used to regenerate RuBP so the cycle continues.
5. RuBisCO (ribulose bisphosphate carboxylase/oxygenase) is the enzyme in the stroma that catalyses the first step of the Calvin cycle: combining CO_2 with the 5-carbon RuBP to form two 3-carbon G3P molecules. This carbon fixation step is the entry point of inorganic CO_2 into organic molecules; without RuBisCO there would be no Calvin cycle and no glucose synthesis from CO_2.

Part 3.3

1. Open: blood (haemolymph) pumped out of the heart into a body cavity (haemocoel) and bathes organs directly; found in insects and molluscs; suitable for slow-moving or small animals. Closed: blood always confined to vessels; exchange through capillary walls; found in annelids and vertebrates; allows higher blood pressure and faster, more controlled delivery of O_2 to tissues.
2. Deoxygenated blood from the body enters the right atrium via the vena cava; passes to the right ventricle; pumped to the lungs via the pulmonary artery; oxygenated in the lungs; returns to the left atrium via the pulmonary veins; passes to the left ventricle; pumped to the body via the aorta; oxygen delivered to tissues; blood returns deoxygenated to the right atrium.
3. Double circulation has two loops: the pulmonary circuit (right side of heart to lungs and back) and the systemic circuit (left side of heart to the body and back). Advantage: blood is re-oxygenated in the lungs and returned to the heart at high pressure before being pumped to the

body, ensuring efficient O2 delivery; oxygenated and deoxygenated blood are kept completely separate.

4. Plasma (liquid; 90% water; transports nutrients, hormones, CO_2, urea, ions); red blood cells (biconcave, no nucleus; haemoglobin transports O_2); white blood cells (neutrophils phagocytose bacteria; lymphocytes produce antibodies); platelets (cell fragments; initiate blood clotting at wound sites).
5. O_2 is transported bound to haemoglobin in red blood cells. In the lungs (high O_2), O_2 binds to haemoglobin forming oxyhaemoglobin. At respiring tissues (low O_2), oxyhaemoglobin dissociates and releases O_2, which diffuses into cells for aerobic respiration. CO_2 is transported mainly as bicarbonate ions (HCO_3^-) in the plasma.

Part 3.4

1. A motor neurone has: dendrites (short projections that receive impulses from other neurones); cell body (contains the nucleus and most organelles); axon (long projection that conducts impulses away from the cell body); myelin sheath (fatty insulating layer that speeds conduction in vertebrates); nodes of Ranvier (gaps in myelin where ionic exchange occurs); and synaptic knobs at the terminal end.
2. A spinal reflex arc for hand withdrawal from heat: hot object (stimulus) → pain receptor in skin → sensory neurone (carries impulse toward spinal cord) → relay neurone in spinal cord grey matter → motor neurone (carries impulse away from spinal cord) → bicep muscle (effector) → arm contracts, hand withdraws (response). This is rapid and automatic; does not involve the brain consciously.
3. IAA is produced in the shoot tip. When light comes from one side, IAA moves laterally to the shaded side. On the shaded side, higher IAA concentration promotes greater cell elongation. On the lit side, lower IAA means less elongation. The differential growth causes the shoot to curve and grow toward the light source (positive phototropism).
4. IAA/auxin (promotes cell elongation; causes phototropism and gravitropism); gibberellin (promotes stem elongation and seed germination; breaks dormancy); cytokinin (promotes cell division; delays leaf senescence); abscisic acid/ABA (promotes stomatal closure during water stress; maintains seed dormancy).
5. Homeostasis is the maintenance of a stable internal environment despite external changes. Negative feedback: when a variable deviates from its set point, receptors detect the change and send signals that trigger effectors to produce a corrective response, returning the variable

to normal. Example: body temperature above 37 degrees Celsius triggers sweating and vasodilation; below 37 degrees Celsius triggers shivering and vasoconstriction.

References and Attributions [Series 3]

Textual References (Books and External Sources)

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- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 3.1: Root hair cell water uptake and apoplast/symplast pathway diagram Attribution: AI generated. Suggested OER search string: "root hair cell water uptake apoplast symplast pathway Casparian strip xylem diagram OER".
- Figure 3.2: Open and closed stoma guard cell mechanism diagram Attribution: AI generated. Suggested OER search string: "stoma open closed guard cells turgid flaccid mechanism diagram OER".
- Figure 3.3: Chloroplast structure cross-section diagram Attribution: AI generated. Suggested OER search string: "chloroplast structure diagram thylakoid grana stroma light reactions Calvin cycle OER".
- Figure 3.4: Photosynthesis summary diagram (light-dependent and Calvin cycle) Attribution: AI generated. Suggested OER search string: "photosynthesis light dependent reactions Calvin cycle summary diagram thylakoid stroma OER".
- Figure 3.5: Open and closed circulatory systems comparison diagram Attribution: AI generated. Suggested OER search string: "open closed circulatory system insect vertebrate comparison diagram haemocoel capillaries OER".
- Figure 3.6: Labelled human heart diagram Attribution: AI generated. Suggested OER search string: "human heart labelled diagram four chambers valves SA node AV node blood flow OER".
- Figure 3.7: Motor neurone and spinal reflex arc diagram Attribution: AI generated. Suggested OER search string: "motor neurone labelled diagram spinal reflex arc receptor sensory relay motor effector OER".

- Figure 3.8: Phototropism and gravitropism diagram Attribution: AI generated. Suggested OER search string: "phototropism gravitropism IAA auxin seedling shoot root growth direction diagram OER".
- Box 3.1: Homeostatic thermoregulation in humans summary Attribution: AI generated. Suggested OER search string: "homeostasis thermoregulation human body temperature negative feedback sweating shivering vasoconstriction vasodilation OER box".

Course code: BIO 102

Course title: General Biology II

Course credit load: 2 Units

Series 4: Nutrition, Respiration, Excretion, and Reproduction

- **Part 4.1: Nutrition in Plants and Animals**
    - Sub Part 4.1.1: Modes of nutrition
    - Sub Part 4.1.2: Digestion in animals
    - Sub Part 4.1.3: Mineral nutrition in plants
- **Part 4.2: Respiration**
    - Sub Part 4.2.1: Aerobic respiration
    - Sub Part 4.2.2: Anaerobic respiration
    - Sub Part 4.2.3: Gas exchange in plants and animals
- **Part 4.3: Excretion**
    - Sub Part 4.3.1: Excretion in plants
    - Sub Part 4.3.2: Excretion in animals
    - Sub Part 4.3.3: The human kidney
- **Part 4.4: Reproduction**
    - Sub Part 4.4.1: Asexual reproduction in plants and animals
    - Sub Part 4.4.2: Sexual reproduction in flowering plants
    - Sub Part 4.4.3: Sexual reproduction in animals

Introduction

Nutrition, respiration, excretion, and reproduction are four of the seven fundamental characteristics of living organisms. All cells require a continuous supply of energy and raw materials; they must remove metabolic waste products; and they must ultimately reproduce. This Series examines how plants and animals carry out these essential life processes, highlighting key similarities and differences between the two kingdoms.

The topics covered include modes of nutrition, digestion in animals, mineral nutrition in plants, aerobic and anaerobic respiration, gas exchange, excretion in plants and animals, the human kidney, and both asexual and sexual reproduction in plants and animals. These topics directly link to the physiology covered in Series 3.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 4.1** distinguish between the modes of nutrition and describe digestion in animals (Linked to Part 4.1),
- **SLO 4.2** describe the mineral nutrition requirements of plants (Linked to Part 4.1),
- **SLO 4.3** describe aerobic and anaerobic respiration and write the relevant equations (Linked to Part 4.2),
- **SLO 4.4** describe gas exchange in plants and animals (Linked to Part 4.2),
- **SLO 4.5** define excretion and describe excretory processes in plants and animals (Linked to Part 4.3),
- **SLO 4.6** describe the structure and function of the human kidney (Linked to Part 4.3),
- **SLO 4.7** describe asexual reproduction and explain sexual reproduction in flowering plants and in animals (Linked to Part 4.4).

4.1 Nutrition in Plants and Animals

4.1.1 Modes of nutrition

Nutrition is the process by which organisms obtain and use food materials for energy, growth, and repair. Two fundamental modes: Autotrophic nutrition: organisms produce their own food from inorganic raw materials; includes photoautotrophs (plants, algae using light energy) and chemoautotrophs (some bacteria using chemical energy). Heterotrophic nutrition: organisms obtain food by consuming organic material produced by other organisms; includes herbivores, carnivores, omnivores, decomposers, and parasites.

Holozoic nutrition (used by most animals): ingestion of solid food; intracellular or extracellular digestion; absorption of digested products; assimilation. Saprotrophic (saprophytic) nutrition (used by fungi and many bacteria): organisms secrete digestive enzymes onto dead organic matter externally; absorb the soluble products. Parasitic nutrition: obtaining food from a living host, harming but rarely immediately killing it. Plants are exclusively autotrophic; animals are heterotrophic.

Fill in the blank: ________ nutrition is used by most animals: solid food is ingested, digested, absorbed, and assimilated; saprotrophic nutrition involves external digestion of dead organic matter by fungi and bacteria.

4.1.2 Digestion in animals

Digestion is the breakdown of large insoluble food molecules into small soluble molecules that can be absorbed across the gut wall. Physical (mechanical) digestion: food is broken into smaller pieces by teeth (mastication), tongue, and stomach churning, increasing the surface area for enzyme action. Chemical digestion: enzymes hydrolyse food molecules into monomers. Carbohydrases (amylase, maltase, sucrase) digest carbohydrates to monosaccharides; proteases (pepsin, trypsin, peptidases) digest proteins to amino acids; lipases digest fats to fatty acids and glycerol.

The human alimentary canal: mouth (teeth and salivary amylase begin starch digestion) → oesophagus (peristalsis moves food to stomach) → stomach (pepsin and HCl; protein digestion; gastric churning) → small intestine (duodenum: bile emulsifies fat; pancreatic amylase, lipase, and protease; ileum: intestinal enzymes; villi and microvilli maximise absorption) → large intestine (water and minerals reabsorbed; faeces formed) → rectum and anus (defecation).

Fill in the blank: In the small intestine, ________ from the liver emulsifies fat into small droplets, greatly increasing the surface area for lipase action; villi and microvilli on the intestinal wall maximise absorption of digested products.

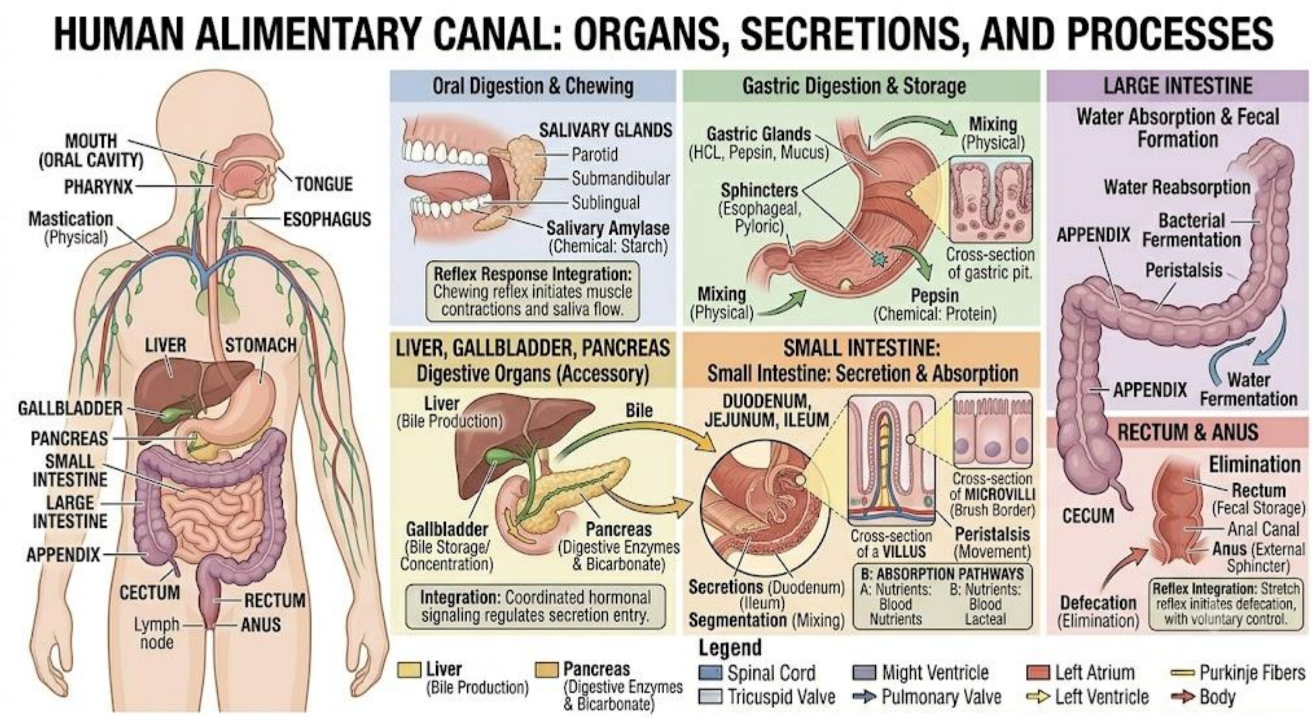

Figure 4.1: Diagram of the human alimentary canal showing organs and digestive processes

4.1.3 Mineral nutrition in plants

Plants require mineral salts in addition to CO2, water, and light. Macronutrients (needed in relatively large quantities): nitrogen (N) for amino acids and nucleic acids; phosphorus (P) for ATP, DNA, and membranes; potassium (K) for stomatal guard cell function and enzyme activation; calcium (Ca) for cell wall middle lamella and membrane permeability; magnesium

(Mg) for chlorophyll synthesis; sulphur (S) for some amino acids. Micronutrients (trace elements): iron (Fe) for cytochrome and haemoglobin; manganese (Mn) for enzyme cofactor; zinc (Zn) for enzyme function.

Deficiency symptoms reveal nutrient functions: nitrogen deficiency causes yellowing (chlorosis) of older leaves and stunted growth; iron deficiency causes chlorosis of young leaves (iron needed for chlorophyll synthesis); phosphorus deficiency causes purple coloration of leaves; calcium deficiency causes tip death (necrosis) of young leaves; magnesium deficiency causes interveinal chlorosis (yellowing between veins) of older leaves. These symptoms are used by agronomists to diagnose soil nutrient deficiencies in Nigeria's farmlands.

Fill in the blank: ________ deficiency causes yellowing (chlorosis) of older leaves and stunted growth because nitrogen is required for amino acid and chlorophyll synthesis; it is the most common crop nutrient deficiency in Nigerian soils.

Pilot questions 4.1

1. Distinguish between autotrophic and heterotrophic nutrition.
2. Describe the digestion of starch from the mouth to the small intestine.
3. Explain the role of bile in digestion.
4. Name four macronutrients required by plants and state the function of each.
5. State the deficiency symptom of nitrogen and of magnesium in plants.

4.2 Respiration

4.2.1 Aerobic respiration

Aerobic respiration is the release of energy from organic molecules using oxygen. The overall equation is: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy (approximately 38 ATP per glucose molecule). It occurs in three stages: glycolysis (in the cytoplasm; glucose split to pyruvate; net 2 ATP produced; no oxygen required); the Krebs cycle (in the mitochondrial matrix; pyruvate converted to acetyl-CoA; CO_2 released; reduced NAD and FAD produced); and oxidative phosphorylation (on the inner mitochondrial membrane; electron transport chain; oxygen acts as final electron acceptor; approximately 34 ATP produced).

Mitochondria are the sites of aerobic respiration; they have an outer membrane, inner membrane (folded into cristae to increase surface area for ATP synthesis), matrix (site of Krebs cycle), and intermembrane space. The overall yield is approximately 38 ATP per glucose, though the actual yield in cells is closer to 30 to 32 ATP due to membrane inefficiencies. This high ATP yield makes aerobic respiration far more efficient than anaerobic respiration and explains why most complex organisms depend on oxygen.

Fill in the blank: Aerobic respiration occurs in three stages: ________ (cytoplasm), Krebs cycle (mitochondrial matrix), and oxidative phosphorylation (inner mitochondrial membrane); oxygen acts as the final electron acceptor in oxidative phosphorylation.

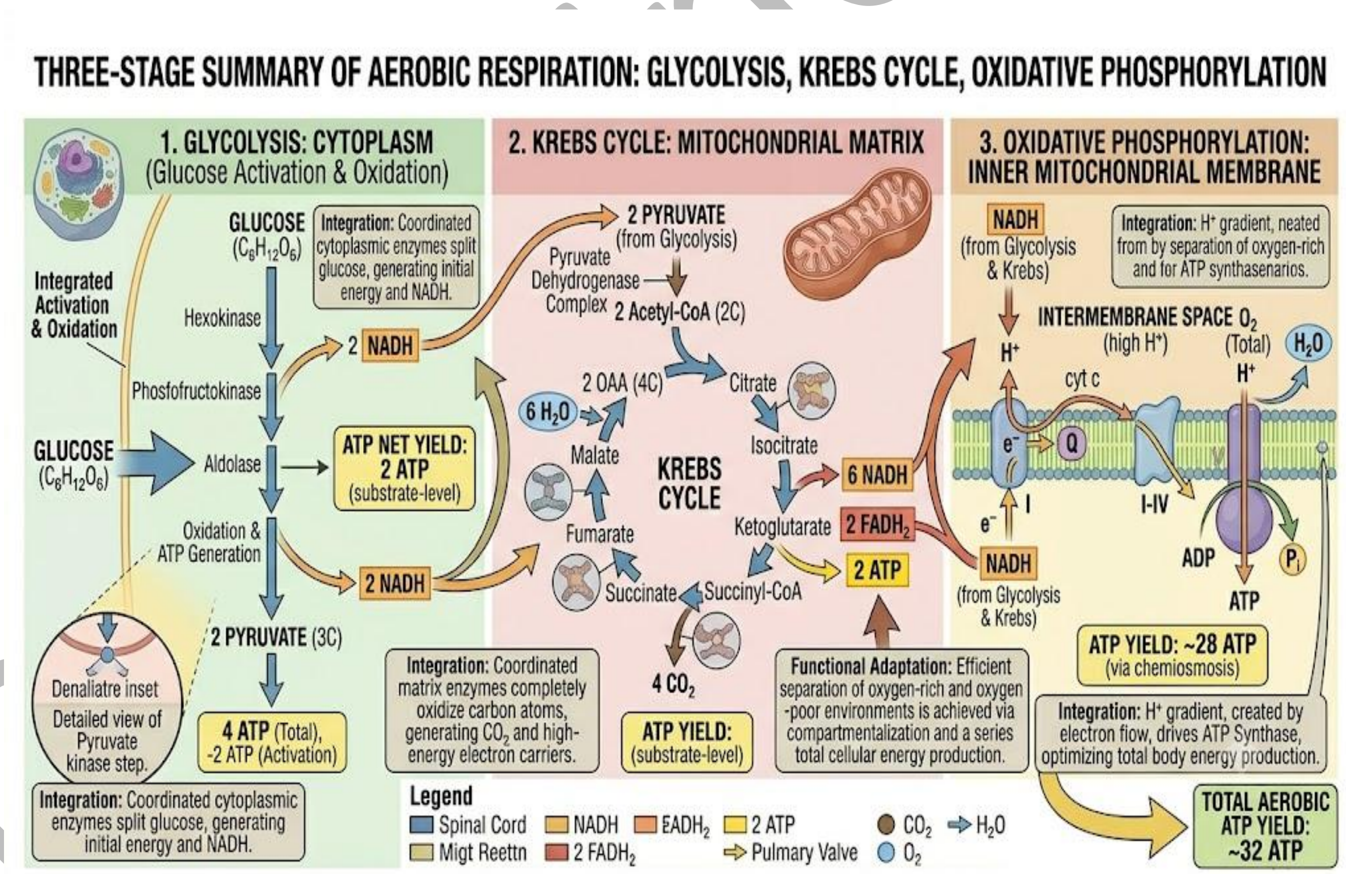

Figure 4.2: Summary diagram of aerobic respiration showing glycolysis, Krebs cycle, and oxidative phosphorylation

4.2.2 Anaerobic respiration

Anaerobic respiration occurs when oxygen is absent or insufficient. Glycolysis still occurs (2 ATP from glucose to pyruvate) but the pyruvate is not fed into the Krebs cycle. Instead, pyruvate is converted to different products depending on the organism. In yeast and plants: pyruvate is decarboxylated to ethanal, then reduced to ethanol + CO_2 (alcoholic fermentation); net yield 2 ATP per glucose. In mammals and bacteria: pyruvate is reduced to lactate (lactic acid fermentation); net yield 2 ATP per glucose.

In humans, lactate fermentation occurs in muscle cells during intense exercise when oxygen delivery cannot keep pace with demand. Lactate accumulates and causes muscle fatigue and the burning sensation during exercise. After exercise, excess oxygen (oxygen debt) is used to oxidise lactate back to pyruvate, which then enters aerobic respiration. Anaerobic respiration in yeast is exploited commercially in bread making (CO_2 causes dough to rise) and in alcohol production (brewing and winemaking).

Fill in the blank: In yeast, anaerobic respiration produces ________ and carbon dioxide from pyruvate; this process is exploited in bread making (CO_2 causes dough to rise) and in alcohol production by brewing and fermentation.

4.2.3 Gas exchange in plants and animals

Gas exchange in plants occurs mainly through stomata in leaves and lenticels in woody stems. During the day, photosynthesis consumes CO_2 and produces O_2 (net movement of CO_2 in and O_2 out). At night, only respiration occurs (net movement of O_2 in and CO_2 out). Gases move by diffusion down concentration gradients through the air spaces of the leaf mesophyll to the stomatal pores. The large internal surface area of the mesophyll (approximately 10 times the external leaf area) facilitates rapid gas exchange.

Gas exchange in animals: fish use gills (counter-current exchange maximises O_2 extraction; water flows over lamellae in the opposite direction to blood flow); amphibians use moist skin and simple lungs; insects use trachea (air tubes opening at spiracles on the abdomen, delivering O_2 directly to tissues); humans and other mammals use lungs (alveoli provide enormous surface area; approximately 70 m2 in adult humans; thin walls and rich blood supply for rapid diffusion; breathing movements ventilate the lungs to maintain concentration gradients).

Fill in the blank: Fish gills use ________ exchange, in which water flows over the gill lamellae in the opposite direction to blood flow, maximising oxygen extraction from the water.

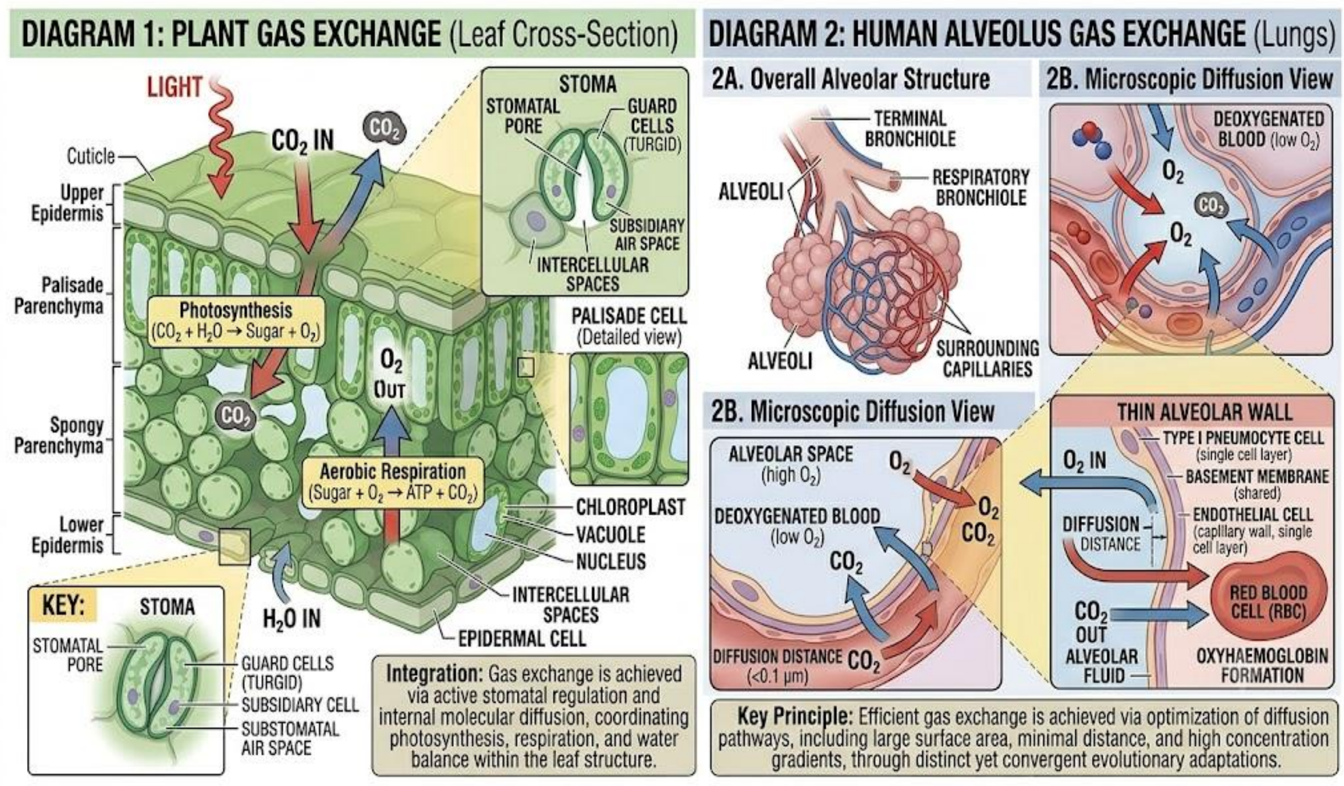

Figure 4.3: Diagram of gas exchange in a leaf and in a human alveolus

Pilot questions 4.2

1. Write the overall equation for aerobic respiration and state where each stage occurs.
2. Compare aerobic and anaerobic respiration in terms of ATP yield and end products.
3. Explain what oxygen debt is and how it is repaid.
4. Describe gas exchange in a leaf.
5. Explain why alveoli are well adapted for gas exchange.

4.3 Excretion

4.3.1 Excretion in plants

Excretion is the removal of the waste products of metabolism from an organism. Plants produce fewer toxic metabolic waste products than animals because they are autotrophic and do not break down protein for energy. The main metabolic wastes in plants are: oxygen (produced by photosynthesis; released through stomata); carbon dioxide (produced by respiration; released through stomata and lenticels); and water vapour (released by transpiration). Some plants also accumulate waste products in vacuoles, dead bark, or fallen leaves (which are shed to remove them).

Plants store some waste compounds in specialised structures rather than excreting them into the environment: calcium oxalate crystals are stored in vacuoles and cell walls of some plants; tannins, resins, and latex are stored in bark or resin canals and may serve dual functions as waste storage and defence against herbivores. Unlike animals, plants do not produce nitrogenous waste such as urea or ammonia because they rarely break down proteins for energy; nitrogen from amino acids is recycled within the plant.

Fill in the blank: The main metabolic waste gases in plants are ________ (from photosynthesis) and CO2 (from respiration), both released through stomata; plants do not produce nitrogenous waste because they do not break down protein for energy.

4.3.2 Excretion in animals

Animals produce nitrogenous waste from the breakdown of amino acids (deamination). The nature of the nitrogenous waste product depends on the availability of water: ammonia (NH3) is highly toxic and very soluble; aquatic animals (fish, aquatic invertebrates) excrete ammonia directly into the water (ammonotelic). Urea (CO(NH2)2) is less toxic and requires more water to excrete; mammals (including humans), cartilaginous fish, and amphibians are ureotelic (excrete urea).

Uric acid is the least soluble nitrogenous waste; it is excreted as a semi-solid paste requiring minimal water; produced by birds, reptiles, and insects (uricotelic). This adaptation is important for water conservation in terrestrial animals and for developing embryos in eggs where water cannot be removed easily. Other animal excretory products: CO_2 (excreted through lungs or gills); excess water and mineral salts (excreted by kidneys, skin, or gills). Skin excretes water, mineral salts, urea, and a small amount of CO_2 through sweat.

Fill in the blank: Birds and reptiles excrete ________ acid as their nitrogenous waste product; it requires very little water for excretion and is therefore well-suited to desert animals and developing embryos in eggs.

4.3.3 The human kidney

The human kidney has three regions: cortex (outer; contains glomeruli and Bowman's capsules); medulla (inner; contains collecting ducts and loops of Henle); pelvis (inner cavity; collects urine which passes to the ureter). The functional unit is the nephron. Bowman's capsule (in cortex) surrounds the glomerulus (a knot of capillaries); high blood pressure in the glomerulus forces small molecules (water, glucose, urea, mineral salts) by ultrafiltration through the glomerular wall into the Bowman's capsule, forming the glomerular filtrate.

From the Bowman's capsule, the filtrate passes through the proximal convoluted tubule (PCT: glucose, amino acids, and most water reabsorbed by active transport and osmosis), the loop of Henle (establishes salt concentration gradient in medulla; important for concentrating urine), the distal convoluted tubule (DCT: regulated reabsorption of water and salts under hormone control by ADH and aldosterone), and the collecting duct (further water reabsorption; final urine concentration). Urine (water, urea, excess mineral salts) passes to the ureter, bladder, and urethra for excretion.

Fill in the blank: In the Bowman's capsule, small molecules are forced into the capsule by ________ from the glomerulus; glucose and amino acids are reabsorbed in the proximal convoluted tubule; urine is concentrated in the loop of Henle and collecting duct.

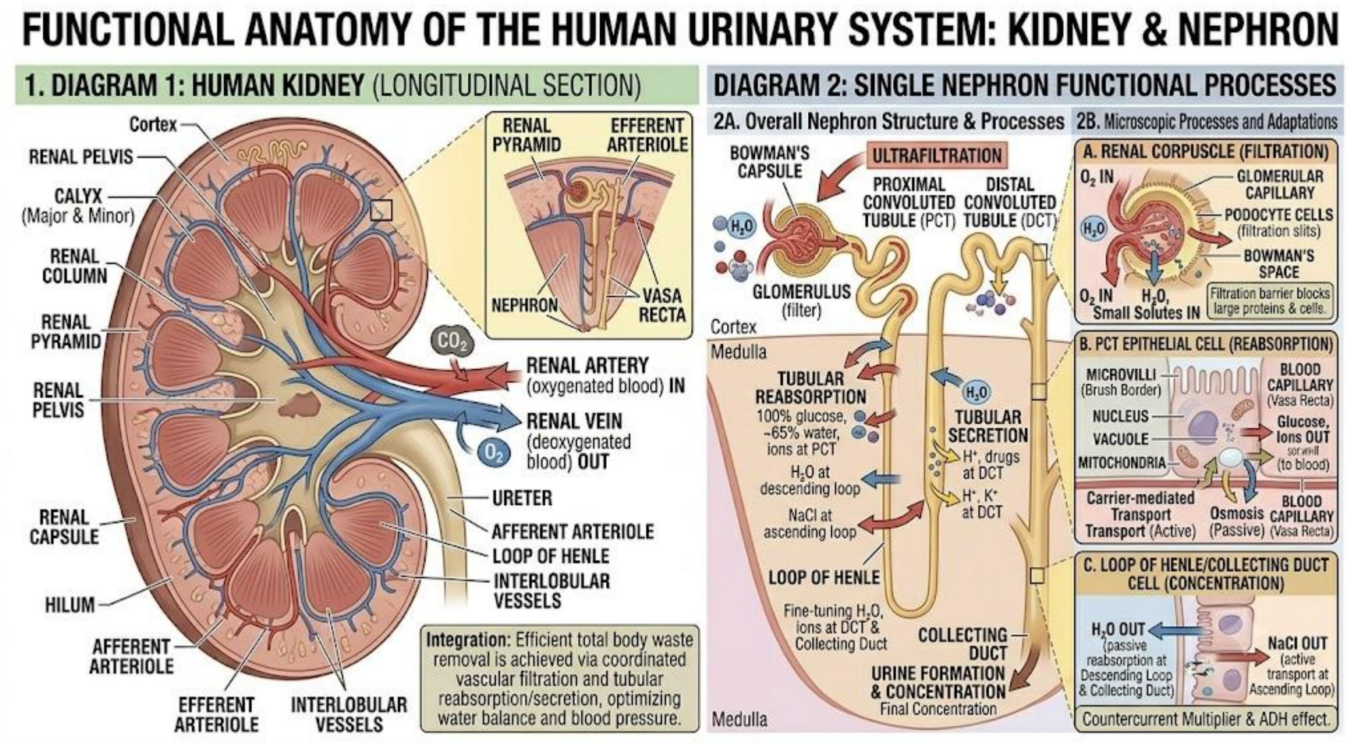

Figure 4.4: Labelled diagram of the human kidney and a nephron

Pilot questions 4.3

1. Define excretion and distinguish it from egestion.
2. Explain why plants produce less nitrogenous waste than animals.
3. Distinguish between ammonotelic, ureotelic, and uricotelic animals.
4. Describe the process of ultrafiltration in the human kidney.
5. Explain what happens to glucose in the nephron.

4.4 Reproduction

4.4.1 Asexual reproduction in plants and animals

Asexual reproduction produces offspring genetically identical to the parent (clones) using only mitosis; no gametes or fertilisation are involved. In plants: vegetative propagation (natural or artificial reproduction from vegetative parts): stolons or runners (horizontal stems that root at nodes; e.g. strawberry); bulbs (underground storage organs; e.g. onion); corms (e.g. cocoyam); rhizomes (horizontal underground stems; e.g. ginger, fern); tubers (swollen underground storage organs; e.g. yam, potato); suckers (shoots from roots; e.g. banana); and budding in Hydra.

In animals: binary fission (Amoeba divides into two identical daughters by mitosis); budding (a bud forms on the parent body, grows, and detaches; e.g. Hydra, yeast); fragmentation (body breaks and each fragment regenerates; e.g. Planaria flatworm, starfish); parthenogenesis (unfertilised eggs develop into individuals; e.g. aphids, some reptiles). Advantages of asexual reproduction: rapid; no mate needed; all offspring are able to reproduce; successful genotypes are preserved. Disadvantage: no genetic variation; entire population susceptible to the same disease.

Fill in the blank: ________ fission is asexual reproduction in Amoeba in which the cell divides by mitosis into two genetically identical daughter cells; binary fission is the most common form of reproduction in prokaryotes.

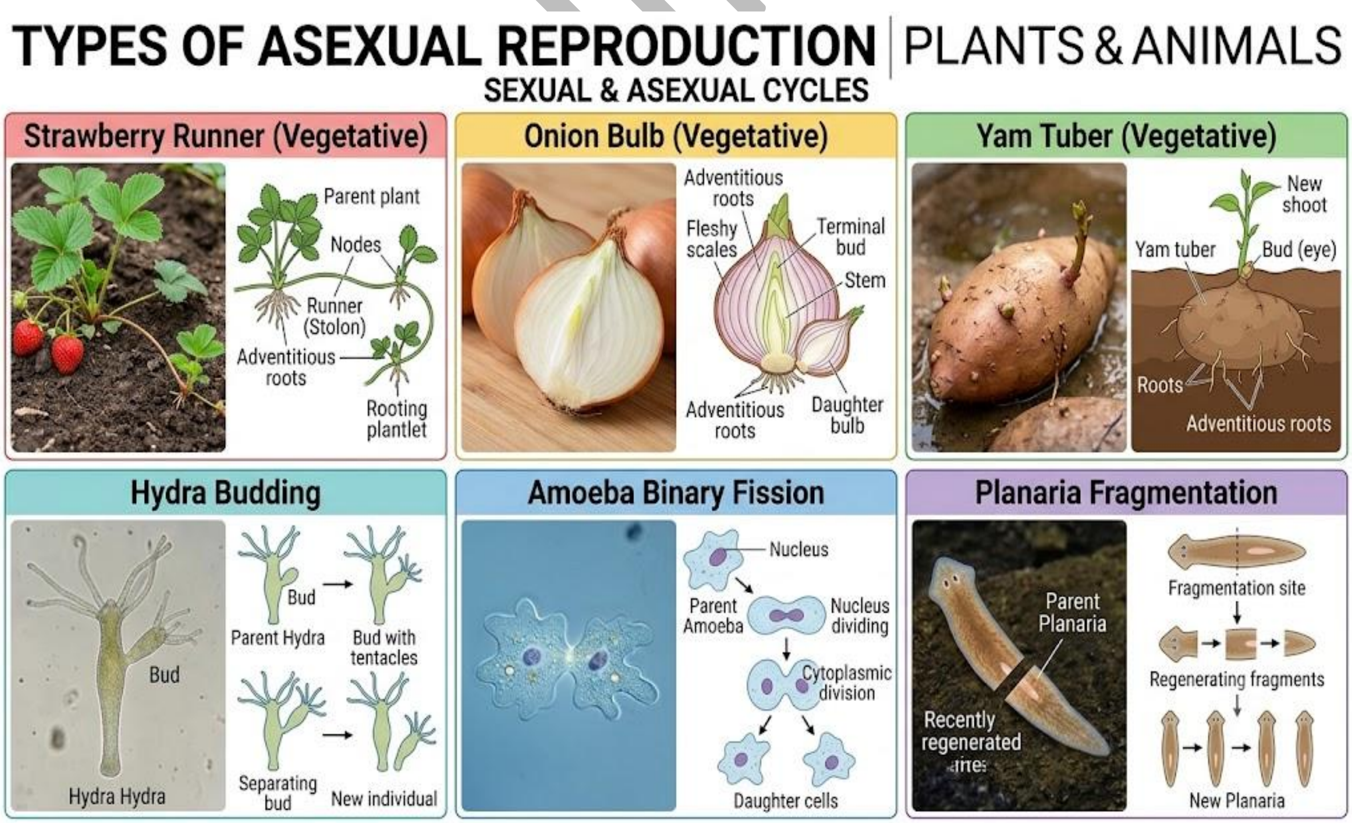

Figure 4.5: Photographs and diagrams of asexual reproduction in plants and animals

4.4.2 Sexual reproduction in flowering plants

Sexual reproduction involves the fusion of male and female gametes to form a genetically unique zygote. In flowering plants, the flower is the reproductive organ. Male part: stamen (anther + filament); anther produces pollen grains (male gametophytes containing the male gamete). Female part: carpel (stigma + style + ovary); ovary contains ovules; each ovule contains the embryo sac with the egg cell (female gamete). Petals attract pollinators; sepals protect the flower bud.

Pollination: transfer of pollen from anther to stigma; may be by wind (anemophily: light pollen, feathery stigma, no petals needed; e.g. grasses, maize) or by insects (entomophily: bright petals, nectar, scented, sticky pollen; e.g. Hibiscus, sunflower). Fertilisation: pollen grain germinates on stigma; pollen tube grows down the style into the ovule; two male nuclei released: one fuses with egg cell (forming zygote, → embryo), the other fuses with polar nuclei (forming endosperm). This double fertilisation is unique to angiosperms.

Fill in the blank: In angiosperms, ________ fertilisation involves the fusion of one male nucleus with the egg cell (forming the zygote) and a second male nucleus with the polar nuclei (forming the endosperm).

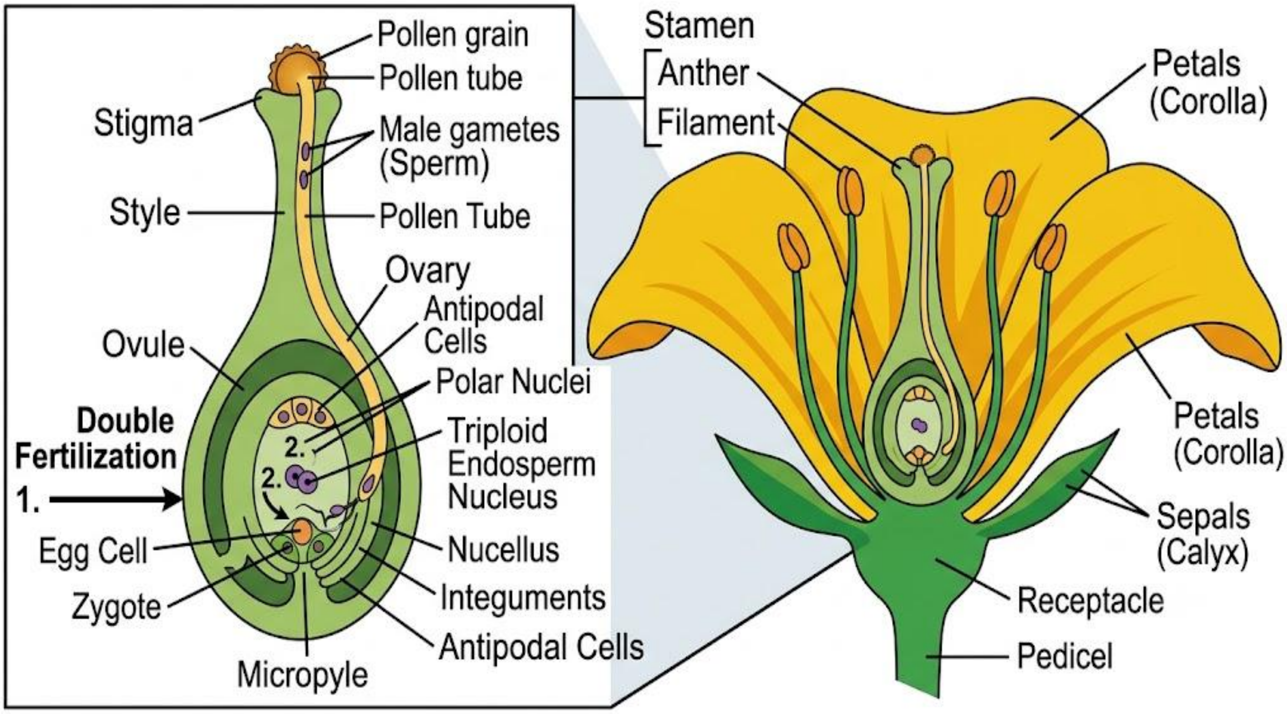

Figure 4.6: Labelled diagram of a typical insect-pollinated flower showing male and female parts

4.4.3 Sexual reproduction in animals

In animals, sexual reproduction involves the production of haploid gametes (sperm and eggs) by meiosis, followed by fertilisation to form a diploid zygote. External fertilisation: gametes released into water; fertilisation occurs outside the body; used by most fish, amphibians, and many aquatic invertebrates; large numbers of eggs produced to compensate for losses. Internal fertilisation: sperm deposited inside the female body; used by reptiles, birds, and mammals; fewer but better-protected offspring.

Human reproduction: sperm are produced in the testes and eggs (ova) in the ovaries. Sperm are small, motile, and produced in millions. Eggs are large, non-motile, and produced one per menstrual cycle (approximately every 28 days). After internal fertilisation in the fallopian tube, the zygote divides and implants in the uterus wall (endometrium) as a blastocyst. The placenta develops to supply the embryo with nutrients and oxygen and remove waste products from fetal blood. Pregnancy lasts approximately 40 weeks (9 months).

Fill in the blank: In humans, the fertilised egg (zygote) implants in the ________ wall of the uterus; the placenta then develops to supply the growing embryo with oxygen and nutrients from the mother's blood.

Aspect	**Asexual Reproduction**	**Sexual Reproduction**
Gametes	Not involved	Involved (male and female gametes)
Fertilisation	Absent	Present (fusion of gametes)
Offspring Genotype	Identical to parent (clones)	Different from parents
Genetic Variation	None or very low	High
Number of Parents	One parent	Two parents
Rate	Fast	Slower
Advantages	Rapid population increase; no mate required	Produces variation; adaptation to environment
Examples	Binary fission in *Amoeba*, budding in *Hydra*, vegetative propagation in plants	Humans, flowering plants, animals

Box 4.1: Comparison of sexual and asexual reproduction

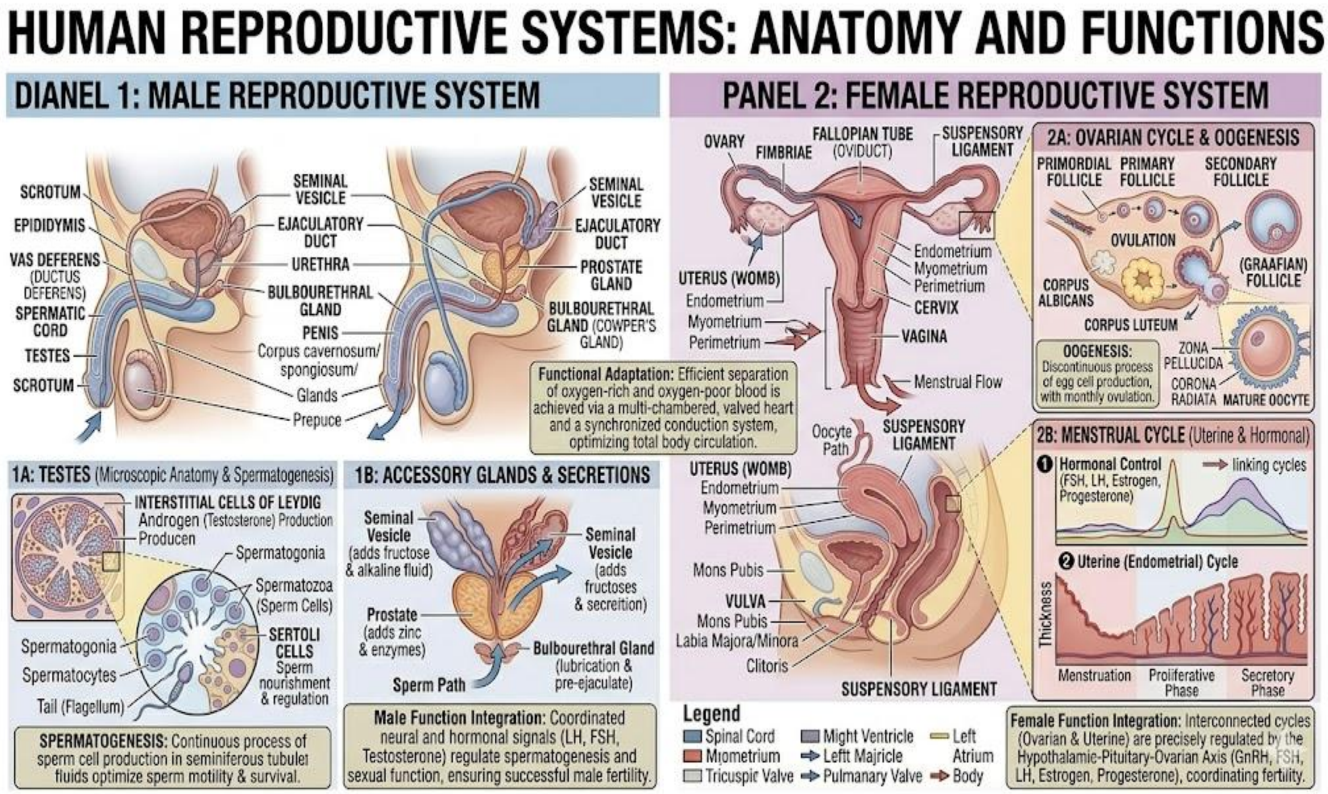

Figure 4.7: Diagram of the human male and female reproductive systems

Pilot questions 4.4

1. State four methods of asexual reproduction in plants with one example of each.
2. State two advantages and one disadvantage of asexual reproduction.
3. Describe pollination and fertilisation in a flowering plant.
4. Distinguish between external and internal fertilisation with one example of each.
5. Explain the role of the placenta in human reproduction.

Series Summary

This Series covered nutrition, respiration, excretion, and reproduction. Nutrition: autotrophic (plants) vs heterotrophic (animals); digestion in animals involves mechanical and chemical breakdown along the alimentary canal; plants require macronutrients (N, P, K, Ca, Mg, S) and micronutrients; nitrogen deficiency causes chlorosis. Respiration: aerobic (38 ATP; glucose + O_2 → CO_2 + H_2O; glycolysis, Krebs cycle, oxidative phosphorylation); anaerobic (2 ATP; produces ethanol/CO_2 in yeast or lactate in mammals). Gas exchange: stomata and lenticels in plants; gills, skin, trachea, or alveoli in animals.

Excretion: plants release O_2 and CO_2 through stomata; animals produce nitrogenous waste (ammonia: aquatic; urea: mammals; uric acid: birds, reptiles, insects); the human kidney performs ultrafiltration (Bowman's capsule), selective reabsorption (PCT), and concentration (loop of Henle, collecting duct). Reproduction: asexual (clones; binary fission, budding, fragmentation, vegetative propagation); sexual (genetic variation; double fertilisation in angiosperms; internal fertilisation in reptiles, birds, and mammals; placenta in humans). By completing this Series, you should achieve all seven SLOs (4.1 to 4.7).

Glossary of Terms

- **Aerobic respiration:** the release of energy from glucose using oxygen; produces approximately 38 ATP; overall equation: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy.
- **Alveolus (plural: alveoli):** tiny air sacs in the mammalian lung providing enormous surface area (approximately 70 m^2 in humans) for gas exchange; surrounded by a dense capillary network.
- **Ammonotelic:** an animal that excretes nitrogenous waste as ammonia; includes most bony fish and aquatic invertebrates; requires abundant water.
- **Anaerobic respiration:** release of energy from glucose without oxygen; produces only 2 ATP per glucose; products are ethanol and CO_2 (yeast) or lactate (mammals).
- **Autotrophic nutrition:** production of food from inorganic raw materials using light (photoautotrophs) or chemical energy (chemoautotrophs); includes all green plants and algae.

- **Bile:** a secretion of the liver, stored in the gall bladder; emulsifies fats in the duodenum into small droplets to increase surface area for lipase action; alkaline; neutralises stomach acid.
- **Binary fission:** asexual reproduction in which a single cell divides into two genetically identical daughter cells by mitosis; common in unicellular organisms such as Amoeba and bacteria.
- **Bowman's capsule:** the cup-shaped beginning of the nephron that surrounds the glomerulus; receives glomerular filtrate produced by ultrafiltration.
- **Deamination:** the removal of an amino group from an amino acid during protein metabolism; produces ammonia, which is converted to urea in the liver of mammals.
- **Double fertilisation:** a process unique to angiosperms in which one male nucleus fuses with the egg cell (forming the zygote) and a second male nucleus fuses with the polar nuclei (forming the triploid endosperm).
- **Egestion:** the removal of undigested food (faeces) from the body through the anus; distinct from excretion, which removes metabolic waste products.
- **Endosperm:** the nutritive tissue in angiosperm seeds that forms from double fertilisation; provides nutrients for the developing embryo.
- **Excretion:** the removal of the metabolic waste products of cellular reactions from an organism; distinct from egestion (removal of undigested food).
- **Glycolysis:** the first stage of respiration occurring in the cytoplasm; glucose (6C) is split into two pyruvate molecules (3C) producing a net gain of 2 ATP and 2 NADH.
- **Glomerulus:** a knot of capillaries inside the Bowman's capsule; the high blood pressure forces small molecules into the capsule by ultrafiltration.
- **Holozoic nutrition:** a mode of heterotrophic nutrition in which solid food is ingested, digested internally, absorbed, and assimilated; used by most animals.
- **Krebs cycle:** the second stage of aerobic respiration occurring in the mitochondrial matrix; acetyl-CoA is oxidised, releasing CO2 and producing reduced NAD and FAD; no O2 required.
- **Loop of Henle:** a hairpin-shaped section of the nephron in the medulla; establishes a salt concentration gradient used to concentrate urine in the collecting duct.

- **Macronutrient:** a mineral element required by plants in relatively large quantities; includes N, P, K, Ca, Mg, and S.
- **Nephron:** the functional unit of the kidney; comprises Bowman's capsule, glomerulus, proximal convoluted tubule, loop of Henle, distal convoluted tubule, and collecting duct.
- **Oxidative phosphorylation:** the third stage of aerobic respiration; electrons from NADH and FADH2 pass along the electron transport chain on the inner mitochondrial membrane; O2 is the final electron acceptor; approximately 34 ATP produced.
- **Pollination:** the transfer of pollen grains from the anther to the stigma of a flower; may be by wind (anemophily) or insects (entomophily).
- **Proximal convoluted tubule (PCT):** the section of the nephron immediately after the Bowman's capsule; actively reabsorbs all glucose, all amino acids, and most water from the glomerular filtrate.
- **Ultrafiltration:** the forced filtration of small molecules from the blood in the glomerulus into the Bowman's capsule; driven by high blood pressure in the glomerular capillaries.
- **Urea:** the nitrogenous waste product of mammals, amphibians, and cartilaginous fish; formed in the liver from ammonia and CO2; excreted in urine by the kidneys.
- **Uric acid:** the nitrogenous waste product of birds, reptiles, and insects; nearly insoluble; excreted as a semi-solid paste requiring minimal water.
- **Ureotelic:** an animal that excretes nitrogenous waste mainly as urea; includes mammals, amphibians, and cartilaginous fish.
- **Uricotelic:** an animal that excretes nitrogenous waste mainly as uric acid; includes birds, reptiles, and insects.

Concept Check Questions [Series 4]

Objective Questions

1. ________ nutrition is used by most animals: solid food is ingested, digested, absorbed, and assimilated. (Linked to SLO 4.1)
2. Aerobic respiration occurs in three stages: ________ (cytoplasm), Krebs cycle (mitochondrial matrix), and oxidative phosphorylation (inner mitochondrial membrane). (Linked to SLO 4.3)
3. In yeast, anaerobic respiration produces ________ and $CO2$; in mammals it produces lactate. (Linked to SLO 4.3)
4. Birds and reptiles excrete ________ acid as their nitrogenous waste; it requires very little water for excretion. (Linked to SLO 4.5)
5. In angiosperms, ________ fertilisation involves one male nucleus fusing with the egg cell and a second fusing with the polar nuclei to form the endosperm. (Linked to SLO 4.7)

Short-Answer Questions

1. Describe the digestion of a protein from the stomach to the small intestine. (Linked to SLO 4.1)
2. Compare aerobic and anaerobic respiration in terms of ATP yield and end products. (Linked to SLO 4.3)
3. Distinguish between ammonotelic, ureotelic, and uricotelic animals with one example each. (Linked to SLO 4.5)
4. Describe the process of ultrafiltration in the kidney. (Linked to SLO 4.6)
5. Distinguish between wind pollination and insect pollination. (Linked to SLO 4.7)

Long-Answer Questions

1. Describe the modes of nutrition, the process of digestion in animals, and the mineral nutrition of plants. (Linked to SLOs 4.1, 4.2)
2. Describe aerobic and anaerobic respiration with equations, and explain gas exchange in plants and in humans. (Linked to SLOs 4.3, 4.4)
3. Define excretion, describe excretion in plants and animals, explain the structure and function of the human kidney, and describe asexual and sexual reproduction in plants and animals. (Linked to SLOs 4.5, 4.6, 4.7)

Answers to Concept Check Questions [Series 4]

Objective Questions

1. Holozoic.
2. Glycolysis.
3. Ethanol.
4. Uric.
5. Double.

Short-Answer Questions

1. In the stomach: pepsin (activated by HCl) hydrolyses proteins to polypeptides. In the duodenum: pancreatic trypsin continues hydrolysis to smaller peptides; bile neutralises stomach acid. In the ileum: peptidases on the brush border complete digestion to amino acids; amino acids absorbed into the blood.
2. Aerobic: 38 ATP per glucose; products are CO_2 and water; requires O_2; occurs in cytoplasm and mitochondria. Anaerobic: 2 ATP per glucose; products are ethanol + CO_2 (yeast) or lactate (mammals); no O_2 required; occurs in cytoplasm only.
3. Ammonotelic: excretes ammonia; toxic; needs abundant water; e.g. bony fish. Ureotelic: excretes urea; less toxic; needs some water; e.g. humans. Uricotelic: excretes uric acid; nearly insoluble; needs minimal water; e.g. birds and reptiles.
4. High blood pressure in the glomerular capillaries forces small molecules (water, glucose, urea, mineral salts) through the glomerular wall into the Bowman's capsule; large molecules (plasma proteins, red blood cells) are too large to filter through and remain in the blood.
5. Wind pollination: no petals or nectar; light, smooth, abundant pollen; feathery stigma; e.g. maize. Insect pollination: bright petals; nectar; scent; sticky or spiky pollen; smaller quantities of pollen; e.g. Hibiscus.

Long-Answer Questions

1. Modes of nutrition: autotrophic (plants; photoautotrophs use light; chemoautotrophs use chemical energy); heterotrophic (animals; holozoic: ingest, digest, absorb; saprotrophic: external digestion of dead matter; parasitic). Digestion: physical (teeth, tongue, stomach churning; increases surface area) and chemical (enzymes hydrolyse bonds). Mouth: salivary

amylase digests starch to maltose. Oesophagus: peristalsis. Stomach: pepsin and HCl digest proteins to polypeptides. Duodenum: bile emulsifies fat; pancreatic amylase, lipase, and trypsin. Ileum: intestinal peptidases; villi and microvilli for absorption. Large intestine: water reabsorption; faeces formed. Mineral nutrition: macronutrients (N: amino acids; P: ATP and DNA; K: guard cells; Ca: cell wall; Mg: chlorophyll; S: amino acids) and micronutrients (Fe, Mn, Zn). Deficiency symptoms: N deficiency causes chlorosis of older leaves; Mg deficiency causes interveinal chlorosis; Ca deficiency causes tip necrosis.

2. Aerobic respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + 38 ATP. Stage 1: glycolysis (cytoplasm; glucose to 2 pyruvate; 2 ATP; 2 NADH). Stage 2: Krebs cycle (mitochondrial matrix; pyruvate to acetyl-CoA; CO_2 released; NADH and $FADH_2$ produced). Stage 3: oxidative phosphorylation (inner mitochondrial membrane; NADH and $FADH_2$ pass electrons to ETC; H^+ pumped across membrane; ATP synthase produces approximately 34 ATP; O_2 is final electron acceptor forming water). Anaerobic: glycolysis only (2 ATP); pyruvate to ethanol + CO_2 in yeast (used in baking and brewing); pyruvate to lactate in mammals during intense exercise (causes oxygen debt repaid after exercise by oxidising lactate). Gas exchange in leaf: CO_2 enters and O_2 leaves through stomata by diffusion; large internal surface area of mesophyll (approximately 10 times external leaf area); gases move through interconnected air spaces. Gas exchange in humans: alveoli (approximately 70 m^2 surface area; one cell thick wall; rich capillary supply); O_2 diffuses from alveolar air into blood; CO_2 diffuses from blood into alveolus; breathing movements ventilate lungs to maintain concentration gradients.
3. Excretion: removal of metabolic waste products (not egestion which removes undigested food). Plant excretion: O_2 (photosynthesis waste) and CO_2 (respiration waste) via stomata and lenticels; water vapour via transpiration; some waste stored in vacuoles or bark; no nitrogenous waste (do not break down protein for energy). Animal excretion: nitrogenous waste from deamination of amino acids: ammonia (ammonotelic; fish; toxic; needs water); urea (ureotelic; mammals; liver converts ammonia to urea); uric acid (uricotelic; birds, reptiles, insects; semi-solid; minimal water). Human kidney: cortex (Bowman's capsule and glomerulus), medulla (loop of Henle and collecting ducts), pelvis (collects urine). Nephron process: ultrafiltration (high pressure in glomerulus forces small molecules into Bowman's capsule); PCT (reabsorbs all glucose, amino acids, and most water by active transport); loop of Henle (creates salt gradient for urine concentration); DCT and collecting duct (water reabsorption regulated by ADH; concentrated urine formed). Asexual reproduction: no gametes; clones; binary fission (Amoeba), budding (Hydra), fragmentation (Planaria),

vegetative propagation (runners, bulbs, tubers, rhizomes). Advantages: rapid; no mate needed. Disadvantage: no genetic variation. Sexual reproduction in plants: flower (anther and pollen; carpel with ovary and ovule); pollination (wind or insect); pollen tube germinates and grows to ovule; double fertilisation (zygote → embryo; polar nuclei + male nucleus → endosperm). Sexual reproduction in animals: external fertilisation (fish, amphibians; many eggs; water needed); internal fertilisation (reptiles, birds, mammals; fewer but protected offspring); human reproduction: sperm from testes; egg from ovary; fertilisation in fallopian tube; implantation in uterus; placenta provides O2 and nutrients to fetus; 40-week pregnancy.

Answers to Pilot Questions [Series 4]

Part 4.1

1. Autotrophic: organisms produce their own food from inorganic raw materials using light (photoautotrophs: plants, algae) or chemical energy (chemoautotrophs: some bacteria); no organic food source needed. Heterotrophic: organisms cannot produce their own food and must obtain it by consuming organic material made by other organisms; includes holozoic, saprotrophic, and parasitic nutrition.
2. In the mouth: salivary amylase hydrolyses starch to maltose (pH 7). In the stomach: no starch digestion (amylase inactivated by HCl). In the duodenum: pancreatic amylase hydrolyses any remaining starch to maltose. In the ileum: brush-border enzyme maltase hydrolyses maltose to glucose; glucose absorbed into the blood through the villi.
3. Bile is produced by the liver and stored in the gall bladder; it is released into the duodenum via the bile duct. Its role in digestion: (1) emulsification of fats (breaks large fat droplets into many small droplets, greatly increasing the surface area for lipase action); (2) neutralisation of the acidic stomach chyme (bile is alkaline, raising pH to approximately 7 to 8, the optimum for pancreatic enzymes).
4. Nitrogen (N): synthesis of amino acids, proteins, and nucleic acids; deficiency causes chlorosis and stunted growth. Phosphorus (P): component of ATP, DNA, RNA, and phospholipid membranes; deficiency causes purple leaf coloration and poor root growth. Potassium (K): stomatal guard cell function and enzyme activation; deficiency causes leaf scorch and wilting. Magnesium (Mg): essential component of chlorophyll; deficiency causes interveinal chlorosis.

5. Nitrogen deficiency: yellowing (chlorosis) of older leaves first (nitrogen is mobilised from older to younger leaves); stunted growth and thin yellow-green stems. Magnesium deficiency: interveinal chlorosis of older leaves (yellowing between the veins, which remain green); older leaves affected first because Mg is also mobilised from older leaves.

Part 4.2

1. Overall equation: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy (approximately 38 ATP). Stage 1: glycolysis (cytoplasm; no O_2). Stage 2: Krebs cycle (mitochondrial matrix; no O_2 directly). Stage 3: oxidative phosphorylation (inner mitochondrial membrane; O_2 required as final electron acceptor).
2. Aerobic: 38 ATP per glucose; products are CO_2 and water; requires O_2; complete oxidation of glucose. Anaerobic: 2 ATP per glucose; products are ethanol + CO_2 (yeast) or lactate (mammals); no O_2; only partial oxidation of glucose via glycolysis.
3. Oxygen debt (excess post-exercise oxygen consumption, EPOC): during intense exercise, muscles respire anaerobically because oxygen supply cannot meet demand; lactate accumulates in muscles causing fatigue. After exercise, extra oxygen (the oxygen debt) is consumed to: oxidise lactate back to pyruvate; oxidise pyruvate completely by aerobic respiration; replenish ATP and phosphocreatine stores; the elevated breathing and heart rate after exercise repay this debt.
4. During the day: CO_2 from the air diffuses through stomata into the leaf air spaces; it diffuses through the mesophyll to chloroplasts for photosynthesis; O_2 produced by photosynthesis diffuses out through stomata. At night: only respiration occurs; O_2 diffuses in through stomata; CO_2 diffuses out. Gases move by diffusion down their concentration gradients; the spongy mesophyll provides a large internal air space surface for gas exchange.
5. Alveoli are adapted for efficient gas exchange because: (1) enormous total surface area (approximately 70 m2 in adult humans) allowing rapid diffusion; (2) very thin walls (one cell thick alveolar epithelium + one cell thick capillary endothelium; total approximately 0.5 micrometres) minimising the diffusion distance; (3) dense surrounding capillary network maintains a steep concentration gradient by continuously removing O_2 and delivering CO_2; (4) moist inner surface allows gases to dissolve for diffusion across the wall.

Part 4.3

1. Excretion: removal of the toxic waste products of metabolism from an organism (e.g. CO_2 from respiration, urea from deamination of amino acids). Egestion: removal of undigested food material (faeces) from the body through the anus; faeces was never actually inside the body cells and is not a metabolic waste product. Egestion is not excretion.
2. Plants produce less nitrogenous waste because they rarely break down proteins for energy; they use carbohydrates (glucose from photosynthesis) as their primary energy source. Nitrogen from amino acids is recycled within the plant rather than excreted. Animals must break down amino acids for energy when carbohydrate reserves are low, releasing the amino group as toxic ammonia, which must be converted and excreted.
3. Ammonotelic: excretes ammonia (NH_3); highly toxic; very soluble; excreted directly into surrounding water; requires abundant water; e.g. bony fish, aquatic invertebrates. Ureotelic: excretes urea; less toxic; moderately soluble; requires some water; e.g. mammals, amphibians, cartilaginous fish. Uricotelic: excretes uric acid; nearly insoluble; semi-solid paste; requires minimal water; ideal for water conservation; e.g. birds, reptiles, insects.
4. Blood enters the glomerulus (a knot of capillaries inside the Bowman's capsule) under high pressure (maintained by the wider afferent arteriole and narrower efferent arteriole). This high hydrostatic pressure forces small molecules (water, glucose, urea, mineral salts, uric acid) through the thin glomerular capillary walls and the inner layer of the Bowman's capsule into the capsule space, forming the glomerular filtrate. Large molecules (plasma proteins, blood cells) are too large to pass through and remain in the blood.
5. All glucose present in the glomerular filtrate is reabsorbed in the proximal convoluted tubule (PCT) by active transport (against a concentration gradient; requires ATP) from the tubule lumen into the surrounding capillaries. Under normal conditions, no glucose appears in the final urine. In uncontrolled diabetes mellitus, blood glucose concentration exceeds the renal threshold (approximately 10 mmol/L); the PCT cannot reabsorb all the glucose and glucose appears in the urine (glycosuria).

Part 4.4

1. Vegetative propagation by stolons/runners (strawberry; horizontal stem roots at nodes); bulbs (onion; underground leaf bases with apical bud); tubers (yam and potato; swollen underground storage organs); rhizomes (ginger; horizontal underground stems that produce new shoots).
2. Two advantages: (1) rapid colonisation of a favourable habitat without the need to find a mate or produce flowers; (2) successful genotypes (well-adapted to current conditions) are

reproduced exactly in all offspring. One disadvantage: no genetic variation in offspring; all individuals are susceptible to the same diseases, pests, or environmental changes; a single pathogen could wipe out the entire clone population.

3. Pollination: transfer of pollen from the anther (of the stamen) to the stigma of the same flower (self-pollination) or a different flower of the same species (cross-pollination); may be by wind (light, smooth pollen; feathery stigma) or insects (bright petals, nectar, sticky pollen). Fertilisation: pollen grain germinates on the stigma; pollen tube grows down the style to the ovule; two male nuclei released; double fertilisation: first fuses with egg cell forming zygote (→ embryo), second fuses with polar nuclei forming endosperm; ovule develops into seed; ovary develops into fruit.
4. External fertilisation: eggs and sperm released into water; fertilisation occurs outside the female body; large numbers of eggs needed to compensate for losses to predation; e.g. most fish, frogs. Internal fertilisation: sperm deposited inside the female reproductive tract; fertilisation occurs inside the female body; fewer offspring but better protected; e.g. reptiles, birds, and mammals including humans.
5. The placenta is a temporary organ that develops in the uterus wall from both embryonic and maternal tissue during pregnancy. It: supplies the fetus with oxygen and nutrients (glucose, amino acids, vitamins) from the mother's blood; removes CO_2 and other waste products from fetal blood back into the mother's blood for excretion; produces hormones (progesterone, oestrogen, HCG) to maintain the pregnancy; acts as a barrier against most pathogens and some harmful substances. The umbilical cord connects the fetus to the placenta.

References and Attributions [Series 4]

Textual References (Books and External Sources)

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Figures, Plates, Tables, and Boxes

- Figure 4.1: Human alimentary canal labelled diagram Attribution: AI generated. Suggested OER search string: "human alimentary canal digestive system labelled diagram stomach small intestine villi OER".
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- Box 4.1: Comparison of sexual and asexual reproduction table Attribution: AI generated. Suggested OER search string: "comparison asexual sexual reproduction table gametes fertilisation genetic variation examples OER box".

Course code: BIO 102

Course title: General Biology II

Course credit load: 2 Units

Series 5: Growth and Development in Plants and Animals

- **Part 5.1: Measurement and Patterns of Growth**
  - Sub Part 5.1.1: Definition and measurement of growth
  - Sub Part 5.1.2: Growth curves in plants and animals
  - Sub Part 5.1.3: Primary and secondary growth in plants
- **Part 5.2: Cell Division and Development**
  - Sub Part 5.2.1: Mitosis
  - Sub Part 5.2.2: Meiosis
  - Sub Part 5.2.3: Differentiation and development
- **Part 5.3: Development in Plants**
  - Sub Part 5.3.1: Seed structure and germination
  - Sub Part 5.3.2: Development of the seedling
  - Sub Part 5.3.3: Vegetative growth and flowering
- **Part 5.4: Development in Animals**
  - Sub Part 5.4.1: Embryonic development
  - Sub Part 5.4.2: Metamorphosis
  - Sub Part 5.4.3: Post-natal growth and ageing

Introduction

Growth is the irreversible increase in the size, mass, and complexity of an organism. Development is the coordinated sequence of changes in form and function that leads from a single cell to a mature multicellular organism. Both processes depend on cell division (mitosis and meiosis), cell differentiation, and the regulation of gene expression.

This final Series covers the measurement and patterns of growth, the cell divisions that underlie growth and reproduction, development in plants from seed germination to flowering, and development in animals from embryo through metamorphosis or post-natal growth to ageing. These topics bring together concepts from all previous Series in a unified account of the biology of the life cycle.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 5.1** define growth, describe how it is measured, and explain the characteristic growth curves of plants and animals (Linked to Part 5.1),
- **SLO 5.2** distinguish between primary and secondary growth in plants (Linked to Part 5.1),
- **SLO 5.3** describe the stages of mitosis and meiosis and explain the significance of each (Linked to Part 5.2),
- **SLO 5.4** define differentiation and explain how a single zygote gives rise to many specialised cell types (Linked to Part 5.2),
- **SLO 5.5** describe seed structure, germination, and the development of the seedling (Linked to Part 5.3),
- **SLO 5.6** describe vegetative growth and the factors controlling flowering (Linked to Part 5.3), and
- **SLO 5.7** describe embryonic development, metamorphosis, and post-natal growth and ageing in animals (Linked to Part 5.4).

5.1 Measurement and Patterns of Growth

5.1.1 Definition and measurement of growth

Growth is the irreversible increase in the dry mass, size, or cell number of an organism. The most accurate measure of growth is dry mass (the mass of tissue after all water is removed), because fresh mass fluctuates with water content. Other measures include: linear measurements (height, length, root length); surface area; and cell count. Growth requires both an increase in cell number (by cell division) and an increase in cell size (by cell enlargement).

A growth rate is the increase in size or mass per unit time. In plants, growth is continuous throughout life (indeterminate) because meristems (zones of dividing cells) persist in roots and shoot tips. In most animals, growth is determinate: it slows and stops when the organism reaches adult size. Factors affecting growth include: nutrition (adequate food supply); water; light (in plants); temperature; hormones; and genetic information.

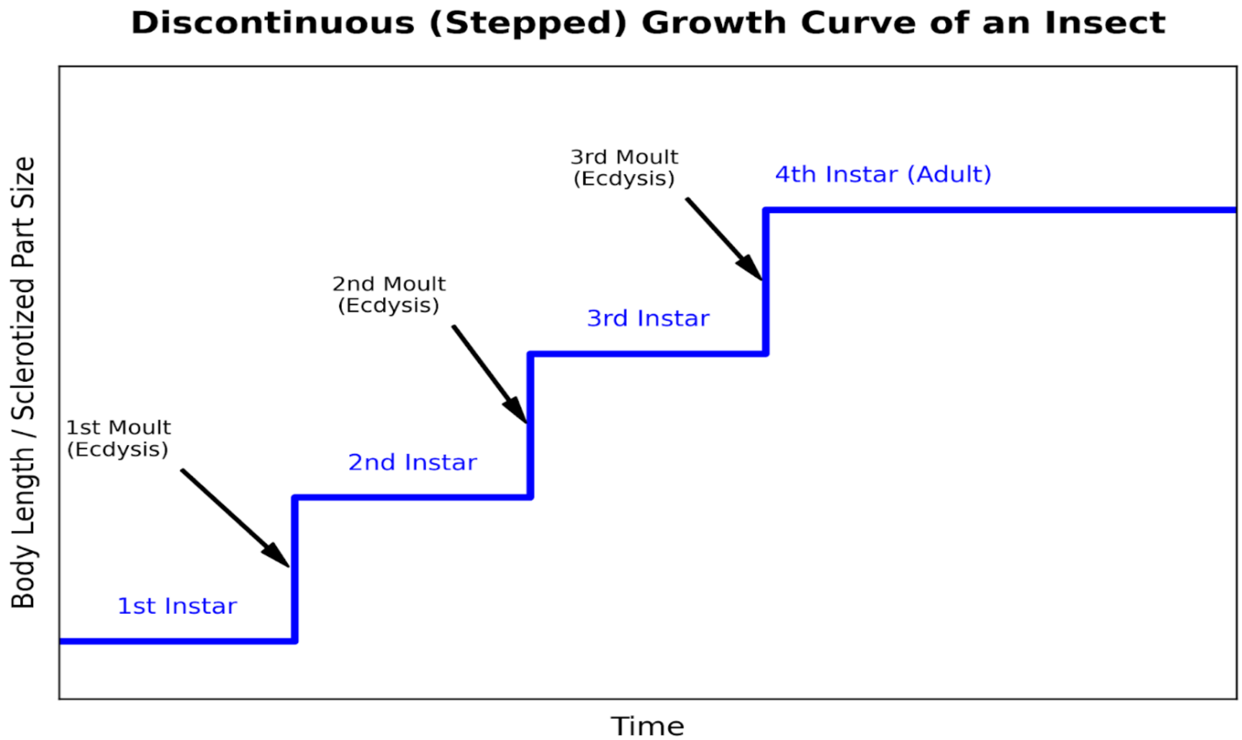
Fill in the blank: The most accurate measure of growth is ________ mass (mass after all water is removed), because fresh mass fluctuates with water content; dry mass directly reflects the amount of organic material in the organism.

5.1.2 Growth curves in plants and animals

When growth (total size or mass) is plotted against time, most organisms show a sigmoid (S-shaped) growth curve with four phases: lag phase (slow initial growth; cells dividing but total size change is small); log (exponential) phase (rapid accelerating growth; abundant resources); deceleration phase (growth slows as resources become limiting or the organism approaches adult size); and stationary or plateau phase (growth stops; adult size reached or a steady state maintained).

Insects (and some other invertebrates) show a stepped growth curve: because the exoskeleton cannot expand, growth occurs in rapid spurts after each moult (ecdysis), when the new soft exoskeleton hardens. The graph shows a staircase pattern of rapid increase followed by a plateau. Annual plants show rapid vegetative growth followed by flowering and seed production, then senescence and death. Perennial plants continue the sigmoid pattern year after year with seasonal variation.

Fill in the blank: Insects show a ________ growth curve because their rigid exoskeleton cannot expand continuously; growth occurs in rapid spurts immediately after each moult (ecdysis) when the new soft exoskeleton can temporarily expand.



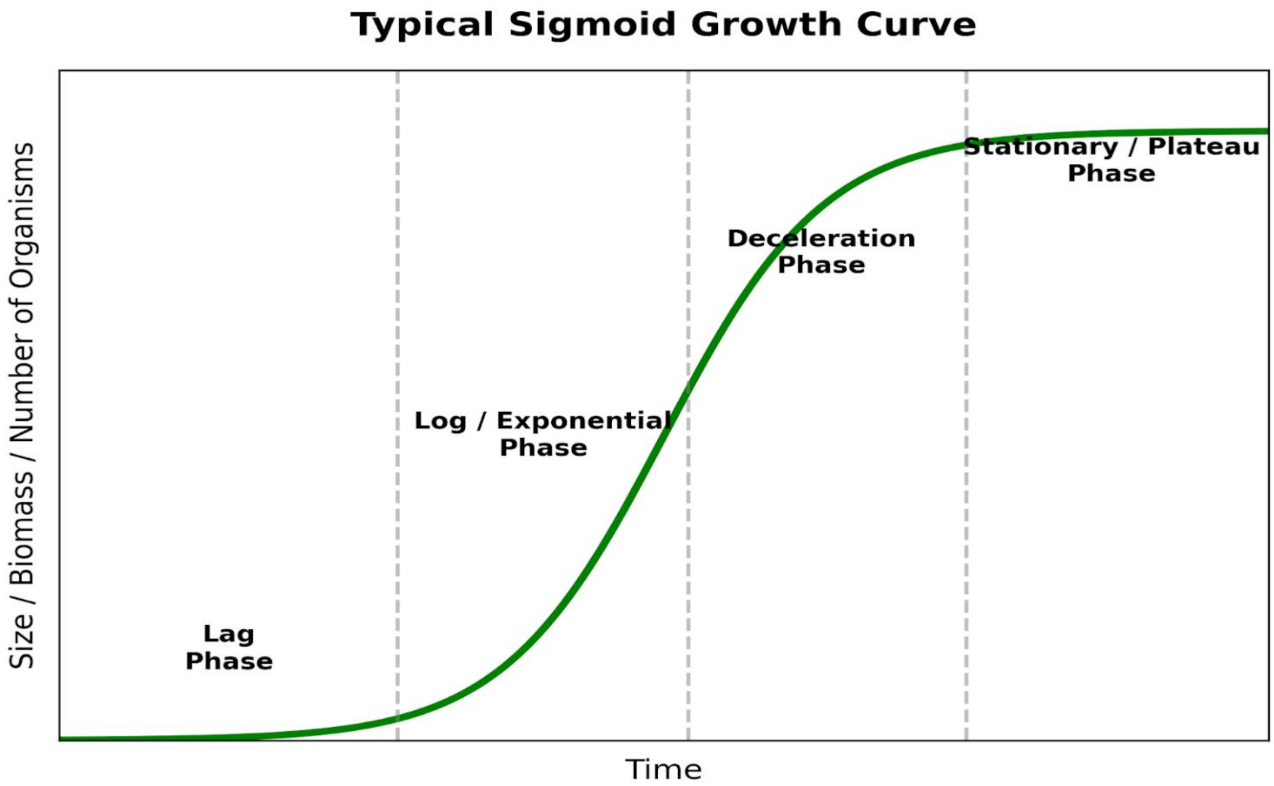


Figure 5.1: Growth curves showing sigmoid curve (typical organism) and stepped curve (insect)

5.1.3 Primary and secondary growth in plants

Primary growth occurs at apical meristems (shoot apex and root tip) and increases the length of shoots and roots. The root tip has three zones: zone of cell division (apical meristem; cells dividing by mitosis); zone of elongation (cells expanding by absorbing water; drives root growth); and zone of maturation (cells differentiating into xylem, phloem, root hairs, cortex). Shoot apical meristems similarly produce new leaves, internodes, and stem tissue.

Secondary growth (thickening) occurs in woody dicots and gymnosperms through the activity of two lateral meristems: the vascular cambium (produces secondary xylem (wood) inward and secondary phloem outward; responsible for trunk diameter increase; annual rings of wood are produced seasonally) and the cork cambium (phellogen; produces bark on the outer surface as the plant grows). Monocots (e.g. palm trees, grasses) and most herbaceous plants do not have true secondary growth.

Fill in the blank: Secondary growth in woody plants is driven by the ________ cambium (producing wood and bark) and cork cambium; it increases stem and root diameter and produces the annual rings visible in cross-sections of tree trunks.

Pilot questions 5.1

1. Define growth and state the most accurate method of measuring it.
2. Describe the four phases of a sigmoid growth curve.
3. Explain why insects show a stepped growth curve.
4. Distinguish between primary and secondary growth in plants.
5. State three factors that affect the rate of growth in organisms.

5.2 Cell Division and Development

5.2.1 Mitosis

Mitosis is a type of cell division that produces two daughter cells genetically identical to the parent cell. It maintains the chromosome number (diploid, 2n). Mitosis is responsible for: growth (increasing cell number); repair and replacement of damaged or worn-out cells; and asexual reproduction. It occurs in all somatic (body) cells. The process is continuous but conventionally divided into four stages: prophase, metaphase, anaphase, and telophase, followed by cytokinesis (division of the cytoplasm).

Stages: Prophase: chromosomes condense and become visible; nuclear envelope breaks down; spindle fibres form from centrioles (animals) or cytoplasm (plants). Metaphase: chromosomes align at the cell equator (metaphase plate); spindle fibres attach to centromeres. Anaphase: sister chromatids are pulled to opposite poles by shortening spindle fibres. Telophase: nuclear envelopes reform around each set of chromosomes; chromosomes decondense. Cytokinesis: cytoplasm divides (in animals: cleavage furrow; in plants: cell plate forms from Golgi vesicles).

Fill in the blank: In ________, chromosomes align at the cell equator and spindle fibres attach to the centromeres of each chromosome; this is the stage most commonly observed in preparations of actively dividing tissue.

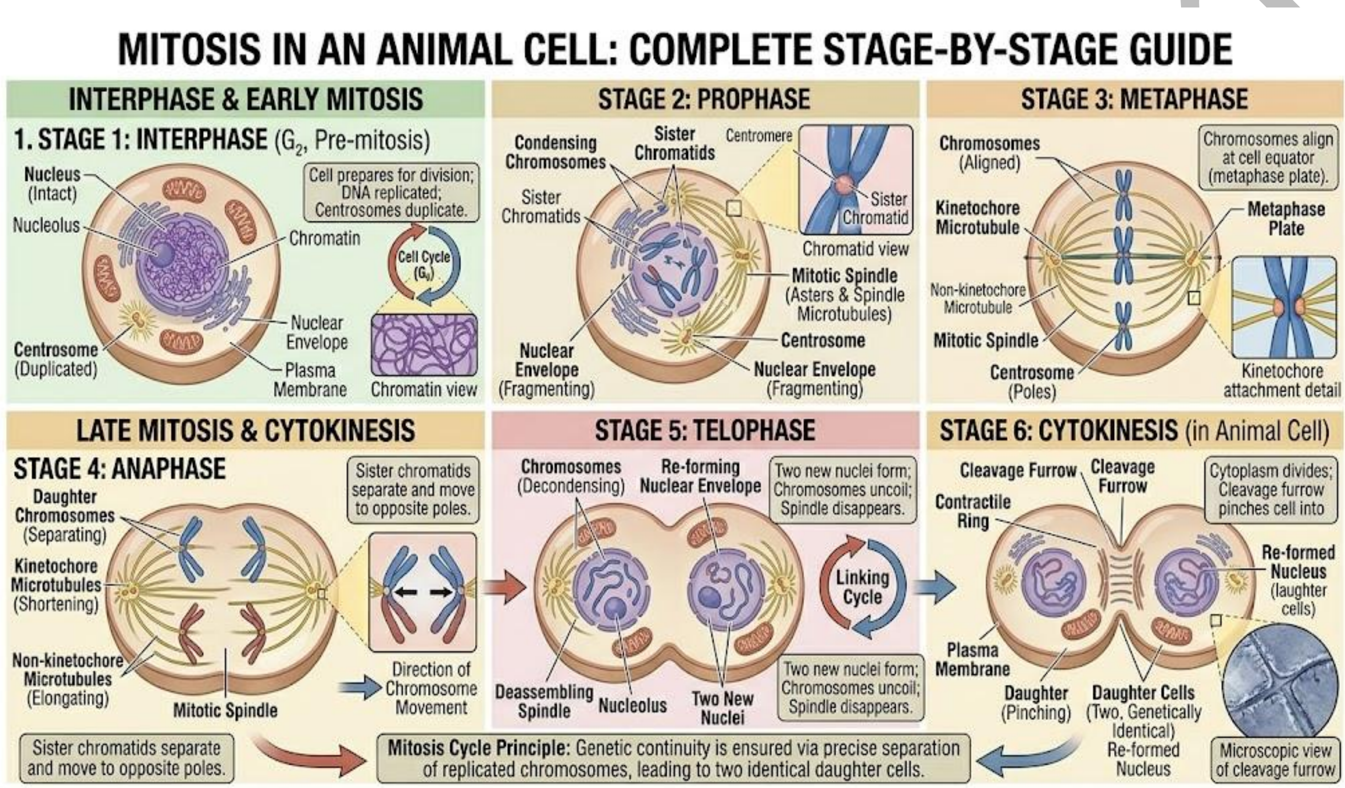


Figure 5.2: Diagrams of the stages of mitosis in an animal cell

5.2.2 Meiosis

Meiosis is a type of cell division that produces four haploid (n) cells from one diploid (2n) parent cell. It occurs only in reproductive organs (gonads in animals; anthers and ovaries in plants) to produce gametes (sperm, eggs, pollen). Meiosis consists of two successive divisions: Meiosis I (separates homologous chromosome pairs; reduces chromosome number from 2n to n) and Meiosis II (separates sister chromatids, similar to mitosis; no DNA replication between Meiosis I and II).

Crucially, Meiosis I includes crossing over (chiasmata formation): during prophase I, homologous chromosomes pair up (bivalents) and exchange segments of DNA, creating new combinations of alleles (genetic recombination). Together with independent assortment of chromosomes at metaphase I, this generates enormous genetic variation in the gametes. This genetic variation is the raw material for evolution by natural selection and is the primary advantage of sexual reproduction over asexual reproduction.

Fill in the blank: During prophase I of meiosis, homologous chromosomes pair up and exchange DNA segments (________ over), creating new allele combinations; this is one of the main sources of genetic variation in sexually reproducing organisms.

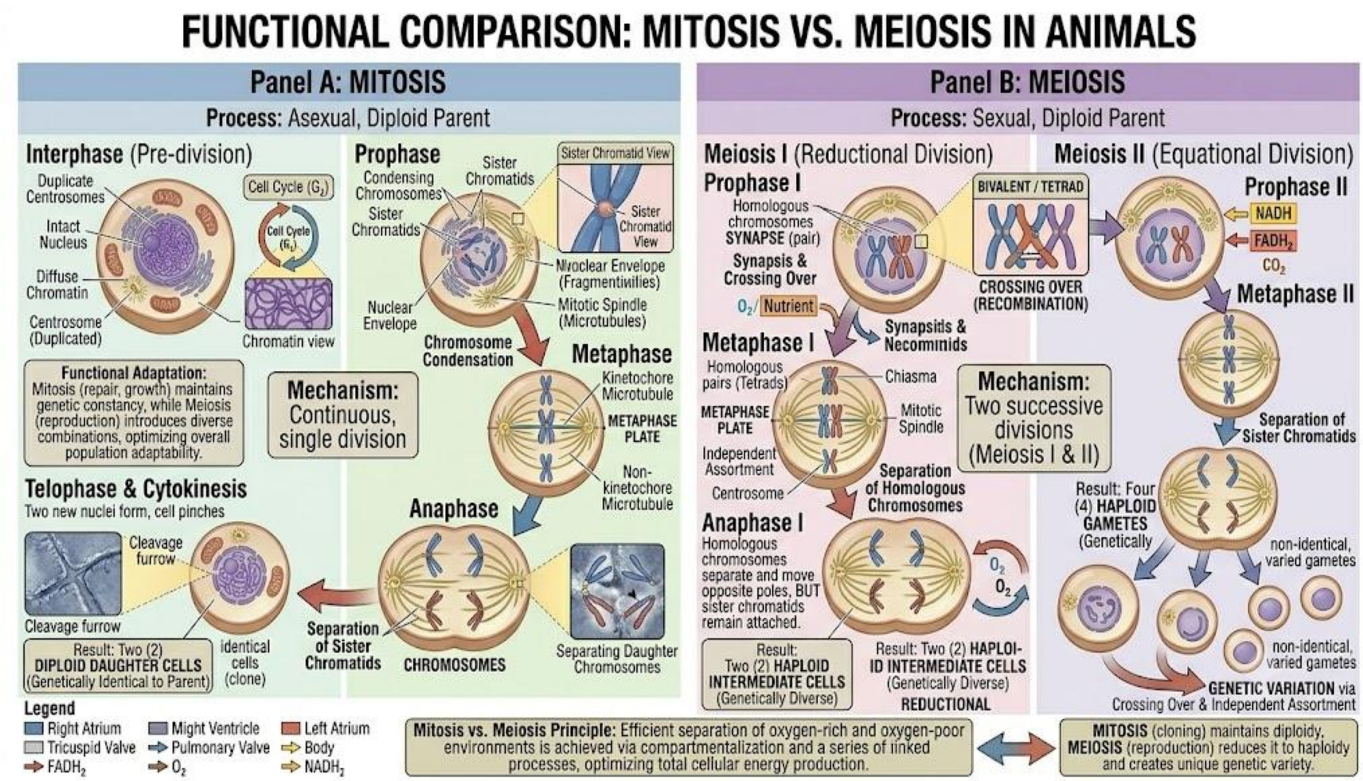


Figure 5.3: Diagram comparing mitosis and meiosis showing chromosome behaviour and outcomes

5.2.3 Differentiation and development

Differentiation is the process by which a cell becomes specialised for a specific function, developing a distinctive structure and biochemistry. All cells in a multicellular organism (except red blood cells) contain the same DNA, yet cells look and function very differently. This is because differentiation involves the selective expression of genes: only a subset of the organism's genes are switched on or off in any given cell type. Stem cells are undifferentiated cells that can divide and differentiate into specialised cell types.

Development is the orderly sequence of changes from zygote to mature organism, including: cleavage (rapid mitotic divisions of the zygote, producing a ball of cells called the morula); blastulation (formation of the blastocyst or blastula, a hollow ball); gastrulation (formation of three germ layers: ectoderm, mesoderm, endoderm); organogenesis (organ formation from germ layers: ectoderm forms skin and nervous system; mesoderm forms muscle, skeleton, kidneys; endoderm forms gut lining, lungs, liver). Plant development proceeds from embryo to seedling to mature plant.

Fill in the blank: ________ is the process by which cells become specialised for specific functions; all body cells contain the same DNA, but differentiation involves selective gene expression, switching on only the genes needed for that cell type.

Pilot questions 5.2

1. State three roles of mitosis in organisms.
2. Describe the stages of mitosis in the correct sequence.
3. State two ways in which meiosis differs from mitosis.
4. Explain the significance of crossing over in meiosis.
5. Define differentiation and explain how cells with the same DNA can have different functions.

5.3 Development in Plants

5.3.1 Seed structure and germination

A seed contains: the embryo (young plant: radicle/embryonic root, plumule/embryonic shoot, cotyledons); the seed coat (testa: protective outer layer); and the endosperm (food reserve in most seeds; replaced by cotyledons in some seeds). In a dicot seed (e.g. bean, Phaseolus): two large fleshy cotyledons store food (starch, protein, fat); no endosperm in the mature seed. In a monocot seed (e.g. maize): one cotyledon called the scutellum absorbs food from the large endosperm.

Germination is the resumption of growth by the embryo, using food stored in the seed. Conditions required: adequate water (to activate enzymes and soften the testa); oxygen (for aerobic respiration to provide ATP for growth); and a suitable temperature (for enzyme activity). Light is not generally required for germination but is required for subsequent seedling growth. Epigeal germination: cotyledons brought above the soil surface (e.g. bean); hypogeal germination: cotyledons remain below the soil (e.g. maize, pea).

Fill in the blank: Germination requires water (activates enzymes), ________ (for aerobic respiration), and a suitable temperature; in epigeal germination the cotyledons are brought above the soil, while in hypogeal germination they remain below ground.

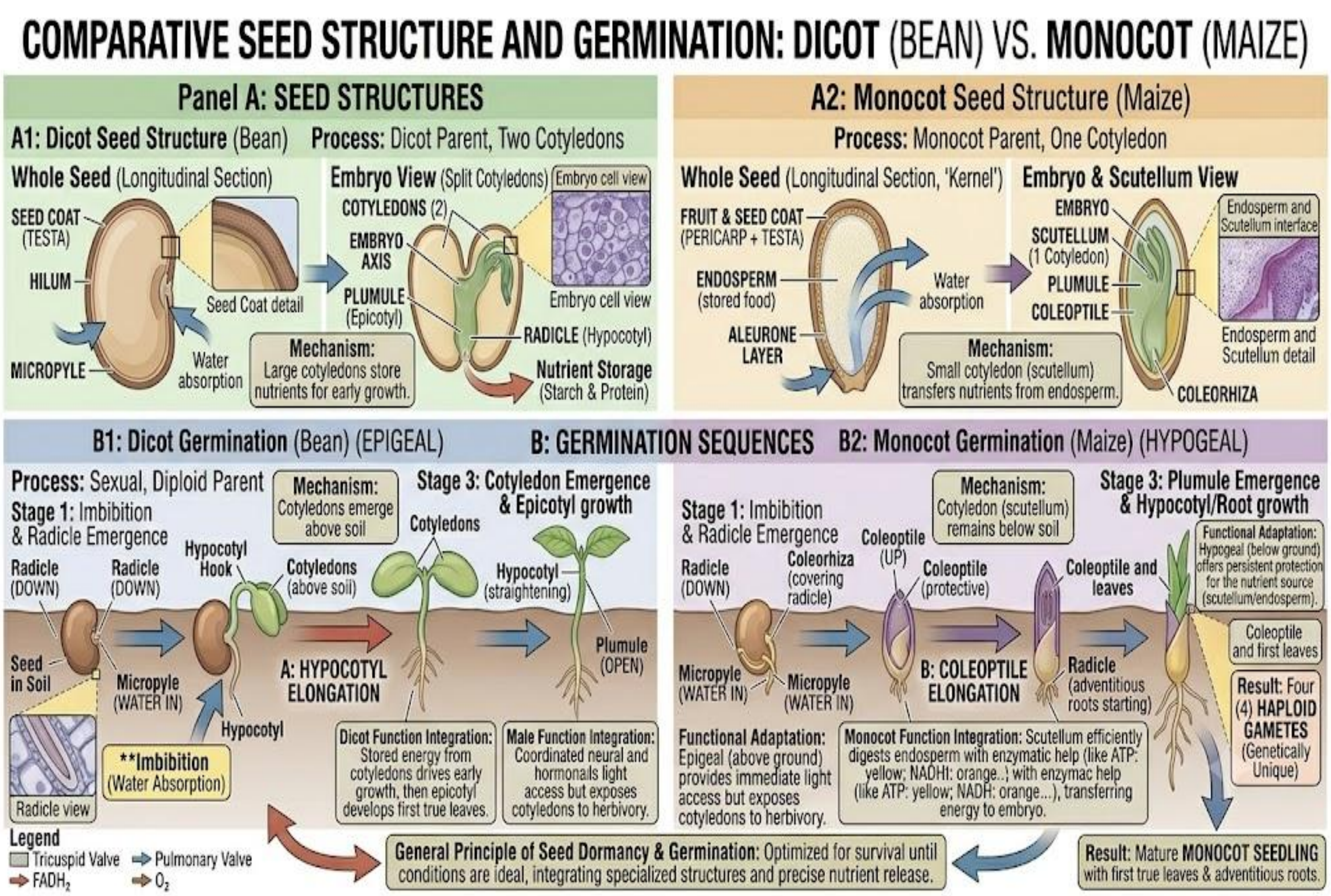


Figure 5.4: Diagrams showing dicot and monocot seed structure and germination types

5.3.2 Development of the seedling

After germination, the seedling develops through several stages. The radicle grows downward (positive gravitropism; negative phototropism) and develops lateral roots and root hairs for water and mineral absorption. The plumule grows upward (positive phototropism; negative gravitropism) and unfolds to produce the first true leaves. The shoot apex continues to produce new leaf primordia and internodes by cell division at the apical meristem.

During the seedling stage, the young plant is dependent on food stored in the cotyledons or endosperm for energy and carbon until the first true leaves are large enough to photosynthesize effectively. The transition from heterotrophic nutrition (using seed reserves) to autotrophic nutrition (photosynthesis) is a critical developmental milestone. If light is insufficient at this stage, the seedling etiolates (becomes pale, elongated, and weak) as it uses all available resources to grow toward light.

Fill in the blank: During seedling development, the young plant is initially ________ (using stored food from seed reserves) until the first true leaves are large enough to photosynthesize and support autotrophic growth.

5.3.3 Vegetative growth and flowering

Vegetative growth is the phase during which the plant increases in size through leaf, stem, and root production without forming reproductive organs. It is driven by apical and axillary meristems and is promoted by the plant hormones auxin and cytokinin. The transition from vegetative to reproductive growth (flowering) is controlled by photoperiodism (the response of the plant to the relative lengths of day and night). The critical night length (dark period) determines whether a plant flowers.

Three photoperiodic categories: short-day plants (SDP) flower when the night is longer than their critical night length (actually respond to long nights); e.g. chrysanthemum, cocklebur, and some sorghum varieties in Nigeria. Long-day plants (LDP) flower when the night is shorter than their critical night length; e.g. spinach, wheat. Day-neutral plants (DNP) flower regardless of photoperiod; e.g. tomato, cucumber, maize. Phytochrome is the photoreceptor pigment that detects the red and far-red light ratio at dusk and dawn, providing the plant with a timing signal.

Fill in the blank: ________ plants flower when the night is longer than their critical night length; long-day plants flower when the night is shorter than their critical length; day-neutral plants flower regardless of photoperiod.

Pilot questions 5.3

1. Label the parts of a dicot seed and state the function of each.
2. State three conditions required for germination.
3. Distinguish between epigeal and hypogeal germination with one example of each.
4. Explain what photoperiodism is and distinguish between short-day and long-day plants.
5. Explain what etiolation is and what causes it.

5.4 Development in Animals

5.4.1 Embryonic development

After fertilisation, the zygote undergoes rapid mitotic divisions (cleavage) without cell growth, producing a morula (solid ball of cells) and then a blastula or blastocyst (hollow ball with an inner cell mass). Gastrulation follows: cells migrate to form three primary germ layers. Ectoderm (outer layer): gives rise to skin epidermis and the nervous system. Mesoderm (middle layer): gives rise to muscle, bone, connective tissue, kidneys, and the circulatory system. Endoderm (inner layer): gives rise to the gut lining, liver, pancreas, and lungs.

Organogenesis is the formation of organs from the germ layers. Neurulation is an early organogenesis event in which the ectoderm folds inward to form the neural tube, giving rise to the brain and spinal cord. The notochord (a rod of mesodermal cells beneath the neural tube) induces neural tube formation by secreting signalling molecules. In humans, organogenesis is largely complete by the 8th week of pregnancy; the embryo is then called a fetus. Birth defects often result from disruptions to organogenesis during this critical window.

Fill in the blank: During gastrulation, three primary germ layers form: ectoderm (skin and nervous system), ________ (muscle, bone, kidney, circulatory system), and endoderm (gut lining, liver, lungs).

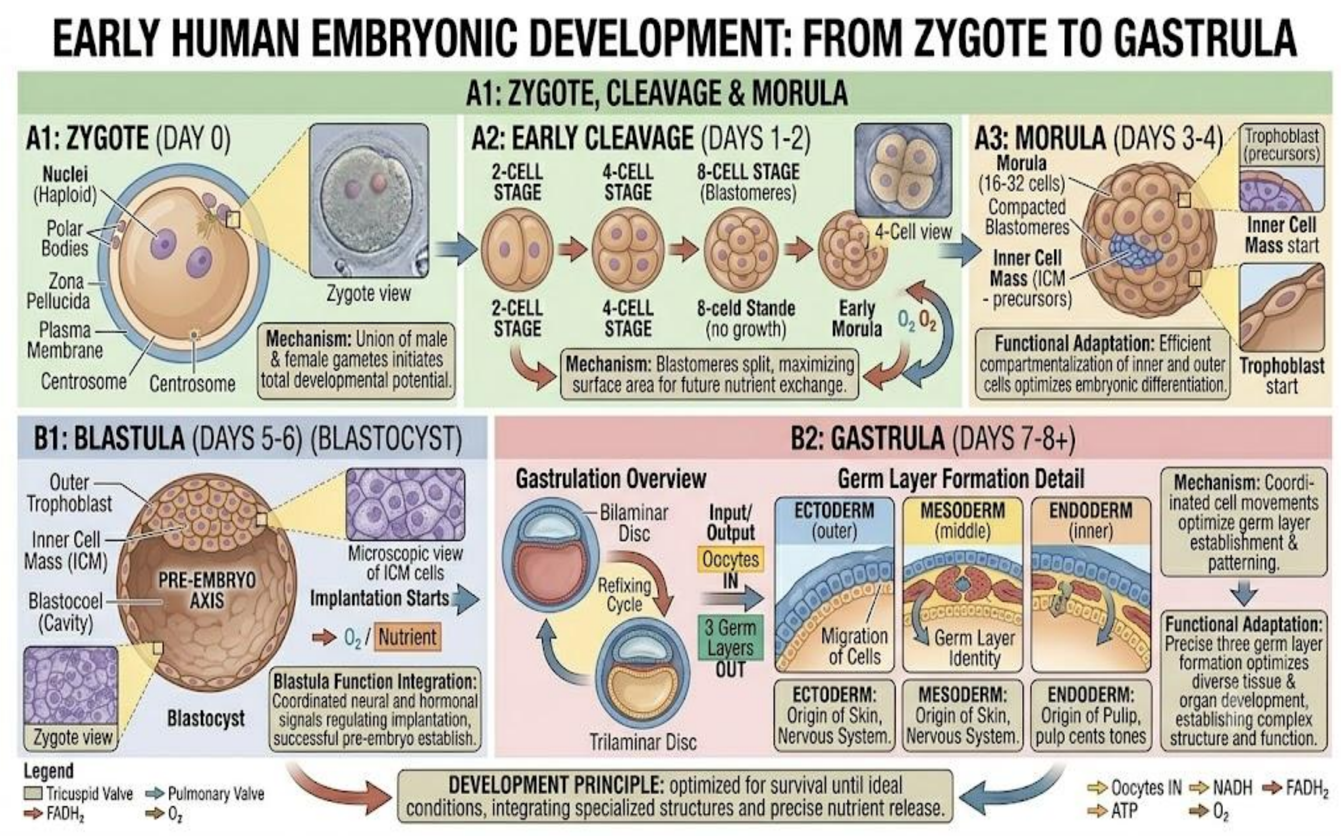


Figure 5.5: Diagram of early embryonic development from zygote to gastrula

5.4.2 Metamorphosis

Metamorphosis is the process of dramatic transformation in body form and physiology that occurs during the development of some animals. Complete metamorphosis (holometabolism): four distinct stages: egg → larva (e.g. caterpillar; feeding and growth stage) → pupa (e.g. chrysalis; no feeding; massive reorganisation of larval tissues) → adult (imago; reproductive stage). Examples: butterflies, moths, flies, beetles, bees. The larva and adult occupy different ecological niches, reducing competition between generations.

Incomplete metamorphosis (hemimetabolism): three stages: egg → nymph (a miniature wingless version of the adult; undergoes several moults, each producing a slightly larger and more developed nymph) → adult. Examples: grasshoppers, cockroaches, dragonflies. The nymph and adult occupy similar niches and eat similar food. In amphibians (e.g. frogs): egg → tadpole (aquatic; gills; no limbs; herbivorous) → adult (terrestrial; lungs; four limbs; carnivorous). This amphibian metamorphosis is regulated by thyroid hormone.

Fill in the blank: Complete metamorphosis has four stages: egg → larva → ________ → adult; the pupa is a non-feeding stage during which larval tissues are reorganised into the adult body; examples include butterflies and flies.

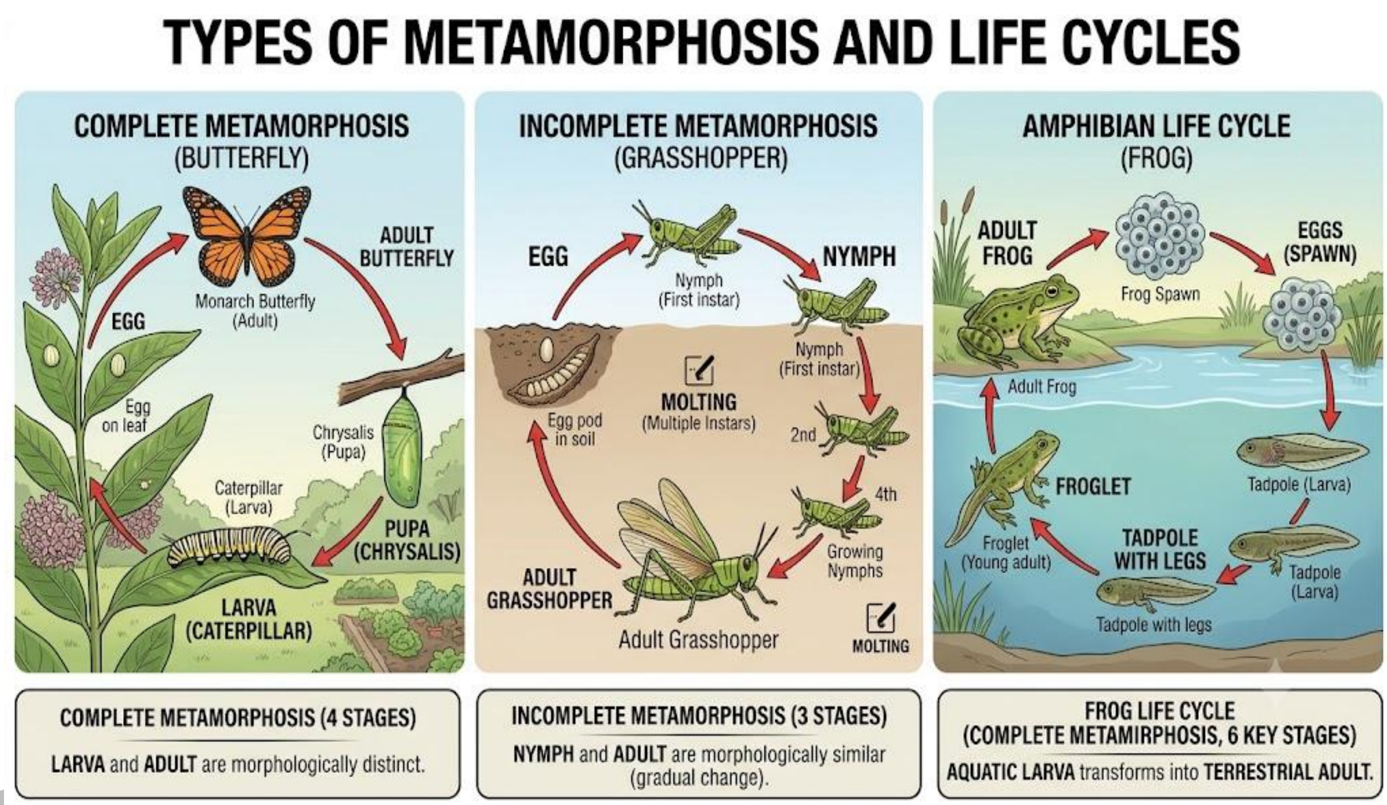


Figure 5.6: Diagram comparing complete and incomplete metamorphosis and frog development

5.4.3 Post-natal growth and ageing

Post-natal (post-birth) growth in mammals follows the sigmoid curve: rapid growth in infancy and childhood; a growth spurt during puberty (stimulated by growth hormone, testosterone in males, and oestrogen in females); deceleration as adult size is approached; and a plateau at adulthood. Growth hormone from the pituitary gland promotes cell division and protein synthesis throughout the growth phase. Thyroid hormone regulates the metabolic rate and is essential for normal brain development and bone growth.

After reaching maturity, organisms eventually show senescence (biological ageing): a progressive decline in physiological function. At the cellular level, ageing involves: shortening of telomeres (protective caps on chromosomes) with each mitotic division until the cell can no longer divide (Hayflick limit); accumulation of DNA damage; decline in mitochondrial efficiency; and failure of repair mechanisms. At the organismal level, ageing involves declining immune function, reduced tissue regeneration, and increased disease susceptibility.

Fill in the blank: During puberty, a growth spurt is stimulated by _________ hormone from the pituitary gland acting together with sex hormones (testosterone in males, oestrogen in females) to promote rapid cell division and protein synthesis.

Aspect	**Plants**	**Animals**
Type of Growth	Indeterminate (continuous throughout life)	Determinate (stops after maturity)
Site	Meristems (apical, lateral, intercalary)	Specific organs/tissues (bones, muscles, organs)
Cell Division	Mitosis in meristematic tissues	Mitosis during growth, meiosis for reproduction
Hormones	Auxins, gibberellins, cytokinins, ethylene	Growth hormone, thyroid hormones, sex hormones
Metamorphosis	Absent	Present in many species (e.g., insects, amphibians)
Ageing	Senescence in leaves, flowers, fruits	Ageing of whole organism leading to death

Box 5.1: Summary of comparison between growth and development in plants and animals

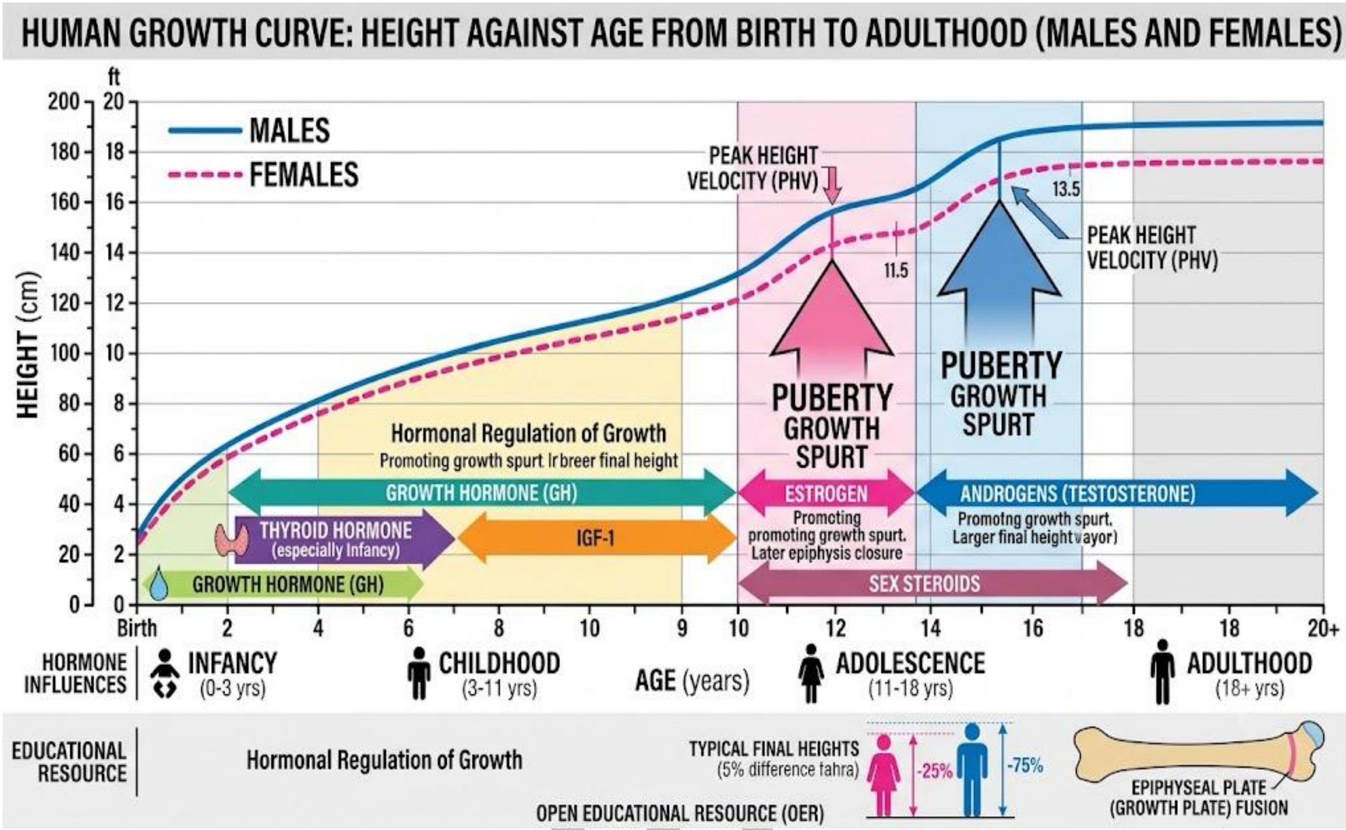


Figure 5.7: Growth curve for humans from birth to adulthood showing puberty growth spurt

Pilot questions 5.4

1. Describe the stages of early embryonic development from zygote to gastrula.
2. State what each of the three germ layers gives rise to.
3. Distinguish between complete and incomplete metamorphosis with one example of each.
4. Describe the life cycle of a frog.
5. Explain what telomere shortening is and how it is related to cellular ageing.

Series Summary

This final Series covered growth and development. Growth is the irreversible increase in dry mass; organisms show sigmoid growth curves with lag, log, deceleration, and plateau phases; insects show stepped curves. Primary growth (meristems) increases length; secondary growth (vascular and cork cambium) increases diameter in woody plants. Mitosis produces two identical diploid daughter cells (growth and repair); meiosis produces four haploid cells (gametes; genetic variation via crossing over and independent assortment). Differentiation: selective gene expression produces specialised cells from a common genome.

Seed structure: testa, embryo (radicle, plumule, cotyledons), endosperm; germination requires water, oxygen, and suitable temperature. Epigeal (bean) vs hypogeal (maize) germination. Seedlings transition from heterotrophic to autotrophic nutrition. Flowering controlled by photoperiodism (short-day, long-day, day-neutral plants; detected by phytochrome). Animal development: cleavage, morula, blastula, gastrulation (three germ layers), organogenesis. Metamorphosis: complete (butterfly: egg-larva-pupa-adult); incomplete (grasshopper: egg-nymph-adult); frog (egg-tadpole-adult). Post-natal growth peaks at puberty (growth hormone, sex hormones); senescence involves telomere shortening and cellular decline. By completing this Series, you should achieve all seven SLOs (5.1 to 5.7) and all course learning outcomes.

Glossary of Terms

- **Apical meristem:** a zone of actively dividing cells at the tip of a shoot or root responsible for primary (lengthwise) growth of the plant.
- **Blastula:** a hollow ball of cells formed by cleavage of the morula; the inner cavity is the blastocoel; in mammals it is called the blastocyst.
- **Cambium:** a lateral meristem in woody plants; vascular cambium produces wood and secondary phloem; cork cambium produces bark.
- **Cleavage:** rapid mitotic divisions of the zygote immediately after fertilisation; cell number increases but total size barely changes; produces the morula.

- **Complete metamorphosis (holometabolism):** a developmental pattern with four distinct stages: egg, larva, pupa, and adult; found in butterflies, flies, beetles, and bees.
- **Crossing over:** the exchange of DNA segments between homologous chromosomes during prophase I of meiosis; creates new allele combinations; a major source of genetic variation.
- **Determinate growth:** growth that stops when an organism reaches adult size; characteristic of most animals.
- **Differentiation:** the process by which a cell becomes specialised in structure and function through selective gene expression; occurs during development.
- **Ectoderm:** the outer primary germ layer formed during gastrulation; gives rise to the skin epidermis, nervous system, and sensory organs.
- **Endoderm:** the inner primary germ layer formed during gastrulation; gives rise to the lining of the digestive tract, liver, pancreas, and respiratory system.
- **Epigeal germination:** germination in which the cotyledons are pushed above the soil surface by the elongating hypocotyl; e.g. bean (Phaseolus).
- **Etiolation:** the pale, elongated, weak growth of seedlings deprived of adequate light; the plant rapidly elongates to reach light at the expense of leaf and chlorophyll development.
- **Gastrulation:** the stage of embryonic development during which the blastula reorganises to form three primary germ layers: ectoderm, mesoderm, and endoderm.
- **Hypogeal germination:** germination in which the cotyledons remain below the soil surface while the epicotyl grows upward; e.g. pea, maize.
- **Incomplete metamorphosis (hemimetabolism):** a developmental pattern with three stages: egg, nymph, and adult; found in grasshoppers, cockroaches, and dragonflies.
- **Indeterminate growth:** growth that continues throughout the life of the organism; characteristic of most plants.
- **Meiosis:** a type of cell division that reduces the chromosome number by half, producing four genetically unique haploid cells; occurs in reproductive organs to produce gametes.
- **Mesoderm:** the middle primary germ layer formed during gastrulation; gives rise to muscle, bone, connective tissue, kidneys, and the circulatory system.

- **Metamorphosis:** a process of dramatic body transformation during development; complete (holometabolism) has four stages; incomplete (hemimetabolism) has three.
- **Mitosis:** a type of cell division producing two genetically identical diploid daughter cells; used for growth, repair, and asexual reproduction.
- **Morula:** a solid ball of cells produced by early cleavage divisions of the zygote, before blastula formation.
- **Neurulation:** the folding of the ectoderm to form the neural tube, which gives rise to the brain and spinal cord; an early organogenesis event.
- **Organogenesis:** the formation of organs from the three primary germ layers during embryonic development.
- **Photoperiodism:** the response of a plant to the relative lengths of day and night; controls flowering in many species; detected by phytochrome.
- **Phytochrome:** a photoreceptor pigment in plants that detects red and far-red light; provides timing information for photoperiodic responses including flowering.
- **Pupa:** a non-feeding, immobile stage between larva and adult in complete metamorphosis; larval tissues are broken down and reorganised to form adult structures.
- **Senescence:** the progressive biological decline in physiological function associated with ageing; involves telomere shortening, DNA damage accumulation, and declining repair mechanisms.
- **Sigmoid growth curve:** an S-shaped growth curve with four phases (lag, log, deceleration, plateau); typical of most populations and organisms growing in a limited environment.
- **Stem cell:** an undifferentiated cell capable of self-renewal by mitosis and differentiation into specialised cell types; embryonic stem cells can form any cell type.
- **Telomere:** a repetitive DNA sequence at the end of a chromosome that protects it from degradation; shortens with each cell division; linked to cellular ageing.
- **Vascular cambium:** a lateral meristem in woody plants that produces secondary xylem (wood) toward the interior and secondary phloem toward the exterior.

Concept Check Questions [Series 5]

Objective Questions

1. The most accurate measure of growth is ________ mass (mass after all water is removed); it directly reflects the amount of organic material. (Linked to SLO 5.1)
2. Insects show a ________ growth curve because their rigid exoskeleton cannot expand between moults. (Linked to SLO 5.1)
3. In ________, chromosomes align at the cell equator and spindle fibres attach to the centromeres. (Linked to SLO 5.3)
4. Germination requires water, ________ (for aerobic respiration), and a suitable temperature. (Linked to SLO 5.5)
5. Complete metamorphosis has four stages: egg, larva, ________, and adult; found in butterflies and flies. (Linked to SLO 5.7)

Short-Answer Questions

1. Describe the four phases of a sigmoid growth curve. (Linked to SLO 5.1)
2. State three roles of mitosis and three roles of meiosis. (Linked to SLO 5.3)
3. Distinguish between epigeal and hypogeal germination. (Linked to SLO 5.5)
4. Distinguish between short-day plants and long-day plants. (Linked to SLO 5.6)
5. State what each of the three germ layers gives rise to. (Linked to SLO 5.7)

Long-Answer Questions

1. Define growth, explain how it is measured, describe growth curves, and distinguish between primary and secondary growth in plants. (Linked to SLOs 5.1, 5.2)
2. Describe the stages of mitosis and meiosis, explain their significance, and define differentiation and development. (Linked to SLOs 5.3, 5.4)
3. Describe seed structure and germination, seedling development, flowering control, embryonic development, metamorphosis, and post-natal growth and ageing. (Linked to SLOs 5.5, 5.6, 5.7)

Answers to Concept Check Questions [Series 5]

Objective Questions

1. Dry.
2. Stepped.
3. Metaphase.
4. Oxygen.
5. Pupa.

Short-Answer Questions

1. Lag phase: slow initial growth; cells dividing but size barely changes. Log (exponential) phase: rapid growth; resources abundant. Deceleration phase: growth slows as resources become limiting. Plateau phase: growth stops; adult size or carrying capacity reached.
2. Mitosis roles: (1) growth (increasing cell number); (2) repair and replacement of damaged cells; (3) asexual reproduction. Meiosis roles: (1) production of haploid gametes for sexual reproduction; (2) generates genetic variation by crossing over; (3) halves chromosome number so fertilisation restores the diploid number.
3. Epigeal: cotyledons pushed above the soil surface by the elongating hypocotyl; e.g. bean (Phaseolus). Hypogeal: cotyledons remain below the soil while the epicotyl and shoot grow upward; e.g. maize (Zea mays) and pea (Pisum sativum).
4. Short-day plants flower when the night is longer than their critical night length (effectively require a long dark period); e.g. chrysanthemum. Long-day plants flower when the night is shorter than their critical night length (require a long day/short night); e.g. spinach and wheat.
5. Ectoderm: skin epidermis, nervous system, and sensory organs. Mesoderm: muscle, bone, connective tissue, kidneys, and circulatory system. Endoderm: lining of the digestive tract, liver, pancreas, and lungs.

Long-Answer Questions

1. Growth: irreversible increase in dry mass, size, or cell number. Most accurate measure: dry mass (unaffected by water content). Other measures: linear measurements, surface area, cell count. Growth curve phases: lag (slow start); log (rapid exponential); deceleration (slowing as

resources limit); plateau (adult size; determinate in most animals; continues in plants which show indeterminate growth). Insects show a stepped curve due to exoskeleton constraints. Sigmoid curves typical of bacteria, populations, and most organisms. Primary growth: at apical meristems (shoot tip and root tip); increases length; three root zones: cell division (mitosis), elongation (water absorption drives extension), maturation (differentiation into xylem, phloem, root hairs). Secondary growth: in woody dicots and gymnosperms; vascular cambium (produces secondary xylem inward = wood; secondary phloem outward); forms annual rings; cork cambium (produces bark); increases diameter. Monocots and most herbaceous plants lack secondary growth.

2. Mitosis: produces 2 diploid (2n) identical daughter cells; continuous but divided into: prophase (chromosomes condense; nuclear envelope breaks down; spindle forms); metaphase (chromosomes align at equator; spindle fibres attach to centromeres); anaphase (sister chromatids pulled to poles by shortening spindle fibres); telophase (nuclear envelopes reform; chromosomes decondense); cytokinesis (cytoplasm divides: cleavage furrow in animals; cell plate in plants). Significance: growth, repair, asexual reproduction. Meiosis: produces 4 haploid (n) genetically unique cells; meiosis I (prophase I: homologous chromosomes pair in bivalents; crossing over occurs at chiasmata; metaphase I: bivalents at equator; anaphase I: homologous pairs separated to poles; telophase I: two haploid cells formed); meiosis II (similar to mitosis; sister chromatids separated; four haploid cells). Significance: produces gametes; halves chromosome number for sexual reproduction; crossing over and independent assortment generate genetic variation. Differentiation: all body cells share the same DNA; differentiation results from selective gene expression; specific genes switched on or off in each cell type; produces specialised cells (nerve, muscle, epithelium, etc.); stem cells can differentiate into many types. Development: cleavage (rapid mitosis of zygote), morula, blastula, gastrulation (ectoderm, mesoderm, endoderm), organogenesis (organ formation from germ layers), neurulation.
3. Seed structure: testa (protective coat); embryo (radicle, plumule, cotyledons); endosperm (food reserve). Dicot seed (bean): two fleshy cotyledons store food; no separate endosperm. Monocot grain (maize): one cotyledon (scutellum) absorbs food from large endosperm. Germination conditions: water (activates enzymes; softens testa); oxygen (aerobic respiration for ATP); suitable temperature (enzyme activity). Epigeal (bean): cotyledons above soil. Hypogeal (maize): cotyledons below soil. Seedling development: radicle grows down; plumule grows up; initially heterotrophic (seed reserves); transitions to autotrophic when leaves expand; etiolation if light is insufficient. Flowering: photoperiodism (response to

day/night length); detected by phytochrome; SDP flower in long nights (e.g. chrysanthemum); LDP flower in short nights (e.g. spinach); DNP flower regardless (e.g. tomato, maize). Embryonic development: zygote → cleavage → morula → blastula → gastrulation (ectoderm: skin, nervous system; mesoderm: muscle, bone, kidney, circulation; endoderm: gut, liver, lung) → organogenesis (organs form from germ layers); neurulation (neural tube → brain and spinal cord). Metamorphosis: complete (butterfly: egg-larva-pupa-adult; larva and adult exploit different niches); incomplete (grasshopper: egg-nymph-adult; nymph resembles adult); frog: egg-aquatic tadpole-adult (thyroid hormone regulated). Post-natal growth: sigmoid curve; puberty growth spurt (growth hormone and sex hormones); adult plateau. Ageing (senescence): telomere shortening with each mitotic division (Hayflick limit); DNA damage accumulation; declining immune function and tissue repair.

Answers to Pilot Questions [Series 5]

Part 5.1

1. Growth is the irreversible increase in the dry mass, size, or cell number of an organism. The most accurate method of measuring growth is dry mass (the mass of the organism after all water has been removed by drying to constant weight at 80 degrees Celsius), because fresh mass fluctuates with water content and does not reliably reflect the actual amount of organic material (true growth) in the organism.
2. Lag phase: slow initial growth; cells are dividing but are small, so total size change is minimal. Log (exponential) phase: rapid growth; conditions are favourable and resources are abundant. Deceleration phase: growth slows as resources become limiting, waste products accumulate, or the organism approaches adult size. Plateau (stationary) phase: net growth stops; the organism reaches its genetically determined adult size (in animals) or a steady state.
3. Insects have a rigid exoskeleton made of chitin that cannot expand gradually as the body grows. Growth can only occur immediately after moulting (ecdysis), when the old exoskeleton is shed and the new one is briefly soft and can expand before hardening. On a growth curve, this produces a staircase pattern: rapid size increase immediately after each moult, followed by a plateau as the new exoskeleton hardens and no further expansion can occur until the next moult.
4. Primary growth: occurs at apical meristems (shoot tip and root tip); increases the length of roots and shoots; present in all vascular plants. Secondary growth: occurs at lateral meristems (vascular cambium and cork cambium); increases the diameter (girth) of stems and roots;

present only in woody dicots and gymnosperms; produces wood (secondary xylem) and bark (cork); responsible for annual rings.

5. Nutrition (adequate supply of food, water, and mineral nutrients for building materials and energy); temperature (affects enzyme activity and therefore metabolic rate and rate of cell division); hormones (growth hormone, sex hormones, auxin, gibberellin regulate cell division and elongation).

Part 5.2

1. Growth (increasing cell number for size increase; e.g. in roots and shoot meristems); repair and replacement (replacing damaged or worn-out cells; e.g. skin cells, red blood cells, gut epithelium); asexual reproduction (producing genetically identical offspring; e.g. binary fission in Amoeba, budding in Hydra, vegetative propagation in plants).
2. Interphase (DNA replicated; centrioles duplicate; normal cell activities). Prophase (chromosomes condense; nuclear envelope breaks down; spindle fibres form from centrioles). Metaphase (chromosomes align at the cell equator; spindle fibres attach to centromeres). Anaphase (sister chromatids pulled to opposite poles by shortening spindle fibres). Telophase (nuclear envelopes reform; chromosomes decondense). Cytokinesis (cytoplasm divides: cleavage furrow in animals; cell plate from Golgi vesicles in plants).
   (1) Meiosis produces four haploid (n) cells; mitosis produces two diploid (2n) cells. (2) Meiosis involves crossing over (genetic recombination) during prophase I and independent assortment at metaphase I, generating genetic variation; mitosis produces genetically identical daughter cells with no recombination.
3. Crossing over occurs during prophase I when homologous chromosomes pair up and exchange segments of DNA at points called chiasmata. This shuffles alleles between the paternal and maternal chromosomes of each homologous pair, producing chromosomes with new combinations of alleles that did not exist in either parent. Together with independent assortment of chromosomes at metaphase I, crossing over enormously increases genetic variation in the gametes, which is the raw material for natural selection and evolution.
4. Differentiation is the process by which an unspecialised cell becomes specialised in structure and biochemistry to perform a specific function. All somatic cells in a multicellular organism contain the same complete genome (except mature red blood cells which have no nucleus). Cells function differently because differentiation involves the selective switching on and off of specific genes: a muscle cell expresses actin and myosin genes; a pancreatic beta cell expresses the insulin gene; other genes are silenced by chemical modifications to histones and

DNA (epigenetic regulation). This differential gene expression produces hundreds of distinct cell types from a single common genome.

Part 5.3

1. Testa (seed coat): hard protective outer layer that prevents water loss and protects against physical damage and pathogens. Cotyledon(s): seed leaf/leaves; store food (starch, protein, fat in dicots); absorb food from endosperm in monocots. Radicle: embryonic root; first structure to emerge at germination; grows downward to anchor the seedling and absorb water. Plumule: embryonic shoot; grows upward after the radicle; produces the first true leaves. Endosperm (in monocot seeds): nutritive tissue storing food reserves for the developing embryo.
2. Water (to activate enzymes that digest stored food; to soften the testa allowing the radicle to emerge; to provide turgor pressure for cell elongation); oxygen (for aerobic respiration to produce ATP for cell division and active growth; anaerobic respiration alone cannot supply sufficient energy); suitable temperature (enzymes involved in germination have an optimum temperature range; too cold slows enzyme activity; too hot denatures enzymes).
3. Epigeal germination: the cotyledons are pushed above the soil surface; the hypocotyl (stem below the cotyledons) elongates rapidly, forming a hook that pushes through the soil and then straightens; cotyledons emerge into light, may temporarily photosynthesize, and eventually shrivel; e.g. bean (Phaseolus vulgaris), sunflower. Hypogeal germination: cotyledons remain in the soil (below ground); the epicotyl (stem above the cotyledons) elongates and the coleoptile (in monocots) or first leaves emerge into the light; food continues to be mobilised from the underground cotyledons; e.g. pea (Pisum sativum), maize (Zea mays).
4. Photoperiodism is the response of an organism to the relative lengths of the light and dark periods of the day (photoperiod). In plants, photoperiodism controls flowering by detecting the length of the uninterrupted dark period using the photoreceptor pigment phytochrome. Short-day plants (SDP): require a dark period longer than a critical threshold to flower (they actually respond to long nights, not short days); flowering is initiated during the short days (long nights) of autumn; e.g. chrysanthemum, cocklebur, rice varieties in some climates. Long-day plants (LDP): require a dark period shorter than a critical threshold to flower (require long days/short nights); flowering is initiated in summer; e.g. spinach, barley, wheat.
5. Etiolation is the abnormal, elongated, pale, weak growth produced by seedlings deprived of adequate light. When light is insufficient, the seedling uses its limited energy reserves to elongate the stem as rapidly as possible (in an attempt to reach light), at the expense of leaf

development and chlorophyll synthesis. The resulting etiolated plant has: very long, spindly internodes; small, unexpanded, pale yellow or white leaves (because chlorophyll cannot be synthesised in the dark); and reduced root growth. It is caused by an absence of light preventing the normal light-regulated inhibition of stem elongation.

Part 5.4

1. Zygote: the single diploid cell formed by fertilisation. Cleavage: rapid mitotic divisions of the zygote; cell number increases but total size barely changes; no cell growth between divisions; cells become progressively smaller. Morula: a solid ball of 16 to 32 cells produced by cleavage. Blastula (blastocyst in mammals): a hollow ball of cells with a fluid-filled cavity (blastocoel); in mammals the inner cell mass (which will form the embryo) is distinct from the outer trophoblast (which will form the placenta). Gastrula: cells migrate and rearrange to form three primary germ layers: ectoderm (outer), mesoderm (middle), and endoderm (inner); the opening where cells invaginate is the blastopore.
2. Ectoderm (outer germ layer): gives rise to the skin epidermis (including hair, nails, sweat glands), the entire nervous system (brain, spinal cord, peripheral nerves), and sensory organs (eye lens, inner ear). Mesoderm (middle germ layer): gives rise to all muscle tissue (skeletal, cardiac, smooth), the skeleton (bone and cartilage), connective tissue, kidneys and reproductive organs, the heart, and most of the circulatory system (blood vessels, blood cells). Endoderm (inner germ layer): gives rise to the epithelial lining of the entire digestive tract (from mouth to anus), the liver, pancreas, thyroid gland, lungs, and the urinary bladder lining.
3. Complete metamorphosis (holometabolism): four completely distinct stages: egg, larva, pupa, and adult; the larva and adult are morphologically very different and occupy different ecological niches (e.g. caterpillar eats leaves; butterfly drinks nectar; reducing competition between generations); pupa is a non-feeding reorganisation stage; e.g. butterfly, moth, beetle, fly, bee. Incomplete metamorphosis (hemimetabolism): three stages: egg, nymph, and adult; the nymph is a miniature wingless version of the adult, occupying the same niche and eating the same food; wings develop gradually through successive moults; no pupal stage; e.g. grasshopper, cockroach, dragonfly.
4. The frog life cycle: adult frogs mate in water; females release eggs (spawn) into water where they are fertilised externally by the male. Eggs hatch into tadpoles (aquatic larvae): tadpoles have gills for gas exchange, a tail for swimming, a two-chambered heart, and are herbivorous (feeding on algae). Metamorphosis (regulated by thyroid hormone): gills replaced by lungs; tail reabsorbed; four legs develop; digestive system changes from herbivore to carnivore;

heart becomes three-chambered. Adult frogs are semi-terrestrial; breathe using lungs and moist skin; carnivorous (feeding on insects); return to water to reproduce.

5. Telomeres are repetitive DNA sequences (TTAGGG in humans) located at the ends of chromosomes; they act as protective caps preventing the chromosome ends from being recognised as broken DNA and repaired incorrectly. With each round of DNA replication and cell division (mitosis), a small portion of the telomere sequence is lost from the chromosome ends because DNA polymerase cannot fully replicate the ends of linear chromosomes. After many cell divisions, telomeres become critically short; the cell can no longer divide safely (this limit is called the Hayflick limit); the cell then enters a non-dividing state (senescence) or undergoes programmed cell death (apoptosis). Telomere shortening is therefore directly linked to cellular ageing and the decline in tissue regeneration capacity seen in older organisms.

References and Attributions [Series 5]

Textual References (Books and External Sources)

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- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 5.1: Sigmoid and stepped growth curves Attribution: AI generated. Suggested OER search string: "sigmoid growth curve insect stepped growth moult ecdysis graph lag log deceleration plateau OER".
- Figure 5.2: Mitosis stages diagram Attribution: AI generated. Suggested OER search string: "mitosis stages diagram interphase prophase metaphase anaphase telophase cytokinesis animal cell OER".
- Figure 5.3: Mitosis and meiosis comparison diagram Attribution: AI generated. Suggested OER search string: "mitosis meiosis comparison diagram diploid haploid crossing over genetic variation OER".
- Figure 5.4: Seed structure and germination diagrams Attribution: AI generated. Suggested OER search string: "seed structure germination dicot bean monocot maize epigeal hypogeal labelled diagram OER".
- Figure 5.5: Early embryonic development diagram Attribution: AI generated. Suggested OER search string: "embryonic development zygote cleavage morula blastula gastrula germ layers diagram OER".
- Figure 5.6: Metamorphosis comparison diagram Attribution: AI generated. Suggested OER search string: "metamorphosis complete butterfly incomplete grasshopper frog life cycle diagram stages OER".
- Figure 5.7: Human growth curve graph Attribution: AI generated. Suggested OER search string: "human growth curve height age puberty growth spurt male female graph OER".

- Box 5.1: Comparison of growth and development in plants and animals Attribution: AI generated. Suggested OER search string: "comparison growth development plants animals table meristems hormones metamorphosis ageing OER box".