



La-Net

BIO 108

GENERAL BIOLOGY PRACTICAL II



Course video is available on our app

lanetonline.com



Course code: BIO 108

Course title: General Biology Practical II

Course credit load: 1 Unit

Series 1: Anatomy of Flowering Plants

- **Part 1.1: Internal Anatomy of the Stem**

- Sub Part 1.1.1: Tissues of the primary vegetative body
- Sub Part 1.1.2: Transverse section of a dicot stem
- Sub Part 1.1.3: Transverse section of a monocot stem

- **Part 1.2: Internal Anatomy of the Root**

- Sub Part 1.2.1: Transverse section of a dicot root
- Sub Part 1.2.2: Transverse section of a monocot root
- Sub Part 1.2.3: Comparison of root and stem anatomy

- **Part 1.3: Internal Anatomy of the Leaf**

- Sub Part 1.3.1: Transverse section of a dorsiventral leaf
- Sub Part 1.3.2: Transverse section of an isobilateral leaf
- Sub Part 1.3.3: Stomata and epidermal structures

Introduction

Anatomy is the study of the internal structure of organisms. In flowering plants, the primary vegetative body comprises the stem, root, and leaf, each containing characteristic arrangements of mature tissues. Examining transverse sections (T.S.) under a microscope reveals these tissue



patterns and allows students to distinguish between dicot and monocot organisation and between stem, root, and leaf.

This Series describes the five major plant tissues visible in sections (parenchyma, collenchyma, sclerenchyma, xylem, and phloem), explains how to interpret transverse sections of dicot and monocot stems, roots, and leaves, and introduces epidermal structures including stomata. This knowledge forms the practical foundation for all plant biology work in this course.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 1.1** describe the five major tissue types of the primary vegetative body and identify them in microscope sections (Linked to Part 1.1),
- **SLO 1.2** describe and draw a labelled transverse section of a dicot and a monocot stem (Linked to Part 1.1),
- **SLO 1.3** describe and draw labelled transverse sections of dicot and monocot roots and compare them with stem sections (Linked to Part 1.2),
- **SLO 1.4** describe and draw a labelled transverse section of a dorsiventral and an isobilateral leaf (Linked to Part 1.3), and
- **SLO 1.5** describe the structure and function of stomata and other epidermal features (Linked to Part 1.3).

1.1 Internal Anatomy of the Stem

1.1.1 Tissues of the primary vegetative body

The primary vegetative body of a flowering plant contains five major tissue types. Parenchyma: thin-walled, living cells with large vacuoles; the most common tissue; functions in storage, photosynthesis, and packing; forms the cortex, pith, and mesophyll. Collenchyma: living cells



with unevenly thickened cellulose walls at corners; provides flexible support in young stems and petioles.

Sclerenchyma: dead cells with thick lignified secondary walls; provides rigid mechanical support; two types: fibres (elongated; provide tensile strength) and sclereids (shorter, irregular; e.g. stone cells in pear fruit). **Xylem:** dead hollow vessels and tracheids with lignified walls; transports water and minerals upward; also provides support. **Phloem:** living sieve tube elements and companion cells; transports organic solutes (mainly sucrose) from leaves to other organs.

Fill in the blank: _____ is the most common plant tissue; its thin-walled living cells with large vacuoles function in storage, photosynthesis, and packing in the cortex, pith, and mesophyll.

FIVE MAJOR PLANT TISSUE TYPES: MICROSCOPE PHOTOGRAPHS

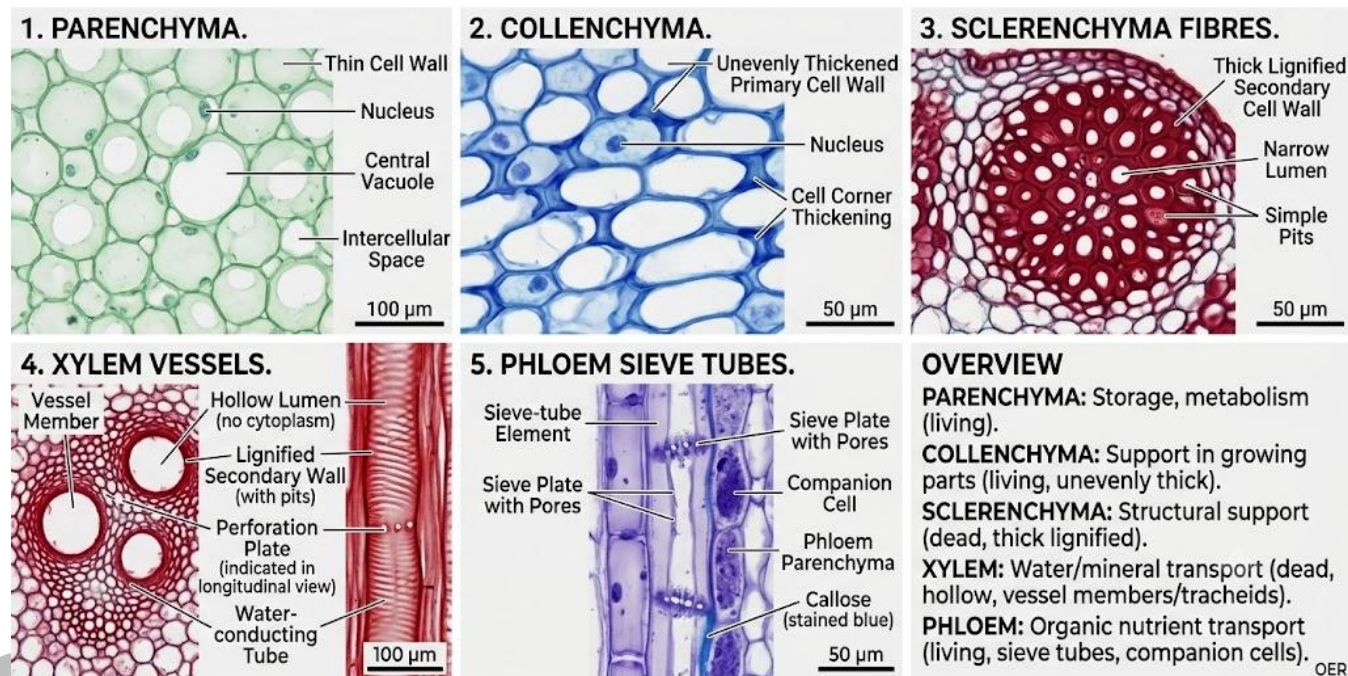


Figure 1.1: Photographs and diagrams of the five major plant tissue types

1.1.2 Transverse section of a dicot stem

A T.S. of a young dicot stem (e.g. *Helianthus*/sunflower or *Ranunculus*/buttercup) shows the following zones from outside to inside: epidermis (one cell thick; may have trichomes/hairs;



waxy cuticle); cortex (parenchyma; may include collenchyma just below the epidermis; sometimes contains chloroplasts); endodermis (not always distinct in stem); pericycle; vascular bundles (arranged in a ring); and pith (central parenchyma).

Each vascular bundle in a dicot stem is collateral: xylem faces the centre (adaxial), phloem faces the outside (abaxial), with a cambium strip between them. A bundle cap of sclerenchyma fibres often sits above the phloem. The vascular bundles are discrete and arranged in a ring. This ring arrangement is the single most diagnostic feature distinguishing a dicot stem from a monocot stem in transverse section.

Fill in the blank: In a dicot stem T.S., vascular bundles are arranged in a _____ with xylem facing the centre and phloem facing the outside; a strip of cambium lies between them (collateral open bundle).



T.S. of Dicot Stem (*Helianthus*): Labelled Diagram and Microscope Photograph

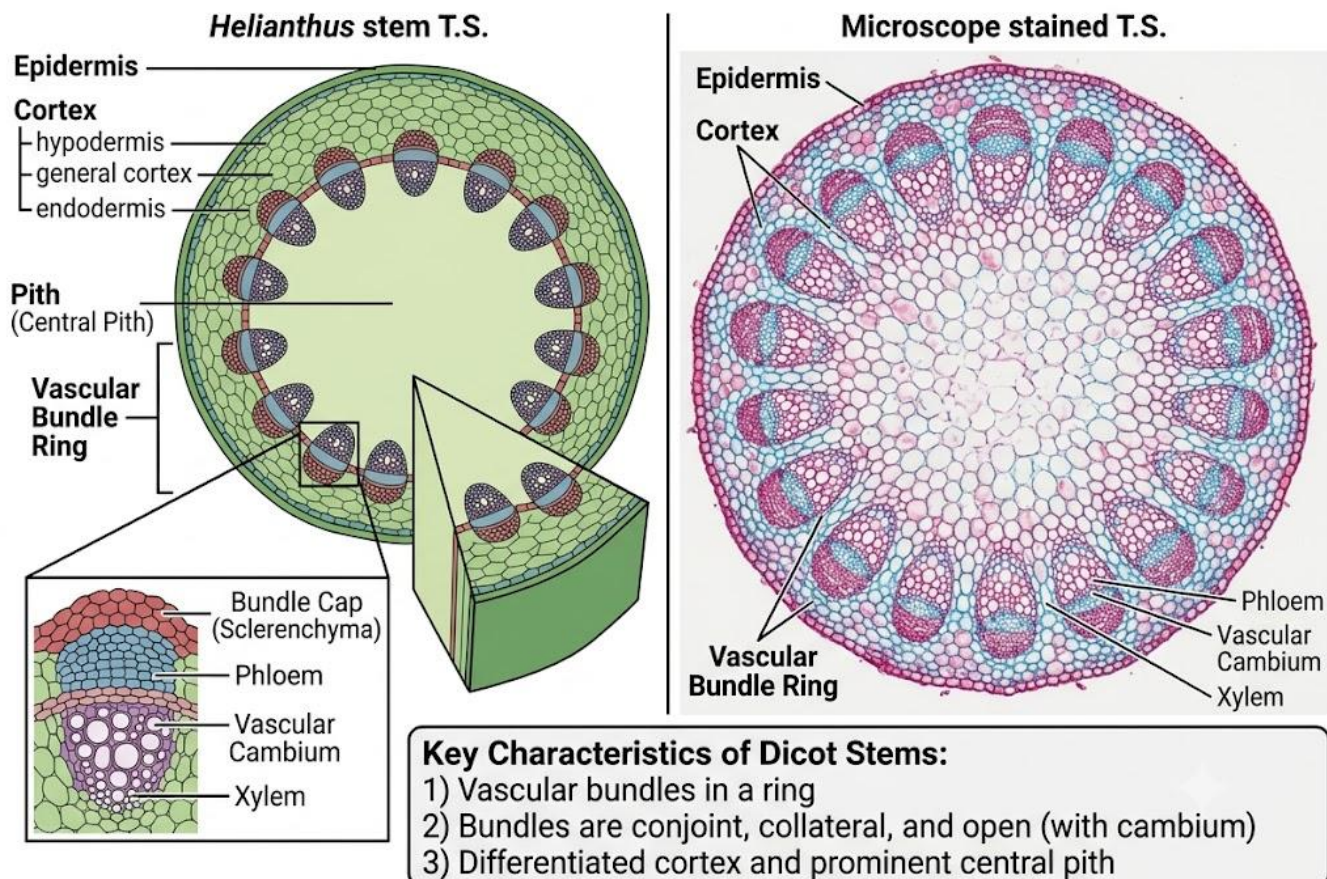


Image: [Your Attribution/OER Logo]

Image: [Your Attribution/OER Logo]

Figure 1.2: Diagram and microscope photograph of a dicot stem T.S.

1.1.3 Transverse section of a monocot stem

A T.S. of a monocot stem (e.g. maize/*Zea mays* or sugarcane) differs from a dicot stem in several key ways. The vascular bundles are scattered throughout the ground tissue (not arranged in a ring); there is no separate cortex or pith (the ground tissue is uniform throughout); there is no cambium between xylem and phloem (closed collateral bundle); and the bundles are typically surrounded by a thick bundle sheath of sclerenchyma.

Individual monocot vascular bundles, when viewed at higher power, show: phloem (sieve tubes and companion cells) on the outer side; xylem on the inner side with a characteristic Y-shape or V-shape formed by two large metaxylem vessels flanking a protoxylem lacuna (an air space

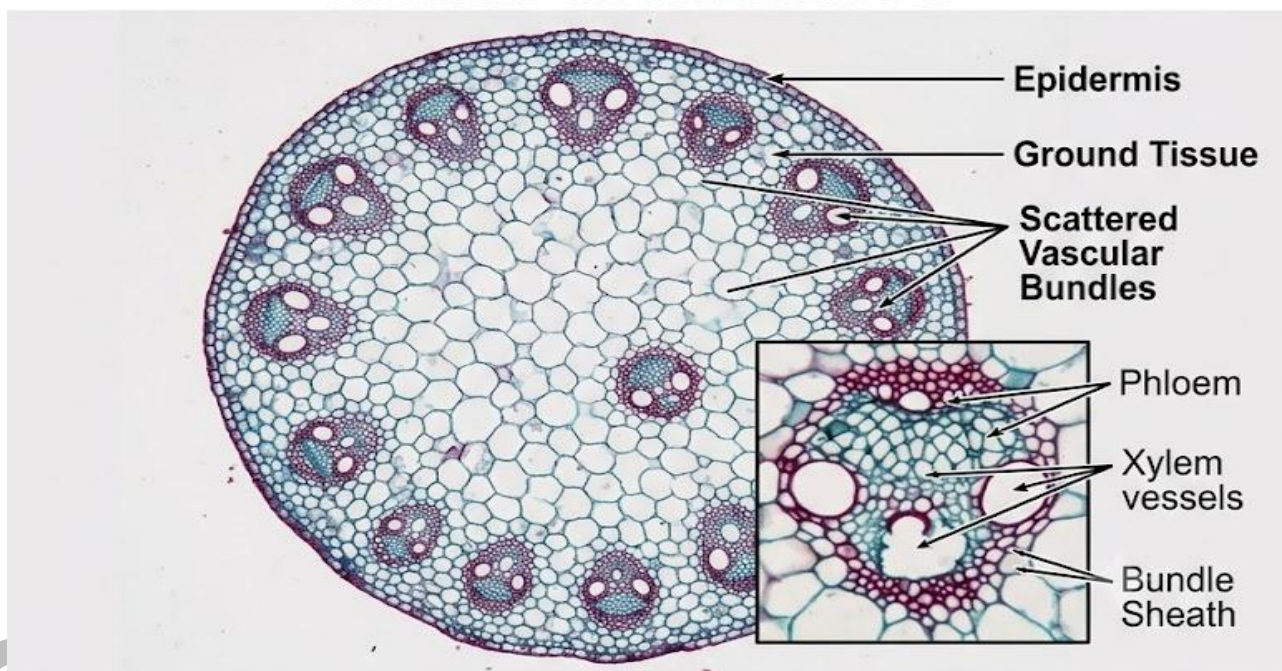
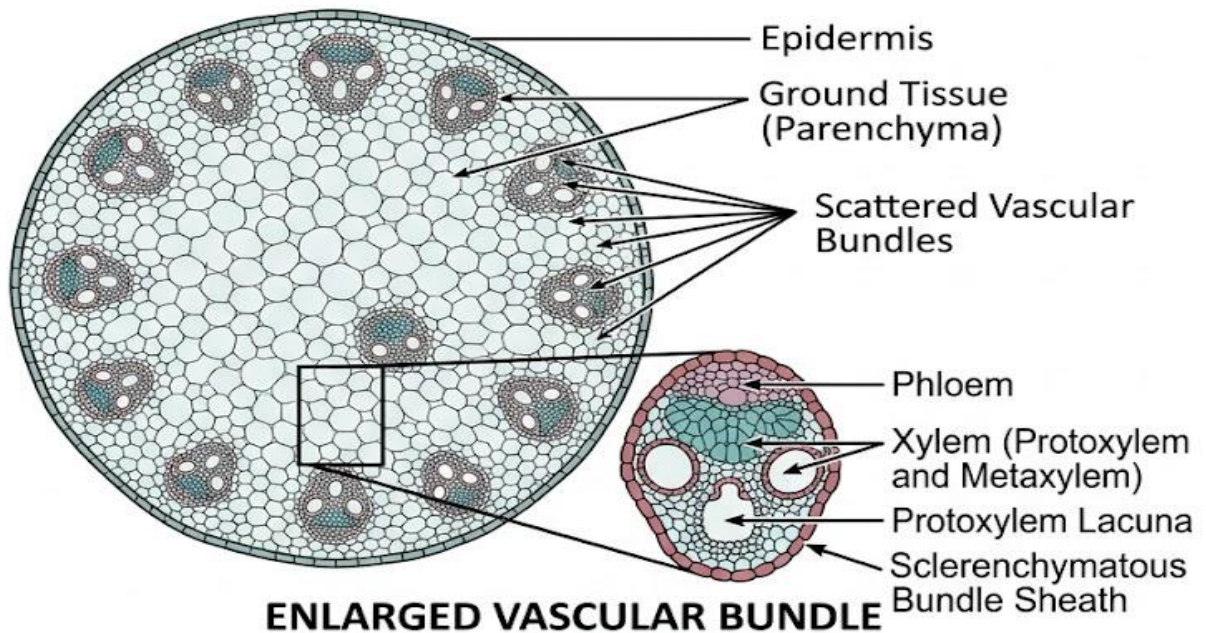


where the first xylem vessels have been torn apart by stem elongation). The absence of cambium means monocot stems cannot undergo secondary growth.

Fill in the blank: In a monocot stem T.S., vascular bundles are _____ throughout the ground tissue; each bundle is a closed collateral bundle (no cambium); the absence of cambium means monocot stems cannot undergo secondary growth.



MONOCOT STEM TRANSVERSE SECTION (*Zea mays*)



OER EDUCATIONAL DIAGRAM & MICROGRAPH

Figure 1.3: Diagram and microscope photograph of a monocot stem T.S.

Pilot questions 1.1

1. State the five major tissue types of the primary vegetative body and give one function of each.



2. Describe how to distinguish sclerenchyma from collenchyma.
3. List the zones seen in a dicot stem T.S. from outside to inside.
4. State three differences between a dicot stem and a monocot stem in transverse section.
5. Explain why a monocot stem cannot undergo secondary (thickening) growth.

1.2 Internal Anatomy of the Root

1.2.1 Transverse section of a dicot root

A T.S. of a young dicot root (e.g. Ranunculus/buttercup or broad bean Vicia) shows, from outside to inside: epidermis (piliiferous layer; produces root hairs; no cuticle or stomata); cortex (wide zone of parenchyma for storage; intercellular spaces present); endodermis (single layer of cells with Casparian strips on radial and transverse walls; controls water entry to the stele); pericycle (one or more layers of cells just inside the endodermis; gives rise to lateral roots).

At the centre of the dicot root is the stele, which contains: alternating strands of xylem and phloem (not in bundles, but in separate alternating strands); the xylem forms an X-shape (or star shape) with usually two to six arms (diarch, triarch, tetrarch, etc. referring to the number of xylem arms); phloem strands lie between the xylem arms. There is no pith in most dicot roots; the centre is occupied by xylem. This alternating arrangement distinguishes the root from the stem.

Fill in the blank: In a dicot root, the _____ strips on the walls of endodermal cells prevent water from passing between cells, forcing all water to pass through the endodermal cell cytoplasm before entering the stele.



DICOT ROOT TRANSVERSE SECTION (*Ranunculus*): DIAGRAM & MICROGRAPH

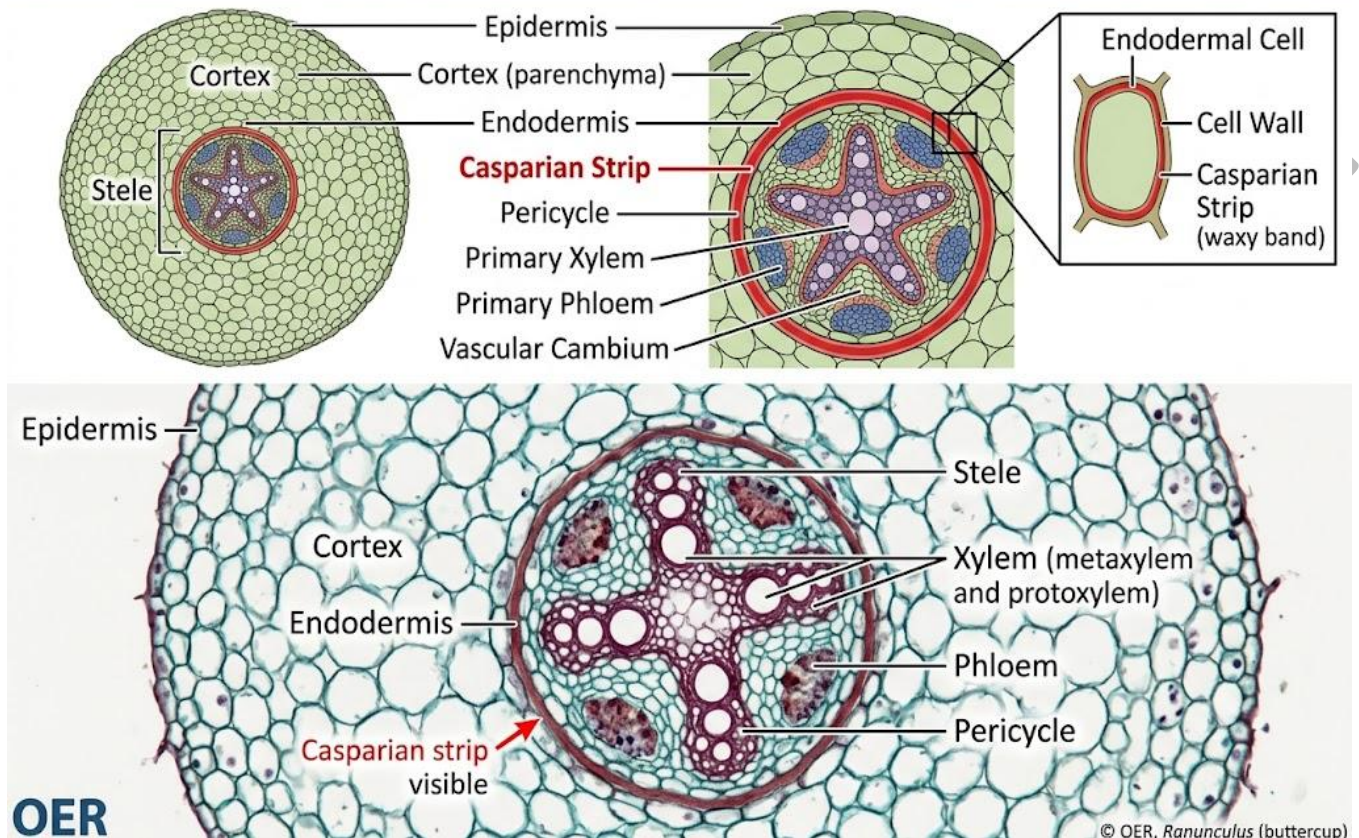


Figure 1.4: Diagram and microscope photograph of a dicot root T.S.

1.2.2 Transverse section of a monocot root

A T.S. of a monocot root (e.g. maize or iris) shows the same basic zones as the dicot root: epidermis, cortex, endodermis with Casparian strips, pericycle, and stele. Key differences from a dicot root: monocot roots typically have many more xylem arms (polyarch: many-armed xylem forming a ring or multiple strands); a prominent central pith of parenchyma (unlike most dicot roots); and a wider stele relative to the cortex in some species.

The endodermis in older monocot roots often shows further thickening on the inner (tangential) walls, forming a U-shaped or O-shaped Casparian band visible as heavily thickened cells. Some endodermal cells remain thin-walled (passage cells) opposite the xylem arms, allowing some water movement. The general organisation of the monocot root stele (xylem and phloem in



alternating strands, not in bundles as in the stem) is similar to the dicot root, making roots more uniform across flowering plant groups than stems.

Fill in the blank: Monocot roots have a _____ (many xylem arms) arrangement and a central pith, unlike most dicot roots which have few xylem arms and no central pith.

1.2.3 Comparison of root and stem anatomy

The table below summarises the key anatomical differences between root and stem. Both dicot and monocot roots have alternating xylem and phloem strands, a prominent endodermis with Casparian strips, and no cambium between xylem and phloem. Stems have xylem and phloem together in vascular bundles (collateral), no prominent endodermis, and in dicots, a cambium between xylem and phloem within each bundle.

Root hairs are extensions of epidermal cells and are found only on roots (piliferous layer). The root cortex is usually wider relative to the stele than in the stem. Roots lack stomata and trichomes. The arrangement of vascular tissue (alternating in roots; bundled in stems) reflects function: roots conduct water from soil through the endodermal filter into the stele, while stems distribute water and food to leaves and other organs through the vascular bundle network.

Fill in the blank: Roots have alternating _____ and phloem strands (not in bundles), a prominent endodermis with Casparian strips, and no stomata; stems have xylem and phloem together in vascular bundles with no prominent endodermis.

<u>Feature</u>	<u>Dicot Stem</u>	<u>Monocot Stem</u>	<u>Dicot Root</u>	<u>Monocot Root</u>
<u>Vascular Arrangement</u>	Vascular bundles arranged in a ring	Vascular bundles scattered	Radial arrangement	Radial arrangement
<u>Cambium</u>	Present (allows secondary growth)	Absent	Present (between xylem and phloem)	Absent
<u>Endodermis</u>	Not distinct	Not distinct	Distinct, with Casparian strip	Distinct, with Casparian strip



<u>Pith</u>	Present, well-developed	Usually absent or reduced	Absent	Present, large and well-developed
<u>Root Hairs</u>	Abundant	Abundant	Present, for absorption	Present, for absorption
<u>Xylem Arms</u>	Triarch, tetrarch, or polyarch (commonly tetrarch)	Polyarch (many arms)	Tetrarch (four arms)	Polyarch (many arms)

Box 1.1: Comparison of dicot stem, monocot stem, dicot root, and monocot root anatomy

Pilot questions 1.2

1. List the zones seen in a dicot root T.S. from outside to inside.
2. Explain the function of the Casparian strip in the endodermis.
3. State two differences between a dicot root and a monocot root.
4. State three differences between a root and a stem in transverse section.
5. Explain why the root epidermis has no cuticle or stomata.

1.3 Internal Anatomy of the Leaf

1.3.1 Transverse section of a dorsiventral leaf

Most dicot leaves are dorsiventral (bifacial): they have distinct upper and lower surfaces with different tissue arrangements. A T.S. shows from top to bottom: upper epidermis (cuticle; no chloroplasts; few stomata); palisade mesophyll (one to three layers of elongated, tightly packed cells with many chloroplasts; main site of photosynthesis); spongy mesophyll (loosely packed, irregular cells with large air spaces; facilitates gas exchange; fewer chloroplasts); lower epidermis (thinner cuticle; most stomata and guard cells).

Vascular bundles (veins) are embedded in the mesophyll. In each vein, xylem faces the upper surface and phloem faces the lower surface. Bundle sheaths of parenchyma or sclerenchyma surround each vein. The overall design maximises photosynthesis: the palisade layer captures



maximum light near the upper surface, while the spongy mesophyll with its large air spaces facilitates rapid CO₂ diffusion from stomata to chloroplasts.

Fill in the blank: In a dorsiventral leaf T.S., the _____ mesophyll (elongated cells with many chloroplasts) lies beneath the upper epidermis and is the primary site of photosynthesis; the spongy mesophyll below it contains large air spaces for gas exchange.

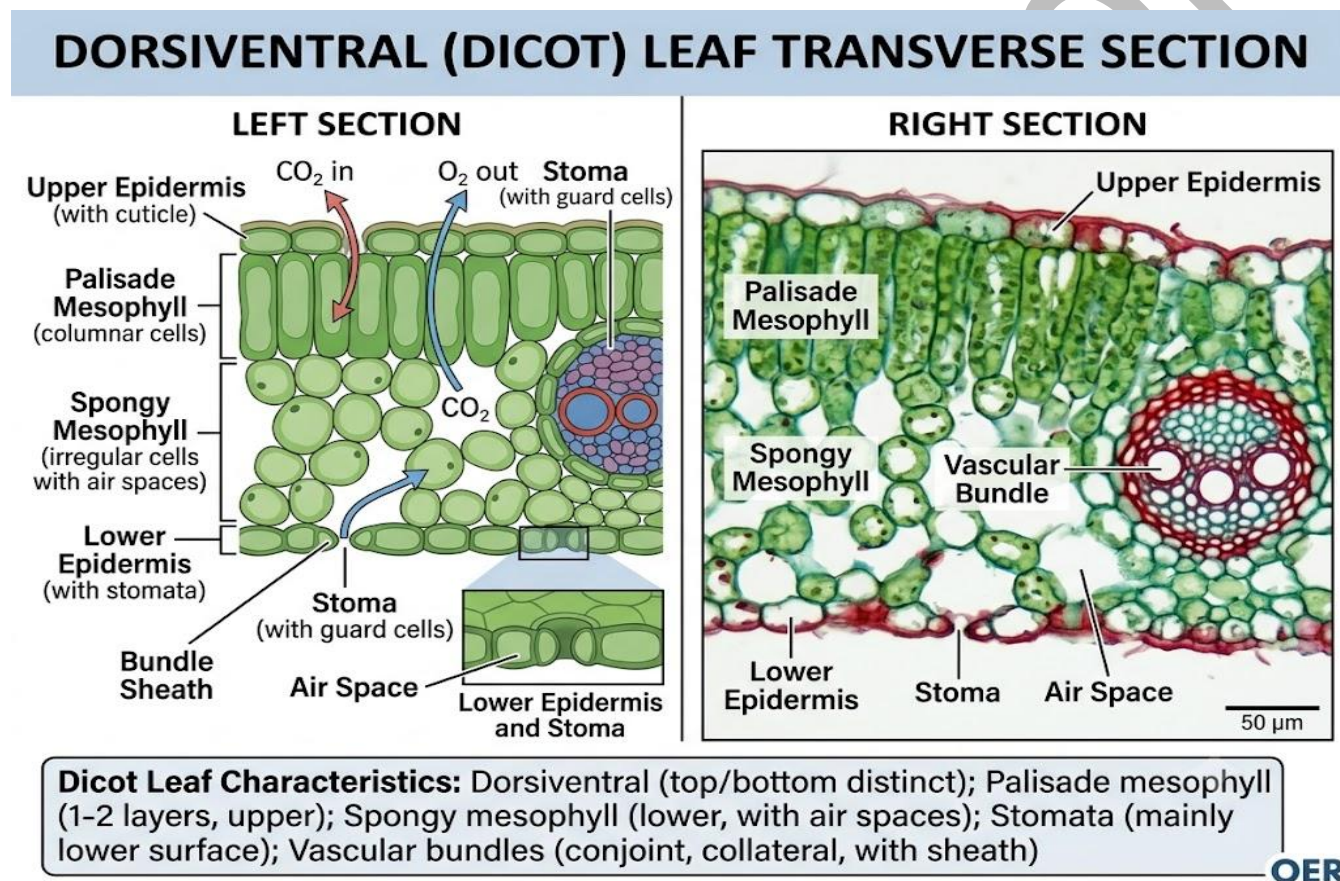


Figure 1.5: Diagram and microscope photograph of a dorsiventral leaf T.S.

1.3.2 Transverse section of an isobilateral leaf

Isobilateral (isolateral) leaves have similar upper and lower surfaces; both epidermises are similar in thickness and stomata distribution. This arrangement is common in monocots (e.g. grasses) and some plants with upright or nearly vertical leaves exposed to light on both sides (e.g. Eucalyptus hanging leaves). In a T.S. of a grass leaf (e.g. maize), palisade mesophyll is



absent; instead, the mesophyll consists of uniformly arranged chlorenchyma cells (thin-walled cells with chloroplasts) distributed throughout.

Grasses and other C₄ plants (including maize) show Kranz anatomy in their leaf T.S.: each vascular bundle is surrounded by a thick, distinctive bundle sheath of large parenchyma cells rich in chloroplasts (the site of the Calvin cycle in C₄ photosynthesis), which is in turn surrounded by a ring of mesophyll cells. This bundle sheath with a ring of mesophyll around it is the hallmark of Kranz anatomy and distinguishes C₄ plants from C₃ plants at the anatomical level.

Fill in the blank: _____ anatomy, seen in grasses and maize leaf T.S., features a conspicuous bundle sheath of large chloroplast-rich cells surrounding each vascular bundle; this arrangement is characteristic of C₄ photosynthesis.

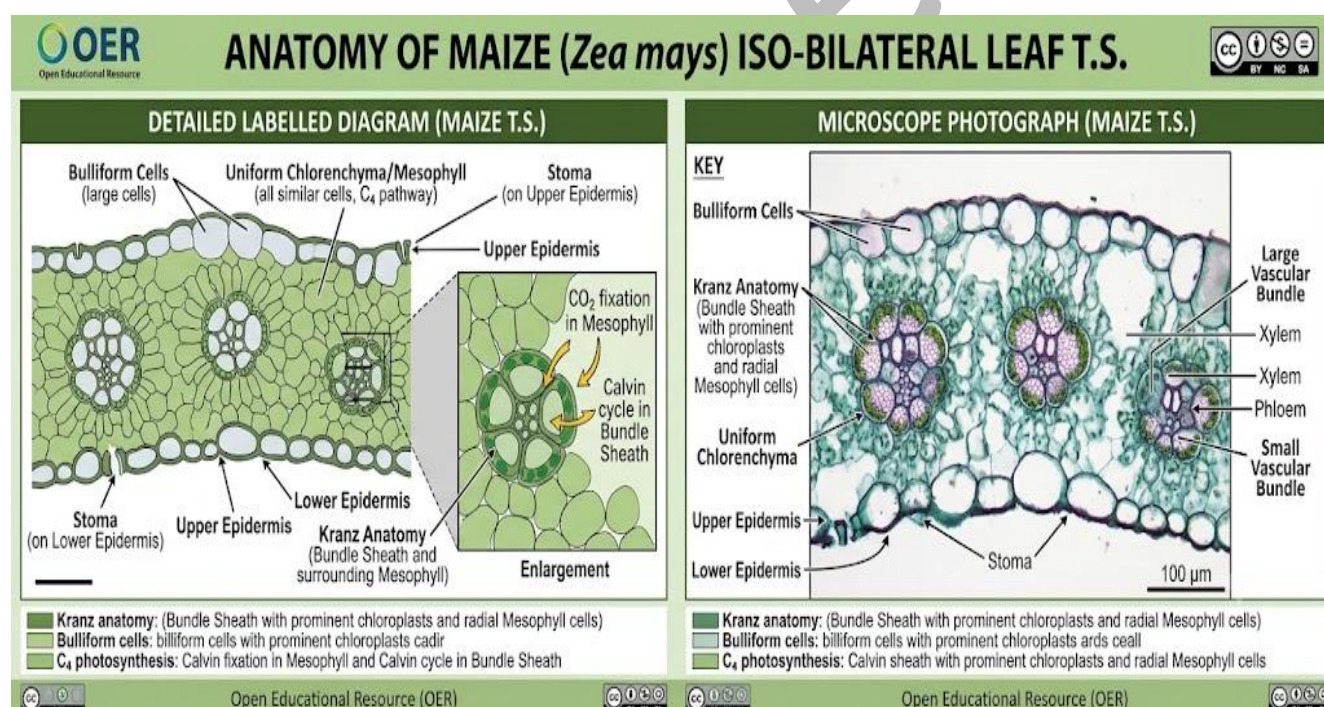


Figure 1.6: Diagram and microscope photograph of an isobilateral (grass/maize) leaf T.S.

1.3.3 Stomata and epidermal structures

Stomata are pores in the leaf epidermis, each flanked by two kidney-shaped guard cells in dicots (or dumbbell-shaped guard cells in grasses). Guard cells contain chloroplasts (unlike other epidermal cells) and regulate the pore opening by changes in turgor. When turgid, guard cells



bow outward opening the pore; when flaccid, they collapse and close it. CO₂ enters and O₂ and water vapour exit through stomata.

Other epidermal structures: trichomes (hairs) on the epidermis of many leaves and stems; may be simple (unicellular or multicellular) or glandular (secreting oils or resins); reduce transpiration and deter herbivores. Bulliform (motor) cells in grass leaves are large, thin-walled colourless epidermal cells; when they lose water, they cause the leaf to roll inward, reducing transpiration. The cuticle is a layer of cutin (a waxy polymer) covering the outer surface of all epidermal cells, waterproofing the leaf surface.

Fill in the blank: Guard cells contain _____ (unlike most other epidermal cells), allowing them to photosynthesize and generate the osmotic potential needed to absorb water and open the stomatal pore.

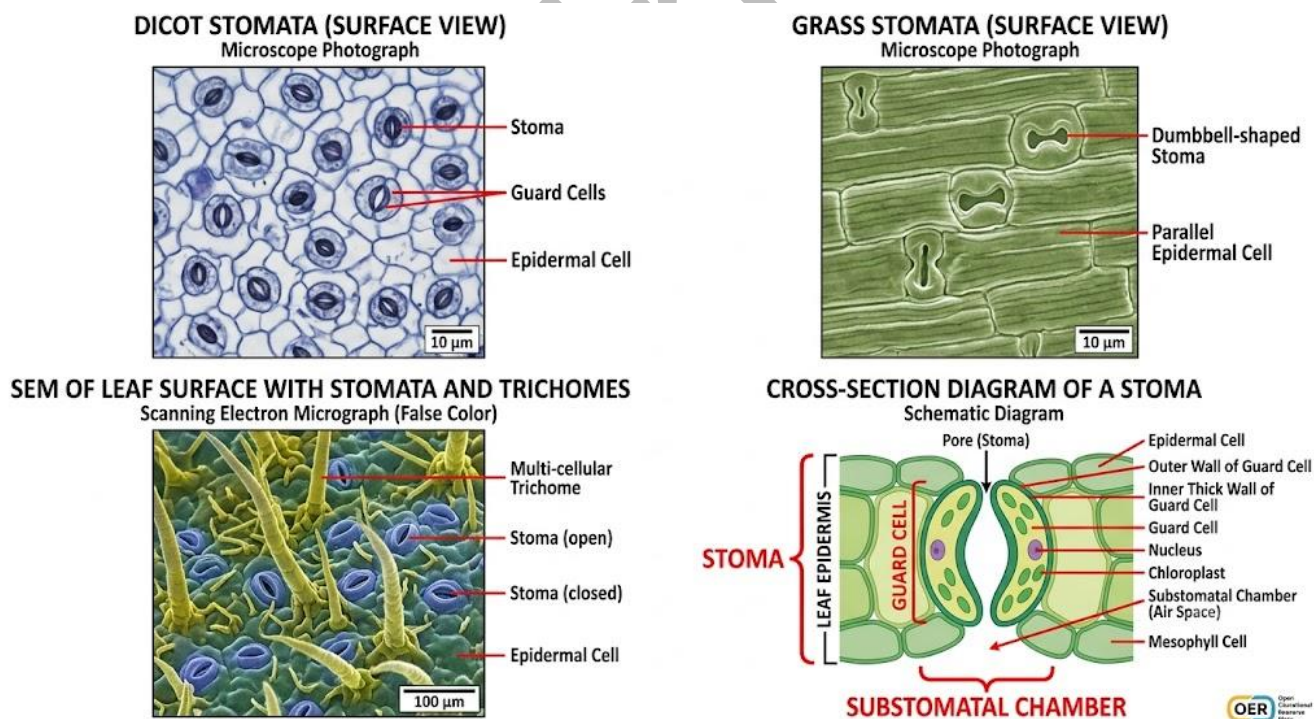


Figure 1.7: Diagrams and microscope photographs of stomata and epidermal structures

Pilot questions 1.3

1. List the zones in a dorsiventral leaf T.S. from upper to lower epidermis.
2. Explain why the palisade mesophyll is the primary site of photosynthesis in dicot leaves.



3. Distinguish between a dorsiventral and an isobilateral leaf.
4. Explain what Kranz anatomy is and in which plants it occurs.
5. Describe the structure of a stoma and explain how guard cells open and close it.



Series Summary

This Series examined the internal anatomy of the three major vegetative organs of flowering plants. The five fundamental plant tissue types were established first: parenchyma for storage and photosynthesis, collenchyma for flexible support in young organs, sclerenchyma for rigid structural reinforcement, xylem for water and mineral transport, and phloem for the movement of organic solutes. These tissues are arranged differently in dicotyledonous and monocotyledonous plants: dicot stems carry open collateral vascular bundles arranged in a ring, while monocot stems have closed collateral bundles scattered throughout the ground tissue. Root anatomy was contrasted across the two groups, with dicot roots showing few xylem arms and monocot roots showing a polyarch arrangement with a central pith, both delimited by an endodermis bearing Casparian strips.

Leaf internal organisation was then examined, distinguishing the dorsiventral leaf of dicots, with its differentiated palisade and spongy mesophyll, from the isobilateral leaf of monocots. The specialised Kranz anatomy of C4 plants such as maize, characterised by large bundle sheath cells surrounded by a ring of mesophyll, was described in relation to its photosynthetic significance. Stomatal structure and mechanism were covered, contrasting kidney-shaped dicot stomata with the dumbbell-shaped guard cells of grasses, and the series concluded with other epidermal features including trichomes, bulliform cells, and the waterproofing cuticle.

Glossary of Terms

- **Bundle sheath:** a layer of cells (parenchyma or sclerenchyma) surrounding a vascular bundle in a leaf; in C4 plants (Kranz anatomy) these cells are large and rich in chloroplasts.
- **Bulliform cells:** large, colourless, thin-walled epidermal cells in grass leaves; when they lose turgor, they cause the leaf to roll inward, reducing transpiration.
- **Casparian strip:** a band of suberin (a waxy material) deposited in the radial and transverse walls of endodermal cells; prevents water moving between cells and forces it through the cytoplasm.
- **Collenchyma:** a living support tissue with unevenly thickened cellulose cell walls at corners; provides flexible mechanical support in young stems and petioles.



- **Cortex:** the zone of parenchyma (and sometimes collenchyma) tissue between the epidermis and the vascular tissue in stems and roots.
- **Cuticle:** a layer of cutin (a waxy polymer) on the outer surface of epidermal cells; reduces water loss and waterproofs the leaf surface.
- **Dorsiventral leaf:** a bifacial leaf with distinct upper and lower surfaces and separate palisade and spongy mesophyll layers; typical of most dicots.
- **Endodermis:** a single layer of cells forming the inner boundary of the cortex in roots; cells have Casparian strips that control water entry to the stele.
- **Ground tissue:** the undifferentiated parenchyma tissue of monocot stems that replaces both the cortex and pith; contains the scattered vascular bundles.
- **Isobilateral leaf:** a leaf with similar upper and lower surfaces; characteristic of most monocots; lacks distinct palisade and spongy mesophyll layers.
- **Kranz anatomy:** a leaf anatomical arrangement in C4 plants characterised by a large, chloroplast-rich bundle sheath surrounding each vascular bundle, in turn surrounded by a ring of mesophyll cells.
- **Palisade mesophyll:** one to three layers of elongated, tightly packed cells directly below the upper epidermis in dorsiventral leaves; contains many chloroplasts; the main site of photosynthesis.
- **Parenchyma:** the most common and least specialised plant tissue; thin-walled living cells with large vacuoles; functions in storage, packing, photosynthesis, and wound healing.
- **Pericycle:** a layer of cells inside the endodermis; gives rise to lateral roots and contributes to secondary growth in the root.
- **Pith:** the central parenchyma tissue in stems; absent from most dicot roots; present in monocot roots and most stems.
- **Sclerenchyma:** a plant support tissue with thick, lignified secondary walls; cells are usually dead at maturity; includes fibres (elongated) and sclereids (shorter).
- **Spongy mesophyll:** loosely arranged, irregularly shaped cells with large intercellular air spaces in the lower portion of dorsiventral leaves; important for gas exchange.



- **Stele:** the central vascular cylinder of a root or stem, bounded externally by the endodermis (in roots) or pericycle; contains the xylem and phloem.
- **Stomata (singular: stoma):** pores in the leaf epidermis through which gas exchange occurs; each is bounded by two guard cells.
- **Trichome:** an epidermal hair; may be simple or glandular; functions in protection against herbivores, reduction of transpiration, or secretion.
- **Xylem:** the vascular tissue that transports water and dissolved minerals upward from roots to leaves; composed mainly of dead, hollow, lignified vessels and tracheids.



Concept Check Questions [Series 1]

Objective Questions

1. _____ is the most common plant tissue; thin-walled living cells with large vacuoles; functions in storage and photosynthesis. (Linked to SLO 1.1)
2. In a dicot stem T.S., vascular bundles are arranged in a _____ with xylem facing the centre and phloem facing the outside. (Linked to SLO 1.2)
3. In a dicot root, _____ strips on the endodermal cell walls prevent water from passing between cells. (Linked to SLO 1.3)
4. In a dorsiventral leaf T.S., the _____ mesophyll (elongated cells with many chloroplasts) is the primary site of photosynthesis. (Linked to SLO 1.4)
5. Guard cells contain _____, which allows them to photosynthesize and generate osmotic potential to open stomata. (Linked to SLO 1.5)

Short-Answer Questions

6. State five tissue types of the primary vegetative body and one function of each. (Linked to SLO 1.1)
7. State three differences between a dicot stem and a monocot stem T.S. (Linked to SLO 1.2)
8. List the zones of a dicot root T.S. from outside to inside and state the function of the endodermis. (Linked to SLO 1.3)
9. Distinguish between a dorsiventral and an isobilateral leaf. (Linked to SLO 1.4)
10. Describe the structure of a stoma and explain how it opens and closes. (Linked to SLO 1.5)

Long-Answer Questions

11. Describe the anatomy of a dicot stem and a monocot stem in transverse section, using labelled diagrams. (Linked to SLOs 1.1, 1.2)
12. Describe the anatomy of a dicot root in transverse section and compare it with a dicot stem and a monocot root. (Linked to SLO 1.3)



13. Describe the internal structure of a dorsiventral and an isobilateral leaf, explain Kranz anatomy, and describe stomata and other epidermal features. (Linked to SLOs 1.4, 1.5)



Answers to Concept Check Questions [Series 1]

Objective Questions

1. Parenchyma.
2. Ring.
3. Casparian.
4. Palisade.
5. Chloroplasts.

Short-Answer Questions

6. Parenchyma (storage, photosynthesis); collenchyma (flexible support); sclerenchyma (rigid support); xylem (water and mineral transport); phloem (organic solute transport).
7. Dicot stem: vascular bundles in a ring; cambium present in each bundle (open); pith present. Monocot stem: bundles scattered in ground tissue; no cambium (closed bundle); no separate pith or cortex.
8. Zones outside to inside: epidermis (piliferous layer; root hairs) → cortex (parenchyma) → endodermis (Casparian strips) → pericycle → stele (alternating xylem and phloem strands). Endodermis function: Casparian strips prevent water passing between cells, forcing all water through the cytoplasm and allowing selective mineral uptake.
9. Dorsiventral leaf: distinct upper and lower surfaces; palisade mesophyll (top), spongy mesophyll (bottom); stomata mainly on lower epidermis; typical of dicots. Isobilateral leaf: similar upper and lower surfaces; no separate palisade or spongy layers; uniform chlorenchyma; stomata on both surfaces; typical of monocots.
10. A stoma is a pore flanked by two guard cells (kidney-shaped in dicots; dumbbell-shaped in grasses). Guard cells contain chloroplasts. When guard cells absorb water they become turgid and bow outward, opening the pore. When they lose water and become flaccid, they collapse and the pore closes.

Long-Answer Questions

11. Dicot stem T.S. (e.g. Helianthus): from outside inward: epidermis (cuticle, trichomes); cortex (parenchyma, collenchyma below epidermis); vascular bundles in a ring, each collateral open bundle (phloem outer, cambium, xylem inner, sclerenchyma bundle cap); pith (central



parenchyma). Monocot stem T.S. (e.g. Zea mays): epidermis; ground tissue (parenchyma; uniform; no separate cortex or pith); vascular bundles scattered throughout (closed collateral: phloem outer, xylem inner with Y-shaped xylem and protoxylem lacuna, no cambium, surrounded by sclerenchyma bundle sheath). Key differences: bundle arrangement (ring vs scattered); cambium (present in dicot, absent in monocot); pith and cortex (present in dicot, absent in monocot). [Student should draw and label both sections].

12. Dicot root T.S. (e.g. Ranunculus): from outside inward: epidermis (piliferous; root hairs; no cuticle or stomata); cortex (wide; parenchyma; intercellular spaces); endodermis (Caspary strips on radial and transverse walls; forces water through cytoplasm); pericycle (one or more layers; gives rise to lateral roots); stele (alternating xylem arms and phloem strands; xylem forms X or star shape; usually 2-6 arms; no central pith in most dicots). Comparison with dicot stem: root has alternating xylem and phloem (not in bundles), distinct endodermis, root hairs, and no cambium; stem has bundles in a ring, cambium, no endodermis, and pith. Comparison with monocot root: similar zones but monocot root has many xylem arms (polyarch) and a central pith; same overall alternating arrangement.
13. Dorsiventral leaf T.S. (typical dicot): upper epidermis (cuticle; no stomata); palisade mesophyll (1-3 layers elongated cells; many chloroplasts; main photosynthesis site); spongy mesophyll (loose, irregular cells; large air spaces; gas exchange); lower epidermis (thin cuticle; stomata and guard cells; most gas exchange). Veins: xylem upper, phloem lower, bundle sheath around each. Isobilateral leaf (grass/maize): similar upper and lower epidermis; no distinct palisade or spongy layers; uniform chlorenchyma; stomata on both surfaces; bulliform cells in upper epidermis (cause leaf rolling when flaccid). Kranz anatomy in C₄ plants (maize): conspicuous large chloroplast-rich bundle sheath surrounding each vein, surrounded in turn by a ring of mesophyll cells; this spatial separation of CO₂ fixation (mesophyll) and Calvin cycle (bundle sheath) reduces photorespiration. Stomata: pore with two guard cells; guard cells have chloroplasts and unequally thickened walls; turgid = open; flaccid = closed; open in light for CO₂ entry. Other epidermal features: trichomes (hairs; reduce transpiration, deter herbivores); bulliform cells (leaf rolling); cuticle (cutin; waterproofing).

Answers to Pilot Questions [Series 1]

Part 1.1



1. Parenchyma (storage, photosynthesis, packing); collenchyma (flexible support in young stems); sclerenchyma (rigid mechanical support; dead lignified walls); xylem (water and mineral transport upward; dead hollow vessels); phloem (organic solute transport from leaves to other organs; living sieve tubes).
2. Collenchyma has living cells with unevenly thickened cellulose walls at corners only; it is flexible and occurs in young growing organs. Sclerenchyma has dead cells with uniformly thick lignified secondary walls all around the cell; it is rigid and provides permanent structural support.
3. From outside to inside: epidermis (cuticle; trichomes); cortex (parenchyma; collenchyma just below epidermis); vascular bundle ring (phloem outer, cambium, xylem inner, bundle cap of sclerenchyma fibres); pith (central parenchyma).
4. (1) Bundle arrangement: dicot has bundles in a ring; monocot has bundles scattered in ground tissue. (2) Cambium: present in dicot (open collateral bundle); absent in monocot (closed bundle). (3) Pith and cortex: separate pith and cortex zones in dicot; no separate pith or cortex in monocot (uniform ground tissue).
5. Monocot stems lack a vascular cambium (the meristematic tissue that produces secondary xylem and phloem in woody plants). Without cambium, no new vascular tissue can be added to increase the stem diameter; monocot stems are therefore permanently the diameter set during primary growth. Bamboo and palm trees achieve structural strength by producing many scattered vascular bundles and thick-walled fibres rather than through true secondary growth.

Part 1.2

1. From outside to inside: epidermis (piliferous layer; produces root hairs; no cuticle or stomata) → cortex (wide zone of parenchyma for storage; intercellular spaces) → endodermis (Casparian strips; controls water entry to stele) → pericycle (gives rise to lateral roots) → stele (alternating xylem arms and phloem strands; xylem forms X-shape or star; no central pith in most dicot roots).
2. The Casparian strip is a band of suberin deposited in the radial and transverse walls of endodermal cells. It blocks the apoplast pathway (movement of water between cells through cell walls). All water and dissolved minerals must therefore pass through the cytoplasm (symplast) of the endodermal cells, allowing the plant to selectively absorb certain ions and exclude others before they enter the stele and xylem.



3. (1) Xylem arms: dicot root has few arms (2 to 6: diarch to hexarch); monocot root has many arms (polyarch). (2) Central pith: monocot root has a central pith of parenchyma; most dicot roots have no pith (xylem extends to the centre).
4. (1) Vascular arrangement: root has alternating xylem and phloem strands; stem has xylem and phloem together in collateral vascular bundles. (2) Endodermis: prominently visible in root with Casparian strips; not distinct in most stems. (3) Root hairs: present in root epidermis (piliferous layer); absent in stem epidermis.
5. The root epidermis (piliferous layer) is adapted for absorption, not waterproofing. Root hair cells are thin-walled extensions of epidermal cells that absorb water and minerals by osmosis and active transport; a cuticle would block this absorption. Stomata are not needed on roots because gas exchange occurs through the large intercellular spaces of the cortex and directly into the soil atmosphere; there is no need to control air flow through pores.

Part 1.3

1. From upper to lower epidermis: upper epidermis (thick cuticle; no stomata or few; no chloroplasts) → palisade mesophyll (elongated cells; tightly packed; many chloroplasts) → spongy mesophyll (loosely arranged cells; large intercellular air spaces; fewer chloroplasts) → lower epidermis (thinner cuticle; stomata and guard cells; subsidiary cells).
2. Palisade mesophyll cells are elongated and tightly packed in layers directly below the upper epidermis, which is the surface that receives the most direct sunlight. Each palisade cell contains many chloroplasts (often 30 to 50 per cell) arranged along the cell walls where light can reach them. The tall columnar shape and close packing mean that light entering from above passes through many chloroplast-rich cells before being scattered by spongy mesophyll air spaces, maximising light capture per unit leaf area.
3. Dorsiventral leaf: distinct upper and lower surfaces; palisade mesophyll on the upper (adaxial) side and spongy mesophyll on the lower (abaxial) side; stomata mainly on the lower epidermis; typical of most dicots (e.g. bean, sunflower). Isobilateral leaf: similar upper and lower surfaces; no distinction between palisade and spongy mesophyll; uniform chlorenchyma throughout; stomata on both surfaces; typical of most monocots (e.g. grasses, irises).
4. Kranz anatomy is a leaf anatomical arrangement in C4 plants characterised by large, conspicuous bundle sheath cells surrounding each vascular bundle; these bundle sheath cells contain many large chloroplasts and are the site of the Calvin cycle (carbon fixation). Surrounding the bundle



sheath is a ring of mesophyll cells where CO₂ is initially fixed into 4-carbon compounds. This spatial separation concentrates CO₂ around RuBisCO in the bundle sheath, minimising photorespiration. Kranz anatomy is found in C₄ plants including maize (*Zea mays*), sugarcane, and sorghum.

5. A stoma is a pore in the leaf epidermis bounded by two guard cells. In dicots, guard cells are kidney-shaped; in grasses they are dumbbell-shaped. Guard cells differ from other epidermal cells in that they contain chloroplasts. Opening mechanism: in light, guard cells photosynthesize and accumulate K⁺ ions by active transport, lowering their water potential; water enters by osmosis making them turgid; the differentially thickened cell walls (thicker on the inner side facing the pore) cause them to bow outward, enlarging the pore. Closing: in darkness or drought, K⁺ leaves the guard cells; they lose water and become flaccid; the pore closes.



References and Attributions [Series 1]

Textual References (Books and External Sources)

- Esau, K. (1977). *Anatomy of seed plants* (2nd ed.). Wiley.
- Raven, P. H., Evert, R. F., & Eichhorn, S. E. (2005). *Biology of plants* (7th ed.). Freeman.
- Fahn, A. (1990). *Plant anatomy* (4th ed.). Pergamon Press.
- FAO (Food and Agriculture Organization of the United Nations). (2025). *Guidelines for sustainable agriculture*. FAO.

Figures, Plates, Tables, and Boxes

- Figure 1.1: Five major plant tissue types microscope photographs Attribution: AI generated. Suggested OER search string: "plant tissues microscope photographs parenchyma collenchyma sclerenchyma xylem phloem labelled OER".
- Figure 1.2: Dicot stem T.S. diagram and microscope photograph Attribution: AI generated. Suggested OER search string: "dicot stem transverse section T.S. Helianthus labelled diagram microscope photograph OER".
- Figure 1.3: Monocot stem T.S. diagram and microscope photograph Attribution: AI generated. Suggested OER search string: "monocot stem transverse section T.S. Zea mays maize labelled diagram scattered vascular bundles OER".
- Figure 1.4: Dicot root T.S. diagram and microscope photograph Attribution: AI generated. Suggested OER search string: "dicot root transverse section T.S. Ranunculus endodermis Casparian strip xylem phloem stele OER".
- Figure 1.5: Dorsiventral leaf T.S. diagram and microscope photograph Attribution: AI generated. Suggested OER search string: "dorsiventral leaf transverse section T.S. palisade spongy mesophyll stomata vascular bundle OER".
- Figure 1.6: Isobilateral (maize) leaf T.S. diagram and microscope photograph Attribution: AI generated. Suggested OER search string: "isobilateral leaf transverse section T.S. maize Kranz anatomy bundle sheath C4 photosynthesis OER".
- Figure 1.7: Stomata and epidermal structures photographs Attribution: AI generated. Suggested OER search string: "stomata guard cells surface view SEM trichomes leaf epidermis microscope photograph OER".



- Box 1.1: Comparison of dicot stem, monocot stem, dicot root, and monocot root Attribution: AI generated. Suggested OER search string: "comparison dicot monocot stem root anatomy table vascular bundle endodermis pith OER box".



Course code: BIO 108

Course title: General Biology Practical II

Course credit load: 1 Unit

Series 2: Fruits and Seeds Differentiation

- **Part 2.1: Structure and Classification of Fruits**

- Sub Part 2.1.1: Definition and development of a fruit
- Sub Part 2.1.2: Simple fleshy fruits
- Sub Part 2.1.3: Simple dry fruits

- **Part 2.2: Compound and False Fruits**

- Sub Part 2.2.1: Aggregate fruits
- Sub Part 2.2.2: Multiple (composite) fruits
- Sub Part 2.2.3: False fruits (pseudocarps)

- **Part 2.3: Structure and Types of Seeds**

- Sub Part 2.3.1: Seed structure in dicots and monocots
- Sub Part 2.3.2: Seed dispersal mechanisms
- Sub Part 2.3.3: Differences between fruits and seeds



Introduction

A fruit is the mature ovary of a flowering plant, often enclosing one or more seeds. Fruits protect seeds and facilitate their dispersal. Seeds contain the embryo that will develop into the next generation of plants. The enormous diversity of fruit and seed forms reflects the variety of dispersal strategies that plants have evolved.

This Series covers the definition and development of fruits, the major types of simple fleshy and dry fruits, aggregate, multiple, and false fruits, the internal structure of dicot and monocot seeds, seed dispersal mechanisms, and the key differences between fruits and seeds. Practical identification skills with real specimens are central to this Series.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 2.1** define a fruit, describe its development from a flower, and classify the major types of fruits (Linked to Part 2.1),
- **SLO 2.2** describe and identify simple fleshy and simple dry fruits with Nigerian examples (Linked to Part 2.1),
- **SLO 2.3** distinguish between aggregate fruits, multiple fruits, and false fruits with examples (Linked to Part 2.2),
- **SLO 2.4** describe the internal structure of a dicot seed and a monocot seed (Linked to Part 2.3),
- **SLO 2.5** describe the major seed dispersal mechanisms and identify adaptations for each (Linked to Part 2.3), and
- **SLO 2.6** state the key differences between a fruit and a seed (Linked to Part 2.3).



2.1 Structure and Classification of Fruits

2.1.1 Definition and development of a fruit

A true fruit is the mature, ripened ovary of a flowering plant, developing after fertilisation. The wall of the ovary becomes the pericarp (fruit wall), which may be fleshy or dry. The pericarp has three layers: the exocarp (outer skin), mesocarp (middle, which becomes the edible flesh in fleshy fruits), and endocarp (innermost layer, which may be stony, papery, or leathery). The seed(s) develop from the fertilised ovule(s) inside the ovary.

The calyx (sepals) may persist on the fruit as in tomato. Fruits are classified in two main ways: by the number of carpels and flowers involved (simple, aggregate, multiple, or false) and by the nature of the pericarp (fleshy or dry). Fleshy fruits have a soft, succulent pericarp at maturity; dry fruits have a dry, papery, or woody pericarp. Dry fruits are further divided into dehiscent (split open at maturity) and indehiscent (do not split open).

Fill in the blank: The wall of the ovary develops into the _____ (fruit wall), which has three layers: exocarp (outer skin), mesocarp (middle flesh), and endocarp (innermost layer).

2.1.2 Simple fleshy fruits

Simple fleshy fruits develop from a single flower with one or more fused carpels and have a soft, succulent pericarp at maturity. Berry: the entire pericarp is fleshy; the seeds are embedded in the flesh; examples: tomato (*Lycopersicon esculentum*), grape (*Vitis*), banana (*Musa*; technically a berry without hard seeds), and pepper (*Capsicum*). Drupe (stone fruit): fleshy mesocarp with a hard stony endocarp (stone) enclosing one seed; examples: mango (*Mangifera indica*), avocado (*Persea*), coconut (the coconut in trade is the endocarp and seed).

Hesperidium: a specialised berry with a leathery rind (exocarp and mesocarp fused) and juicy segments derived from the endocarp; characteristic of citrus fruits (orange, lemon, lime, grapefruit). Pepo: a berry with a tough rind derived from the fused thalamus and exocarp; characteristic of cucurbits (watermelon, cucumber, pumpkin). Pome: a false fruit in many



references, but structurally it is a fleshy fruit where the edible part is the enlarged thalamus (floral receptacle); the true ovary becomes the core (e.g. apple, pear); covered in Part 2.2.

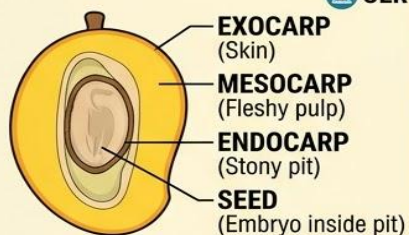
Fill in the blank: A _____ is a simple fleshy fruit in which the entire pericarp is fleshy and seeds are embedded in the flesh; examples include tomato, grape, and banana.

CLASSIFICATION OF SIMPLE FLESHY FRUITS

SECTION 1

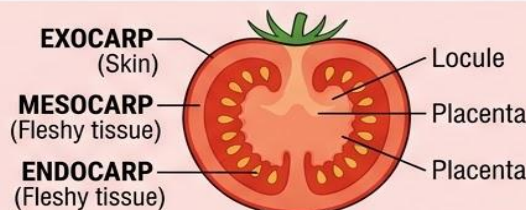
1. DRUPE (Mango)

OER



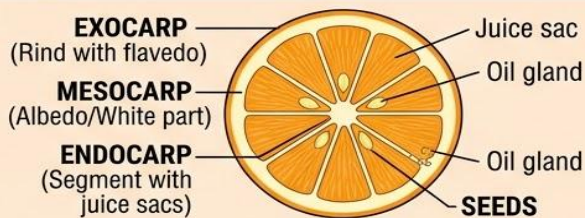
2. BERRY (Tomato)

OER



3. HESPERIDIUM (Orange)

OER



4. PEPO (Watermelon)

OER

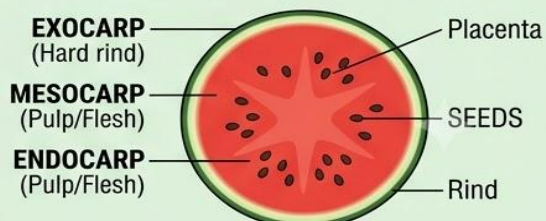


Figure 2.1: Photographs and labelled cross-sections of simple fleshy fruit types

2.1.3 Simple dry fruits

Simple dry fruits have a dry, papery, or woody pericarp at maturity. Dehiscent dry fruits split open to release seeds: legume/pod (developed from one carpel; splits along both sutures; e.g.



cowpea *Vigna*, groundnut *Arachis*, cassia); follicle (splits along one suture only; e.g. Delphinium); silique (two-carpelled; seeds on a central septum; e.g. cabbage family); capsule (developed from several fused carpels; several methods of opening; e.g. cotton *Gossypium*, okra *Abelmoschus*, flamboyant *Delonix*).

Indehiscent dry fruits do not split open at maturity; seeds are dispersed within the fruit: achene (one seed; pericarp free from seed coat; e.g. sunflower seed-like fruit); caryopsis (grain; pericarp fused to seed coat; typical of grasses; e.g. maize grain, wheat grain, rice grain); nut (hard woody pericarp; one seed; e.g. groundnut, cashew nut is actually the seed; true nut examples: hazel, chestnut); samara (winged achene for wind dispersal; e.g. ash, maple); schizocarp (splits into one-seeded sections called mericarps at maturity; e.g. carrot, coriander).

Fill in the blank: A _____ (grain) is an indehiscent dry fruit in which the pericarp is completely fused to the seed coat; it is characteristic of all grasses including maize, rice, and wheat.

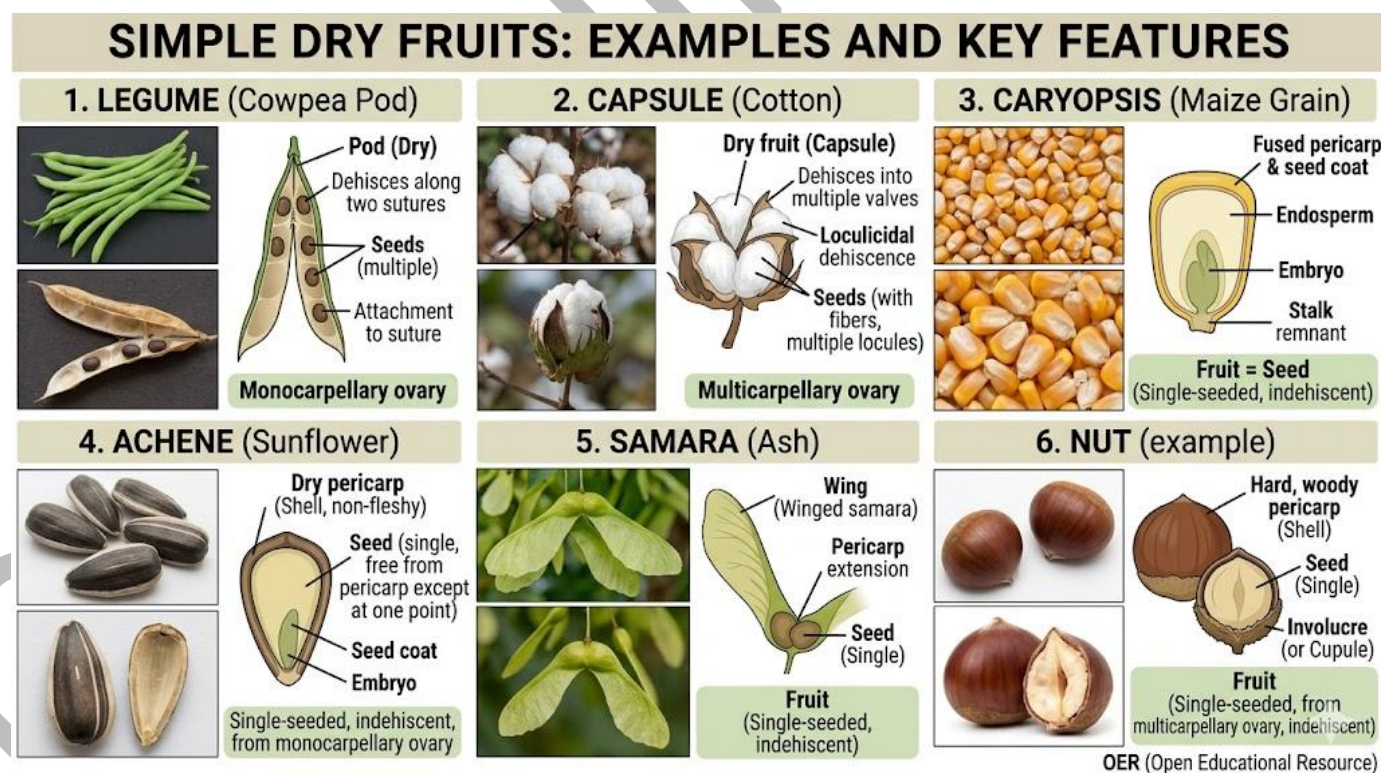


Figure 2.2: Photographs and diagrams of simple dry fruit types



Pilot questions 2.1

1. Define a true fruit and name the three layers of the pericarp.
2. Distinguish between a drupe and a berry with one example of each.
3. Name four dehiscent dry fruits and give one Nigerian example of each.
4. Distinguish between a caryopsis and an achene.
5. Explain why a legume is considered dehiscent and give two Nigerian examples.

2.2 Compound and False Fruits

2.2.1 Aggregate fruits

An aggregate fruit develops from a single flower that has many separate (apocarpous) carpels, all on the same receptacle. Each carpel develops into a small fruitlet (often a drupelet or achene), and all the fruitlets together form the aggregate fruit. The individual fruitlets may be fleshy drupelets (e.g. raspberry, blackberry: each tiny sphere is a separate drupelet from one carpel) or achenes sitting on a fleshy receptacle (e.g. strawberry, where the true fruits are the small achenes on the surface of the red fleshy receptacle).

To identify an aggregate fruit: look for multiple small fruit units (fruitlets) derived from multiple carpels of a single flower. In Nigerian contexts, the African breadfruit (*Treculia africana*) is sometimes used as a teaching example, though it is technically a multiple fruit. The soursop (*Annona muricata*) is a true aggregate of many fleshy carpels fused together on a common receptacle and is widely available in Nigeria, making it an excellent specimen for practical identification of aggregate fruit structure.

Fill in the blank: An aggregate fruit develops from a single flower with many _____ carpels; each carpel develops into a fruitlet; soursop (*Annona muricata*) is a Nigerian example.

2.2.2 Multiple (composite) fruits

A multiple fruit (composite or collective fruit) develops from an inflorescence (a cluster of many flowers), not from a single flower. The ovaries of many separate flowers fuse together, often



with other floral parts, to form a single mass of tissue that looks like one fruit. Examples: pineapple (*Ananas comosus*; the fruits of hundreds of flowers fuse with the fleshy axis and bracts to form the pineapple; the "eyes" on the surface are the individual flower bases); mulberry (*Morus*; berries from individual flowers fuse together); breadfruit (*Artocarpus altilis*).

Fig (*Ficus carica*) is a unique multiple fruit where the inflorescence is inverted (an enclosed receptacle called the syconium); hundreds of tiny flowers line the inside of the fleshy receptacle; after fertilisation all these develop into tiny achene-like fruits inside the swollen receptacle. In Nigeria, *Ficus* species are common. To distinguish multiple from aggregate fruits: multiple fruits arise from many flowers of an inflorescence; aggregate fruits arise from many carpels of a single flower.

Fill in the blank: A multiple fruit develops from an _____ (many flowers); examples include pineapple, breadfruit, and mulberry; the individual fruits from many separate flowers fuse together to form a single structure.

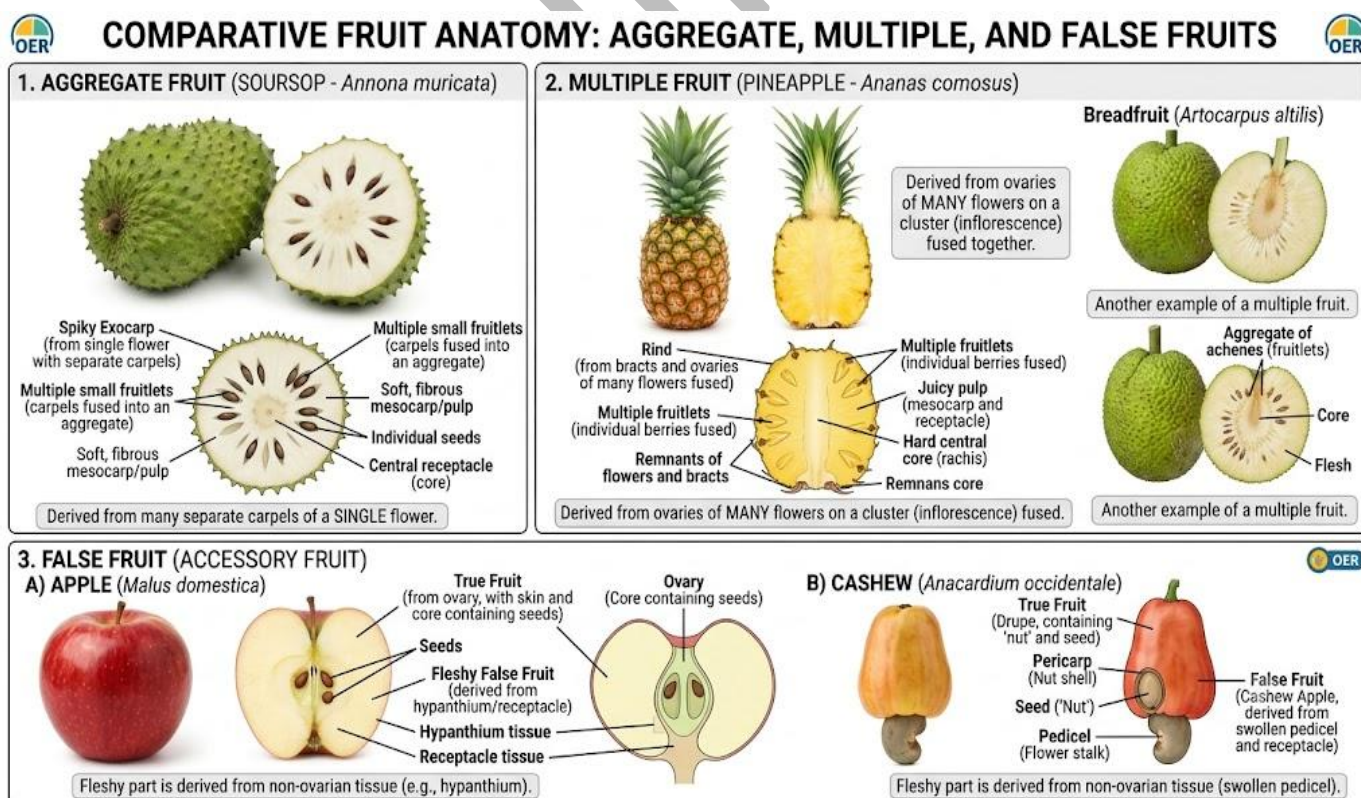


Figure 2.3: Photographs comparing aggregate fruits, multiple fruits, and false fruits



2.2.3 False fruits (pseudocarps)

A false fruit (pseudocarp) is one in which parts other than the ovary contribute substantially to the structure of the fruit. The non-ovary tissue (such as the thalamus, calyx, or peduncle) becomes the edible or conspicuous part. Apple and pear: the edible fleshy part is the greatly enlarged thalamus (floral receptacle); the true fruit is only the core containing the seeds. This structure (a fleshy thalamus enclosing the true fruit) is called a pome.

Cashew (*Anacardium occidentale*): the true fruit is the kidney-shaped cashew nut (a drupe); the bright red or yellow fleshy swollen structure (cashew apple) is the enlarged peduncle (flower stalk), not the ovary. Strawberry: the red fleshy part is the enlarged receptacle; the true fruits are the tiny achenes embedded on its surface. Rose hip: the fleshy receptacle forms a cup enclosing the achenes. Recognising false fruits requires identifying which non-ovary tissue has become the dominant structure.

Fill in the blank: In the cashew, the true fruit is the kidney-shaped _____ (nut) which is a drupe; the edible "cashew apple" is the enlarged _____ (flower stalk), not the ovary.

Pilot questions 2.2

1. Define an aggregate fruit and give two examples.
2. Define a multiple fruit and give two examples.
3. Distinguish between an aggregate fruit and a multiple fruit.
4. Explain why an apple is described as a false fruit.
5. State what part of the cashew plant forms the edible "cashew apple".

2.3 Structure and Types of Seeds

2.3.1 Seed structure in dicots and monocots

A seed develops from a fertilised ovule and contains the embryo, the food reserve, and the seed coat (testa). Dicot seed structure (e.g. bean, *Phaseolus vulgaris*): testa (outer seed coat, often marked with hilum where seed was attached to pod, micropyle for water entry, and raphe); two



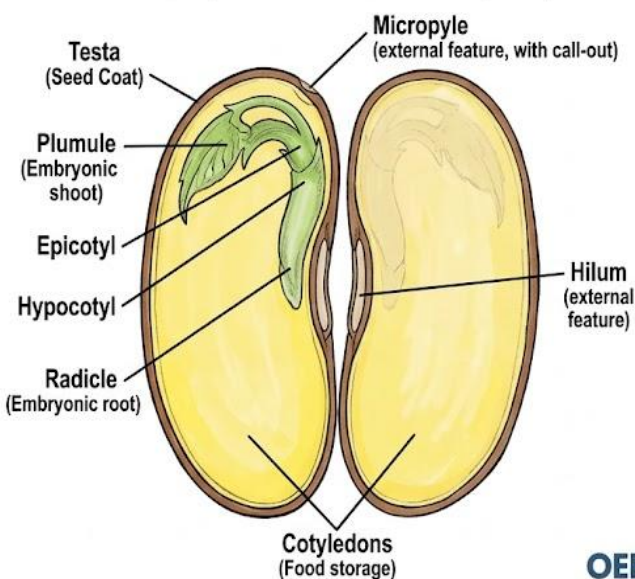
cotyledons (large, fleshy food stores; absorb and store starch, protein, and fat); embryonic axis (radicle/embryonic root, plumule/embryonic shoot, and hypocotyl between them). No endosperm in bean at maturity (absorbed into cotyledons during development).

Monocot seed structure (e.g. maize grain, *Zea mays*): the maize grain is a caryopsis (pericarp fused to seed coat). The grain contains: endosperm (large starchy food store, the bulk of the grain); one cotyledon called the scutellum (absorbs food from the endosperm and passes it to the embryo during germination); embryo (radicle enclosed in coleorhiza; plumule enclosed in coleoptile; scutellum attached to embryo axis). The coleoptile and coleorhiza are protective sheaths unique to grasses.

Fill in the blank: In a maize grain, the plumule is enclosed in a sheath called the _____ and the radicle is enclosed in the coleorhiza; these protective sheaths are unique to grasses (Poaceae).

STRUCTURAL COMPARISON: DICOT SEED (Bean) VS. MONOCOT GRAIN (*Maize*) L.S. (Longitudinal Section)

1. DICOT SEED (Bean – *Phaseolus vulgaris*) L.S.



2. MONOCOT GRAIN (Maize - *Zea mays*) L.S.

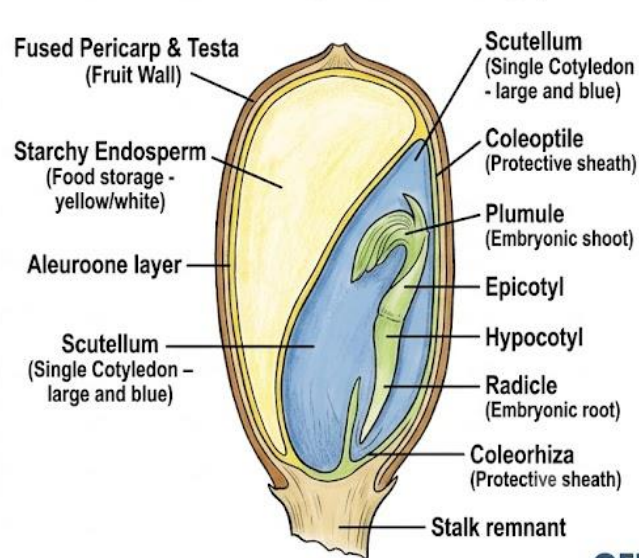


Figure 2.4: Labelled diagrams of a dicot seed (bean) and a monocot grain (maize)



2.3.2 Seed dispersal mechanisms

Seeds and fruits have evolved a remarkable diversity of adaptations for dispersal away from the parent plant. Wind dispersal (anemochory): seeds or fruits are light with wings, hairs, or plumes. Examples: winged samara of ash (*Fraxinus*) and maple (*Acer*); feathery pappus of dandelion (*Taraxacum*) and tridax; cotton seed with long hairs; kapok (*Ceiba pentandra*) with silky fibres. The large surface-area-to-mass ratio allows seeds to be carried on air currents.

Animal dispersal (zoochory): two sub-types. Epizoochory: fruits with hooks, spines, or sticky surfaces attach to animal fur or clothing (e.g. *Desmodium*, *Bidens pilosa* "black-jack", *Xanthium* "burr"). Endozoochory: fleshy edible fruits are eaten; seeds pass through the gut undamaged and are deposited elsewhere in faeces (e.g. mango, tomato, fig, bird-cherry). Water dispersal (hydrochory): seeds or fruits float on water currents (e.g. coconut; its fibrous mesocarp traps air). Explosive dispersal (autochory): fruits burst suddenly, ejecting seeds (e.g. castor oil *Ricinus*, *Impatiens*, rubber *Hevea*).

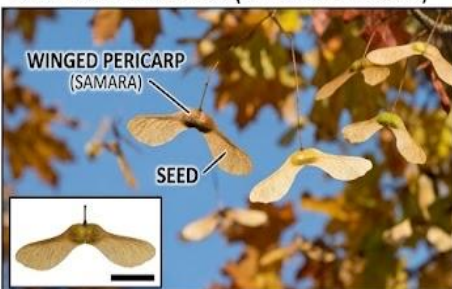
Fill in the blank: Endozoochory is a form of animal dispersal in which animals _____ fleshy fruits; seeds pass through the digestive system undamaged and are deposited in faeces away from the parent plant.



FIVE EXAMPLES OF SEED DISPERSAL ADAPTATIONS

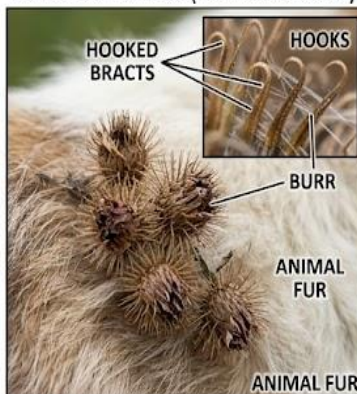
OER

1. WINGED SAMARA (WIND DISPERSAL)



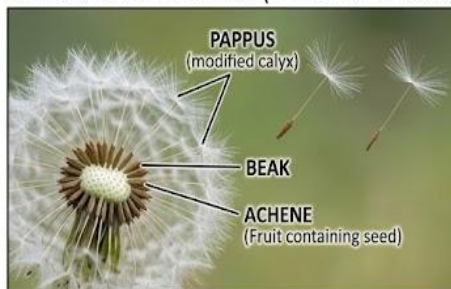
Adaptation for gliding and prolonged air travel by wind.

3. BURR HOOKS (EPIZOOCHORY)



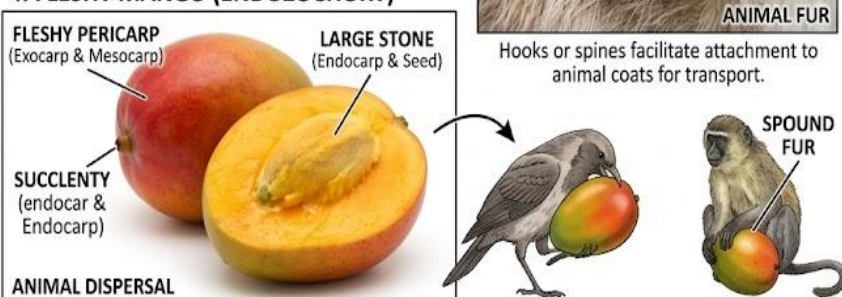
Hooks or spines facilitate attachment to animal coats for transport.

2. DANDELION PAPPUS (WIND DISPERSAL)



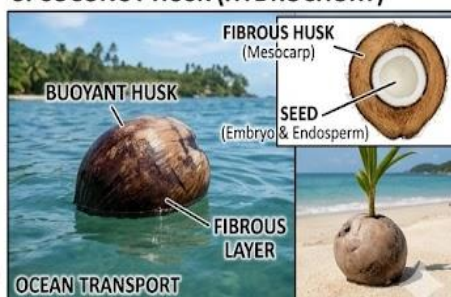
Modified sepals form a light parachute to catch air currents.

4. FLESHY MANGO (ENDOZOOCHORY)



Attracts animals to eat and pass seeds in droppings, often with nutrient packet.

5. COCONUT HUSK (HYDROCHORY)



Fibrous, buoyant husk protects the seed during long sea journeys.

OER

Figure 2.5: Photographs of seed and fruit dispersal adaptations

2.3.3 Differences between fruits and seeds

Students frequently confuse fruits and seeds. The key distinction: a fruit develops from the ovary wall (and sometimes other floral parts); a seed develops from the ovule. A fruit may contain one or many seeds. The fruit wall (pericarp) surrounds the seed(s). Some structures commonly called "seeds" in everyday speech are actually fruits: the sunflower "seed" is an achene (fruit); the maize "kernel" is a caryopsis (fruit); the groundnut "nut" in its shell is a seed inside a legume fruit.

Conversely, some everyday "nuts" are seeds inside hard-shelled fruits. The coconut sold in Nigerian markets consists of: the hard brown shell (endocarp), the white flesh (endosperm of the seed), and the liquid (liquid endosperm inside the seed); the outer green husk (mesocarp and exocarp) has usually been removed. The cashew nut in the shell is the true fruit (drupe); the cashew nut without the shell is the seed. Understanding this distinction is essential for accurate botanical description.



Fill in the blank: A fruit develops from the _____ of the flower; a seed develops from the ovule; the sunflower "seed" is actually an achene (a dry indehiscent fruit), not a true seed.

<u>Common Name</u>	<u>Botanical Classification</u>
<u>Sunflower seed</u>	Achene (a dry, one-seeded fruit that does not open at maturity)
<u>Maize kernel</u>	Caryopsis (grain; seed fused with fruit wall)
<u>Groundnut</u>	Legume (fruit develops from a single carpel and splits open)
<u>Coconut</u>	Drupe (fibrous outer layer, hard endocarp enclosing seed)
<u>Cashew apple</u>	Accessory fruit (fleshy pedicel; true fruit is the nut)
<u>Tomato</u>	Berry (fleshy fruit with seeds embedded in pulp)

Box 2.1: Common everyday names versus correct botanical classification

Pilot questions 2.3

1. Describe the internal structure of a bean seed and label the parts.
2. Explain the function of the coleoptile and coleorhiza in a maize grain.
3. Name four seed dispersal mechanisms and state one adaptation for each.
4. State three differences between a fruit and a seed.
5. Explain why the maize kernel is a fruit and not a seed.



Series Summary

This Series covered the structure, classification, and dispersal of fruits and seeds. A true fruit develops from the ovary wall after fertilisation, with the pericarp differentiated into three layers: exocarp, mesocarp, and endocarp. Simple fleshy fruits were classified into berries, drupes, hesperidia, and pepos, while simple dry fruits were distinguished as either dehiscent (legumes, follicles, and capsules that split at maturity) or indehiscent (achenes, caryopses, nuts, and samaras that do not). Aggregate fruits such as soursop arise from multiple carpels of a single flower, multiple fruits such as pineapple from the flowers of an entire inflorescence, and false fruits such as the apple and cashew apple from tissue other than the ovary wall.

Seed structure was compared between dicots and monocots: dicot seeds such as the bean have two cotyledons, a testa, radicle, plumule, and hypocotyl with no persistent endosperm, while monocot seeds retain a large endosperm absorbed through the specialised scutellum, with shoot and root protected by the coleoptile and coleorhiza respectively. Dispersal mechanisms were surveyed, covering wind dispersal through wings and pappus structures, animal dispersal through external attachment and ingestion, water dispersal through buoyant structures such as the fibrous coconut husk, and explosive autochory. The Series closed by reinforcing the key distinction between fruit and seed, clarifying common misconceptions such as the maize kernel and sunflower seed, both of which are fruits, and the groundnut pod, which is a fruit enclosing seeds.

Glossary of Terms

- **Achene:** a small, dry, indehiscent one-seeded fruit in which the pericarp is free from the seed coat; e.g. sunflower "seed".
- **Aggregate fruit:** a fruit developing from a single flower with many separate (apocarpous) carpels; each carpel forms a fruitlet; e.g. soursop (*Annona muricata*).
- **Anemochory:** dispersal of seeds or fruits by wind; adaptations include wings (samara), hairs or pappus (dandelion, cotton), and balloon-like structures.



- **Autochory:** self-dispersal of seeds by the plant's own explosive or contractile mechanisms; e.g. castor oil (*Ricinus*), *Impatiens*, *Hevea*.
- **Berry:** a simple fleshy fruit with an entirely fleshy pericarp and seeds embedded in the flesh; e.g. tomato, grape, banana.
- **Caryopsis:** a dry indehiscent one-seeded fruit (grain) in which the pericarp is completely fused to the seed coat; characteristic of all grasses; e.g. maize, wheat, rice.
- **Coleoptile:** a protective sheath enclosing the young shoot (plumule) in grass seeds; pierces the soil during germination before unsheathing the first leaves.
- **Coleorhiza:** a protective sheath enclosing the young root (radicle) in grass seeds; protects the radicle as it pushes through the soil.
- **Dehiscent:** a dry fruit that splits open at maturity to release seeds; examples include legumes (pods), follicles, siliquae, and capsules.
- **Drupe:** a simple fleshy fruit with a fleshy mesocarp and a hard, stony endocarp enclosing a single seed; e.g. mango (*Mangifera indica*), avocado.
- **Endosperm:** the nutritive tissue inside a seed that provides food for the developing embryo; large in monocot seeds (e.g. maize endosperm); absorbed into cotyledons in many dicot seeds.
- **Epizoochory:** animal dispersal of seeds or fruits that adhere to the outside of animal bodies by hooks, spines, or sticky substances; e.g. *Bidens* (black-jack).
- **Endozoochory:** animal dispersal of seeds through consumption of fleshy fruits; seeds pass through the digestive tract undamaged and are deposited in faeces.
- **Exocarp:** the outermost layer of the pericarp (fruit wall); forms the outer skin of the fruit.
- **False fruit (pseudocarp):** a fruit in which non-ovary tissues (e.g. thalamus, peduncle, calyx) contribute substantially to the edible structure; e.g. apple (thalamus), cashew apple (peduncle).
- **Hesperidium:** a specialised berry with a leathery aromatic rind and juicy internal segments; characteristic of citrus fruits.
- **Hilum:** the scar on the seed coat marking the point where the seed was attached to the funiculus (seed stalk) in the ovary.



- **Hydrochory:** dispersal of seeds or fruits by water; adaptations include air spaces and fibrous tissues for buoyancy; e.g. coconut.
- **Indehiscent:** a dry fruit that does not split open at maturity; the seed is dispersed within the fruit; examples include achene, caryopsis, nut, and samara.
- **Legume (pod):** a dehiscent dry fruit developed from one carpel that splits along both sutures to release seeds; characteristic of the Fabaceae family; e.g. cowpea, groundnut.
- **Mesocarp:** the middle layer of the pericarp; becomes the edible fleshy part in drupes and berries.
- **Micropyle:** a tiny pore in the seed coat (testa) through which water enters during germination; the original pore in the ovule through which the pollen tube grew.
- **Multiple fruit:** a fruit developing from an inflorescence (many flowers); ovaries of many flowers fuse to form a single structure; e.g. pineapple, breadfruit, mulberry.
- **Pericarp:** the fruit wall, derived from the ovary wall; composed of three layers: exocarp, mesocarp, and endocarp.
- **Pepo:** a specialised berry with a tough rind derived from the fused thalamus and exocarp; characteristic of cucurbit fruits; e.g. watermelon, cucumber, pumpkin.
- **Pome:** a false fruit characteristic of the rose family (Rosaceae) in which the fleshy edible part is the enlarged thalamus; the true ovary forms the core; e.g. apple, pear.
- **Samara:** a winged, dry indehiscent fruit; the wing is an extension of the pericarp; wind-dispersed; e.g. ash (*Fraxinus*), maple (*Acer*).
- **Scutellum:** the single cotyledon of a grass (monocot) seed; lies against the endosperm and secretes enzymes to digest and absorb stored food during germination.
- **Testa:** the seed coat; the tough outer covering of the seed, derived from the integuments of the ovule; protects the embryo.



Concept Check Questions [Series 2]

Objective Questions

6. The wall of the ovary develops into the _____ (fruit wall) which has three layers: exocarp, mesocarp, and endocarp. (Linked to SLO 2.1)
7. A _____ is a simple fleshy fruit with an entirely fleshy pericarp and seeds embedded in the flesh; examples include tomato, grape, and banana. (Linked to SLO 2.2)
8. A _____ fruit develops from an inflorescence (many flowers); pineapple and breadfruit are examples. (Linked to SLO 2.3)
9. In a maize grain, the plumule is enclosed in the _____ and the radicle is enclosed in the coleorhiza. (Linked to SLO 2.4)
10. A fruit develops from the _____ of the flower; a seed develops from the ovule. (Linked to SLO 2.6)

Short-Answer Questions

11. Distinguish between a drupe and a berry with one example each. (Linked to SLO 2.2)
12. Name three dehiscent dry fruits and give one example of each. (Linked to SLO 2.2)
13. Distinguish between an aggregate fruit and a multiple fruit. (Linked to SLO 2.3)
14. Describe the internal structure of a bean seed. (Linked to SLO 2.4)
15. Name four seed dispersal mechanisms and state one adaptation for each. (Linked to SLO 2.5)

Long-Answer Questions

14. Classify fruits into their major types, describe simple fleshy and dry fruits, and give Nigerian examples of each. (Linked to SLOs 2.1, 2.2)
15. Distinguish between aggregate, multiple, and false fruits with examples; describe the internal structure of a dicot and a monocot seed. (Linked to SLOs 2.3, 2.4)
16. Describe the major seed dispersal mechanisms with adaptations, and explain the key differences between fruits and seeds using specific examples. (Linked to SLOs 2.5, 2.6)



Answers to Concept Check Questions [Series 2]

Objective Questions

6. Pericarp.
7. Berry.
8. Multiple.
9. Coleoptile.
10. Ovary.

Short-Answer Questions

11. Drupe: fleshy mesocarp with a hard stony endocarp enclosing one seed; e.g. mango. Berry: entire pericarp fleshy; seeds embedded in flesh throughout; no stony endocarp; e.g. tomato.
12. Legume/pod (cowpea; splits along two sutures); capsule (cotton; opens by valves or pores); follicle (Delphinium; splits along one suture).
13. Aggregate fruit: develops from one flower with many separate carpels; each carpel forms a fruitlet; e.g. soursop. Multiple fruit: develops from many flowers of an inflorescence; ovaries of many flowers fuse together; e.g. pineapple.
14. From outside to inside: testa (seed coat; marked with hilum and micropyle); two fleshy cotyledons (food store); embryonic axis consisting of radicle (embryonic root), hypocotyl, and plumule (embryonic shoot). No endosperm in bean at maturity.
15. Wind (anemochory): wings or hairs e.g. samara (ash) or pappus (dandelion). Animal-external (epizoochory): hooks e.g. Bidens (black-jack). Animal-internal (endozoochory): fleshy edible fruit e.g. mango. Water (hydrochory): fibrous buoyant husk e.g. coconut.

Long-Answer Questions

14. Classification: fruits are simple (one flower, one or more fused carpels), aggregate (one flower, many free carpels), multiple (many flowers fused), or false (non-ovary tissue dominates). Pericarp: fleshy or dry. Simple fleshy: berry (tomato, grape; entire pericarp fleshy; seeds embedded in flesh); drupe (mango, avocado; fleshy mesocarp + stony endocarp; one seed); hesperidium (orange, lemon; leathery rind; juicy internal segments); pepo (watermelon, cucumber; tough rind from fused thalamus and exocarp). Simple dry dehiscent: legume/pod (cowpea, groundnut; splits both sutures); capsule (cotton, okra; splits by valves); follicle (splits



one suture); siliqua (cabbage family; central septum). Simple dry indehiscent: caryopsis/grain (maize, wheat, rice; pericarp fused to seed coat); achene (sunflower; free pericarp); nut (hazel, chestnut; hard woody pericarp); samara (ash; winged achene for wind dispersal).

15. Aggregate fruit: one flower, many free carpels; each forms a fruitlet; soursop (*Annona*): many fleshy carpels fused on one receptacle; raspberry: many drupelets from one flower. Multiple fruit: inflorescence (many flowers); pineapple (hundreds of flowers fuse with axis and bracts; "eyes" = individual flower bases); breadfruit, mulberry. False fruit: non-ovary tissue dominates; apple (pome: enlarged thalamus = edible part; core = true ovary); cashew (cashew apple = swollen peduncle; true fruit = cashew nut drupe at tip); strawberry (enlarged receptacle = edible part; achenes = true fruits on surface). Dicot seed (bean): testa (hilum, micropyle, raphe); two large fleshy cotyledons (food store: starch, protein, fat); embryonic axis (radicle, hypocotyl, plumule); no endosperm in mature bean. Monocot grain (maize caryopsis): pericarp fused to seed coat; large starchy endosperm; scutellum (single cotyledon; absorbs endosperm food); embryo with coleoptile (protecting plumule) and coleorhiza (protecting radicle).
16. Dispersal mechanisms: (1) Wind (anemochory): light weight; large surface area; adaptations: wings (samara of ash, maple), feathery hairs or pappus (dandelion, *Tridax*, cotton seed), air sacs. (2) Animal-external (epizoochory): hooks, spines, or sticky surfaces attach to fur or clothing; e.g. *Bidens pilosa* (black-jack), *Desmodium*, *Xanthium*. (3) Animal-internal (endozoochory): edible fleshy fruits attract animals; seeds pass through gut unharmed and deposited in faeces; e.g. mango, tomato, fig. (4) Water (hydrochory): buoyant fibrous mesocarp traps air; e.g. coconut can float for months. (5) Explosive (autochory): sudden release by hygroscopic tension or turgor; e.g. *Ricinus* (castor oil), *Impatiens*, *Hevea*. Fruit vs seed: fruit is derived from the ovary wall (pericarp), sometimes with additional non-ovary tissue; seed is derived from the ovule; a fruit may contain one or many seeds; the pericarp surrounds the seed(s). Common confusions: maize kernel = caryopsis (fruit; pericarp fused to seed coat); sunflower "seed" = achene (fruit; pericarp free); groundnut "seed" = true seed inside a legume fruit; coconut sold in markets = seed (endosperm and embryo) enclosed in the endocarp (hard shell) of a drupe; cashew "apple" = enlarged peduncle (false fruit); cashew nut = true fruit (drupe).



Answers to Pilot Questions [Series 2]

Part 2.1

6. A true fruit is the mature ripened ovary of a flowering plant after fertilisation. The three layers of the pericarp: exocarp (outer skin), mesocarp (middle; becomes fleshy in fleshy fruits), and endocarp (innermost layer; may be stony, papery, or leathery).
7. Drupe: fleshy mesocarp surrounding a hard stony endocarp; one seed enclosed in the stone; e.g. mango (*Mangifera indica*). Berry: entire pericarp is fleshy from exocarp to endocarp; seeds are embedded in the fleshy tissue; no stony endocarp; e.g. tomato (*Lycopersicon esculentum*).
8. Dehiscent dry fruits with Nigerian examples: (1) Legume/pod (cowpea *Vigna unguiculata*; groundnut *Arachis hypogaea*); (2) Capsule (cotton *Gossypium hirsutum*; okra *Abelmoschus esculentus*); (3) Follicle (*Delphinium*; *Calotropis*); (4) Siliqua (*Raphanus*; *Brassica*, though less common in Nigeria than the first two types).
9. Caryopsis (grain): the pericarp is completely fused to the seed coat; the two cannot be separated; characteristic of grasses; e.g. maize grain, wheat grain. Achene: the pericarp is free from the seed coat (it can be peeled away from the seed); e.g. sunflower "seed" (the thin papery or leathery coat is the pericarp; the true seed with a brown seed coat lies inside it).
10. A legume (pod) is dehiscent because at maturity the pericarp dries out and creates tension that causes the pod to split along two lines of weakness: the dorsal suture (the midrib of the original carpel) and the ventral suture (the edge where the carpel margins fused); this explosive splitting forcibly ejects the seeds. Two Nigerian examples: cowpea (*Vigna unguiculata*) and soyabean (*Glycine max*).

Part 2.2

6. An aggregate fruit develops from a single flower that has multiple separate (free) carpels on a common receptacle; each carpel matures into a small fruitlet, and all the fruitlets together form the aggregate structure. Examples: (1) soursop (*Annona muricata*; each segment is a separate fleshy carpel; fruitlets fused together on a common axis); (2) raspberry (*Rubus*; each tiny sphere is a separate drupelet from one carpel).
7. A multiple fruit develops from an entire inflorescence (a cluster of many individual flowers); the ovaries and sometimes other floral parts of all the individual flowers fuse together to produce a



single fruit-like structure. Examples: (1) pineapple (*Ananas comosus*; hundreds of flowers fuse with the fleshy axis and bracts; each "eye" represents one flower); (2) breadfruit (*Artocarpus altilis*; common in southern Nigeria; the ovaries and perianths of many flowers fuse into a starchy mass).

8. Key distinction: Aggregate fruit: arises from ONE flower that has MANY separate carpels; each carpel forms a fruitlet; the fruitlets are grouped on the receptacle of a single flower. Multiple fruit: arises from MANY flowers forming an inflorescence; the individual ovaries (and sometimes other floral parts) of all these separate flowers fuse together into a single structure. The clearest test: if you can find a single flower that gives rise to the whole fruit structure, it is aggregate; if many flowers contributed, it is multiple.
9. An apple is a false fruit (pome) because the major edible part of the apple is NOT derived from the ovary. In the apple flower, the ovary is inferior (sunken into the thalamus/receptacle) and surrounded by the fleshy hypanthium (the enlarged floral tube formed from the fused base of the sepals, petals, and stamens). As the fruit develops, this fleshy hypanthium/thalamus enlarges enormously and becomes the crisp, sweet, edible part; the true ovary forms only the core (the tough, papery central region containing the seeds).
10. The "cashew apple" is formed by the greatly enlarged and fleshy peduncle (flower stalk) of the cashew flower; it is the swollen pedicel/receptacle that turns bright red or yellow at maturity and develops a juicy, astringent flesh. The true fruit of the cashew plant is the kidney-shaped cashew nut at the tip of the cashew apple, which is a drupe: it has a thin exocarp, a fleshy mesocarp, and a hard endocarp enclosing the single seed (the edible cashew nut kernel).

Part 2.3

6. A bean seed (*Phaseolus vulgaris*) in longitudinal section shows: testa (outer seed coat; marked by the hilum where the seed was attached to the pod, and the micropyle for water entry); two large fleshy cotyledons (store food as starch, protein, and fat; they are the dominant structure of the seed and absorb all the endosperm during seed development); embryonic axis connecting the two cotyledons: radicle (embryonic root; points toward the micropyle), hypocotyl (short stem between radicle and cotyledons), and plumule (embryonic shoot; tiny leaves visible above the attachment point of the cotyledons).
7. The coleoptile is a hollow, cone-shaped protective sheath that encloses and protects the delicate plumule (embryonic shoot and first leaves) as it pushes up through the soil during germination;



once the coleoptile tip emerges into light it stops elongating and splits to allow the first leaves to emerge into the light. The coleorhiza is a sheath that encloses and protects the radicle (embryonic root) as it pushes downward through the soil; the radicle quickly breaks through the coleorhiza as germination proceeds. Both sheaths protect the tender growing points from abrasion by soil particles.

8. Four dispersal mechanisms with adaptations: (1) Wind (anemochory): wings extending from the pericarp increase surface area for air resistance (samara of ash); feathery pappus hairs (dandelion, *Tridax*, cotton seed fibres); very small and light seeds. (2) Animal external (epizoochory): hooked spines, barbs, or sticky glandular hairs adhere to animal fur or clothing (*Bidens pilosa*/black-jack; *Xanthium*). (3) Animal internal (endozoochory): edible, brightly coloured, sweet fleshy fruit attracts animals; hard seed coat resists digestive enzymes; seeds unharmed in faeces (mango, tomato). (4) Water (hydrochory): fibrous, air-containing mesocarp provides buoyancy and waterproofing; seeds can remain viable in seawater for months (coconut).
9. Three differences between a fruit and a seed: (1) Origin: a fruit develops from the ovary wall (and sometimes other floral parts); a seed develops from the ovule inside the ovary. (2) Structure: a fruit has a pericarp (exocarp, mesocarp, endocarp) surrounding the seed(s); a seed has a testa (seed coat) enclosing the embryo and food reserve. (3) Content: a fruit may contain one or many seeds; a seed contains the embryo (radicle, plumule, cotyledon(s)) and food reserve (endosperm or cotyledons) but no other seeds inside it.
10. The maize kernel is a fruit (specifically a caryopsis) because it developed from the ovary of the maize flower, not from the ovule alone. The outer covering (the hard yellowish coat on the outside of the kernel) is the pericarp (fruit wall = matured ovary wall), not the seed coat (testa). In a caryopsis, the pericarp is completely and inseparably fused to the underlying seed coat (testa); the two cannot be separated. The kernel therefore contains both a fruit wall (pericarp fused to seed coat) and the seed (endosperm, scutellum, and embryo) within it. Because it has a pericarp derived from the ovary, it is by definition a fruit.



References and Attributions [Series 2]

Textual References (Books and External Sources)

- Esau, K. (1977). *Anatomy of seed plants* (2nd ed.). Wiley.
- Raven, P. H., Evert, R. F., & Eichhorn, S. E. (2005). *Biology of plants* (7th ed.). Freeman.
- Corner, E. J. H. (1976). *The seeds of dicotyledons*. Cambridge University Press.
- FAO (Food and Agriculture Organization of the United Nations). (2025). *Guidelines for sustainable agriculture*. FAO.

Figures, Plates, Tables, and Boxes

- Figure 2.1: Simple fleshy fruit types photographs and cross-sections Attribution: AI generated. Suggested OER search string: "simple fleshy fruits drupe mango berry tomato hesperidium orange pepo watermelon cross section labelled OER".
- Figure 2.2: Simple dry fruit types photographs and diagrams Attribution: AI generated. Suggested OER search string: "simple dry fruits legume pod cowpea capsule cotton caryopsis maize grain achene samara nut labelled OER".
- Figure 2.3: Aggregate, multiple, and false fruit comparison photographs Attribution: AI generated. Suggested OER search string: "aggregate fruit soursop multiple fruit pineapple false fruit apple cashew comparison photographs cross section labelled OER".
- Figure 2.4: Dicot seed (bean) and monocot grain (maize) labelled diagrams Attribution: AI generated. Suggested OER search string: "dicot seed bean longitudinal section monocot grain maize coleoptile coleorhiza endosperm labelled diagram OER".
- Figure 2.5: Seed dispersal adaptations photographs Attribution: AI generated. Suggested OER search string: "seed dispersal adaptations wind samara dandelion pappus animal burr hooks mango hydrochory coconut photographs labelled OER".
- Box 2.1: Common everyday names versus correct botanical classification table Attribution: AI generated. Suggested OER search string: "common everyday plant names botanical classification fruit seed achene caryopsis drupe berry table OER box".



Course code: BIO 108

Course title: General Biology Practical II

Course credit load: 1 Unit

Series 3: Handling and Care of Biological Wares

- **Part 3.1: The Microscope and Optical Instruments**
 - Sub Part 3.1.1: Types of microscopes
 - Sub Part 3.1.2: Parts of the compound light microscope and their functions
 - Sub Part 3.1.3: Use, care, and maintenance of the microscope
- **Part 3.2: Dissecting Kits and Laboratory Glassware**
 - Sub Part 3.2.1: Dissecting instruments and their uses
 - Sub Part 3.2.2: Common laboratory glassware
 - Sub Part 3.2.3: Preparation of temporary microscope slides
- **Part 3.3: Laboratory Safety, Fixation, and Preservation**
 - Sub Part 3.3.1: Laboratory safety rules
 - Sub Part 3.3.2: Fixation and preservation of biological specimens
 - Sub Part 3.3.3: Staining techniques for biological specimens

Introduction

The quality of biological observation depends entirely on the quality of the tools used and the care taken in using them. Microscopes, dissecting instruments, laboratory glassware, and chemical reagents are expensive and fragile; their proper use and maintenance is a core practical



skill. Preserved and stained specimens reveal structures invisible to the naked eye, making good preparation technique essential.

This Series covers the major types of microscopes and their optical principles, the parts and functions of the compound light microscope, correct microscope technique and maintenance, dissecting instruments and their uses, common laboratory glassware, preparation of temporary slides, laboratory safety rules, fixation and preservation of specimens, and staining techniques used in biological microscopy.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 3.1** describe the types of microscopes and explain the optical principles of the compound light microscope (Linked to Part 3.1),
- **SLO 3.2** identify and state the function of each part of a compound light microscope (Linked to Part 3.1),
- **SLO 3.3** describe the correct procedure for using, cleaning, and storing a compound microscope (Linked to Part 3.1),
- **SLO 3.4** identify dissecting instruments and state the use of each (Linked to Part 3.2),
- **SLO 3.5** identify common laboratory glassware and prepare a temporary microscope slide (Linked to Part 3.2),
- **SLO 3.6** state the laboratory safety rules relevant to biological practical work (Linked to Part 3.3), and
- **SLO 3.7** describe the fixation, preservation, and staining of biological specimens (Linked to Part 3.3).

3.1 The Microscope and Optical Instruments

3.1.1 Types of microscopes

Several types of microscopes are used in biology. The compound light microscope (CLM): uses visible light and two sets of lenses (objective and eyepiece) to magnify specimens up to



approximately 1,000 times (1000x); resolving power approximately 0.2 micrometres; suitable for cells, tissues, and microorganisms. The dissecting (stereo) microscope: uses two eyepieces giving a three-dimensional view; low magnification (7x to 45x); used for dissection and examination of whole specimens; working distance is large.

The transmission electron microscope (TEM): uses a beam of electrons instead of light; magnification up to 1,000,000x; resolving power 0.1 nanometres; reveals ultrastructure of cells (organelles, membranes); specimens must be very thin slices, stained with heavy metals, viewed in a vacuum. The scanning electron microscope (SEM): scans an electron beam over the specimen surface; produces three-dimensional surface images; resolving power 1 to 20 nm; specimens are coated in gold or platinum; used to examine surface features. Phase contrast and fluorescence microscopes are used for live cells.

Fill in the blank: The compound light microscope uses _____ light and two sets of lenses to magnify specimens up to approximately 1,000 times; its resolving power is approximately 0.2 micrometres.

3.1.2 Parts of the compound light microscope and their functions

Mechanical parts: eyepiece (ocular lens): the lens the observer looks through; usually 10x magnification; may have a pointer or graticule. Nosepiece (revolving): holds objective lenses; rotates to change magnification. Objective lenses: 4x (scanning), 10x (low power), 40x (high power), 100x (oil immersion); provide primary magnification. Coarse focus knob: large outer knob; moves stage or body tube rapidly for initial focusing. Fine focus knob: small inner knob; used for precise focusing. Stage: flat platform holding the slide; may have mechanical stage with x-y controls. Stage clips: hold the slide on the stage.

Optical parts: eyepiece (ocular lens) already described; objective lenses already described; condenser: lens below the stage that concentrates light onto the specimen; diaphragm (iris diaphragm): controls the amount of light reaching the specimen; adjusting it improves contrast. Illumination: built-in electric lamp (modern microscopes) or mirror (older models) reflects light



from an external source. Body tube: connects eyepiece to nosepiece. Arm: supports the body tube; used to carry the microscope. Base: the flat bottom of the microscope; supports everything. Total magnification = eyepiece magnification x objective lens magnification.

Fill in the blank: Total magnification of a compound microscope = _____ magnification multiplied by objective lens magnification; with a 10x eyepiece and 40x objective, total magnification is 400x.

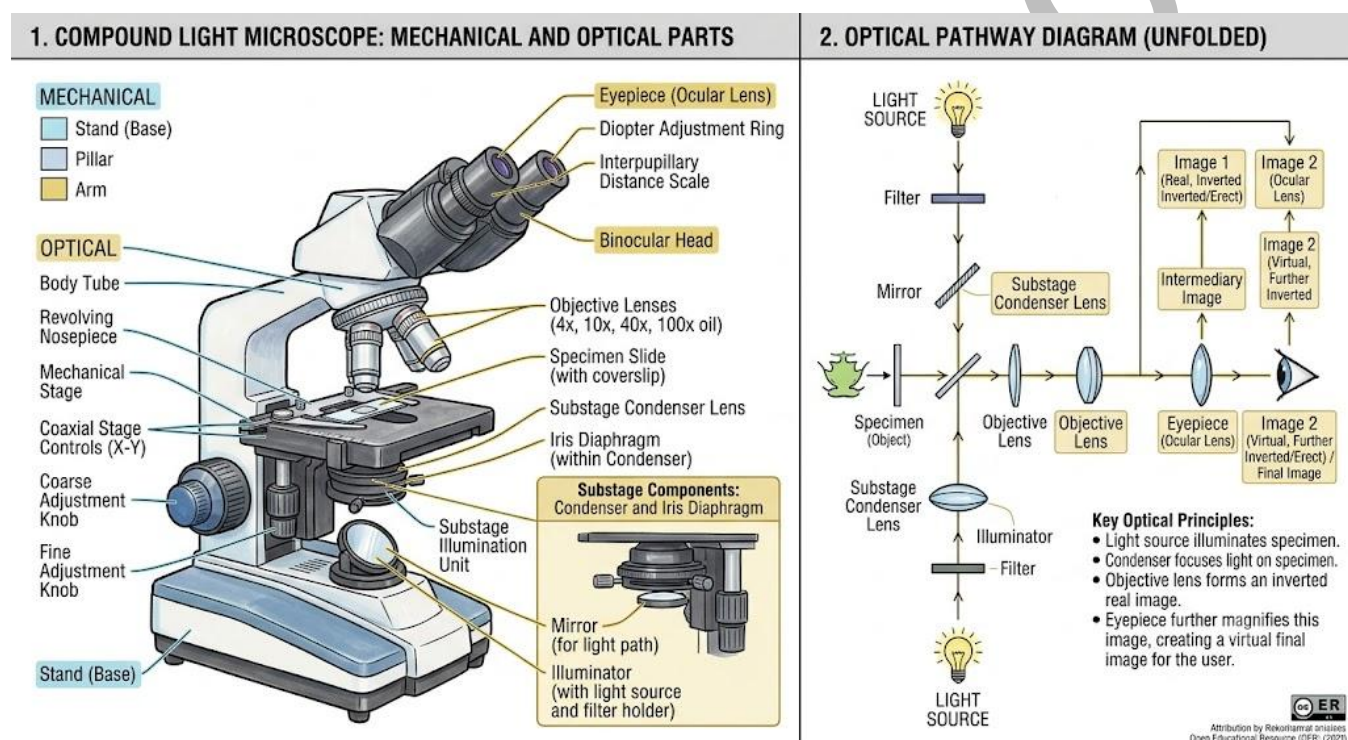


Figure 3.1: Labelled diagram of a compound light microscope

3.1.3 Use, care, and maintenance of the microscope

Correct procedure for using a compound microscope: (1) carry with two hands (one on arm, one on base); (2) plug in and switch on light; (3) click the lowest power objective (4x) into place; (4) place the slide on the stage and secure with clips; (5) use coarse focus to bring specimen approximately into focus while looking from the side; (6) look through eyepiece and refine with



coarse then fine focus; (7) centre the specimen in the field of view; (8) increase magnification by rotating to a higher objective; (9) use only fine focus at high power.

Care and maintenance: never touch lens surfaces with fingers (use lens tissue only); never force the nosepiece or focus knobs; clean lenses with lens tissue and appropriate cleaning fluid; always store the microscope with the lowest power objective in place and the stage lowered; cover with a dust cover when not in use; report any damage immediately. At high power (40x and above), the condenser should be raised and the iris diaphragm opened wider to allow more light. Oil immersion (100x) requires one drop of immersion oil on the coverslip; clean oil from the lens immediately after use with lens tissue.

Fill in the blank: Always store a microscope with the lowest power (_____ x) objective in place; carry it with one hand on the arm and one hand on the base; never touch lens surfaces with fingers.

Pilot questions 3.1

1. State four types of microscopes and give one use of each.
2. Name eight parts of the compound microscope and state the function of each.
3. Calculate the total magnification when using a 10x eyepiece with a 40x objective.
4. Describe the correct procedure for focusing a specimen using the compound microscope.
5. State four rules for the care and maintenance of a compound microscope.

3.2 Dissecting Kits and Laboratory Glassware

3.2.1 Dissecting instruments and their uses

A standard dissecting kit contains the following instruments. Dissecting scissors: straight-bladed scissors for cutting through large tissues; may be fine-pointed or blunt-ended. Dissecting forceps (tweezers): for gripping and holding tissue; fine-pointed (watchmaker's) for delicate work; blunt-ended for general use. Dissecting needles (seeker needles): stiff wire mounted in a handle; used to separate tissues, tease apart structures, and pin specimens. Scalpel (or dissecting knife): a flat-bladed cutting instrument with replaceable blades; used for precise incisions.



Teasing needles: two fine flexible needles mounted in handles; used to tease apart soft tissues for microscopic examination. Pins (entomological pins or dissecting pins): for pinning specimens to a wax-lined dissecting tray. Dissecting tray (wax tray): a rectangular tray with a wax or rubber base into which pins are inserted to hold dissected specimens flat. Hand lens (magnifying glass): a simple convex lens giving magnification of 5x to 10x; used for examination of whole specimens or gross dissection before using the microscope. Probes: blunt or rounded metal rods for exploring body cavities and lifting organs.

Fill in the blank: A _____ (or dissecting knife) is used for precise incisions during dissection; its blades are replaceable, and it must always be handled with the blade pointing away from the body.



Figure 3.2: Photograph of a standard dissecting kit showing each instrument labelled

3.2.2 Common laboratory glassware

Beaker: a cylindrical glass vessel with a spout; used for mixing, heating, and holding liquids; comes in various sizes (50 mL to 5,000 mL). Conical flask (Erlenmeyer flask): a flask with a



conical base and narrow cylindrical neck; used for swirling liquids, boiling, and titrations; the narrow neck reduces evaporation and splashing. Measuring cylinder (graduated cylinder): used for measuring volumes of liquid; the meniscus is read at eye level. Pipette: a narrow glass tube for transferring exact volumes of liquid.

Test tube: a small glass tube closed at one end; used for small-scale reactions, culturing, and heating small quantities of liquid; held in test tube racks. Watch glass: a small concave glass dish; used for evaporation, holding small specimens, and as a cover for beakers. Petri dish: a shallow circular glass or plastic dish with a lid; used for culturing microorganisms and holding specimens. Microscope slide: a flat glass rectangle (75 mm x 25 mm) on which specimens are placed for microscopic examination. Coverslip: a very thin square of glass placed over the specimen on a slide to flatten and protect it.

Fill in the blank: A _____ is read at eye level with the meniscus at the marked line to measure volumes of liquid accurately; the meniscus is the curved surface of liquid in a glass container.

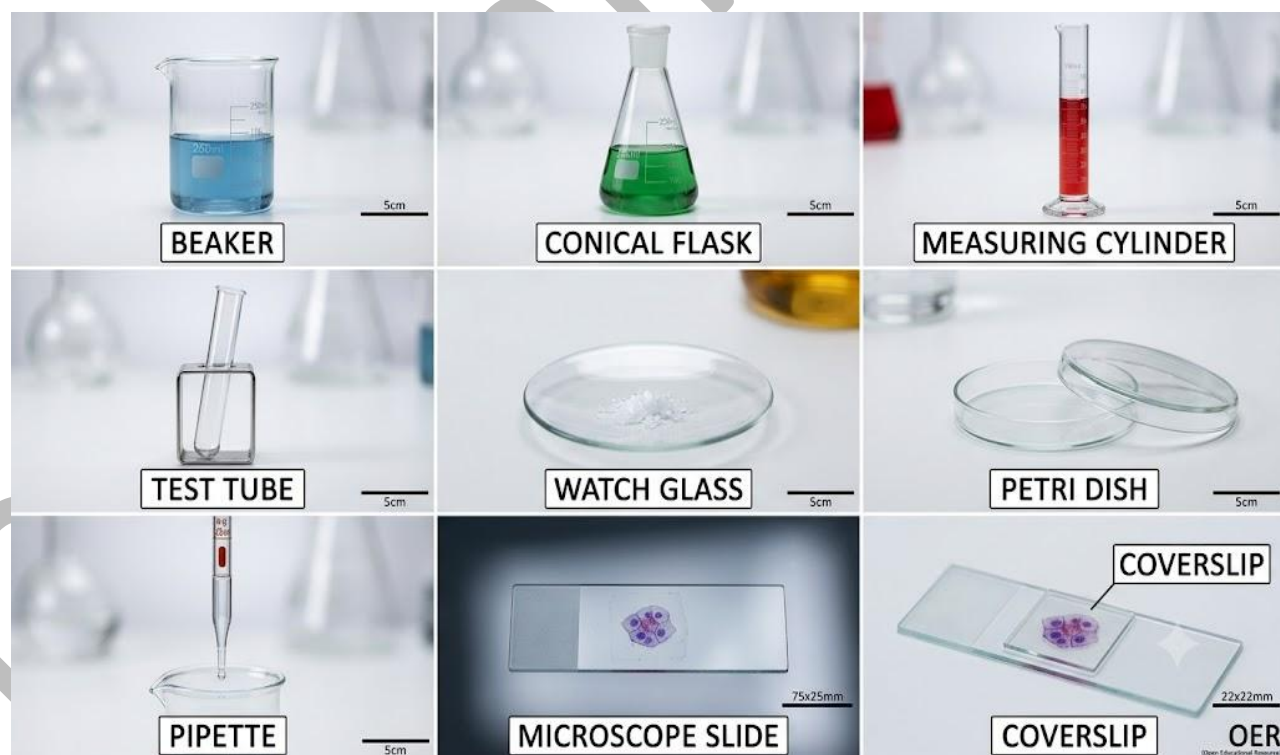


Figure 3.3: Photographs of common laboratory glassware labelled



3.2.3 Preparation of temporary microscope slides

A temporary wet mount slide is prepared as follows: (1) clean the microscope slide with a lint-free cloth; (2) place a small drop of water or appropriate mounting medium (e.g. glycerol for plant material; normal saline for animal material) in the centre of the slide; (3) place the specimen (a thin slice, smear, squash, or teased preparation) into the drop; (4) hold a clean coverslip at 45 degrees to the slide and lower it slowly to avoid trapping air bubbles; (5) remove excess liquid with blotting paper at the edge of the coverslip.

Types of preparation: thin section (T.S. or L.S. cut by hand or with a microtome; requires a razor blade or microtome and practice); smear (a thin film of material spread across the slide; used for blood smears, bacteria cultures, and vaginal swabs); squash preparation (soft tissue placed on slide and squashed under the coverslip; used for root tip squash to see mitosis); maceration (chemical treatment to separate cells; used for teasing apart vascular tissue). Sections should be thin enough to allow light to pass through; staining greatly improves visibility of structures.

Fill in the blank: When lowering a coverslip onto a wet mount, hold it at _____ degrees to the slide and lower it slowly; this prevents air bubbles from being trapped, which would obscure the specimen.

Pilot questions 3.2

1. Name eight dissecting instruments and state the use of each.
2. Explain how to use a scalpel safely in the laboratory.
3. Name six items of laboratory glassware and state the use of each.
4. Describe the steps for preparing a temporary wet mount microscope slide.
5. Explain how a squash preparation is made and state what it is used for.

3.3 Laboratory Safety, Fixation, and Preservation

3.3.1 Laboratory safety rules

General laboratory safety rules for biological practical work: always wear a laboratory coat; tie back long hair; wear safety goggles when handling corrosive or volatile chemicals; never eat,



drink, or smoke in the laboratory; wash hands thoroughly before leaving; label all containers clearly; never pipette by mouth (use a pipette filler or bulb). When handling dissecting instruments, always cut away from the body; pass scalpels and scissors handle-first; report all cuts and accidents immediately to the demonstrator.

Handling chemical fixatives and preservatives: formalin (formaldehyde solution) is toxic and a suspected carcinogen; always use in a fume cupboard or well-ventilated area; wear nitrile gloves and goggles; avoid inhalation; wash any skin contact immediately. Ethanol is flammable; keep away from open flames. Acetic acid (glacial) is corrosive; handle with gloves. Dispose of biological waste (animal tissue, cultures) in designated clinical waste bins, not in general waste. Sharps (scalpel blades, needles) go in puncture-resistant sharps containers.

Fill in the blank: Formalin (formaldehyde solution) is toxic and a suspected carcinogen; it must always be used in a _____ cupboard or well-ventilated area; wear nitrile gloves and goggles when handling it.



Figure 3.4: Photographs of laboratory safety equipment and hazard symbols



3.3.2 Fixation and preservation of biological specimens

Fixation is the rapid killing and chemical hardening of biological tissue to preserve its structure as close to the living state as possible. Good fixation prevents autolysis (self-digestion by endogenous enzymes), prevents bacterial decomposition, hardens tissues for sectioning, and makes them more permeable to stains. Fixatives work by cross-linking proteins and denaturing enzymes. The most common fixatives: 10% formalin (10% formaldehyde in water or saline); widely used for animal tissues; penetrates well; can be used for long-term storage.

Bouin's fluid: a mixture of picric acid, formalin, and glacial acetic acid; provides excellent preservation of soft tissues and is good for subsequent staining; tissues become yellow.

Glutaraldehyde: superior for electron microscopy; preserves ultrastructure. After fixation, tissues are preserved in 70% alcohol (ethanol) for long-term storage. Whole specimens (frogs, fish, insects) are preserved in 10% formalin or 70% ethanol in sealed jars. Dry preservation: insects are pinned and dried; plant specimens are pressed and dried as herbarium sheets mounted on card.

Fill in the blank: _____ is the most widely used fixative for animal tissues in biological laboratories; it consists of 10 per cent formaldehyde in water or saline and preserves tissue structure close to the living state.



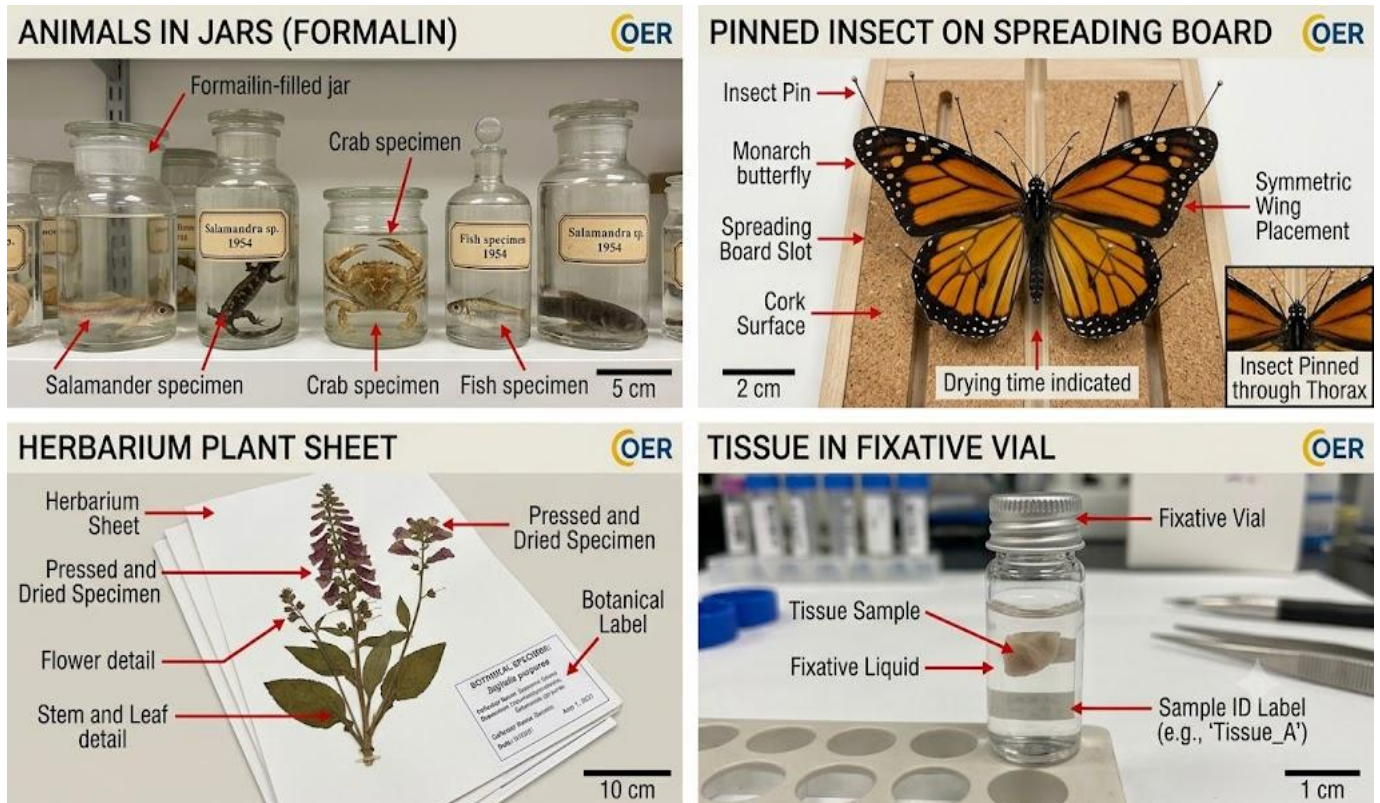


Figure 3.5: Photographs of specimen preservation methods

3.3.3 Staining techniques for biological specimens

Staining makes biological structures visible under the microscope by adding colour to specific cellular components. Most stains are dissolved in water or ethanol and bind to specific chemical groups in the cell. Haematoxylin: a basic (alkaline) dye that stains nuclei and other acidic components blue-purple; widely used in histology. Eosin: an acidic dye that stains cytoplasm and extracellular proteins pink to red; haematoxylin and eosin (H and E) together are the most commonly used staining pair in animal histology.

Iodine solution (Lugol's iodine): turns starch blue-black; used to demonstrate starch in plant sections and food tests. Acetocarmine or aceto-orcein: stains chromosomes red; used for root tip squash preparations to demonstrate mitosis. Safranin: stains lignified cell walls, xylem, and nuclei red or orange; used for plant anatomy sections. Fast green or light green: counterstain for cellulose cell walls (green) after safranin; together they give a two-colour contrast. Methylene blue: stains nuclei blue; used for demonstration of animal cells (cheek cells) and bacteria.



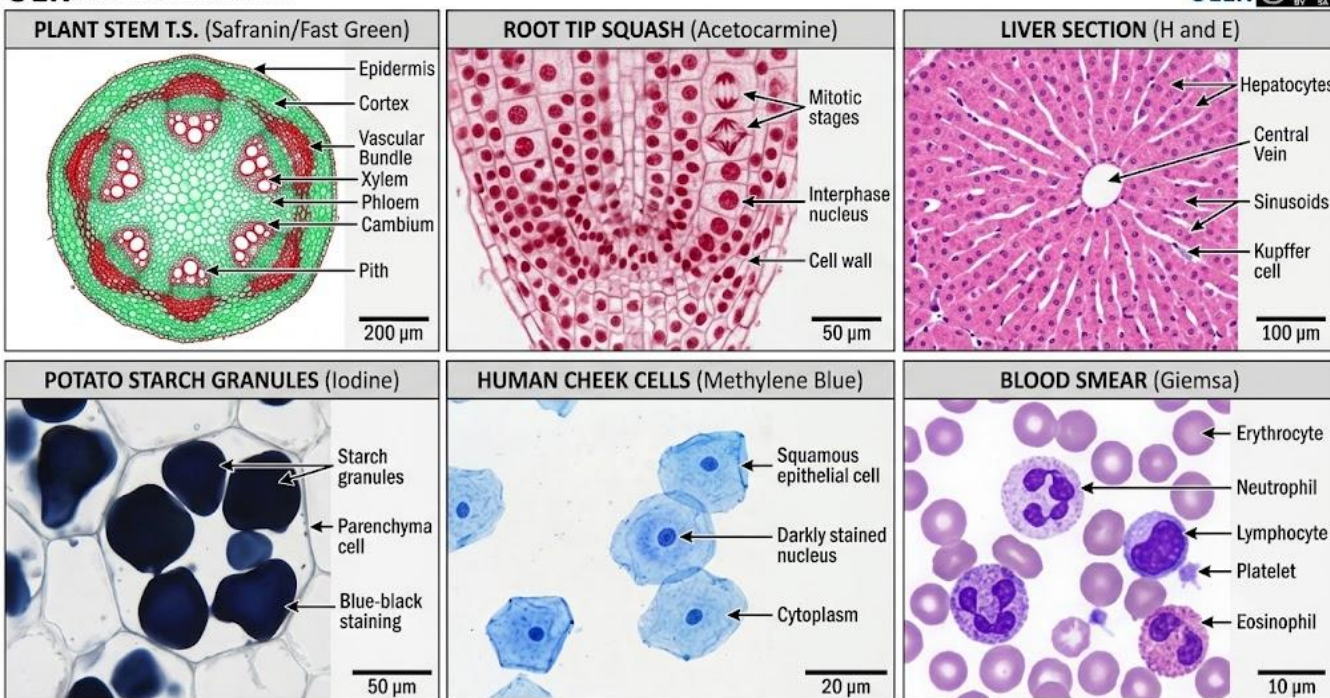
Fill in the blank: _____ solution turns starch blue-black and is used to identify starch in plant sections and food samples; haematoxylin stains nuclei blue-purple and eosin stains cytoplasm pink in the standard H and E stain.

<u>Stain</u>	<u>Structure Stained</u>	<u>Colour Produced</u>	<u>Material Type</u>
<u>Haematoxylin</u>	Nuclei (DNA, chromatin)	Blue-purple	Animal tissues
<u>Eosin</u>	Cytoplasm, proteins	Pink-red	Animal tissues
<u>Safranin</u>	Lignified and cutinized cell walls	Red	Plant tissues
<u>Iodine</u>	Starch granules	Blue-black	Plant tissues
<u>Acetocarmine</u>	Chromosomes	Red	Plant tissues (root tips, pollen)
<u>Methylene Blue</u>	Nuclei, DNA	Blue	Both plant and animal tissues

Box 3.1: Summary of common biological stains, what they stain, and their colour

OER (Open Educational Resource)

OER (Open Educational Resource)



Open Educational Resource – Chart © OER (Open Educational Resource)

OER (Open Educational Resource) by Tiark

Figure 3.6: Microscope photographs of stained biological preparations



Pilot questions 3.3

1. State six laboratory safety rules for biological practical work.
2. Explain what fixation is and state two reasons why it is carried out.
3. Name three common fixatives used in biological work and state one advantage of each.
4. Name six stains used in biological microscopy and state what each stains.
5. Explain the difference between a basic dye and an acidic dye with one example of each.



Series Summary

This Series covered the practical instruments, glassware, and chemical reagents that form the working toolkit of the biology laboratory. Four types of microscope were examined: the compound light microscope (CLM), capable of up to 1,000x magnification with a resolution of 0.2 micrometres; the dissecting or stereo microscope for three-dimensional low-power observation; the transmission electron microscope (TEM) for ultrastructural detail at up to one million times magnification; and the scanning electron microscope (SEM) for surface imaging. The parts, operating procedure, and care of the CLM were covered in detail, including the rule that total magnification equals eyepiece multiplied by objective lens power.

Common laboratory glassware including beakers, conical flasks, Petri dishes, measuring cylinders, and pipettes was surveyed alongside the correct procedure for preparing wet mount slides. The dissecting kit and its components were described, and laboratory safety protocols including the use of personal protective equipment and correct disposal of sharps and biological waste were established. Fixatives used in biological specimen preparation, including ten percent formalin, Bouin's fluid, and glutaraldehyde, were covered, and the major biological stains and their target structures and colours were identified, completing the practical foundation needed for microscopy and specimen work throughout the remainder of the course.

Glossary of Terms

- **Acetocarmine:** a stain that colours chromosomes deep red; used in root tip squash preparations to demonstrate mitosis.
- **Autolysis:** self-digestion of cells and tissues by their own endogenous enzymes after death; prevented by fixation.
- **Bouin's fluid:** a fixative consisting of picric acid, formalin, and glacial acetic acid; gives excellent preservation and good stain uptake; tissues turn yellow.



- **Compound light microscope (CLM):** a microscope using visible light and two sets of lenses to magnify specimens; total magnification up to approximately 1,000x; resolving power approximately 0.2 micrometres.
- **Condenser:** a lens beneath the stage of the compound microscope that concentrates light onto the specimen; raised for higher magnification objectives.
- **Coverslip:** a very thin square of glass placed over a specimen on a microscope slide to flatten and protect it and prevent the objective lens from touching the specimen.
- **Dissecting (stereo) microscope:** a binocular low-power microscope (7x to 45x) giving a three-dimensional view; used for examination of whole specimens and dissection.
- **Eosin:** an acidic dye that stains cytoplasm and extracellular proteins pink to red; used with haematoxylin in the standard H and E staining procedure.
- **Fine focus knob:** the small inner focussing knob of the compound microscope; used for precise focussing, especially at high magnification.
- **Fixation:** the rapid killing and chemical hardening of biological tissue to preserve its structure; prevents autolysis and bacterial decomposition.
- **Formalin:** a 10% solution of formaldehyde in water or saline; the most widely used fixative for biological tissues; toxic and a suspected carcinogen.
- **Glutaraldehyde:** a chemical fixative that provides superior preservation of ultrastructure; used for specimens to be examined by electron microscopy.
- **Haematoxylin:** a basic (alkaline) dye that stains nuclei and chromatin blue-purple; used with eosin in H and E staining.
- **Herbarium sheet:** a pressed, dried plant specimen mounted on a card with label information; used for long-term dry preservation and identification of plant material.
- **Iris diaphragm:** an adjustable aperture below the condenser in the compound microscope; controls the amount of light reaching the specimen and affects image contrast.
- **Iodine solution (Lugol's iodine):** a stain that turns starch blue-black; used to identify starch in plant sections and as a food test reagent.



- **Magnification:** the ratio of the apparent size of the image to the actual size of the object; total magnification = eyepiece magnification x objective magnification.
- **Methylene blue:** a basic dye that stains nuclei blue; used for animal cell preparations (e.g. cheek cells) and bacteria.
- **Nosepiece (revolving nosepiece):** the rotating attachment at the base of the body tube that holds the objective lenses and allows them to be clicked into place.
- **Objective lens:** the lens closest to the specimen in the compound microscope; provides primary magnification; standard powers are 4x, 10x, 40x, and 100x (oil immersion).
- **Resolving power:** the ability of a microscope to distinguish two closely adjacent points as separate; the smaller the value, the better the resolution; CLM resolves approximately 0.2 micrometres.
- **Safranin:** a plant histology stain that colours lignified cell walls (xylem, sclerenchyma), nuclei, and chromosomes red to orange.
- **Scanning electron microscope (SEM):** an electron microscope that scans an electron beam over the specimen surface to produce a three-dimensional surface image.
- **Scalpel:** a dissecting instrument with a flat blade and replaceable blades; used for precise incisions; must be handled with blade pointing away from the body.
- **Smear preparation:** a thin film of material (blood, bacteria, vaginal cells) spread across a microscope slide for microscopic examination.
- **Squash preparation:** a microscope preparation in which soft tissue is placed on a slide and compressed under a coverslip to separate cells; used for root tip mitosis preparations.
- **Transmission electron microscope (TEM):** an electron microscope that transmits an electron beam through an ultra-thin specimen; magnification up to 1,000,000x; reveals cell ultrastructure.
- **Wet mount:** the simplest type of temporary microscope slide preparation; specimen placed in a drop of liquid on a slide and covered with a coverslip.



Concept Check Questions [Series 3]

Objective Questions

1. The compound light microscope uses visible _____ and two sets of lenses to magnify specimens up to approximately 1,000 times. (Linked to SLO 3.1)
2. Total magnification of a compound microscope = _____ magnification multiplied by objective lens magnification. (Linked to SLO 3.2)
3. Always store a microscope with the lowest power (_____ x) objective in place and the stage lowered. (Linked to SLO 3.3)
4. _____ solution turns starch blue-black and is used to identify starch in plant sections and food tests. (Linked to SLO 3.7)
5. Formalin is toxic and a suspected carcinogen; it must always be used in a _____ cupboard. (Linked to SLO 3.6)

Short-Answer Questions

1. Name eight parts of the compound microscope and state the function of each. (Linked to SLO 3.2)
2. State four rules for the care and maintenance of the compound microscope. (Linked to SLO 3.3)
3. Name six dissecting instruments and state the use of each. (Linked to SLO 3.4)
4. Describe the steps for preparing a temporary wet mount slide. (Linked to SLO 3.5)
5. Name five stains used in biological microscopy and state what each stains and the colour produced. (Linked to SLO 3.7)

Long-Answer Questions

1. Describe the types of microscopes used in biology and explain the parts and correct use of the compound light microscope. (Linked to SLOs 3.1, 3.2, 3.3)
2. Describe the dissecting instruments in a standard kit, the common laboratory glassware, and the preparation of temporary microscope slides. (Linked to SLOs 3.4, 3.5)
3. State the laboratory safety rules, describe fixation and preservation of biological specimens, and explain the staining techniques used in biological microscopy. (Linked to SLOs 3.6, 3.7)



Answers to Concept Check Questions [Series 3]

Objective Questions

1. Light.
2. Eyepiece.
3. 4.
4. Iodine.
5. Fume.

Short-Answer Questions

1. Eyepiece (magnifies image; 10x); objective lens (primary magnification; 4x, 10x, 40x, 100x); nosepiece (holds objectives; rotates to change); coarse focus (rapid initial focusing); fine focus (precise final focusing); stage (holds slide); condenser (concentrates light on specimen); iris diaphragm (controls light amount and contrast).
2. Clean lenses only with lens tissue and appropriate cleaning fluid (never fingers); always store with lowest power (4x) objective; lower the stage before removing a slide; cover with dust cover after use.
3. Dissecting scissors (cutting large tissue); fine forceps (gripping delicate structures); blunt forceps (general gripping); scalpel (precise incisions); dissecting needle/seeker (separating tissues); hand lens (gross examination before microscopy).
 - (1) Clean the slide; (2) place a drop of water or mounting medium in the centre; (3) place the specimen in the drop; (4) hold a coverslip at 45 degrees and lower it slowly to avoid air bubbles; (5) remove excess liquid with blotting paper at the edge.
4. Haematoxylin (nuclei; blue-purple); eosin (cytoplasm; pink); safranin (lignified walls; red-orange); iodine/Lugol's (starch; blue-black); acetocarmine (chromosomes; deep red).

Long-Answer Questions

1. Types of microscopes: CLM (visible light; 2 lens sets; up to 1,000x; 0.2 micrometre resolution; for cells and tissues); dissecting/stereo (binocular; 7-45x; 3D; for whole specimens and dissection); TEM (electrons; up to 1,000,000x; ultrastructure; vacuum; heavy metal staining); SEM (surface scan; 3D surface image; gold/platinum coating; 1-20 nm resolution). Parts of CLM: eyepiece (10x; observer lens); objective lenses (4x, 10x, 40x,



100x; primary magnification); nosepiece (revolving; holds objectives); coarse focus (rapid stage movement); fine focus (precise adjustment); stage with clips (holds slide); condenser (concentrates light); iris diaphragm (controls light and contrast); light source; arm and base. Total magnification = eyepiece x objective (e.g. 10x x 40x = 400x). Use procedure: carry with both hands; lowest power first; coarse then fine focus; centre specimen; increase magnification; use only fine focus at high power. Oil immersion (100x): add one drop immersion oil; clean immediately after. Care: lens tissue only for cleaning; store with 4x objective; cover with dust cover; report damage.

2. Dissecting instruments: scissors (cutting large tissue); fine forceps/tweezers (gripping delicate structures); blunt forceps (general gripping and holding); scalpel with replaceable blades (precise incisions; always cut away from body); dissecting needles/seeker needles (separating tissues, pinning); teasing needles (teasing apart soft tissue for microscopy); pins (pinning specimens to dissecting tray); hand lens (5-10x magnification for gross examination); probe (exploring cavities); dissecting tray with wax base (holds pinned specimens). Common glassware: beaker (mixing, heating); conical flask (swirling, boiling, titrations; narrow neck reduces evaporation); measuring cylinder (accurate volume measurement; read meniscus at eye level); test tube (small-scale reactions; heating); watch glass (evaporation, holding small specimens); Petri dish (culturing; holding specimens); pipette (exact volume transfer); microscope slide (holds specimen); coverslip (protects specimen; flattens it). Wet mount preparation: clean slide; drop of water or mounting medium (water for plant; saline for animal); specimen placed in drop; coverslip held at 45 degrees and lowered slowly; blot excess liquid. Other preparations: smear (spread film; blood, bacteria); squash (compress tissue; root tip mitosis); thin section (microtome or razor blade; plant anatomy).
3. Laboratory safety: wear lab coat, goggles, gloves; tie back hair; no eating, drinking, or smoking; never pipette by mouth; wash hands before leaving; cut away from body; pass scalpels handle-first; report all cuts; use fume cupboard for volatile chemicals (formalin, glacial acetic acid); sharps in sharps containers; biological waste in clinical waste bins; label all containers; know location of eyewash and fire extinguisher. Fixation: rapid killing and chemical hardening of tissue to preserve living structure; prevents autolysis (self-digestion by enzymes) and bacterial decomposition; hardens tissue for sectioning; increases stain uptake. Common fixatives: 10% formalin (most widely used; penetrates well; long-term storage; toxic, use in fume cupboard); Bouin's fluid (picric acid + formalin + acetic acid; excellent for soft tissue; tissues turn yellow; good staining); glutaraldehyde (superior ultrastructure preservation for electron microscopy). After fixation: store in 70% ethanol. Dry preservation:



insects pinned and dried; plants pressed as herbarium sheets. Staining: haematoxylin (basic dye; nuclei; blue-purple); eosin (acidic dye; cytoplasm; pink); safranin (lignified walls, nuclei; red-orange); fast green (cellulose walls; green; counterstain to safranin); iodine/Lugol's (starch; blue-black); acetocarmine (chromosomes; deep red; root tip squash); methylene blue (nuclei, bacteria; blue); toluidine blue (lignified walls; blue). Basic dye: positively charged; binds to negatively charged nucleic acids and acidic components (e.g. haematoxylin). Acidic dye: negatively charged; binds to positively charged proteins in cytoplasm (e.g. eosin).

Answers to Pilot Questions [Series 3]

Part 3.1

11. (1) Compound light microscope (CLM): examining cells, tissues, and microorganisms at up to 1,000x magnification. (2) Dissecting/stereo microscope: examination and dissection of whole specimens in three dimensions at low magnification (7-45x). (3) Transmission electron microscope (TEM): examining internal ultrastructure of cells and organelles at up to 1,000,000x. (4) Scanning electron microscope (SEM): examining the three-dimensional surface topography of specimens at high resolution.
12. Eyepiece (ocular lens): the lens the observer looks through; usually 10x; magnifies the intermediate image formed by the objective. Objective lens: provides primary magnification; comes in 4x (scanning), 10x (low power), 40x (high power), 100x (oil immersion). Nosepiece (revolving): holds and rotates the objective lenses for changing magnification. Coarse focus knob: rapidly moves the stage or body tube for initial focussing. Fine focus knob: makes precise small adjustments; used for final focussing at high magnification. Stage: flat platform on which the microscope slide is placed and secured with stage clips. Condenser: lens below the stage concentrating light onto the specimen. Iris diaphragm: adjustable aperture below the condenser controlling the amount and angle of light for optimal contrast.
13. Total magnification = eyepiece magnification x objective lens magnification. With a 10x eyepiece and 40x objective: $10 \times 40 = 400x$ total magnification.
14. (1) Carry the microscope with one hand on the arm and one under the base to the bench. (2) Click the 4x (scanning) objective into place. (3) Place the slide on the stage and secure with clips. (4) While watching from the side (not through the eyepiece), use the coarse focus knob to bring the



objective close to the slide. (5) Look through the eyepiece and use the coarse focus knob to bring the specimen approximately into focus. (6) Use the fine focus knob to sharpen the image. (7) Centre the specimen in the field of view. (8) Switch to a higher power objective by rotating the nosepiece; use only fine focus at high power. (9) Raise the condenser and open the iris diaphragm slightly when using higher power objectives.

15. (1) Clean lenses only with lens tissue and appropriate lens cleaning solution; never use paper, cloth, or fingers on any lens surface. (2) Always store the microscope with the 4x (scanning/lowest power) objective clicked into place and the stage in the lowest position. (3) Cover the microscope with a dust cover when not in use; store in a cabinet if available. (4) Report any damage to the instructor immediately; never attempt to disassemble or repair any part of the microscope yourself.

Part 3.2

1. Dissecting scissors (cutting through large tissues and organs during dissection; may be straight or curved, fine-pointed or blunt-ended); fine-pointed dissecting forceps (gripping and manipulating delicate or small tissues; used for picking up small specimens for microscopy); blunt dissecting forceps (general gripping and holding of larger tissues); scalpel (precise clean incisions through tissue; blades are replaceable); dissecting needles/seeker needles (separating and teasing apart tissues; tracing nerves and blood vessels; pinning small specimens); teasing needles (pair of fine flexible needles for teasing soft tissue apart for microscopic examination); dissecting pins (pinning specimens to the wax dissecting tray to hold them in position during dissection); hand lens/magnifying glass (5-10x magnification for examining gross features before using the microscope).
2. Safe scalpel use: (1) always carry a scalpel with the blade pointing downward and away from the body; (2) when cutting, always direct the blade away from your own body and away from others nearby; (3) change blades using a blade removal tool or forceps, never with bare fingers; (4) when passing a scalpel to another person, always lay it on the bench for them to pick up or hand it handle-first; (5) when not in use, lay the scalpel flat on the bench with the blade facing away from the edge; (6) dispose of used blades in a designated sharps container, not in the general waste bin.
3. Beaker (mixing, heating, and holding liquids; available in multiple sizes from 50 mL to 5,000 mL); conical flask/Erlenmeyer flask (swirling liquids without splashing; heating under reflux;



- titrations; narrow neck reduces evaporation); measuring cylinder (accurately measuring liquid volumes; read the meniscus at eye level); test tube (small-scale chemical reactions and heating of small volumes; held in test tube racks); Petri dish (culturing microorganisms on agar; holding specimens for examination; staining small tissue pieces); microscope slide with coverslip (mounting specimens for microscopic examination).
4. Steps: (1) wipe a microscope slide clean with a lint-free cloth to remove dust and grease; (2) place a small drop of appropriate mounting medium in the centre of the slide (distilled water for plant material; isotonic saline for animal material; glycerol for more permanent temporary mounts); (3) place the specimen in the drop (thin section, smear, teased preparation, or small organism); (4) hold a clean coverslip between thumb and forefinger, place one edge on the slide at approximately 45 degrees to the surface, and slowly lower the other edge onto the drop; the liquid should spread evenly under the coverslip without trapping air bubbles; (5) if excess liquid squeezes out around the coverslip, draw it off by touching the edge of the coverslip with a piece of blotting paper; (6) the slide is now ready to place on the stage and examine.
 5. A squash preparation is made by placing a small piece of very soft tissue (typically a 2-3 mm tip of a young root that has been hydrolysed in hydrochloric acid and stained with acetocarmine or aceto-orcein) on a clean microscope slide in a drop of stain or water, covering with a coverslip, and then pressing firmly down on the coverslip with the thumb (squashing the tissue) while simultaneously sliding the thumb forward slightly to spread the cells out in a single layer. It is used primarily for observing stages of mitosis in actively dividing cells of root tips (e.g. *Allium*/onion root, *Vicia*/broad bean root); the squashing separates individual cells so that their chromosomes can be seen clearly and counted.

Part 3.3

1. Six laboratory safety rules: (1) always wear a laboratory coat, safety goggles, and nitrile gloves when handling biological specimens or chemicals; (2) never eat, drink, smoke, or apply cosmetics in the laboratory; (3) when using dissecting instruments, always cut and direct sharp edges away from your own body and from other people; (4) handle formalin (formaldehyde) and other volatile toxic fixatives only in a fume cupboard or well-ventilated area; wear gloves and goggles; (5) dispose of sharps (scalpel blades, needles) only in puncture-resistant sharps containers; dispose of biological waste (animal tissue, bacterial



- cultures) in designated clinical waste bins with biohazard labelling; (6) wash hands thoroughly with soap and water before leaving the laboratory.
2. Fixation is the rapid killing and chemical hardening of biological tissue using chemical agents (fixatives) to preserve the tissue's structure as closely as possible to its living state. Two reasons it is carried out: (1) to prevent autolysis (the self-digestion of cells and tissues by their own endogenous hydrolytic enzymes after the organism dies; without fixation, cellular structure disintegrates within hours); (2) to prevent bacterial and fungal decomposition (microbial enzymes would rapidly break down the protein, carbohydrate, and lipid components of unfixed tissue, destroying all recognisable cell structure within days).
 3. Three common fixatives: (1) 10% formalin (10% formaldehyde in water or saline): the most widely used general fixative; excellent penetration into tissue; suitable for both short- and long-term storage; can be used with most subsequent staining protocols; disadvantage: toxic and carcinogenic, requiring fume cupboard use. (2) Bouin's fluid (picric acid, formalin, glacial acetic acid): provides excellent structural preservation of soft tissues; gives good uptake of most subsequent stains; tissues turn yellow; disadvantage: picric acid is explosive when dry; tissue should not remain in Bouin's for more than 24-48 hours or it becomes over-hardened. (3) Glutaraldehyde: provides the best preservation of subcellular ultrastructure (membranes, organelles); essential for transmission electron microscopy (TEM); disadvantage: poor penetration compared with formalin; must be used at cool temperatures; expensive.
 4. Six stains with structures and colours: (1) Haematoxylin: stains nuclei, chromatin, rough endoplasmic reticulum; colour: blue-purple; used for animal histology sections. (2) Eosin: stains cytoplasm and extracellular proteins (collagen, muscle fibres); colour: pink to red; used as a counterstain with haematoxylin in the H and E procedure. (3) Safranin: stains lignified cell walls (xylem, sclerenchyma), nuclei, and chromosomes; colour: red to orange; used for plant anatomy sections. (4) Iodine (Lugol's iodine): stains starch granules; colour: blue-black; used for plant anatomy and food tests. (5) Acetocarmine (or aceto-orcein): stains chromosomes; colour: deep red; used for root tip squash preparations to observe mitosis. (6) Methylene blue: stains nuclei and ribosomes; colour: blue; used for animal cells (cheek cell smears) and bacterial preparations.
 5. A basic dye (also called a cationic dye) carries a net positive charge on its coloured portion (the chromophore); it binds to negatively charged (acidic) cellular components such as nucleic acids (DNA and RNA) and the phosphate groups of the cell membrane; examples: haematoxylin, methylene blue, crystal violet, acetocarmine. An acidic dye (anionic dye)



carries a net negative charge on its chromophore; it binds to positively charged (basic) cellular components such as most cytoplasmic proteins (which carry net positive charge at physiological pH); examples: eosin, acid fuchsin, fast green. This difference in charge affinity is the basis of the contrast produced when basic and acidic dyes are used together: haematoxylin stains the nucleus blue-purple while eosin simultaneously stains the cytoplasm pink, providing instant colour contrast that clearly distinguishes the two compartments.



References and Attributions [Series 3]

Textual References (Books and External Sources)

- Bancroft, J. D., & Gamble, M. (Eds.). (2008). Theory and practice of histological techniques (6th ed.). Churchill Livingstone.
- Ross, M. H., & Pawlina, W. (2011). Histology: A text and atlas (6th ed.). Lippincott Williams and Wilkins.
- Bradbury, S. (1989). An introduction to the optical microscope (revised ed.). Oxford University Press.
- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 3.1: Labelled compound light microscope diagram Attribution: AI generated. Suggested OER search string: "compound light microscope labelled diagram parts eyepiece objective nosepiece stage condenser OER".
- Figure 3.2: Dissecting kit instruments labelled photograph Attribution: AI generated. Suggested OER search string: "dissecting kit instruments labelled photograph scissors forceps scalpel needles pins probe OER".
- Figure 3.3: Laboratory glassware labelled photographs Attribution: AI generated. Suggested OER search string: "laboratory glassware labelled photographs beaker conical flask measuring cylinder test tube Petri dish OER".
- Figure 3.4: Laboratory safety equipment and hazard symbols photographs Attribution: AI generated. Suggested OER search string: "laboratory safety equipment photographs fume cupboard sharps container gloves hazard symbols OER".
- Figure 3.5: Specimen preservation methods photographs Attribution: AI generated. Suggested OER search string: "specimen preservation formalin ethanol pinned insect herbarium sheet plant fixation labelled photographs OER".
- Figure 3.6: Stained biological preparations microscope photographs Attribution: AI generated. Suggested OER search string: "stained biological preparations microscope photographs safranin fast green haematoxylin eosin acetocarmine iodine OER".



- Box 3.1: Common biological stains summary table Attribution: AI generated. Suggested OER search string: "biological stains table haematoxylin eosin safranin iodine acetocarmine methylene blue OER box".



Course code: BIO 108

Course title: General Biology Practical II

Course credit load: 1 Unit

Series 4: Histology of Animal Tissues

- **Part 4.1: Epithelial Tissues**

- Sub Part 4.1.1: Simple epithelia
- Sub Part 4.1.2: Stratified and pseudostratified epithelia
- Sub Part 4.1.3: Glandular epithelium

- **Part 4.2: Connective Tissues**

- Sub Part 4.2.1: Loose and dense connective tissue
- Sub Part 4.2.2: Specialised connective tissues: cartilage and bone
- Sub Part 4.2.3: Blood as a connective tissue

- **Part 4.3: Muscle and Nervous Tissues**

- Sub Part 4.3.1: Types of muscle tissue
- Sub Part 4.3.2: Nervous tissue
- Sub Part 4.3.3: Identification of tissues in microscope sections

Introduction

Histology is the microscopic study of tissues. Animal tissues are grouped into four primary types: epithelial, connective, muscle, and nervous. Each type has a characteristic cellular organisation, extracellular matrix, and set of functions. Recognising tissues in stained sections is



an essential practical skill that underpins the study of organ systems, pathology, and comparative zoology.

This Series describes the major subtypes of each of the four primary animal tissues, explains the identifying features visible in stained microscope sections (usually haematoxylin and eosin, H and E), and provides guidance on tissue identification from photomicrographs. The staining techniques introduced in Series 3 are directly applied here to real histological preparations.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 4.1** describe the types of simple, stratified, and glandular epithelium and identify each in microscope sections (Linked to Part 4.1),
- **SLO 4.2** describe loose, dense, cartilage, bone, and blood as types of connective tissue and identify each in sections (Linked to Part 4.2),
- **SLO 4.3** describe the three types of muscle tissue and identify each in section (Linked to Part 4.3),
- **SLO 4.4** describe the cellular components of nervous tissue and identify neurones in section (Linked to Part 4.3), and
- **SLO 4.5** apply a systematic approach to identifying unknown tissues in stained microscope sections (Linked to Part 4.3).

4.1 Epithelial Tissues

4.1.1 Simple epithelia

Epithelial tissue covers body surfaces, lines body cavities, and forms glands. All epithelial cells rest on a basal lamina (basement membrane). Key identifying features in H and E sections: cells are closely packed with little or no extracellular matrix between them; one surface faces the



lumen or exterior (apical surface); nuclei are usually large and prominent. Simple epithelia have one cell layer; stratified epithelia have two or more layers.

Simple squamous epithelium: a single layer of flat, scale-like cells; nuclei appear disc-shaped; cytoplasm very thin; found lining blood vessels (endothelium), lymph capillaries, alveoli, and body cavities (mesothelium). **Simple cuboidal epithelium:** a single layer of cube-shaped cells; nucleus is round and central; found in kidney tubules, thyroid follicles, and small ducts. **Simple columnar epithelium:** a single layer of tall, column-shaped cells; nucleus oval and basally placed; found lining the stomach, small intestine (often with microvilli/brush border and goblet cells), and large intestine.

Fill in the blank: Simple squamous epithelium consists of a single layer of flat, scale-like cells lining blood vessels () and alveoli; it is identified by disc-shaped nuclei and extremely thin cytoplasm.

TYPES OF SIMPLE EPITHELIA: H&E STAINED HISTOLOGY

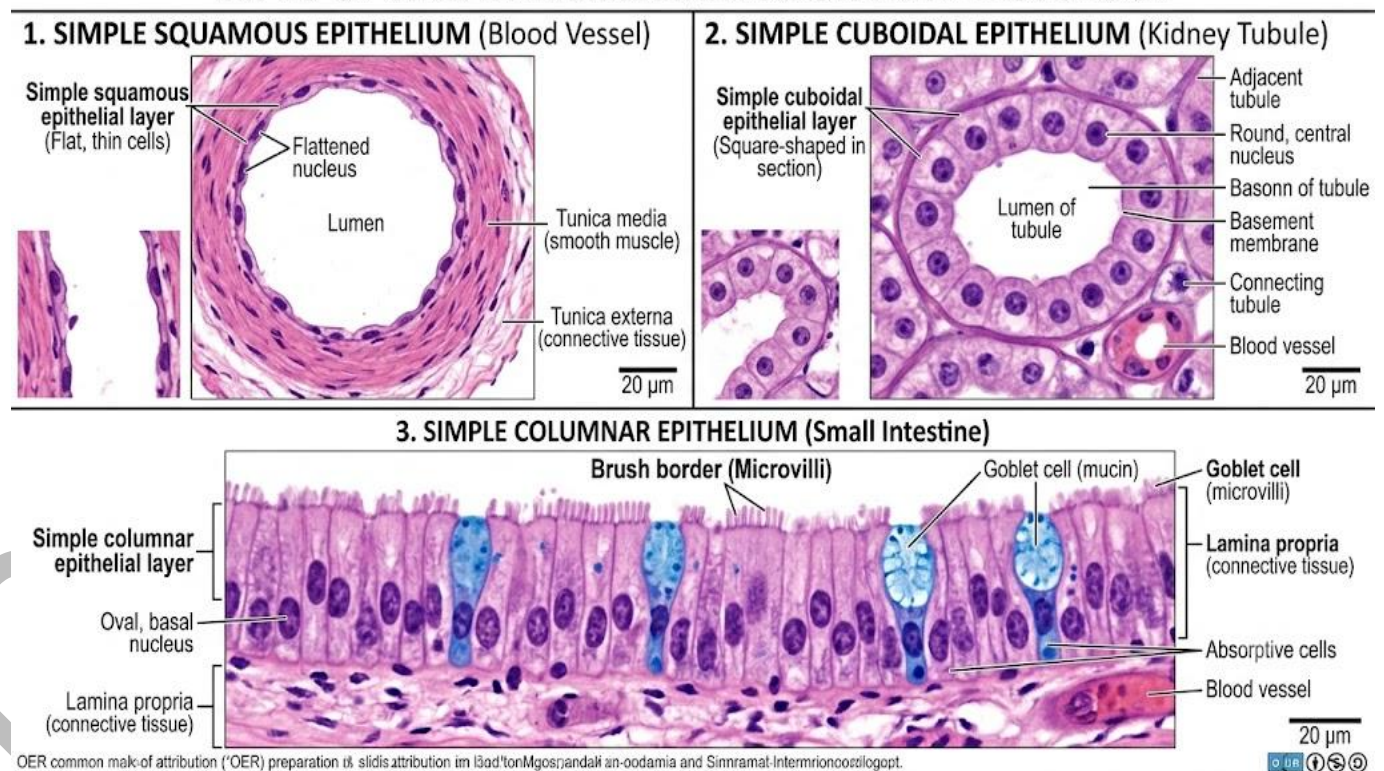


Figure 4.1: Microscope photographs of simple epithelium types



4.1.2 Stratified and pseudostratified epithelia

Stratified squamous epithelium: multiple layers of cells; basal cells are cuboidal or columnar; apical cells are flattened squames; provides mechanical protection. Non-keratinised form: found in the oral cavity, oesophagus, vagina; cells are living throughout. Keratinised form: found in the epidermis of skin; the outermost cells are dead and filled with the protein keratin, forming a waterproof barrier. In section, keratinised epidermis shows a pink (eosin-staining) keratin layer at the surface with the basal cell layer close to the dermis.

Stratified cuboidal and stratified columnar epithelia: less common; found in some ducts and glands. Transitional epithelium (urothelium): found exclusively in the urinary tract (renal pelvis, ureter, bladder); can stretch when the bladder fills; cells appear dome-shaped (umbrella cells) when relaxed and flattened when stretched. Pseudostratified columnar epithelium: appears stratified because nuclei are at different heights, but all cells contact the basement membrane; found lining the trachea and bronchi, often ciliated (pseudostratified ciliated columnar epithelium).

Fill in the blank: _____ epithelium appears stratified because nuclei are at different levels, but all cells contact the basement membrane; it lines the trachea and bronchi and is usually ciliated.



THREE TYPES OF STRATIFIED EPITHELIA: H&E STAINED HISTOLOGY

OER

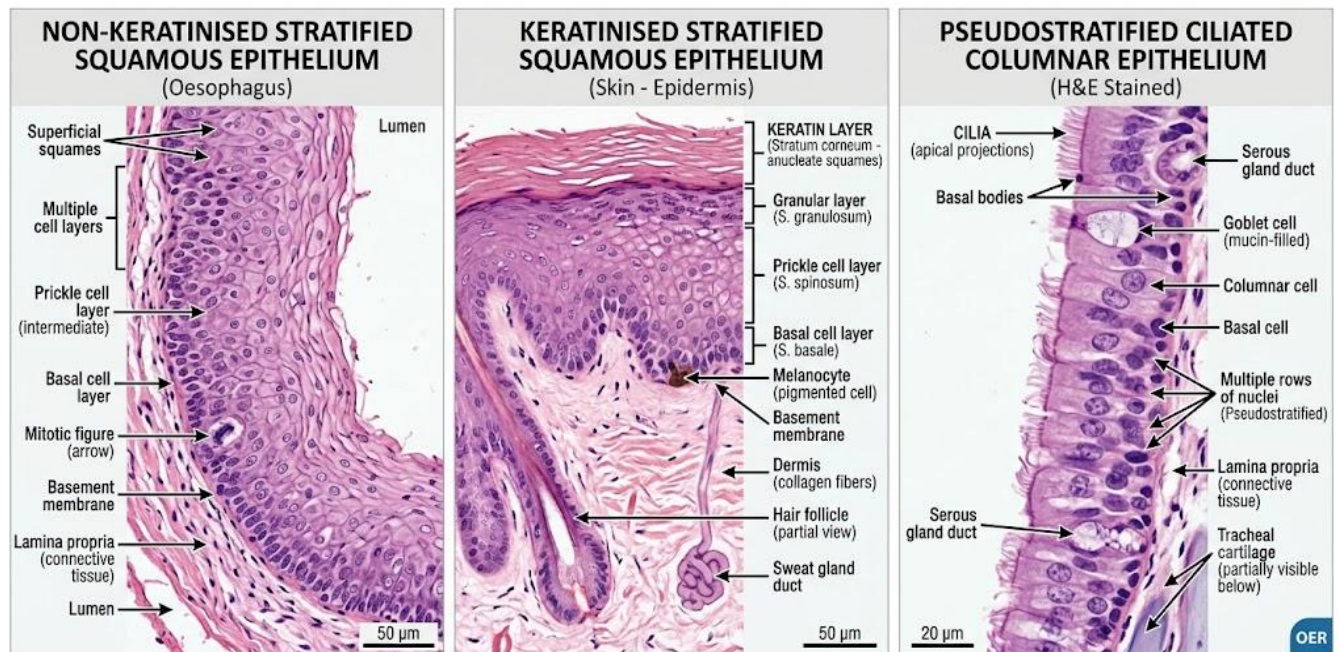


Figure 4.2: Microscope photographs of stratified and pseudostratified epithelia

4.1.3 Glandular epithelium

Glandular epithelium is specialised for secretion. Exocrine glands secrete through ducts onto a surface. Unicellular exocrine glands: goblet cells (single mucus-secreting cells interspersed in the lining epithelium of the intestine and trachea; appear as pale empty-looking cells with a basal nucleus in H and E sections). Multicellular exocrine glands: classified by structure (tubular, alveolar/acinar, or tubuloacinar) and by secretion mechanism (merocrine: secretion by exocytosis; apocrine: apical cytoplasm lost with secretion; holocrine: whole cell disintegrates).

Endocrine glands have no ducts; they secrete hormones directly into the blood. Examples: thyroid gland (spherical follicles lined by simple cuboidal epithelium, filled with colloid staining pink in H and E); islets of Langerhans in the pancreas (clusters of pale-staining cells among the darker exocrine acini); adrenal gland (cortex and medulla visible in section). In a mixed gland like the pancreas, the exocrine acini (serous secretory cells with basal nuclei and apical granules) surround central lumen ducts, while endocrine islets appear as pale islands between the acini.



Fill in the blank: _____ glands secrete through ducts onto a surface (exocrine) while endocrine glands have no ducts and secrete hormones directly into the blood; goblet cells are unicellular exocrine glands secreting mucus.

Pilot questions 4.1

1. State the identifying features of epithelial tissue in H and E sections.
2. Distinguish between simple squamous, cuboidal, and columnar epithelium.
3. Describe the appearance of keratinised stratified squamous epithelium in section.
4. Explain what pseudostratified epithelium is and where it is found.
5. Distinguish between exocrine and endocrine glands with one example of each.

4.2 Connective Tissues

4.2.1 Loose and dense connective tissue

Connective tissue is characterised by cells widely scattered in an abundant extracellular matrix (ECM) of fibres and ground substance. In H and E sections, connective tissue is identified by: sparse cells in a large amount of stained matrix; fibres visible in the background; and the tissue usually underlying epithelium or surrounding organs. Three main fibre types in the ECM: collagen fibres (thick, pink-staining in H and E; high tensile strength); elastic fibres (thin, wavy; require special stains); reticular fibres (very thin; form mesh; require silver staining).

Loose (areolar) connective tissue: the most widespread connective tissue; contains collagen and elastic fibres loosely arranged in an amorphous ground substance; cells include fibroblasts (produce ECM; spindle-shaped nuclei), mast cells, macrophages, and plasma cells; found beneath all epithelia, between organs, and in the dermis. Dense connective tissue: collagen fibres densely packed, leaving little space for cells. Dense regular: fibres aligned parallel (tendons, ligaments; enormous tensile strength in one direction). Dense irregular: fibres in multiple directions (dermis of skin; periosteum; organ capsules).



Fill in the blank: Connective tissue is identified in H and E sections by cells widely scattered in an abundant _____ matrix containing pink-staining collagen fibres and ground substance; fibroblasts are the most common connective tissue cell.

H and E MICROSCOPE PHOTOGRAPHS OF CONNECTIVE TISSUE

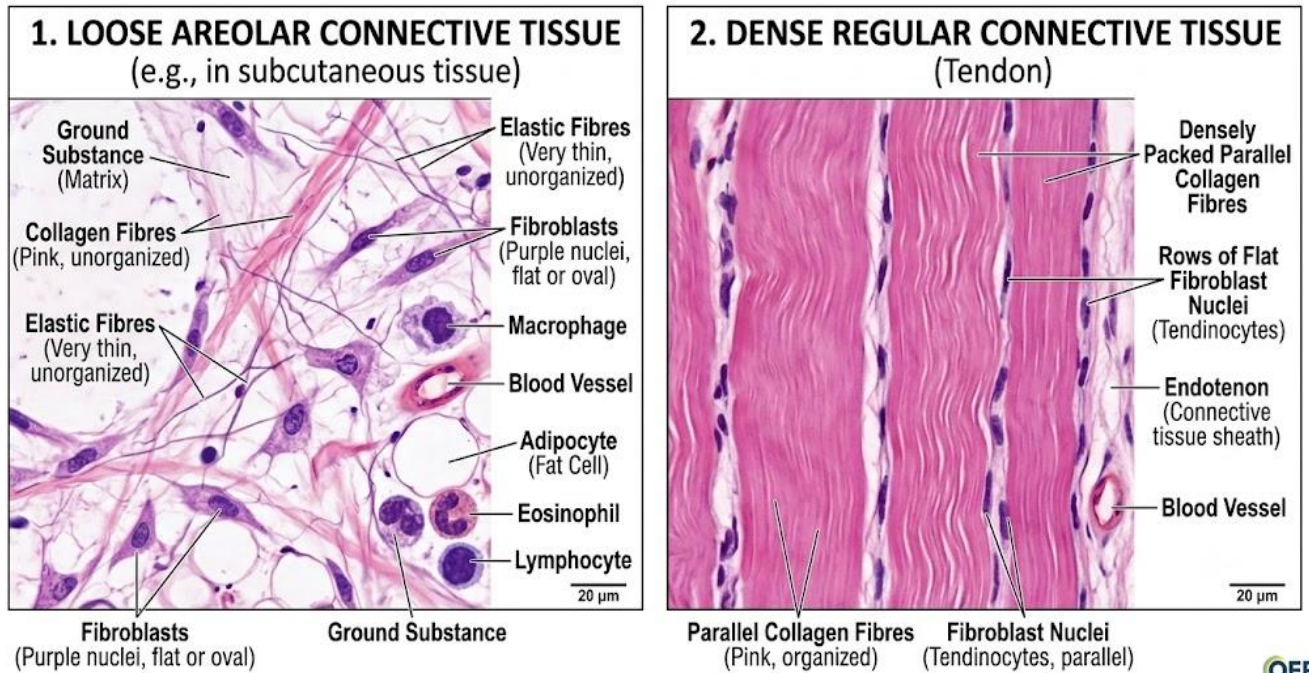


Figure 4.3: Microscope photographs of loose and dense connective tissue

4.2.2 Specialised connective tissues: cartilage and bone

Cartilage: a firm but flexible connective tissue with no blood vessels. Three types: hyaline cartilage (most common; glassy, pale-blue or pink matrix of collagen and proteoglycans; chondrocytes (cartilage cells) sit in rounded spaces called lacunae; found in articular surfaces of joints, tracheal rings, fetal skeleton; covered by perichondrium). Fibrocartilage (dense collagen fibres in matrix; found in intervertebral discs, pubic symphysis; no perichondrium). Elastic cartilage (elastic fibres in matrix; found in ear pinna, epiglottis).

Bone (osseous tissue): the hardest connective tissue; ECM is mineralised with calcium phosphate hydroxyapatite. Compact bone structure in cross-section: Haversian systems (osteons) consisting of concentric rings of bone matrix (lamellae) around a central Haversian canal containing blood



vessels and nerves; osteocytes (bone cells) sit in lacunae between lamellae; canaliculi (tiny channels) connect lacunae to each other and to the Haversian canal. Spongy (cancellous) bone: irregular trabeculae of bone with bone marrow between.

Fill in the blank: In compact bone, _____ (bone cells) are located in spaces called lacunae within the concentric lamellae of each Haversian system; they communicate with each other through canaliculi.

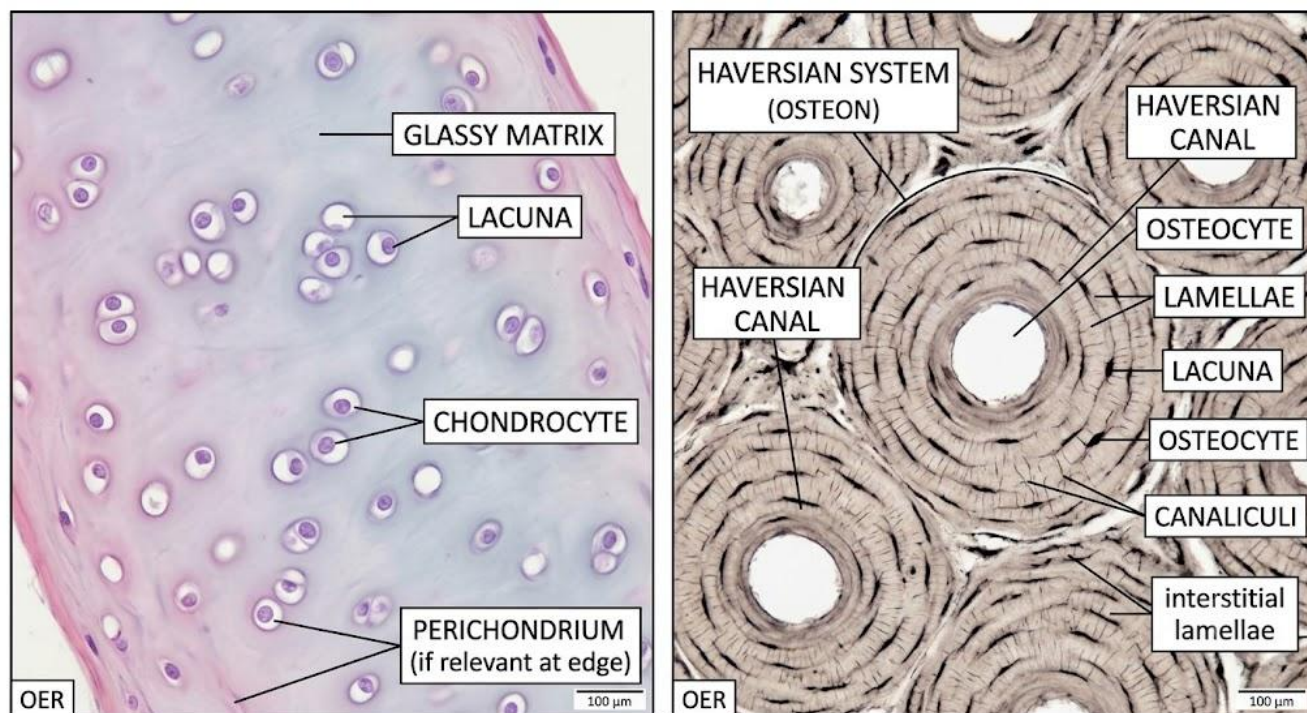


Figure 4.4: Microscope photographs of hyaline cartilage and compact bone

4.2.3 Blood as a connective tissue

Blood is classified as a connective tissue because it consists of cells (and cell fragments) suspended in a liquid extracellular matrix (plasma). A standard blood smear stained with Giemsa or Leishman stain shows: erythrocytes (red blood cells/RBCs): the most numerous cells; biconcave, non-nucleated discs in mammals; stain pink; approximately 7.5 micrometres in diameter; transport oxygen. Platelets (thrombocytes): tiny cell fragments; no nucleus; appear as small purple dots around cells; involved in clotting.



Leucocytes (white blood cells/WBCs): far fewer than RBCs; five types visible in blood smears. Neutrophils: most common WBC (60 to 70%); multi-lobed (polymorphonuclear) purple nucleus; pink granular cytoplasm; phagocytose bacteria. Eosinophils: bi-lobed nucleus; large red or orange granules; 2 to 4% of WBCs. Basophils: bi-lobed nucleus; large blue-purple granules; rarest WBC (less than 1%). Lymphocytes: large round purple nucleus occupying most of the cell; thin rim of blue cytoplasm; 20 to 30%; involved in immunity. Monocytes: largest WBC; kidney-shaped nucleus; grey-blue cytoplasm; 3 to 8%; become macrophages.

Fill in the blank: _____ are the most common white blood cells (60 to 70%); they have a multi-lobed purple nucleus, pink granular cytoplasm, and function by phagocytosing bacteria at sites of infection.

Pilot questions 4.2

1. State three identifying features of connective tissue in H and E sections.
2. Distinguish between loose and dense connective tissue.
3. Describe the microscopic appearance of hyaline cartilage.
4. Describe the structure of a Haversian system in compact bone.
5. Name five types of white blood cell and state one function of each.

4.3 Muscle and Nervous Tissues

4.3.1 Types of muscle tissue

Three types of muscle tissue are distinguished by structure, location, and control. Skeletal (striated voluntary) muscle: long cylindrical multinucleated fibres; cross-striations (alternating dark A-bands and light I-bands) visible at high magnification; nuclei peripherally placed (at the edge of the fibre); under voluntary control; found in muscles attached to the skeleton. In H and E longitudinal section, fibres appear as long parallel bands with peripheral nuclei and visible striations.



Cardiac muscle: found only in the heart wall (myocardium); short branched fibres; one or two central nuclei per cell; cross-striations visible; cells are joined end-to-end by intercalated discs (dense transverse bands visible in H and E as dark lines crossing the fibre); involuntary. Smooth (non-striated, involuntary) muscle: found in walls of hollow organs (intestine, blood vessels, uterus, bladder); spindle-shaped cells; single central nucleus; no cross-striations; cells arranged in sheets; in cross-section appear as small circles, some with a nucleus visible, others without.

Fill in the blank: Cardiac muscle cells are joined end to end by _____ discs, which appear as dark transverse lines in H and E sections; this feature uniquely identifies cardiac muscle among the three muscle types.

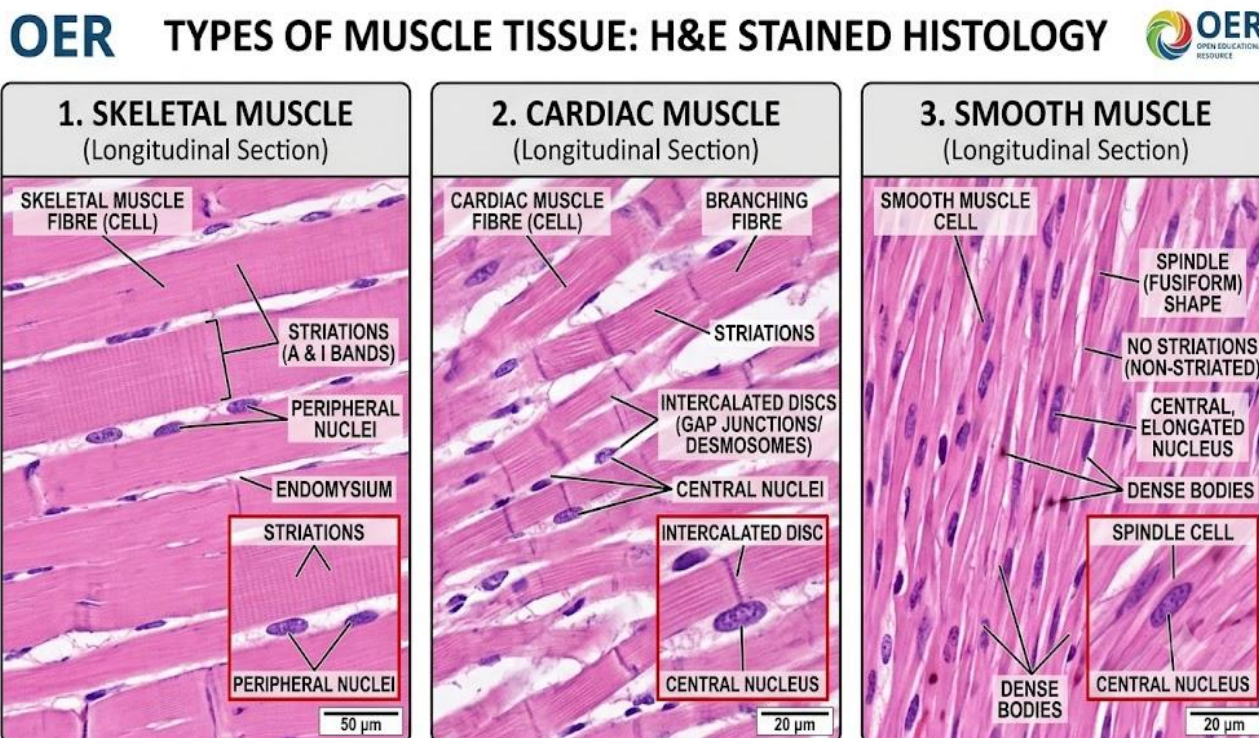


Figure 4.5: Microscope photographs of the three types of muscle tissue

4.3.2 Nervous tissue

Nervous tissue consists of two cell types: neurones (nerve cells) and neuroglia (glial cells). A motor neurone has: a large cell body (perikaryon) with a prominent nucleus and nucleolus; Nissl bodies (clumps of rough ER staining basophilic/blue-purple in H and E or Nissl stain); several



short branching dendrites; and one long axon (which may be myelinated or unmyelinated). In H and E sections of the spinal cord anterior horn, large motor neurone cell bodies with prominent nucleoli are easily identified.

Neuroglia (glial cells) are supporting cells of the nervous system; they outnumber neurones approximately 10:1. Types: astrocytes (star-shaped; structural support; blood-brain barrier); oligodendrocytes (myelinate axons in the CNS); Schwann cells (myelinate axons in the PNS); microglia (resident immune cells of the CNS); ependymal cells (line ventricles). In routine H and E sections, glial cells are difficult to identify individually; special stains (GFAP immunostain for astrocytes, Luxol fast blue for myelin) are needed. Peripheral nerve sections show bundles of myelinated axons surrounded by endoneurium, perineurium, and epineurium.

Fill in the blank: _____ bodies are clumps of rough endoplasmic reticulum in the cytoplasm of neurone cell bodies; they stain blue-purple in H and E and Nissl stains and reflect the high protein synthesis activity of active neurones.

Figure 1: Labeled Microscope Photographs of Nervous Tissue

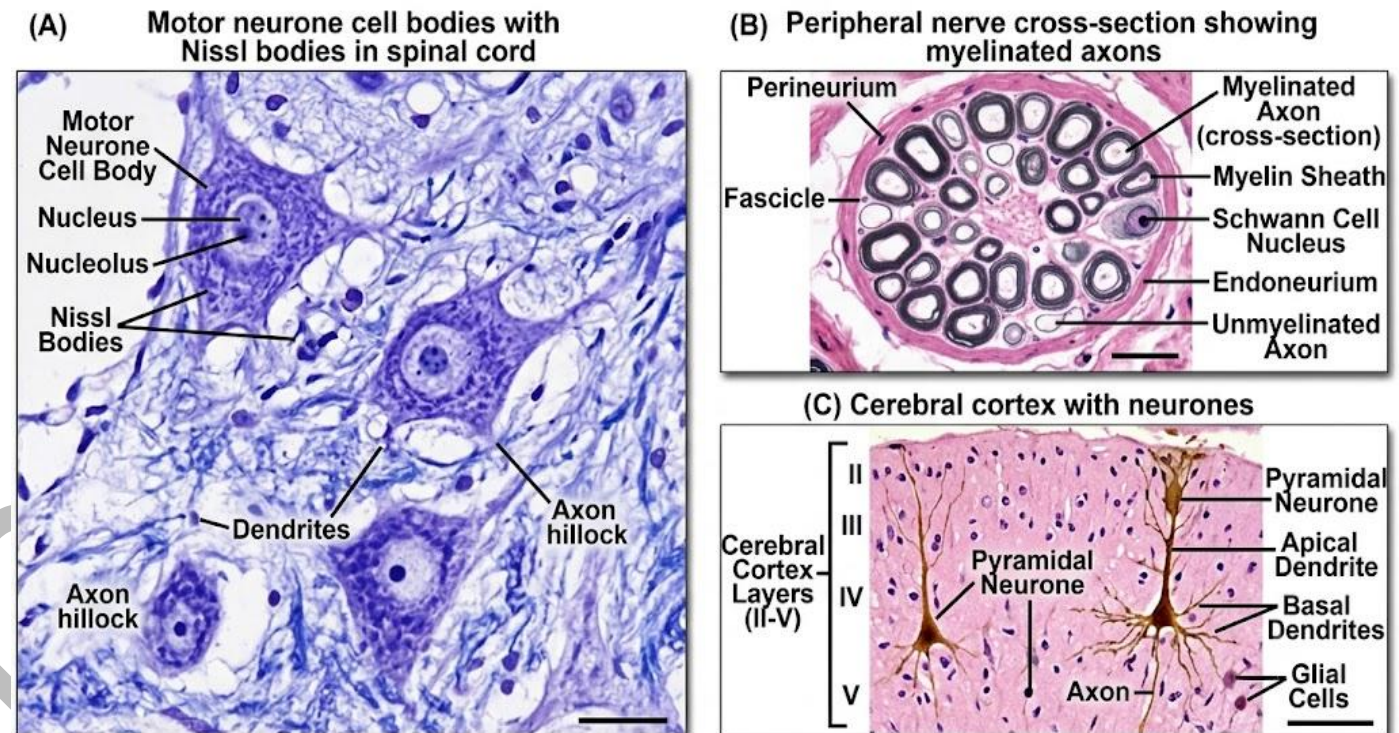


Figure 1: Labeled Microscope Photographs of Nervous Tissue

Figure 4.6: Microscope photographs of nervous tissue



4.3.3 Identification of tissues in microscope sections

A systematic approach to identifying unknown tissue sections: Step 1: look at the section at low power. Identify whether it is a sheet of tightly packed cells (epithelium), cells in abundant matrix (connective tissue), bundles of elongated cells (muscle), or large cells with prominent nuclei scattered in a matrix (nervous tissue). Step 2: note the staining pattern. Nuclei stain blue-purple (haematoxylin); cytoplasm, collagen, and keratin stain pink (eosin). A dominant blue-purple indicates nuclei-rich tissue; dominant pink indicates collagen or keratin.

Step 3: move to high power to identify cell shape, nuclear position, and special features (striations, lacunae, Nissl bodies, intercalated discs, basement membrane). Step 4: consider the organ context if recognisable. A section with villi and goblet cells is likely small intestine; a section with Haversian systems is bone; a section with follicles is thyroid. Step 5: rule out possibilities systematically. Developing the habit of working from low power to high power, using the staining pattern, and identifying specific diagnostic features will correctly classify any routine tissue section.

Fill in the blank: When identifying an unknown tissue section, always begin at _____ power to assess overall architecture; then increase magnification to identify cell shape, nuclear position, and specific diagnostic features.

<u>Tissue</u>	<u>Cell Arrangement</u>	<u>ECM</u>	<u>H&E Features</u>
<u>Epithelial</u>	Closely packed cells in continuous sheets	Minimal ECM	Darkly stained nuclei, thin cytoplasm, clear boundaries; lining surfaces
<u>Connective</u>	Loosely arranged cells scattered in matrix	Abundant ECM (fibers + ground substance)	Pink eosinophilic collagen fibers, sparse nuclei, variable cell types
<u>Muscle</u>	Elongated fibers arranged in bundles	Moderate ECM	Striations in skeletal muscle, elongated nuclei; smooth muscle shows spindle-shaped cells



<u>Nervous</u>	Neurons with supporting glial cells	Minimal ECM	Large neuron cell bodies with prominent nuclei, axons/dendrites visible, basophilic Nissl substance
----------------	-------------------------------------	-------------	---

Box 4.1: Summary of the four primary animal tissues and their identifying features in H and E sections

Pilot questions 4.3

1. State three differences between skeletal, cardiac, and smooth muscle.
2. Describe the appearance of cardiac muscle in longitudinal H and E section.
3. Describe the features of a motor neurone visible in H and E section.
4. State the five types of neuroglia and give one function of each.
5. Describe a systematic approach to identifying an unknown tissue in a microscope section.



Series Summary

This Series examined the histology of the four primary animal tissue types. Epithelial tissue was classified by cell layer number and shape: simple squamous, cuboidal, and columnar epithelia line vessels, kidney tubules, and the intestine respectively, while stratified forms protect surfaces subject to abrasion, and pseudostratified ciliated epithelium lines the trachea. Glandular epithelium was distinguished as exocrine (secreting through ducts) or endocrine (releasing hormones directly into the blood). Connective tissue was surveyed in its major forms: loose areolar tissue with fibroblasts and fibres, dense regular and irregular arrangements in tendons and dermis, the three cartilage types with their characteristic lacunae and chondrocytes, compact bone organised into Haversian osteon systems, and blood with its complement of erythrocytes, platelets, and the five categories of leucocyte.

The three muscle tissue types were contrasted by fibre shape, nuclear position, presence of striations, and voluntary or involuntary control: skeletal muscle with peripheral nuclei and cross-striations, cardiac muscle with branched fibres and intercalated discs, and smooth muscle with spindle-shaped cells lacking striations. Nervous tissue was described through its two cellular components: neurones bearing a cell body with Nissl bodies, dendrites, and an axon, and the five classes of neuroglia supporting and insulating the neurones. The Series concluded with a systematic approach to tissue identification under the microscope, moving from low-power architectural assessment through staining interpretation to high-power examination of diagnostic cellular features in organ context.

Glossary of Terms

- **Astrocyte:** a star-shaped neuroglial cell providing structural support and contributing to the blood-brain barrier; identified by GFAP immunostaining.
- **Basal lamina (basement membrane):** a thin sheet of extracellular matrix underlying all epithelial cells; provides structural support and acts as a selective filter.



- **Canaliculi:** tiny channels radiating from lacunae in bone; allow osteocytes to communicate with each other and with Haversian canals via cell processes.
- **Cardiac muscle:** involuntary striated muscle of the heart; branched fibres with central nuclei joined by intercalated discs.
- **Chondrocyte:** a cartilage cell; sits in a rounded space (lacuna) within the cartilage matrix; responsible for maintaining the matrix.
- **Collagen fibres:** thick, pink-staining fibres in connective tissue ECM; composed of collagen protein; provide high tensile strength.
- **Dense regular connective tissue:** connective tissue with collagen fibres arranged in parallel bundles; found in tendons and ligaments; resists tension in one direction.
- **Endocrine gland:** a ductless gland that secretes hormones directly into the bloodstream; examples include thyroid, adrenal, and islets of Langerhans.
- **Eosinophil:** a white blood cell with a bi-lobed nucleus and large red-orange granules; 2 to 4% of WBCs; involved in allergic responses and defence against parasites.
- **Erythrocyte:** a red blood cell; biconcave, non-nucleated disc in mammals; contains haemoglobin for oxygen transport.
- **Exocrine gland:** a gland that secretes its products through a duct onto a body surface; examples include salivary glands, sweat glands, and pancreatic acini.
- **Fibroblast:** the principal cell of connective tissue; produces and maintains the extracellular matrix (collagen, elastin, ground substance); spindle-shaped with elongated nucleus.
- **Goblet cell:** a unicellular exocrine gland interspersed in lining epithelia; secretes mucus; appears as a pale, empty-looking cell with a basal nucleus in H and E.
- **Haversian canal:** the central canal of an osteon in compact bone; contains blood vessels and nerves; surrounded by concentric lamellae of bone matrix.
- **Haversian system (osteon):** the structural unit of compact bone; concentric rings of bone matrix (lamellae) around a central Haversian canal; osteocytes in lacunae between lamellae.
- **Hyaline cartilage:** the most common type of cartilage; glassy pale matrix of collagen and proteoglycans; chondrocytes in lacunae; found in articular surfaces and tracheal rings.



- **Intercalated disc:** a specialised cell junction connecting adjacent cardiac muscle cells end-to-end; appears as a dark transverse line in H and E sections; allows electrical coupling.
- **Keratin:** a tough fibrous protein filling the dead cells of keratinised stratified squamous epithelium; stains pink (eosinophilic) in H and E.
- **Lacuna (plural: lacunae):** a small rounded space in the extracellular matrix of cartilage or bone occupied by a chondrocyte or osteocyte.
- **Loose (areolar) connective tissue:** the most widespread connective tissue; loosely arranged collagen and elastic fibres with fibroblasts, mast cells, and macrophages in an amorphous ground substance.
- **Lymphocyte:** a white blood cell with a large round purple nucleus occupying most of the cell; 20 to 30% of WBCs; B-lymphocytes produce antibodies; T-lymphocytes mediate cellular immunity.
- **Monocyte:** the largest white blood cell; kidney-shaped nucleus; grey-blue cytoplasm; 3 to 8% of WBCs; leaves the blood and becomes a macrophage in tissues.
- **Neutrophil:** the most common white blood cell (60 to 70%); multi-lobed nucleus; pink granular cytoplasm; phagocytoses bacteria at sites of infection.
- **Nissl bodies:** clumps of rough endoplasmic reticulum in neurone cell bodies; stain blue-purple in H and E; reflect the high protein synthesis activity of neurones.
- **Osteocyte:** a bone cell; sits in a lacuna within the bone matrix of Haversian systems; communicates via cell processes in canaliculi.
- **Pseudostratified epithelium:** an epithelium that appears stratified because nuclei are at different levels, but all cells contact the basement membrane; lines the trachea and bronchi.
- **Schwann cell:** a neuroglial cell of the peripheral nervous system; wraps around axons to form the myelin sheath, which insulates and speeds nerve impulse conduction.
- **Simple squamous epithelium:** a single layer of flat, scale-like cells; lines blood vessels (endothelium), alveoli, and body cavities (mesothelium).
- **Skeletal muscle:** voluntary, striated muscle attached to the skeleton; long multinucleated fibres with peripheral nuclei and visible A and I band cross-striations.



- **Smooth muscle:** involuntary, non-striated muscle in walls of hollow organs; spindle-shaped cells with a single central nucleus; no cross-striations.
- **Stratified squamous epithelium:** multiple layers of cells; apical cells are flat squames; protects surfaces subject to abrasion; keratinised in skin, non-keratinised in oesophagus.
- **Transitional epithelium (urothelium):** a specialised stratified epithelium lining the urinary tract; can stretch when the bladder fills; dome-shaped umbrella cells at the apical surface when relaxed.



Concept Check Questions [Series 4]

Objective Questions

1. Simple squamous epithelium lining blood vessels is called _____; it is identified by a single layer of flat cells with disc-shaped nuclei. (Linked to SLO 4.1)
2. _____ epithelium appears stratified because nuclei are at different levels, but all cells contact the basement membrane; it lines the trachea. (Linked to SLO 4.1)
3. In compact bone, _____ (bone cells) sit in lacunae within the concentric lamellae of each Haversian system. (Linked to SLO 4.2)
4. Cardiac muscle cells are joined end to end by _____ discs, which appear as dark transverse lines in H and E sections. (Linked to SLO 4.3)
5. _____ bodies in neurone cytoplasm are clumps of rough ER that stain blue-purple in H and E; they reflect the high protein synthesis of neurones. (Linked to SLO 4.4)

Short-Answer Questions

1. Distinguish between simple squamous, cuboidal, and columnar epithelia. (Linked to SLO 4.1)
2. Describe the microscopic appearance of hyaline cartilage in H and E section. (Linked to SLO 4.2)
3. Name five types of white blood cell and state one function of each. (Linked to SLO 4.2)
4. State three differences between skeletal, cardiac, and smooth muscle in H and E section. (Linked to SLO 4.3)
5. Describe a systematic approach for identifying an unknown tissue in a microscope section. (Linked to SLO 4.5)

Long-Answer Questions

1. Describe the types of epithelial tissue, including simple, stratified, pseudostratified, and glandular epithelia, with their locations and identifying microscopic features. (Linked to SLO 4.1)
2. Describe loose connective tissue, cartilage, compact bone, and blood as types of connective tissue; give the identifying features of each in microscope sections. (Linked to SLO 4.2)



3. Describe the three types of muscle tissue and nervous tissue with their histological features; explain the systematic approach to tissue identification in unknown sections. (Linked to SLOs 4.3, 4.4, 4.5)

Answers to Concept Check Questions [Series 4]

Objective Questions

1. Endothelium.
2. Pseudostratified.
3. Osteocytes.
4. Intercalated.
5. Nissl.

Short-Answer Questions

1. Simple squamous: single layer of flat cells; disc-shaped nuclei; lining blood vessels and alveoli. Simple cuboidal: single layer of cube-shaped cells; round central nucleus; kidney tubules. Simple columnar: single layer of tall cells; oval basal nucleus; intestinal lining; may have goblet cells and microvilli.
2. Pale glassy matrix (collagen and proteoglycans); chondrocytes in rounded spaces called lacunae; some lacunae in pairs (isogenous groups); surrounded by fibrous perichondrium; no blood vessels in the matrix.
3. Neutrophils (multi-lobed nucleus; phagocytose bacteria; 60-70%); eosinophils (bi-lobed; large red granules; defence against parasites; 2-4%); basophils (bi-lobed; large blue-purple granules; less than 1%); lymphocytes (large round purple nucleus; immunity; 20-30%); monocytes (kidney-shaped nucleus; largest WBC; become macrophages; 3-8%).
4. Skeletal: long fibres; peripheral nuclei; cross-striations; voluntary. Cardiac: branched fibres; central nuclei; striations; intercalated discs; involuntary. Smooth: spindle-shaped cells; central nucleus; no striations; involuntary.
5. Step 1: low power to assess overall architecture (sheet of cells = epithelium; cells in matrix = connective; bundles of elongated cells = muscle; large cells with prominent nuclei = nerve). Step 2: note staining (blue nuclei, pink collagen/keratin). Step 3: high power for cell shape,



nuclear position, and specific features. Step 4: consider organ context. Step 5: rule out systematically.

Long-Answer Questions

1. All epithelium: tightly packed cells on a basal lamina; little ECM; apical-basal polarity. Simple squamous (flat; disc-shaped nuclei; endothelium in vessels; mesothelium in body cavities; alveoli). Simple cuboidal (cube-shaped; round central nuclei; kidney tubules; thyroid follicles). Simple columnar (tall; basal oval nuclei; intestine; stomach; may have microvilli/brush border and goblet cells). Stratified squamous keratinised (multiple layers; dead keratinised surface cells staining pink; basal cuboidal cells; skin epidermis). Non-keratinised (living cells throughout; oesophagus, oral cavity). Pseudostratified ciliated columnar (all cells touch basement membrane; nuclei at different heights; cilia at apical surface; goblet cells; trachea and bronchi). Transitional (urothelium; urinary tract; stretches; dome-shaped umbrella cells at rest). Glandular: exocrine (duct; goblet cells unicellular; multicellular: tubular, alveolar, tubuloacinar; salivary glands, pancreatic acini); endocrine (ductless; hormones into blood; thyroid follicles; islets of Langerhans; adrenal cortex).
2. Connective tissue general: cells widely spaced in abundant ECM; fibroblasts most common cell; collagen fibres stain pink in H and E. Loose areolar: loosely arranged collagen and elastic fibres; ground substance; fibroblasts, mast cells, macrophages; beneath all epithelia. Dense regular (tendons, ligaments; parallel collagen fibres; fibroblast nuclei squeezed between fibres). Dense irregular (dermis; fibres in multiple directions). Cartilage: no blood vessels; cells (chondrocytes) in lacunae. Hyaline: pale glassy matrix; chondrocytes in lacunae; perichondrium; articular surfaces, tracheal rings. Fibrocartilage: dense collagen + chondrocytes; intervertebral discs. Elastic: elastic fibres visible; ear pinna. Compact bone: Haversian systems (osteons); concentric lamellae around Haversian canal; osteocytes in lacunae; canaliculi connect lacunae; Volkmann's canals connect Haversian canals. Blood: plasma (liquid ECM); erythrocytes (biconcave, non-nucleated, pink; transport O₂); platelets (small purple fragments; clotting); leucocytes: neutrophils (multi-lobed; phagocytosis; 60-70%); eosinophils (bi-lobed; red granules; 2-4%); basophils (blue-purple granules; rare); lymphocytes (large round nucleus; immunity; 20-30%); monocytes (kidney-shaped nucleus; largest; become macrophages; 3-8%).
3. Skeletal muscle: long cylindrical multinucleated fibres; peripheral nuclei; A and I band cross-striations at high power; parallel arrangement; voluntary; H and E shows long parallel bands with peripheral blue nuclei and pink striated cytoplasm. Cardiac muscle: branched fibres;



single central nucleus; cross-striations; intercalated discs (dark transverse lines) are the key diagnostic feature; involuntary; found only in heart myocardium. Smooth muscle: spindle-shaped cells; single central nucleus; no striations; involuntary; walls of hollow organs; cross-section shows small circles of varying size (depending on whether nucleus is in the plane of section); longitudinal section shows spindle shapes. Nervous tissue: neurones (large cell body/perikaryon; large vesicular nucleus with prominent nucleolus; Nissl bodies in cytoplasm; dendrites and axon; motor neurones visible as large cells in spinal cord anterior horn). Neuroglia: astrocytes (star-shaped; structural support; GFAP+); oligodendrocytes (myelinate CNS axons); Schwann cells (myelinate PNS axons; myelin = pink ring around axon in cross-section); microglia (CNS immune cells); ependymal (line ventricles). Tissue identification: (1) low power: architecture; (2) staining pattern; (3) high power: cell shape, nuclei, diagnostic features; (4) organ context; (5) eliminate alternatives systematically.

Answers to Pilot Questions [Series 4]

Part 4.1

1. In H and E sections, epithelial tissue is identified by: (1) tightly packed cells with little or no extracellular matrix between them (the cells appear to touch each other directly with only a thin line of pink between them); (2) a visible basal lamina (basement membrane) separating the epithelium from the underlying connective tissue (visible as a thin pink line); (3) polarity (cells have a distinct apical surface facing the lumen or exterior and a basal surface resting on the basement membrane); (4) prominent nuclei that stain blue-purple with haematoxylin.
2. Simple squamous: a single layer of flat, plate-like cells; nuclei appear as flattened discs seen face-on, or as thin elongated profiles seen in section; the cytoplasm is extremely thin; identified in blood vessel walls and alveoli. Simple cuboidal: a single layer of cells approximately as wide as they are tall (cube-shaped); nuclei are round and located centrally; identified in kidney tubules and thyroid follicles. Simple columnar: a single layer of tall cells clearly taller than wide; nuclei are oval and positioned at the base of the cell; identified in the stomach and intestine, often with a brush border (microvilli) and interspersed goblet cells.
3. Keratinised stratified squamous epithelium is recognisable in H and E sections by several layers of cells. From deep to superficial: basal cell layer (single layer of columnar or cuboidal cells with dark-staining nuclei and active mitosis); spinous layer (several layers of polygonal



cells with "spiky" cell boundaries formed by desmosomes); granular layer (flattened cells containing dark-staining keratohyalin granules); stratum lucidum (thin pale homogeneous zone; only in thick skin); stratum corneum (outer zone of dead, anucleate cells completely filled with pink-staining keratin protein; no nuclei visible; this pink anucleate surface layer is the single most diagnostic feature of keratinised stratified squamous epithelium).

4. Pseudostratified epithelium is a single-layered epithelium that gives the false appearance of being stratified. All cells contact the basement membrane, but the cells are of unequal heights; their nuclei are positioned at different levels within the epithelium (some nuclei are high, some low), which is what creates the false impression of multiple layers. In the trachea and bronchi, pseudostratified ciliated columnar epithelium is found; the cells are columnar, their apical surfaces bear cilia (visible as fine hair-like projections in H and E), and goblet cells (mucus-secreting cells with pale, unstained apical cytoplasm and basal nuclei) are interspersed among the ciliated cells.
5. Exocrine glands secrete their products through a duct onto an epithelial surface (external or internal). The duct connects the secretory cells to the target surface. Examples: salivary glands (mucus and serous secretion into the oral cavity), pancreatic acini (digestive enzymes into the duodenum via the pancreatic duct), sweat glands (sweat onto the skin surface). Endocrine glands have no ducts; they are derived from epithelium but lose their connection to any surface; instead, they are richly supplied with blood vessels and capillaries into which they secrete their hormone products directly. Examples: thyroid gland (secretes thyroxine into the blood from follicular cells), islets of Langerhans (secrete insulin and glucagon from beta and alpha cells), adrenal glands (secrete adrenaline and cortisol).

Part 4.2

1. Three identifying features of connective tissue in H and E sections: (1) cells are widely scattered and separated from each other by large amounts of extracellular matrix (the cells are not touching each other, unlike epithelium); (2) collagen fibres are visible in the extracellular matrix as thick, wavy, pink (eosinophilic) strands or bundles filling the space between cells; (3) the most common cell type is the fibroblast, identified by an elongated spindle-shaped nucleus with condensed chromatin, lying within or between the collagen bundles.
2. Loose (areolar) connective tissue: collagen and elastic fibres are loosely and randomly arranged with abundant amorphous ground substance between them; cells (fibroblasts, mast



cells, macrophages) are numerous relative to the amount of fibre; the tissue has an open, loosely organised appearance at low power; found beneath all epithelia and between organs; provides metabolic support and a route for diffusion. Dense connective tissue: collagen fibres are tightly packed and dominate the section; very little ground substance or amorphous material is visible; cells (mainly fibroblasts) are compressed between fibre bundles and their nuclei appear flattened; dense regular (fibres parallel: tendons, ligaments) or dense irregular (fibres in multiple directions: dermis).

3. In H and E sections, hyaline cartilage shows: (1) a pale, homogeneous or faintly granular matrix that stains pale blue or pink (the matrix contains type II collagen and proteoglycans); (2) chondrocytes (cartilage cells) sitting in rounded spaces called lacunae within the matrix; in living tissue the chondrocytes fill the lacuna, but in fixed sections the cells often shrink slightly away from the lacuna wall leaving a clear halo; (3) isogenous groups: two or four chondrocytes in adjacent lacunae derived from the same parent cell by mitosis, often seen together; (4) perichondrium: a layer of dense fibrous connective tissue surrounding the cartilage (not present in fibrocartilage or articular cartilage); (5) no blood vessels within the cartilage matrix itself.
4. A Haversian system (osteon) is the structural unit of compact bone visible in cross-section. At the centre is the Haversian canal, a circular space approximately 50 micrometres in diameter containing one or two blood vessels (capillaries or small arterioles), lymph vessels, and nerve fibres. Surrounding the canal are 4 to 20 concentric rings of mineralised bone matrix called lamellae (each lamella approximately 3 to 7 micrometres thick); the collagen fibres in adjacent lamellae run in alternating directions, giving the system strength. Between the lamellae are small lens-shaped spaces called lacunae, each occupied by one osteocyte (bone cell). From each lacuna, tiny channels called canaliculi radiate outward (and inward) to connect adjacent lacunae and the Haversian canal, allowing osteocytes to exchange nutrients and waste via cell processes.
5. Neutrophils (60 to 70%; multi-lobed purple nucleus; phagocytose bacteria and cellular debris at acute infection sites; the first WBC to arrive at a site of bacterial infection). Eosinophils (2 to 4%; bi-lobed nucleus; large bright red-orange specific granules; defend against parasitic worms; involved in allergic and asthmatic inflammation). Basophils (less than 1%; bi-lobed nucleus; large blue-purple specific granules containing histamine and heparin; involved in allergic responses and inflammation). Lymphocytes (20 to 30%; large round or slightly kidney-shaped purple nucleus occupying most of the cell; thin rim of pale blue cytoplasm; B-lymphocytes produce antibodies; T-lymphocytes mediate cellular immunity). Monocytes (3



to 8%; largest WBC; kidney-shaped or horseshoe-shaped nucleus; grey-blue abundant cytoplasm; migrate from blood into tissues and differentiate into macrophages, which phagocytose pathogens, dead cells, and debris).

Part 4.3

1. Skeletal vs cardiac vs smooth: (1) Nucleus position: skeletal has multiple peripheral nuclei at the edge of the fibre; cardiac has one or two central nuclei; smooth has one central nucleus. (2) Cross-striations: skeletal has prominent A and I band striations; cardiac also has striations; smooth has no striations. (3) Cell shape and connections: skeletal fibres are long and cylindrical and not connected to adjacent fibres (they are independent); cardiac fibres are short and branched and connected end-to-end by intercalated discs; smooth cells are independent spindle-shaped cells arranged in sheets.
2. In H and E longitudinal section, cardiac muscle appears as: short branched fibres (not as long as skeletal muscle fibres) that branch and interconnect to form a network; each fibre has one or two centrally placed oval nuclei (never peripheral as in skeletal muscle) that stain blue-purple; the cytoplasm (sarcoplasm) appears pink and shows faint cross-striations (alternating A and I bands) at high magnification; the single most diagnostic feature is the presence of intercalated discs: dark transverse lines crossing the width of the fibre at irregular intervals, marking the junctions between adjacent cardiac muscle cells; these are visible at medium and high power as dense eosin-staining or haematoxylin-staining step-like transverse bands.
3. In H and E sections of the spinal cord anterior horn or cerebral cortex, motor neurones are identified by: (1) a large cell body (perikaryon), much larger than surrounding glial cell nuclei (the cell body of a spinal motor neurone may be 50 to 100 micrometres across); (2) a large, pale, vesicular (open) nucleus with one very prominent nucleolus visible as a dark dot; (3) Nissl bodies: dark-staining (basophilic) granules or clumps in the cytoplasm; these are clumps of rough endoplasmic reticulum and ribosomes visible at high magnification as blue-purple granules throughout the cell body; (4) pale-staining axon hillock: a cone-shaped region at the base of the axon where Nissl bodies are absent; (5) short, tapering dendrite processes extending from the cell body (only visible near the cell body in routine sections).
4. Five types of neuroglia: (1) Astrocytes: star-shaped; the most numerous glial cell; provide structural support and form the blood-brain barrier; regulate the ionic environment around synapses; identified by GFAP (glial fibrillary acidic protein) immunostaining; not readily



distinguished in routine H and E. (2) Oligodendrocytes: small cells with round dark nuclei; form the myelin sheath around CNS axons; each oligodendrocyte can myelinate segments of multiple axons. (3) Schwann cells: the myelinating cells of the peripheral nervous system; each Schwann cell wraps around a segment of one axon to form one internode of myelin; identified in peripheral nerve sections. (4) Microglia: small elongated cells derived from monocytes; the resident immune cells of the CNS; become activated and phagocytic in response to injury or infection. (5) Ependymal cells: cuboidal or columnar ciliated cells lining the ventricles of the brain and central canal of the spinal cord; produce and circulate cerebrospinal fluid (CSF).

5. A systematic five-step approach: Step 1 (low power, 4x or 10x): assess the overall architecture of the section. Ask: are the cells tightly packed (epithelium)? Are cells sparse in abundant pink matrix (connective tissue)? Are there bundles of elongated parallel cells (muscle)? Are there scattered large cells with prominent nuclei in a fibrous background (nervous tissue)? Step 2 (low power; staining pattern): dominant blue-purple staining suggests nuclei-rich tissue (epithelium, lymphoid); dominant pink suggests collagen (connective), keratin (keratinised epithelium), or muscle fibres. Step 3 (medium to high power, 40x): identify cell shape, nuclear position (peripheral or central), and specific diagnostic features (striations, intercalated discs, lacunae, Nissl bodies, basement membrane, goblet cells, Haversian canals). Step 4 (context): if the overall shape of the section is recognisable (e.g. kidney tubules surrounded by glomeruli, intestinal villi with core of connective tissue, a circular trachea with cartilage rings), use this to confirm the tissue identification. Step 5 (elimination): rule out the tissues that definitely do not match and confirm the one that best fits all the features observed.



References and Attributions [Series 4]

Textual References (Books and External Sources)

- Ross, M. H., & Pawlina, W. (2011). Histology: A text and atlas (6th ed.). Lippincott Williams and Wilkins.
- Young, B., Lowe, J. S., Stevens, A., & Heath, J. W. (2006). Wheater's functional histology (5th ed.). Churchill Livingstone.
- Junqueira, L. C., & Carneiro, J. (2005). Basic histology: Text and atlas (11th ed.). Lange Medical Books.
- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 4.1: Simple epithelium types microscope photographs Attribution: AI generated. Suggested OER search string: "simple epithelium microscope photograph squamous cuboidal columnar H and E stained histology OER".
- Figure 4.2: Stratified and pseudostratified epithelia microscope photographs Attribution: AI generated. Suggested OER search string: "stratified epithelium keratinised skin pseudostratified trachea H and E microscope histology OER".
- Figure 4.3: Loose and dense connective tissue microscope photographs Attribution: AI generated. Suggested OER search string: "loose areolar connective tissue dense regular tendon H and E microscope histology OER".
- Figure 4.4: Hyaline cartilage and compact bone microscope photographs Attribution: AI generated. Suggested OER search string: "hyaline cartilage chondrocytes lacunae compact bone Haversian system osteocyte microscope histology OER".
- Figure 4.5: Three muscle tissue types microscope photographs Attribution: AI generated. Suggested OER search string: "skeletal cardiac smooth muscle histology H and E microscope photograph intercalated discs striations OER".
- Figure 4.6: Nervous tissue microscope photographs Attribution: AI generated. Suggested OER search string: "nervous tissue neurone Nissl bodies spinal cord peripheral nerve myelinated axon histology microscope OER".



- Box 4.1: Summary of four primary animal tissues in H and E sections Attribution: AI generated.
Suggested OER search string: "four primary animal tissues identification H and E table epithelial connective muscle nervous histology OER box".



Course code: BIO 108

Course title: General Biology Practical II

Course credit load: 1 Unit

Series 5: Identification of Animal Kingdom Groups

- **Part 5.1: Identification of Invertebrate Phyla**
 - Sub Part 5.1.1: Porifera, Cnidaria, and Platyhelminthes
 - Sub Part 5.1.2: Annelida, Nematoda, and Mollusca
 - Sub Part 5.1.3: Arthropoda and Echinodermata
- **Part 5.2: Identification of Vertebrate Groups**
 - Sub Part 5.2.1: Fish: Chondrichthyes and Osteichthyes
 - Sub Part 5.2.2: Amphibia and Reptilia
 - Sub Part 5.2.3: Aves and Mammalia
- **Part 5.3: Practical Specimen Examination and Keys**
 - Sub Part 5.3.1: Use of dichotomous identification keys
 - Sub Part 5.3.2: Drawing biological specimens
 - Sub Part 5.3.3: Writing systematic descriptions of specimens

Introduction

The Animal Kingdom contains over one million described species organised into more than 30 phyla. Practical identification of animals to the correct phylum or class requires knowledge of the defining external features of each group. This skill is exercised using preserved or live



specimens, photographs, and dichotomous keys, and forms the foundation of zoology and comparative anatomy.

This final Series covers the identifying features of the major invertebrate phyla (Porifera, Cnidaria, Platyhelminthes, Annelida, Nematoda, Mollusca, Arthropoda, and Echinodermata) and the vertebrate classes (cartilaginous fish, bony fish, amphibians, reptiles, birds, and mammals), the use of dichotomous identification keys, making accurate biological drawings, and writing systematic specimen descriptions.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 5.1** identify specimens of Porifera, Cnidaria, Platyhelminthes, Annelida, Nematoda, Mollusca, Arthropoda, and Echinodermata and state the key diagnostic features of each phylum (Linked to Part 5.1),
- **SLO 5.2** identify specimens of Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves, and Mammalia and state the key diagnostic features of each class (Linked to Part 5.2),
- **SLO 5.3** use a dichotomous key to identify an unknown animal specimen to phylum or class (Linked to Part 5.3),
- **SLO 5.4** make an accurate biological drawing of an animal specimen with correct labelling (Linked to Part 5.3), and
- **SLO 5.5** write a systematic external description of an animal specimen in the correct format (Linked to Part 5.3).

5.1 Identification of Invertebrate Phyla

5.1.1 Porifera, Cnidaria, and Platyhelminthes

Phylum Porifera (sponges): the simplest multicellular animals; no true tissues or organs; body perforated by pores (ostia) through which water enters and a large opening (osculum) through which water exits; skeleton of spicules (calcium carbonate or silica) or spongin fibres; sessile; aquatic (mostly marine). Identifying features: asymmetrical or radially symmetrical; porous



body; no mouth; no nervous system. Nigerian freshwater sponges occur on submerged rocks and vegetation.

Phylum Cnidaria (jellyfish, corals, sea anemones, Hydra): radial symmetry; true tissues but no organs; stinging cells called cnidocytes (nematocysts) present; two body layers (ectoderm and endoderm) separated by mesoglea; single body opening (mouth/anus); two body forms: polyp (sessile; e.g. Hydra, sea anemone) and medusa (free-swimming; e.g. jellyfish). Identifying features: radial symmetry; tentacles with cnidocytes around the mouth. Phylum Platyhelminthes (flatworms, tapeworms, flukes): bilaterally symmetrical; acoelomate (no body cavity); dorsoventrally flattened body; no circulatory or respiratory system; examples: Dugesia (free-living), Taenia (tapeworm; parasite), Schistosoma (blood fluke; causes bilharzia in Nigeria).

Fill in the blank: Members of Phylum Cnidaria possess stinging cells called _____ (nematocysts) used to capture prey; they have radial symmetry and two body forms: the sessile polyp and the free-swimming medusa.

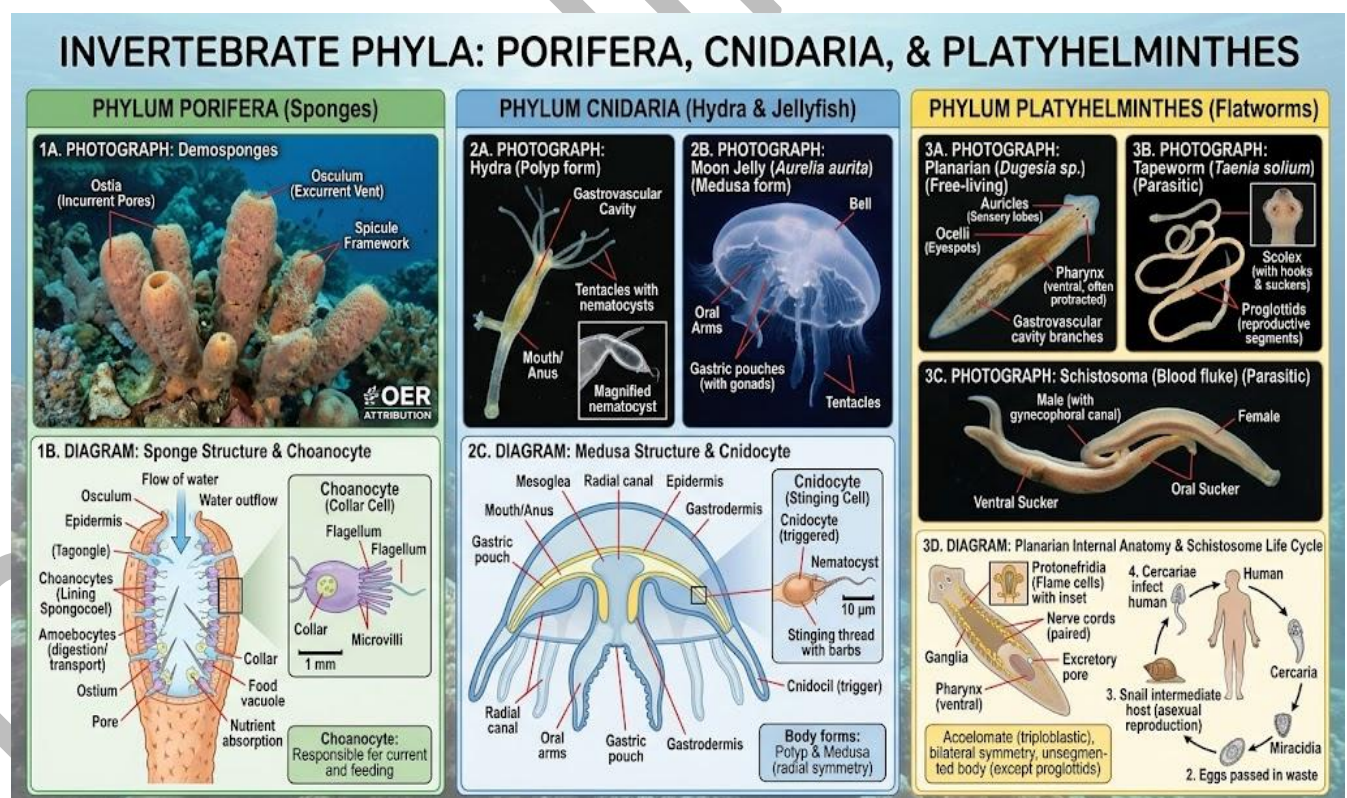


Figure 5.1: Photographs and diagrams of Porifera, Cnidaria, and Platyhelminthes



5.1.2 Annelida, Nematoda, and Mollusca

Phylum Annelida (segmented worms): bilaterally symmetrical; true coelom; body divided into segments (metameres) externally visible as rings; each segment may have chaetae (bristles).

Three classes: Oligochaeta (earthworm *Lumbricus*; few chaetae; clitellum for reproduction; no parapodia); Polychaeta (marine ragworms; many chaetae; parapodia; separate sexes); Hirudinea (leeches; no chaetae; anterior and posterior suckers; hermaphrodite). Earthworms are commonly examined in Nigerian practical classes.

Phylum Nematoda (roundworms): bilaterally symmetrical; pseudocoelomate (false body cavity); cylindrical, non-segmented; cuticle covers body; tapered at both ends; no circular muscles (only longitudinal, giving a thrashing movement). Many are parasitic: *Ascaris lumbricoides* (intestinal roundworm; common in Nigeria), *Wuchereria bancrofti* (causes filariasis), hookworms, pinworms. Phylum Mollusca (snails, clams, squids, octopus): bilaterally symmetrical; soft unsegmented body; usually have a mantle (secretes shell), a muscular foot for locomotion, and a radula (rasping tongue; absent in bivalves). Three common classes: Gastropoda (snails; single coiled shell; e.g. *Achatina africana* the giant African land snail, common in Nigeria); Bivalvia (clams, oysters; two-valved shell; no radula); Cephalopoda (squids, octopus; no external shell or reduced; most advanced invertebrate brain).

Fill in the blank: Phylum Annelida is identified by the presence of body _____ (metameres) visible externally as rings; the earthworm (*Lumbricus*) is the most commonly examined annelid specimen in biology practical classes.



COMPARATIVE ANATOMY: ANNELIDA, NEMATODA, & MOLLUSCA

OER

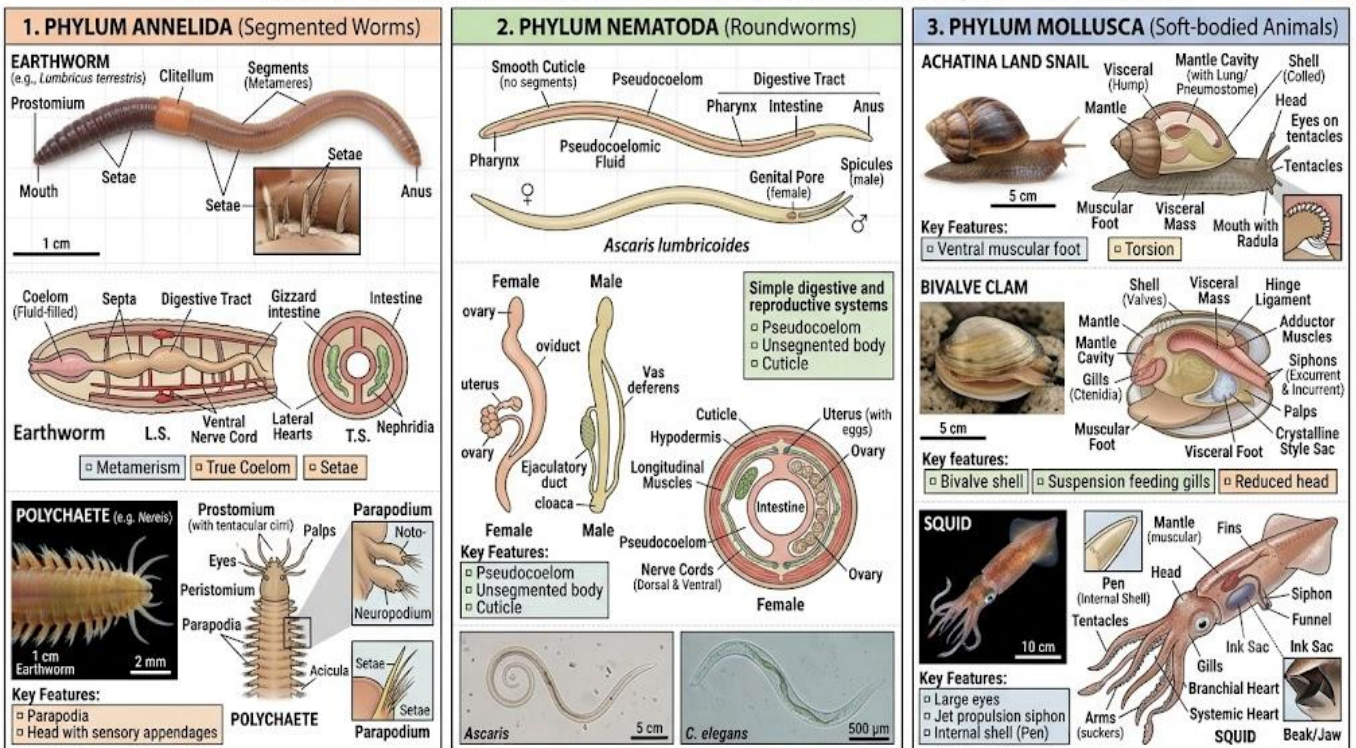


Figure 5.2: Photographs and diagrams of Annelida, Nematoda, and Mollusca

5.1.3 Arthropoda and Echinodermata

Phylum Arthropoda: the largest animal phylum; bilaterally symmetrical; exoskeleton of chitin; jointed appendages; segmented body; open circulatory system; growth by moulting (ecdysis).

Four major classes in Nigeria. **Insecta** (insects): three body regions (head, thorax, abdomen); three pairs of legs on thorax; one pair of antennae; one or two pairs of wings (sometimes absent); e.g. cockroach (*Periplaneta americana*), grasshopper (*Schistocerca*), mosquito (*Anopheles*), housefly (*Musca domestica*). **Arachnida** (spiders, scorpions, mites, ticks): two body regions (cephalothorax and abdomen); four pairs of legs; no antennae; no wings; chelicerae and pedipalps.

Crustacea (crabs, shrimps, crayfish): two body regions (cephalothorax and abdomen); five or more pairs of legs; two pairs of antennae; gills for gas exchange; mostly aquatic; e.g. *Callinectes* (blue crab), *Macrobrachium* (freshwater prawn; important Nigerian food source). **Chilopoda** (centipedes): one pair of legs per body segment; one pair of antennae; venomous claws



(forcipules) on first segment. Phylum Echinodermata (sea stars, sea urchins, sea cucumbers): radial symmetry in adults (bilateral as larvae); spiny skin; water vascular system (hydraulic system operating tube feet for locomotion and feeding); exclusively marine; no Nigerian freshwater or terrestrial examples. Classes: Asteroidea (sea stars), Echinoidea (sea urchins), Holothuroidea (sea cucumbers), Crinoidea (feather stars).

Fill in the blank: Insects are identified by three pairs of _____ attached to the thorax, three body regions (head, thorax, abdomen), and one pair of antennae; they are the most diverse class in Phylum Arthropoda.

Pilot questions 5.1

1. State three identifying features of Phylum Porifera.
2. Distinguish between a cnidarian polyp and a medusa.
3. State four identifying features of Phylum Annelida.
4. State the three classes of Mollusca and give one example of each.
5. State four features that identify an insect, distinguishing it from an arachnid.

5.2 Identification of Vertebrate Groups

5.2.1 Fish: Chondrichthyes and Osteichthyes

All fish are aquatic vertebrates with gills for gas exchange, fins for locomotion, and a streamlined body. Class Chondrichthyes (cartilaginous fish: sharks, rays, skates): skeleton entirely of cartilage (no bone); skin covered in dermal denticles (placoid scales) giving a sandpaper texture; no swim bladder (buoyancy maintained by large oily liver); separate gill slits visible on the sides (no operculum); spiracle present; heterocercal tail (upper lobe larger than lower). Examples: dogfish (*Scyliorhinus*), sharks, stingrays.

Class Osteichthyes (bony fish): skeleton of bone; skin covered in overlapping bony scales (cycloid or ctenoid); swim bladder for buoyancy control; gill slits covered by a bony operculum; lateral line system for detecting vibrations; homocercal tail (symmetrical). This is the largest



class of vertebrates. Important Nigerian examples: Tilapia (Nile tilapia; widely farmed), Clarias (African catfish; important food fish; has accessory air-breathing organs; no scales), Heterotis (elephant snout fish), mackerel, herrings. Identifying feature of bony fish: bony operculum covering the gills.

Fill in the blank: Class Osteichthyes (bony fish) is identified by a bony _____ covering the gill slits; bony scales; and a swim bladder for buoyancy; this is the largest class of vertebrates.

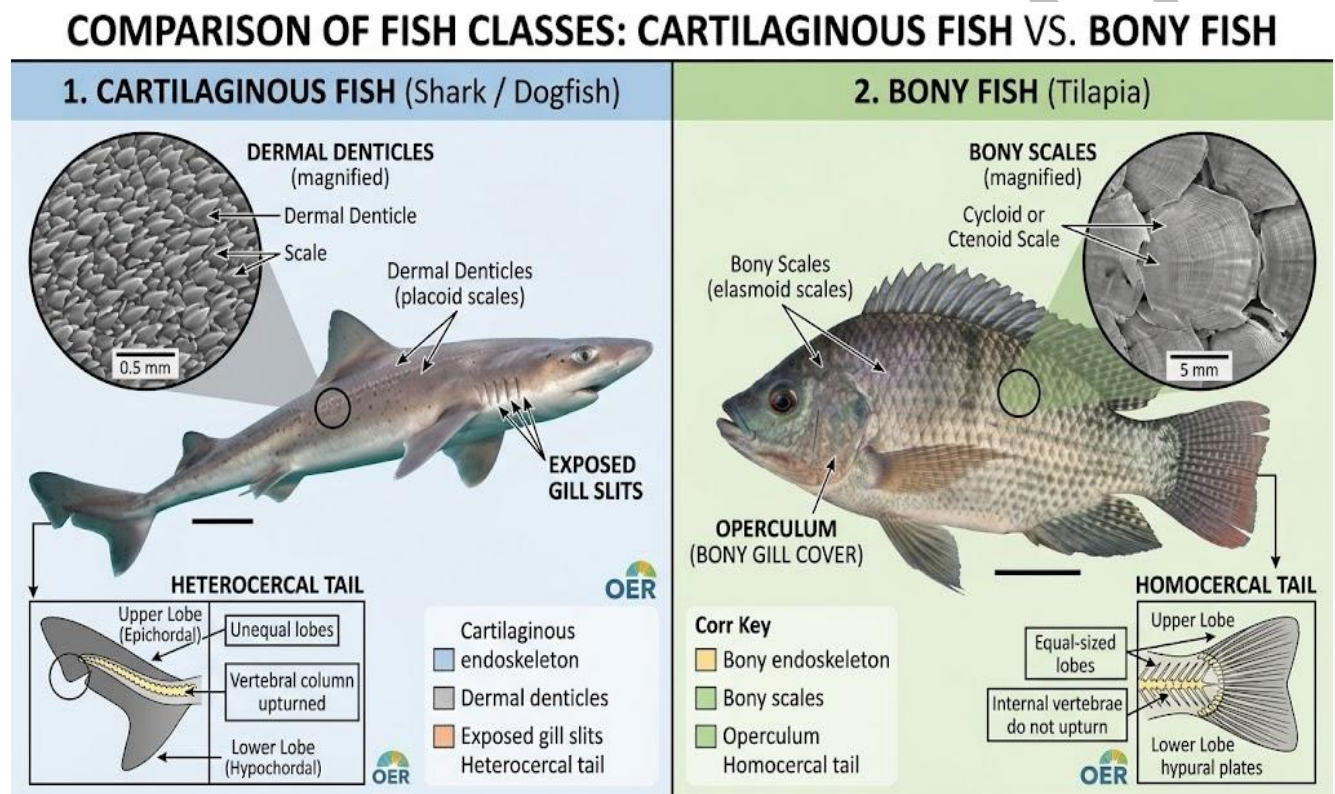


Figure 5.3: Photographs and diagrams of cartilaginous and bony fish

5.2.2 Amphibia and Reptilia

Class Amphibia (frogs, toads, salamanders, newts, caecilians): the first vertebrates to colonise land; ectothermic; moist, smooth, glandular skin (no scales); rely on moist skin and simple lungs for gas exchange; most undergo metamorphosis; eggs laid in water without a shell; fertilisation usually external. Identifying features of a frog (*Rana*): moist smooth skin; prominent bulging eyes; tympanic membrane (eardrum) behind the eye; no neck; webbed hind feet; no tail in adult.



Nigerian examples: *Xenopus laevis* (clawed frog), *Bufo* (toad; has dry warty skin), *Phrynobatrachus* (puddle frog).

Class Reptilia (lizards, snakes, crocodilians, turtles): ectothermic; dry, scaly skin (keratin scales prevent water loss); amniote egg (internal membranes allow land reproduction); no metamorphosis; fertilisation internal. Identifying features: dry scaly skin; no moist glands; claws on toes (in most); ear opening usually visible. Nigerian reptiles: *Agama agama* (rainbow lizard; males have blue-green head and orange body); *Naja* (cobra); *Python sebae* (African rock python); *Crocodylus niloticus* (Nile crocodile); *Testudo* (tortoise). Key distinction from amphibians: dry scales vs moist smooth skin; amniote egg vs water-dependent egg.

Fill in the blank: Amphibians are distinguished from reptiles by their _____, smooth, glandular skin (no scales) and their dependence on water for egg-laying; reptiles have dry scaly skin and lay amniote eggs on land.

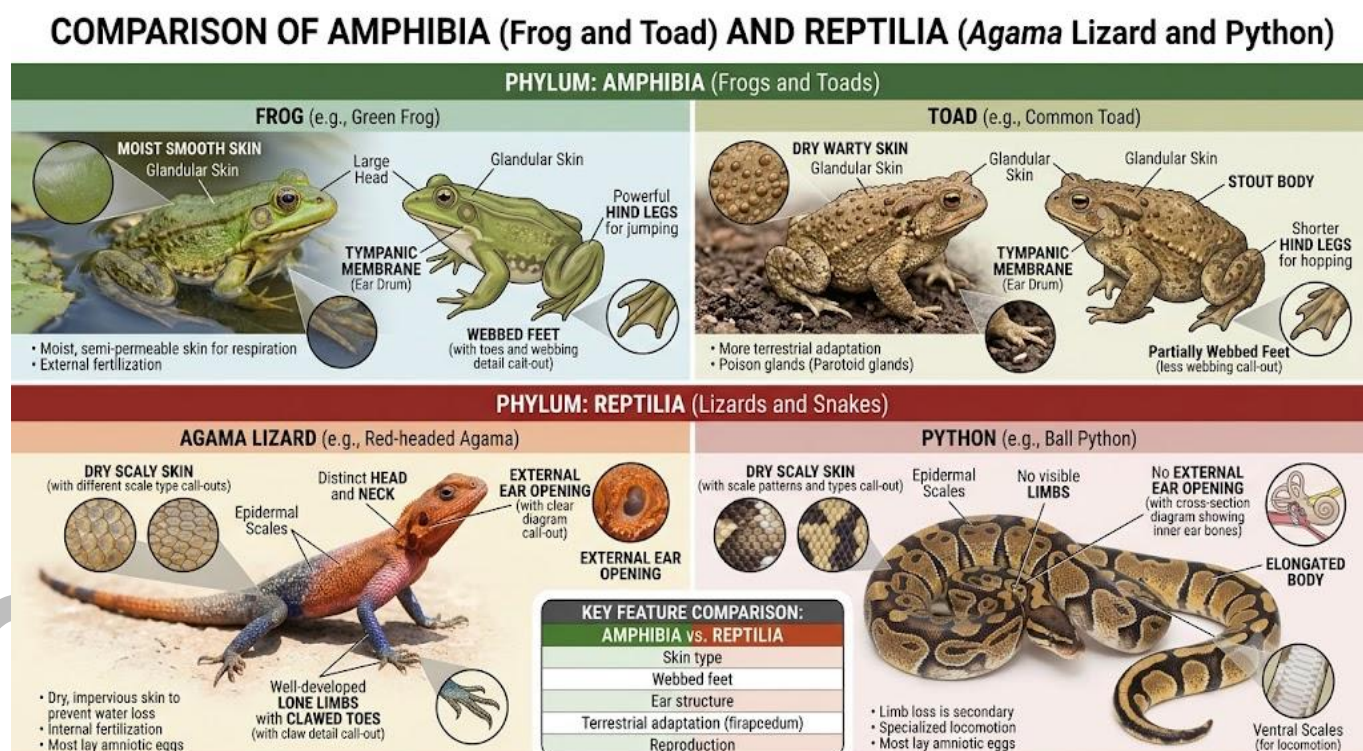


Figure 5.4: Photographs of Amphibia and Reptilia with identifying features labelled



5.2.3 Aves and Mammalia

Class Aves (birds): endothermic; body covered with feathers; forelimbs modified into wings; hollow bones to reduce weight; beak (bill) with no teeth; lay hard-shelled amniote eggs; four-chambered heart; high metabolic rate. Identifying features: feathers (unique to birds); wings; beak; scaled legs; warm-blooded. Nigerian birds: *Struthio camelus* (ostrich; farmed); *Numida meleagris* (helmeted guinea fowl; widespread); *Columba* (pigeon); *Ploceus* (weaver bird; characteristic woven nests); various raptors (*Aquila* eagle, *Buteo* buzzard).

Class Mammalia (mammals): endothermic; body covered with hair or fur; mammary glands producing milk to nourish young; most are viviparous (give birth to live young); four-chambered heart; diaphragm for breathing; three middle ear ossicles (malleus, incus, stapes); dentition varied and specialised. Identifying features: hair or fur; external pinnae (ear flaps) in most; usually viviparous; suckle young. Nigerian mammals: *Bos* (cattle); *Ovis* (sheep); *Capra* (goat); *Sus* (pig); *Oryctolagus* (rabbit); *Homo sapiens*; primates (chimpanzee *Pan troglodytes*, baboon *Papio*). Key distinction between birds and mammals: feathers vs hair; eggs vs live young (in most); beak vs teeth.

Fill in the blank: Mammals are uniquely identified by the presence of _____ glands that produce milk to nourish young; they also have hair or fur and three middle ear ossicles (malleus, incus, stapes).



NIGERIAN ANIMAL PROFILES: AVES AND MAMMALIA



Figure 5.5: Photographs of Aves and Mammalia with identifying features labelled

Pilot questions 5.2

1. State three differences between cartilaginous fish and bony fish.
2. State four identifying features of Class Amphibia.
3. Distinguish between amphibians and reptiles based on skin, egg, and gas exchange.
4. State five identifying features of Class Aves.
5. State five features that uniquely identify mammals.

5.3 Practical Specimen Examination and Keys

5.3.1 Use of dichotomous identification keys

A dichotomous key is a tool for identifying an unknown organism by presenting a series of pairs of contrasting statements (couplets). At each couplet, the user selects the statement that matches the specimen and is directed to the next couplet or to the identification. The key proceeds from



the broadest distinguishing features to the most specific. Each couplet must present two mutually exclusive alternatives. Well-written keys use features that are easy to observe and measure, avoid ambiguous terms, and cover all possible specimens in the intended scope.

To use a key: (1) begin at couplet 1; (2) read both alternatives carefully; (3) choose the statement that matches the specimen and note the number or name it directs you to; (4) proceed to that couplet and repeat; (5) continue until the key gives a name rather than a couplet number. Verify the identification by reading a full description of the named taxon and checking all features match the specimen. If the specimen does not match, retrace steps to find where the wrong choice was made. Keys work best when the specimen is in good condition and all features are visible.

Fill in the blank: A _____ key presents a series of pairs of contrasting statements (couplets); at each step the observer selects the statement that matches the specimen and is directed to the next couplet or to the identification.

<u>Couplet</u>	<u>Feature Observed</u>	<u>Go To/Identify</u>
1a. Body covered with feathers	Warm-blooded, forelimbs modified as wings	<u>Aves</u>
1b. Body not covered with feathers	—	Go to 2
2a. Body covered with hair/fur, mammary glands present	Warm-blooded	<u>Mammalia</u>
2b. Body not covered with hair/fur	—	Go to 3
3a. Skin moist, smooth, no scales; can live both in water and on land	Cold-blooded	<u>Amphibia</u>
3b. Skin dry, covered with scales	Cold-blooded	<u>Reptilia</u>
4a. Body covered with scales, lives in water, skeleton cartilaginous	Cold-blooded	<u>Chondrichthyes</u> (cartilaginous fishes like sharks)



4b. Body covered with scales, lives in water, skeleton bony	Cold-blooded	<u>Osteichthyes</u> (bony fishes like tilapia)
--	--------------	--

Box 5.1: A simple dichotomous key to the six vertebrate classes

5.3.2 Drawing biological specimens

Accurate biological drawing is a core practical skill. Rules for biological drawings: use a sharp HB or 2H pencil; draw on plain (unlined) white paper; use a single unbroken line (no shading with hatching; stippling may be used for texture); draw the specimen large enough to fill most of the available space; maintain correct proportions (use actual measurements if possible); do not draw artistic shadows or highlights. Label lines should be horizontal, drawn with a ruler, and should not cross each other; the label should be at the end of the line, not alongside it.

Every biological drawing must include: a title (the common and scientific name of the specimen, the view, and the type of preparation, e.g. "External features of *Lumbricus terrestris* (earthworm), dorsal view, preserved specimen"); magnification or scale (e.g. "x1.5" or a scale bar); labels for all visible structures using correct anatomical terms. The drawing should represent what is actually seen, not what is expected to be seen. If a structure is not visible on the specimen, it should not be drawn. Drawings are assessed on accuracy, proportion, labelling, and presentation.

Fill in the blank: Biological drawings must include a _____, magnification or scale bar, and labels for all visible structures; shading by hatching is not used; stippling may be used to indicate texture.



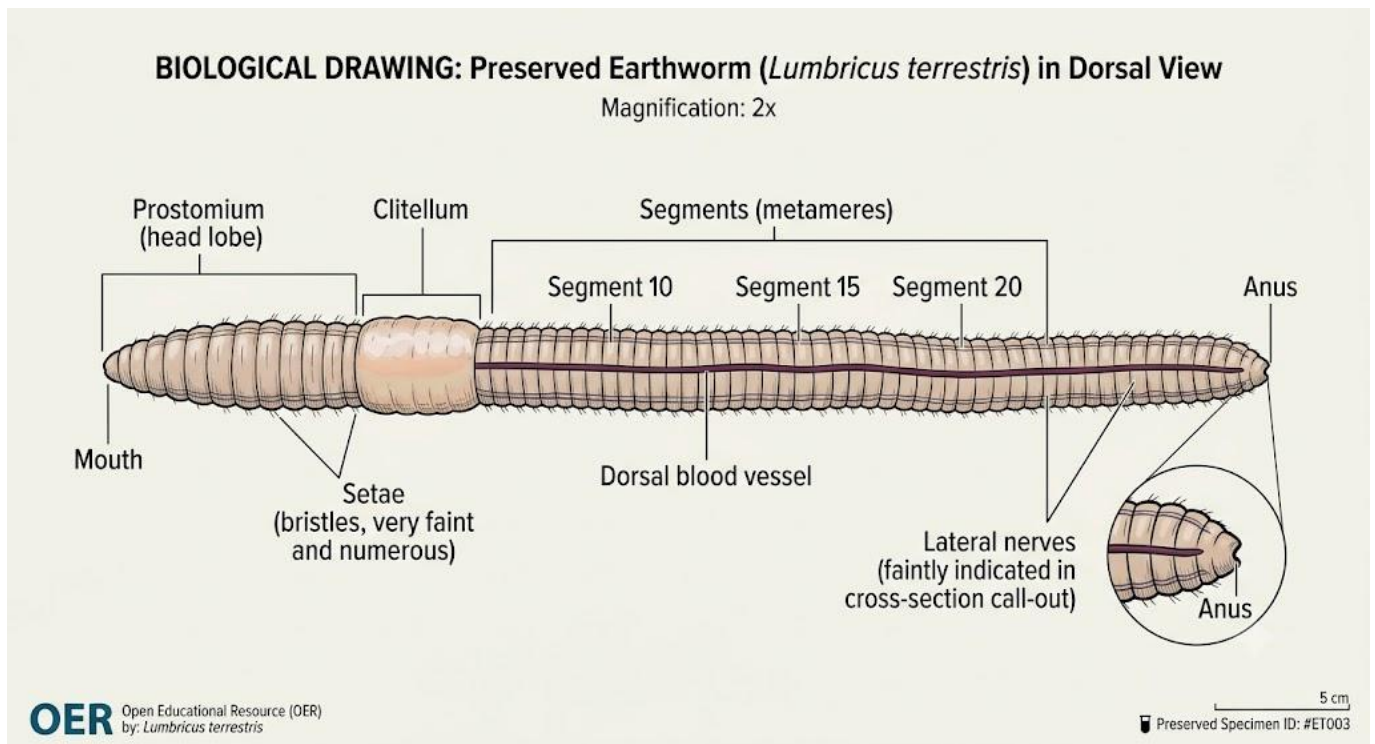


Figure 5.6: Example of a well-executed biological drawing of an earthworm

5.3.3 Writing systematic descriptions of specimens

A systematic external description presents the observable features of a specimen in a logical, standardised order, allowing another person to identify the same specimen from the description alone. For an animal specimen, the standard order is: (1) General form: overall body shape, symmetry, and size; (2) Body regions: number and names of major body divisions; (3) Appendages: type, number, and position; (4) Integument: covering (skin, scales, feathers, hair, cuticle); (5) Sense organs: eyes, antennae, ears; (6) Openings: mouth, anus, spiracles; (7) Distinctive features: colour, markings, special structures.

Example systematic description of a preserved cockroach (*Periplaneta americana*): (1) General form: bilaterally symmetrical; dorsoventrally flattened body; approximately 35 to 45 mm in length; brown in colour. (2) Body regions: three: head, thorax, and abdomen. (3) Appendages: three pairs of jointed legs (one pair per thoracic segment); two pairs of wings (tegmina and hindwings, folded over abdomen); two long multi-segmented antennae on the head; pair of cerci at the posterior end of the abdomen. (4) Integument: tough exoskeleton of chitin; brown and



shiny. (5) Sense organs: two large compound eyes; antennae. (6) Openings: mouth ventrally on the head; anus at the posterior tip.

Fill in the blank: A systematic external description of an animal specimen should be presented in the standard order: general form, body _____, appendages, integument, sense organs, and distinctive features.

GUIDE TO ANIMAL KINGDOM IDENTIFICATION: PRACTICAL SPECIMENS



Figure 5.7: Photographs of preserved specimens used in animal kingdom identification practicals

Pilot questions 5.3

1. Explain how to use a dichotomous key to identify an unknown specimen.
2. State five rules for making a biological drawing.
3. State what information must appear on every biological drawing.
4. Write a systematic external description of a preserved frog.
5. Write a systematic external description of a cockroach.



Series Summary

This final Series surveyed the major groups of the animal kingdom and the practical skills for their identification. Eight invertebrate phyla were covered, each characterised by a distinctive combination of body plan features: Porifera by porosity and asymmetry, Cnidaria by radial symmetry and stinging cnidocytes, Platyhelminthes by a flattened acoelomate body, Annelida by segmentation and a true coelom, Nematoda by a pseudocoelomate cylindrical form, Mollusca by a soft body with mantle and radula across three classes, Arthropoda by a chitinous exoskeleton and jointed appendages across four classes, and Echinodermata by spiny skin and a water vascular system in exclusively marine, radially symmetrical adults.

The six vertebrate classes were then distinguished by their skeletal composition, integument, reproductive strategy, and thermoregulatory status: from the cartilaginous Chondrichthyes and bony Osteichthyes of the fishes through the moist-skinned metamorphosing Amphibia, the scale-bearing amniote Reptilia, and the feathered endothermic Aves, to the Mammalia defined by hair, mammary glands, endothermy, and three middle ear ossicles. The Series integrated these taxonomic concepts with three practical identification skills: working through a dichotomous key systematically by reading both couplet options before choosing, producing correctly executed biological drawings in pencil with titles, scale bars, and labels, and applying a structured descriptive approach covering body form, regions, appendages, integument, sense organs, and openings.

Glossary of Terms

- **Acoelomate:** an animal without a true body cavity; the space between the body wall and gut is filled with mesenchyme (parenchyma cells); e.g. flatworms (Platyhelminthes).
- **Arachnida:** a class of arthropods with two body regions (cephalothorax and abdomen), four pairs of legs, chelicerae, and no antennae; includes spiders, scorpions, mites, and ticks.
- **Bilateral symmetry:** a body plan in which the body can be divided into two mirror-image halves along a single plane; characteristic of most animals above Cnidaria.



- **Bivalvia:** a class of Mollusca with two hinged shells (valves), no radula, and a filter-feeding lifestyle; includes clams, oysters, and mussels.
- **Cephalopoda:** a class of Mollusca with a well-developed head surrounded by tentacles, no external shell (or a reduced internal one), and the most advanced brain of all invertebrates; includes squid, octopus, and cuttlefish.
- **Chaetae (setae):** chitinous bristles on annelid body segments; assist in locomotion; absent from leeches; few in Oligochaeta; many in Polychaeta.
- **Chilopoda:** a class of arthropods (centipedes) with one pair of legs per body segment, one pair of antennae, and venomous forcipules on the first body segment.
- **Chondrichthyes:** cartilaginous fish; skeleton of cartilage; skin with dermal denticles; no swim bladder; exposed gill slits; heterocercal tail; examples: sharks, rays.
- **Clitellum:** a thickened, saddle-shaped ring of segments on the body of oligochaete annelids (earthworms); secretes a mucus cocoon for egg deposition; indicates sexual maturity.
- **Cnidocyte:** a stinging cell unique to Cnidaria; contains a nematocyst; used to capture prey and for defence.
- **Crustacea:** a class of arthropods with two pairs of antennae, a cephalothorax, and gills; mostly aquatic; includes crabs, shrimps, and crayfish.
- **Dermal denticles (placoid scales):** tooth-like scales covering the skin of cartilaginous fish; give a sandpaper texture; composed of dentine and enamel.
- **Dichotomous key:** an identification tool presenting a series of couplets of contrasting statements; at each step the user selects the matching option and proceeds to the next couplet until the organism is identified.
- **Echinodermata:** a phylum of exclusively marine invertebrates with spiny skin, radial symmetry in adults, and a water vascular system operating tube feet; includes sea stars, sea urchins, and sea cucumbers.
- **Ectothermic:** an animal that regulates body temperature primarily through behaviour and environmental heat sources, not internal metabolism; includes fish, amphibians, and reptiles.



- **Endothermic:** an animal that maintains a constant body temperature through internal metabolic heat production; includes birds and mammals.
- **Gastropoda:** a class of Mollusca characterised by a single (often coiled) shell, a muscular foot for locomotion, and a radula; includes snails and slugs.
- **Heterocercal tail:** a fish tail in which the vertebral column extends into the larger upper lobe; characteristic of cartilaginous fish (sharks).
- **Homocercal tail:** a fish tail with two symmetrical lobes; the vertebral column does not extend into the tail fin; characteristic of most bony fish.
- **Insecta:** the largest class of arthropods; three body regions (head, thorax, abdomen); three pairs of legs on thorax; one pair of antennae; often winged.
- **Mammalia:** a class of endothermic vertebrates with hair or fur, mammary glands producing milk, and usually viviparity; three middle ear ossicles (malleus, incus, stapes).
- **Mantle:** a fold of tissue in molluscs that secretes the shell and encloses the visceral mass; lines the mantle cavity in which gills or lungs are located.
- **Nematocyst:** a coiled, barbed, hollow thread inside a cnidocyte; fired on contact to inject venom into prey or predators.
- **Operculum:** a bony cover over the gill slits in bony fish; its presence is the single most reliable feature distinguishing Osteichthyes from Chondrichthyes externally.
- **Osteichthyes:** bony fish; skeleton of bone; scales of bone (cycloid or ctenoid); swim bladder; operculum; homocercal tail; lateral line.
- **Ostium (plural: ostia):** a pore in the body wall of a sponge through which water enters the body; part of the water filtration system of Porifera.
- **Pseudocoelom:** a body cavity that is not fully lined by mesoderm; found in Nematoda; provides a hydrostatic skeleton.
- **Radula:** a rasping, tongue-like feeding organ in most molluscs (absent in Bivalvia); used to scrape food from surfaces.
- **Spiracle:** in cartilaginous fish, a modified gill slit behind the eye used for water intake when resting on the sea bottom; in insects, an opening in the cuticle leading to the tracheal system.



- **Strobila:** the chain of proglottids (segments) that make up the body of a tapeworm; each proglottid is a self-contained reproductive unit.
- **Water vascular system:** a hydraulic system in echinoderms consisting of fluid-filled canals connected to tube feet; used for locomotion, feeding, and gas exchange.



Concept Check Questions [Series 5]

Objective Questions

1. Members of Phylum Cnidaria possess stinging cells called _____ used to capture prey; they exist as sessile polyps and free-swimming medusae. (Linked to SLO 5.1)
2. Phylum Annelida is identified by body _____ (metameres) visible as rings; the earthworm (*Lumbricus*) is the most examined annelid in practical classes. (Linked to SLO 5.1)
3. Insects are identified by three pairs of legs on the thorax, three body regions, and one pair of _____; they are distinguished from arachnids which have four pairs of legs and no antennae. (Linked to SLO 5.1)
4. Class Osteichthyes (bony fish) is identified by a bony _____ covering the gill slits and bony scales; it has a swim bladder for buoyancy. (Linked to SLO 5.2)
5. Mammals are uniquely identified by the presence of _____ glands producing milk; they also have hair or fur and three middle ear ossicles. (Linked to SLO 5.2)

Short-Answer Questions

1. State three differences between cartilaginous fish and bony fish. (Linked to SLO 5.2)
2. Distinguish between amphibians and reptiles based on skin, egg, and body temperature regulation. (Linked to SLO 5.2)
3. State five identifying features of Class Aves. (Linked to SLO 5.2)
4. State five rules for making a biological drawing. (Linked to SLO 5.4)
5. Explain how to use a dichotomous key to identify an unknown specimen. (Linked to SLO 5.3)

Long-Answer Questions

1. Describe the identifying features of the eight major invertebrate phyla: Porifera, Cnidaria, Platyhelminthes, Annelida, Nematoda, Mollusca, Arthropoda, and Echinodermata. Give one Nigerian example for each. (Linked to SLO 5.1)
2. Describe the identifying features of the six vertebrate classes and state the key differences between cartilaginous and bony fish, amphibians and reptiles, and birds and mammals. (Linked to SLO 5.2)



3. Explain how to use a dichotomous key to identify a vertebrate specimen; state the rules for biological drawing; and write a systematic external description of a cockroach and a frog.
(Linked to SLOs 5.3, 5.4, 5.5)

Answers to Concept Check Questions [Series 5]

Objective Questions

1. Cnidocytes.
2. Segments.
3. Antennae.
4. Operculum.
5. Mammary.

Short-Answer Questions

1. Cartilaginous fish: cartilage skeleton; dermal denticles (sandpaper skin); gill slits exposed (no operculum); no swim bladder; heterocercal tail. Bony fish: bone skeleton; bony scales; operculum covering gills; swim bladder; homocercal tail.
2. Skin: amphibians have moist smooth glandular skin; reptiles have dry keratinised scales. Egg: amphibians lay unshelled eggs in water; reptiles lay amniote eggs on land. Temperature: both ectothermic, but reptiles tolerate drier environments because their skin and eggs prevent water loss.
3. Body covered with feathers (unique to birds); forelimbs modified into wings; beak with no teeth; hollow bones; endothermic (warm-blooded); lay hard-shelled amniote eggs.
4. Use a sharp pencil (HB or 2H); draw with a single unbroken line; no shading by hatching; maintain correct proportions; draw large enough to fill most of the space; use horizontal label lines that do not cross.
5. Begin at couplet 1; read both alternatives carefully; select the statement that matches the specimen; go to the directed couplet number; repeat until the key gives a name; verify the identification against a full description.



Long-Answer Questions

1. Porifera (sponges): porous body (ostia and osculum); no true tissues; sessile; asymmetrical or radial; Nigerian freshwater sponges on submerged rocks. Cnidaria: radial symmetry; cnidocytes with nematocysts; two body layers; polyp and medusa forms; e.g. Hydra (freshwater). Platyhelminthes: bilaterally symmetrical; flat, acoelomate; parasitic and free-living; e.g. Schistosoma (blood fluke; bilharzia in Nigeria). Annelida: bilaterally symmetrical; segmented; true coelom; chaetae; e.g. Lumbricus (earthworm). Nematoda: cylindrical; non-segmented; pseudocoelomate; tapered ends; thrashing movement; e.g. Ascaris lumbricoides (intestinal roundworm). Mollusca: soft body; mantle; radula; three classes (Gastropoda: snails e.g. Achatina africana; Bivalvia: clams, oysters; Cephalopoda: squids, octopus). Arthropoda: chitin exoskeleton; jointed appendages; segmented; moult for growth; four classes (Insecta: three body regions, three pairs of legs, one pair antennae, e.g. cockroach; Arachnida: four pairs of legs, no antennae, e.g. scorpion; Crustacea: two pairs antennae, e.g. freshwater prawn Macrobrachium; Chilopoda: one leg pair per segment, e.g. centipede). Echinodermata: radial symmetry in adults; spiny skin; water vascular system with tube feet; exclusively marine; e.g. sea star, sea urchin.
2. Chondrichthyes: cartilage skeleton; dermal denticles; exposed gill slits (no operculum); no swim bladder; heterocercal tail; e.g. dogfish, shark. Osteichthyes: bone skeleton; bony scales; operculum; swim bladder; lateral line; homocercal tail; e.g. Tilapia, Clarias. Amphibia: moist smooth glandular skin; metamorphosis; external fertilisation; unshelled eggs in water; simple lungs and moist skin for gas exchange; ectothermic; e.g. frogs, toads. Reptilia: dry keratinised scaly skin; amniote eggs laid on land; internal fertilisation; no metamorphosis; ectothermic; e.g. Agama lizard, python, crocodile. Key amphibian vs reptile differences: skin (moist smooth vs dry scaly); egg (unshelled aquatic vs shelled amniote); gas exchange (lungs and skin vs lungs only). Aves: feathers unique to birds; wings (modified forelimbs); beak (no teeth); hollow bones; endothermic; four-chambered heart; hard-shelled amniote eggs; e.g. guinea fowl, eagle. Mammalia: hair or fur; mammary glands producing milk; mostly viviparous; endothermic; four-chambered heart; diaphragm; three middle ear ossicles; diverse dentition; e.g. goat, rabbit, human. Key bird vs mammal differences: feathers vs hair; eggs vs live young (mostly); beak vs teeth.
3. Dichotomous key use: start at couplet 1; read both alternatives of the pair; choose the one that matches the specimen's observable feature; go to the directed couplet; repeat until a name is given; verify by checking the full description. Biological drawing rules: (1) use a sharp pencil



(HB or 2H); (2) draw with a single unbroken line; (3) no shading by hatching (stippling for texture only); (4) maintain correct proportions relative to the actual specimen; (5) draw large, filling most of the available space; (6) use horizontal ruled label lines that do not cross each other; (7) include title (common name, scientific name, view, preparation type), magnification or scale bar, and labels for all visible structures. Systematic description of a cockroach (*Periplaneta americana*): (1) General form: bilaterally symmetrical; dorsoventrally flattened; approximately 35-45 mm long; brown and shiny. (2) Body regions: three regions: head, thorax (prothorax, mesothorax, metathorax), abdomen (10 visible segments). (3) Appendages: three pairs of jointed legs (one on each thoracic segment); two pairs of wings (outer tegmina leathery, inner hindwings membranous, folded under tegmina); two long multi-segmented antennae on head; pair of cerci at posterior end. (4) Integument: hard exoskeleton of chitin; brown. (5) Sense organs: two compound eyes; antennae (chemo and mechanoreceptors). (6) Openings: mouth ventrally on head (mandibles, labrum, labium visible); spiracles on thorax and abdomen for gas exchange; anus at posterior tip. Systematic description of a frog (*Rana*): (1) General form: bilaterally symmetrical; compact body; 4-10 cm long; no neck; green-brown with dark mottling. (2) Body regions: head and trunk (no separate neck); no tail in adult. (3) Appendages: four limbs; forelimbs short with four unwebbed digits; hindlimbs long and muscular with five webbed digits (for swimming and jumping). (4) Integument: moist, smooth, glandular skin; no scales; permeable to water and gases. (5) Sense organs: two prominent bulging eyes with horizontal pupils; tympanic membrane (eardrum) behind each eye; two nostrils. (6) Openings: wide terminal mouth; nostrils (external nares); cloaca (single posterior opening for reproductive, excretory, and digestive products).

Answers to Pilot Questions [Series 5]

Part 5.1

1. Three identifying features of Phylum Porifera: (1) body perforated by numerous pores (ostia) through which water enters and a single large opening (osculum) through which filtered water exits; (2) no true tissues or organs (the simplest level of multicellular organisation, between a colonial organism and a tissue-grade animal); (3) sessile (permanently attached to a



- substrate); body asymmetrical or at most radially symmetrical; supported by a skeleton of spicules (calcium carbonate or silica) or spongin fibres.
2. A cnidarian polyp is the sessile, attached form: it is cylindrical with the mouth and tentacles directed upward; the base is attached to a substrate; polyps are typically colonial (in corals) or solitary (in Hydra and sea anemones). A medusa is the free-swimming, pelagic form: it is bell-shaped or umbrella-shaped with the mouth directed downward and tentacles hanging from the bell margin; it is usually the sexual reproductive form. Both forms have radial symmetry, cnidocytes on their tentacles, two body layers (ectoderm and endoderm) separated by mesoglea, and a single opening serving as both mouth and anus.
 3. Four identifying features of Phylum Annelida: (1) body divided into repeated segments (metameres) visible externally as a series of rings along the body; internally the segments are separated by transverse walls called septa; (2) true coelom (a fluid-filled body cavity completely lined by mesoderm; the coelomic fluid acts as a hydrostatic skeleton for locomotion); (3) chaetae (setae; chitinous bristles on most segments that anchor the worm to the substrate during peristaltic movement; absent from leeches); (4) a well-developed closed circulatory system with dorsal and ventral blood vessels; blood contains haemoglobin dissolved in the plasma (not in cells in earthworms).
 4. Three classes of Mollusca: (1) Gastropoda (snails and slugs): single shell (usually coiled); muscular foot for crawling; head with eyes and tentacles; radula for rasping food; e.g. *Achatina africana* (giant African land snail). (2) Bivalvia (clams, oysters, mussels): two hinged shells (valves); no radula; no distinct head; filter feeders using siphons to draw water over gills; laterally compressed body; e.g. *Ostrea* (oyster). (3) Cephalopoda (squid, octopus, cuttlefish, nautilus): head surrounded by tentacles bearing suckers; no external shell (or reduced internal shell); well-developed eyes similar to vertebrate eyes; the most intelligent invertebrates; e.g. *Sepia* (cuttlefish), *Octopus*.
 5. Insects vs arachnids: (1) Legs: insects have three pairs of legs (six legs total) attached to the thorax; arachnids have four pairs of legs (eight legs total) attached to the cephalothorax. (2) Body regions: insects have three distinct regions (head, thorax, abdomen); arachnids have two regions (cephalothorax fused head and thorax, and abdomen). (3) Antennae: insects have one pair of antennae on the head; arachnids have no antennae. (4) Wings: most insects have one or two pairs of wings (though some are secondarily wingless); arachnids never have wings.



Part 5.2

1. Skeleton: cartilaginous fish have a skeleton entirely of cartilage (no bone); bony fish have a skeleton partly or entirely of bone. (2) Skin covering: cartilaginous fish have dermal denticles (placoid scales; tooth-like; give sandpaper texture); bony fish have overlapping bony scales (cycloid or ctenoid; smooth or comb-edged). (3) Gill covering: cartilaginous fish have separate exposed gill slits on the side of the head (no operculum); bony fish have a single bony operculum covering all gill slits on each side.
2. Skin: amphibians have moist, smooth, glandular skin with no scales; it is permeable to water and gases and used for cutaneous gas exchange; reptiles have dry, keratinised, scaly skin (keratin scales) that is impermeable to water, preventing desiccation on land. Egg: amphibians lay unshelled, gelatinous eggs in water (or moist environments) because the embryo has no waterproof membrane and must remain moist; reptiles lay amniote eggs with extraembryonic membranes (amnion, chorion, allantois) and a leathery or calcareous shell that prevent water loss, allowing reproduction entirely on land. Body temperature: both groups are ectothermic (cannot generate significant metabolic heat); reptiles are better adapted to drier terrestrial conditions because their waterproof skin reduces water loss.
3. Five identifying features of Class Aves: (1) body covered with feathers (unique to birds among all animals; serves for insulation, flight, and display); (2) forelimbs modified into wings (used for flight in most species, though some birds are secondarily flightless e.g. ostrich, penguin); (3) beak (bill) with no teeth (the beak is covered in a horny keratin rhamphotheca); (4) hollow bones (pneumatized long bones reduce weight for flight); (5) endothermic (maintain a constant high body temperature of approximately 40 to 42 degrees Celsius through internal metabolic heat).
4. Five unique features of mammals: (1) mammary glands: all female mammals have mammary glands that produce milk to nourish offspring after birth; this is the defining feature of Class Mammalia; (2) hair or fur: all mammals have hair at some stage of their life cycle; hair provides thermal insulation, camouflage, and sensory function (vibrissae/whiskers); (3) viviparity (in most): most mammals give birth to live young (exceptions: monotremes such as platypus and echidna, which lay eggs); (4) endothermic: mammals maintain a constant body temperature (approximately 36 to 38 degrees Celsius in most species) by metabolic heat production; (5) three middle ear ossicles (malleus, incus, stapes): a unique feature of mammals; derived evolutionarily from the jaw bones of cynodont reptiles; transmit vibrations from the eardrum to the cochlea and account for the acute hearing of mammals.



Part 5.3

1. How to use a dichotomous key: (1) Examine the specimen carefully before starting; note the major external features (body symmetry, body regions, appendages, covering, sense organs). (2) Begin at couplet 1; read both alternative statements of the pair completely before deciding. (3) Select the statement that most accurately matches the specimen's features and note the number or name it directs you to. (4) Proceed to the directed couplet number and again read both alternatives of the new couplet. (5) Continue this process step by step until the key directs you to a name (taxon name) rather than another couplet number. (6) Verify the identification: look up a full description or illustration of the named taxon and confirm that all features of your specimen match. If they do not match, go back through the key to find where the incorrect choice was made.
2. Five rules for biological drawing: (1) use a sharp pencil (HB or 2H); never use a pen, coloured pencil, or felt-tip for line work; (2) draw with a single unbroken pencil line representing each structure; never draw double lines, scribble, or sketch with multiple overlapping strokes; (3) no shading by hatching, cross-hatching, or pencil smudging; stippling (series of fine dots) is the only acceptable method for showing texture or density differences; (4) draw the specimen large, filling the majority of the available space (a small drawing loses detail and is difficult to label clearly); (5) maintain correct proportions (the relative sizes of different parts must match the actual specimen; measure with a ruler if necessary and calculate the required magnification).
3. Every biological drawing must include: (1) a title below the drawing stating the common name and the scientific name (genus and species in italics or underlined), the view (e.g. dorsal, lateral, ventral), and the type of preparation (e.g. preserved specimen, live specimen, whole mount, T.S.); (2) magnification or scale (either a magnification factor such as "x2" calculated from the drawing size divided by the actual specimen size, or a scale bar of known length drawn next to the specimen); (3) labels for all visible and identifiable structures, written in pencil, using correct anatomical terminology (not everyday descriptions), connected to the structure by a straight, horizontal, ruled line that does not cross any other label line.
4. Systematic external description of a preserved frog (*Rana* sp.): (1) General form: bilaterally symmetrical; compact body without a neck; approximately 5 to 9 cm in total length (head-body; no tail); green to brown dorsal surface with dark irregular mottling; paler, yellowish or cream ventral surface. (2) Body regions: two main regions: head (blunt-snouted; wide) and



trunk (robust; no visible separation from head at the neck); no tail in adult. (3) Appendages: four limbs; forelimbs short (approximately one-third the length of hindlimbs) with four smooth unwebbed digits; hindlimbs long, muscular, adapted for jumping and swimming, with five webbed digits. (4) Integument: moist, smooth, glandular skin; no scales or hair; skin permeable to water and gases for cutaneous respiration. (5) Sense organs: two large, prominent, bulging eyes with horizontal elliptical pupils; tympanic membrane (circular, flat, eardrum) visible on each side of the head posterior to the eye; two small circular external nostrils (nares) near the tip of the snout. (6) Openings: wide, terminal mouth; external nares as above; cloaca (combined reproductive, excretory, and digestive opening) at the posterior end of the trunk.

5. Systematic external description of a cockroach (*Periplaneta americana*): (1) General form: bilaterally symmetrical; dorsoventrally flattened (oval in dorsal view); approximately 35 to 45 mm in total body length; uniformly brown to dark reddish-brown and shiny. (2) Body regions: three distinct regions: head (small, triangular, directed downward/hypognathous); thorax (divided into prothorax, mesothorax, and metathorax; each bearing one pair of appendages); abdomen (elongated; 10 visible segments). (3) Appendages: one pair of long, slender, multi-segmented antennae arising from the head (as long as or longer than the body); two pairs of wings (the outer pair are leathery tegmina, folded over the abdomen at rest; the inner pair are membranous hindwings folded beneath the tegmina; both pairs are present in adults of both sexes though flight is rare); three pairs of jointed legs (one pair per thoracic segment; each leg bears claws and adhesive pads for climbing); a pair of short, multi-segmented cerci projecting from the posterior end of the abdomen. (4) Integument: hard, shiny exoskeleton composed of chitin; brown; articulated at segment joints for flexibility. (5) Sense organs: two compound eyes (large, kidney-shaped, one on each side of the head); antennae (chemoreceptors and mechanoreceptors); cerci (mechanoreceptors detecting air currents). (6) Openings: mouth ventrally on the head, surrounded by mandibles (for biting), labrum (upper lip), labium (lower lip), and maxillae (accessory mouthparts); ten pairs of spiracles (small oval openings in the cuticle of the thorax and abdomen; lead to the tracheal respiratory system); anus at the posterior end of the abdomen.



References and Attributions [Series 5]

Textual References (Books and External Sources)

- Hickman, C. P., Roberts, L. S., Keen, S. L., Larson, A., & Eisenhour, D. J. (2011). Animal diversity (6th ed.). McGraw-Hill.
- Ruppert, E. E., Fox, R. S., & Barnes, R. D. (2004). Invertebrate zoology: A functional evolutionary approach (7th ed.). Brooks/Cole.
- Kardong, K. V. (2012). Vertebrates: Comparative anatomy, function, evolution (6th ed.). McGraw-Hill.
- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 5.1: Porifera, Cnidaria, and Platyhelminthes photographs and diagrams Attribution: AI generated. Suggested OER search string: "Porifera sponge Cnidaria Hydra jellyfish Platyhelminthes planarian tapeworm photographs labelled OER".
- Figure 5.2: Annelida, Nematoda, and Mollusca photographs and diagrams Attribution: AI generated. Suggested OER search string: "Annelida earthworm Nematoda Ascaris Mollusca Achatina land snail bivalve cephalopod photographs labelled OER".
- Figure 5.3: Cartilaginous and bony fish comparison photographs Attribution: AI generated. Suggested OER search string: "cartilaginous fish shark dogfish bony fish Tilapia comparison photographs labelled operculum gill slits OER".
- Figure 5.4: Amphibia and Reptilia photographs Attribution: AI generated. Suggested OER search string: "Amphibia frog toad Reptilia lizard Agama python photographs labelled identifying features OER".
- Figure 5.5: Aves and Mammalia photographs Attribution: AI generated. Suggested OER search string: "Aves bird guinea fowl Mammalia mammal goat rabbit feathers fur mammary glands photographs labelled OER".
- Figure 5.6: Example biological drawing of earthworm Attribution: AI generated. Suggested OER search string: "biological drawing earthworm Lumbricus dorsal view labelled clitellum segments example OER".



- Figure 5.7: Animal kingdom practical identification specimen photographs Attribution: AI generated. Suggested OER search string: "animal kingdom identification practical specimens sponge Hydra earthworm snail cockroach frog lizard pigeon labelled OER".
- Box 5.1: Dichotomous key to the six vertebrate classes Attribution: AI generated. Suggested OER search string: "dichotomous key vertebrate classes Aves Mammalia Reptilia Amphibia fish identification couplets OER box".

