ANATOMY OF FLOWERING PLANTS

- Anatomy is the study of internal structure of plants and other organisms.

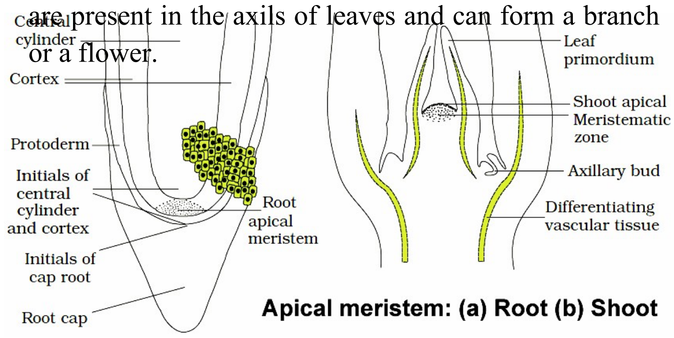
THE TISSUES

- A tissue is a group of cells having common origin and function.
- Based on the capability of cell division, plant tissues are 2 groups: **Meristematic** and **Permanent.**

MERISTEMATIC TISSUES (MERISTEMS)

These are the tissues where active cell division and growth occurs. Based on the position, meristems are 3 types:

- **Apical meristems:** They occur at the tips of roots and shoots and produce primary tissues. It is 2 types:
  - **Root apical meristem:** It occupies the tip of a root.
  - **Shoot apical meristem:** It occupies the distant most region of the stem axis. Some cells 'left behind' from shoot apical meristem, constitute the **axillary bud**. They are present in the axils of leaves and can form a branch or a flower.



Apical meristem: (a) Root (b) Shoot

- **Intercalary meristems:** They occur between mature tissues. They occur in grasses and regenerate parts removed by the grazing herbivores.
  Apical and intercalary meristems are **primary meristems** because they appear early in a plant life and contribute to the formation of primary plant body. During that, specific regions of the apical meristem produce **dermal tissues, ground tissues** and **vascular tissues.**
- **Secondary (lateral) meristems:** The meristems that occur in mature regions of roots and shoots. They are cylindrical meristems. They are seen in gymnosperms and dicots.
  E.g. **Fascicular vascular cambium, interfascicular cambium & cork cambium.** These are responsible for producing the secondary tissues.

PERMANENT (MATURE) TISSUES

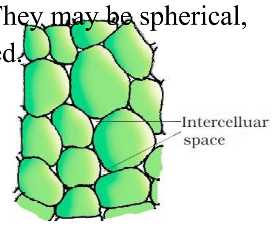
- The cells produced by primary and secondary meristems, become structurally and functionally specialized and lose the ability to divide. They are called **permanent (mature) cells** and constitute the **permanent tissues.**
- They are 2 types: Simple and Complex.

1. Simple Permanent Tissues

- The tissues having all cells similar in structure & function.
- 3 types: Parenchyma, Collenchyma and Sclerenchyma.

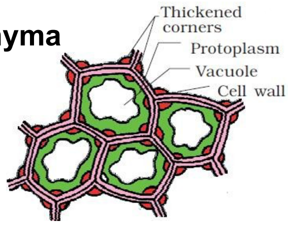
a. Parenchyma

- It forms the major component within organs.
- Cells are generally isodiametric. They may be spherical, oval, round, polygonal or elongated.



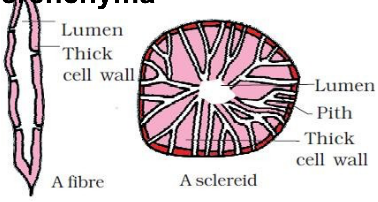
- Their walls are thin and made up of cellulose.
- Cells are closely packed or have small intercellular spaces.
- **Functions:** Photosynthesis, storage, secretion etc.

b. Collenchyma



- It occurs in layers below the epidermis in dicot plants.
- It is found as a homogeneous layer or in patches.
- It consists of cells with much thickened corners due to deposition of cellulose, hemicellulose and pectin.
- Intercellular spaces are absent.
- Cells are oval, spherical or polygonal and often contain chloroplasts.
- **Functions:** They provide mechanical support to the growing parts such as young stem and petiole of a leaf. The cells that contain chloroplasts assimilate food.

c. Sclerenchyma



- It consists of long, narrow cells with thick and lignified cell walls having a few or numerous pits.
- They are usually dead without protoplasts.
- Based on the form, structure, origin and development, sclerenchyma is 2 types: fibres & sclereids.
  - **Fibres:** These are thick-walled, elongated and pointed cells, generally occurring in groups.
  - **Sclereids:** These are spherical, oval or cylindrical, highly thickened dead cells with very narrow cavities (lumen). These are found in the fruit walls of nuts; pulp of fruits like guava, pear and sapota; seed coats of legumes and leaves of tea.
- **Function:** It provides mechanical support to organs.

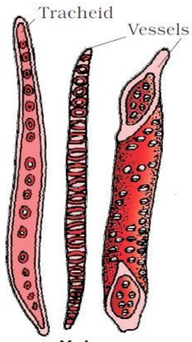
2. Complex Permanent Tissues

- These are made of more than one type of cells and they work together as a unit.
- 2 types: Xylem and Phloem.

a. Xylem

- It functions as a conducting tissue for water and minerals from roots to the stem and leaves.
- It also provides mechanical strength to the plant parts.
- It is composed of 4 kinds of elements: **tracheids, vessels, xylem fibres** and **xylem parenchyma.**

- **Tracheids:** These are elongated tube like dead cells with thick and lignified walls and tapering ends. Protoplasm absent. The inner layers of cell walls have thickenings which vary in form. In flowering plants, tracheids & vessels are the main water transporting elements.



Xylem

- **Vessel:** It is a long cylindrical tube-like structure made up of many cells **(vessel members),** each with lignified walls and a large central cavity. Protoplasm absent. Vessel members are interconnected through perforations in their common walls. The vessels are a characteristic feature of angiosperms. Gymnosperms lack vessels.
- **Xylem fibres:** They have highly thickened walls and obliterated central lumens. They are septate or aseptate.
- **Xylem parenchyma:** Living and thin-walled cells with cellulosic cell walls. They store food materials (starch or fat) and other substances like tannins. Radial conduction of water takes place by the ray parenchymatous cells.

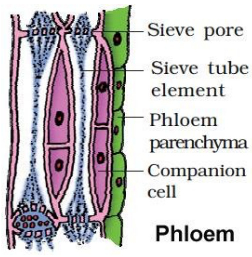
- Primary xylem is 2 types:
  - **Protoxylem:** The first formed primary xylem.
  - **Metaxylem:** The later formed primary xylem.
- In stems, the protoxylem lies towards the centre (pith) and the metaxylem lies towards the periphery of the organ. This type of primary xylem is called **endarch**.
- In roots, the protoxylem lies towards periphery and metaxylem lies towards the centre. Such arrangement of primary xylem is called **exarch.**

b. Phloem (Bast)

It transports food materials from leaves to other parts.

In angiosperms, phloem is composed of **sieve tube elements, companion cells, phloem parenchyma & phloem fibres.** Gymnosperms have albuminous cells and sieve cells. They lack sieve tubes and companion cells.

- **Sieve tube elements:** These are long, tube-like structures, arranged longitudinally and are associated with companion cells. Their end walls are perforated to form the **sieve plates.** A mature sieve element has a peripheral cytoplasm and a large vacuole but lacks a nucleus. The functions of sieve tubes are controlled by the nucleus of companion cells.



  The first formed primary phloem **(protophloem)** consists of narrow sieve tubes. The later formed phloem **(metaphloem)** has bigger sieve tubes.
  Function: Conduction of food materials from leaves.
- **Companion cells:** Specialized parenchymatous cells closely associated with sieve tube elements. Sieve tube elements & companion cells are connected by pit fields present between their common longitudinal walls.
  Function: Maintain the pressure gradient in sieve tubes.
- **Phloem parenchyma:** It is made up of elongated, tapering cylindrical cells which have dense cytoplasm and nucleus. The cell wall is composed of cellulose and has pits through which plasmodesmatal connections exist between the cells. Phloem parenchyma is absent in most of the monocots.
  Function: It stores food material and other substances like resins, latex and mucilage.
- **Phloem fibres (bast fibres):** These are made up of sclerenchymatous cells. Generally absent in primary phloem but are found in the secondary phloem. These are much elongated, unbranched and have pointed, needle like apices. Cell wall is quite thick. At maturity, these fibres lose their protoplasm and become dead. Phloem fibres of jute, flax and hemp are used commercially.
  Function: Mechanical support & protection to soft tissues.

THE TISSUE SYSTEM

Based on structure and location, tissue systems are 3 types:

- **Epidermal tissue system**
- **Ground (fundamental) tissue system**
- **Vascular (conducting) tissue system**

1. Epidermal Tissue System

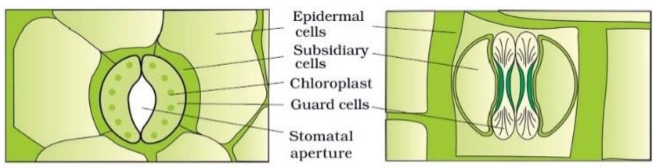
- It forms the outer-most covering of the whole plant body.
- It comprises **epidermal cells, stomata** and **epidermal appendages (trichomes & hairs).**

Epidermis

- It is the outermost layer of the primary plant body.
- Epidermis is usually single layered.
- It is made up of elongated, compactly arranged parenchymatous cells with a small amount of cytoplasm lining the cell wall and a large vacuole.
- The outside of the epidermis is often covered with a waxy thick layer **(cuticle).** It prevents the loss of water. Cuticle is absent in roots.

Stomata

- These are structures present in the epidermis of leaves.
- Stomata regulate the transpiration and gaseous exchange.
- A stoma is made of two bean-shaped cells **(guard cells).**
- In grasses, the guard cells are dumbbell shaped.



Stomata with bean-shaped guard cells   Stomata with dumb-bell shaped guard cell

- The outer walls of guard cells (away from the stomatal pore) are thin and the inner walls (towards the stomatal pore) are highly thickened.
- The guard cells possess chloroplasts and regulate the opening and closing of stomata.
- Sometimes, a few epidermal cells near the guard cells become specialized in their shape and size. They are known as **subsidiary cells.**

- The stomatal aperture, guard cells and the surrounding subsidiary cells are together called **stomatal apparatus.**

Epidermal appendages

- The cells of epidermis bear many hairs.
- **Root hairs:** Unicellular elongations of the epidermal cells. They help to absorb water and minerals from the soil.
- **Trichomes:** They are the epidermal hairs on the stem. They are usually multicellular, branched or unbranched and soft or stiff. They may be secretory. Trichomes help to prevent water loss due to transpiration.

2. The Ground Tissue System

- All tissues except epidermis and vascular bundles constitute the **ground tissue.**
- It consists of **simple tissues** (parenchyma, collenchyma and sclerenchyma).
- Parenchymatous cells are present in cortex, pericycle, pith and medullary rays, in the primary stems and roots.
- In leaves, the ground tissue consists of thin-walled chloroplast containing cells and is called **mesophyll**.

3. The Vascular Tissue System

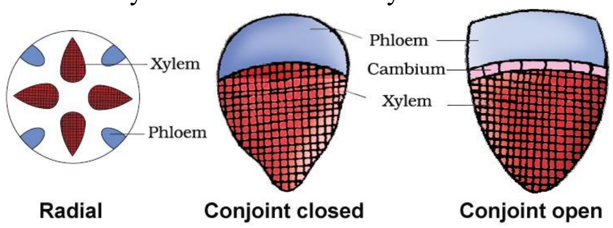
It consists of **complex tissues** (xylem and phloem).

Xylem and Phloem together constitute **vascular bundles.** Based on the presence or absence of **cambium,** vascular bundles are 2 types:

- **Open type:** In this, cambium is present between phloem and xylem. So vascular bundles can form secondary xylem and phloem tissues. E.g. **dicotyledonous** stems.
- **Closed type:** In this, cambium is absent. Hence, they do not form secondary tissues. E.g. **monocotyledons.**

Based on the arrangement of xylem and phloem, vascular bundles are 2 types:

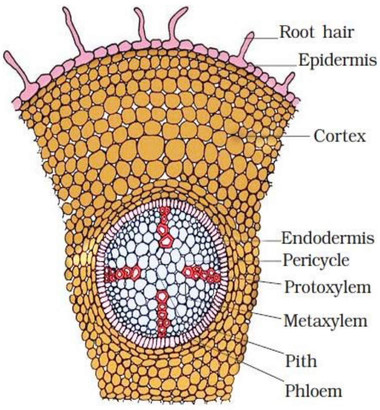
- **Radial type:** Xylem and phloem are arranged in an alternate manner on different radii. Seen in roots.
- **Conjoint type:** Xylem and phloem are jointly situated at the same radius of vascular bundles. Seen in stems and leaves. Conjoint vascular bundles usually have phloem located only on the outer side of xylem.



ANATOMY OF DICOTYLEDONOUS & MONOCOTYLEDONOUS PLANTS

Dicotyledonous (Dicot) Root

Transverse section of the sunflower root shows the following tissue organization:

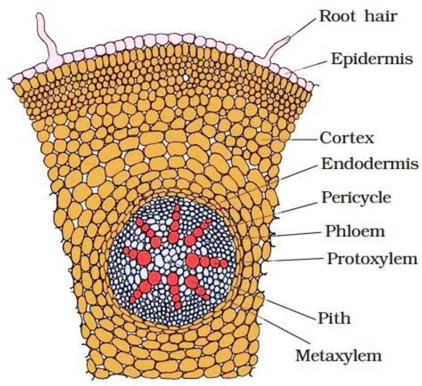


T.S of Dicot root (Primary)

- **<u>Epidermis (epiblema):</u>** The outermost layer. Many cells of epiblema protrude in the form of unicellular root hairs.
- **<u>Cortex:</u>** It consists of several layers of thin-walled parenchyma cells with intercellular spaces.
- **<u>Endodermis:</u>** Innermost layer of the cortex. It comprises a single layer of barrel-shaped cells without intercellular spaces.
  The tangential as well as radial walls of the endodermal cells have a deposition of water impermeable, waxy material-suberin-in the form of **casparian strips**.
- **<u>Stele:</u>** All tissues on the inner side of the endodermis together constitute stele. They include
  - **Pericycle:** A few layers of thick-walled parenchyomatous cells next to endodermis. Initiation of lateral roots and vascular cambium during the secondary growth takes place in these cells.
  - **Pith:** Innermost region of the stele. It is small or inconspicuous.
  - **Conjunctive tissue:** The parenchymatous cells which lie between the xylem and the phloem.
  - **Vascular bundles:** 2-4 xylem & phloem patches. Later, a cambium ring develops between the xylem & phloem.

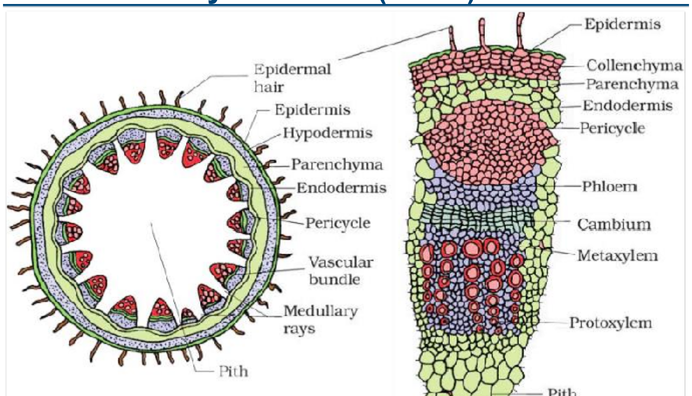
Monocotyledonous (Monocot) Root

- It has **epidermis, cortex, endodermis, pericycle, vascular bundles** and **pith.**
- There are usually more than six **(polyarch)** xylem bundles.
- Pith is large and well developed.
- Monocot roots do not undergo any secondary growth.



T.S of Monocot root

Dicotyledonous (Dicot) Stem



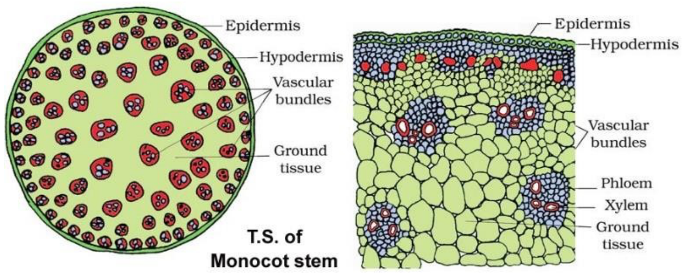
T.S. of Dicot stem

- **<u>Epidermis:</u>** Outermost protective layer. Covered with a thin layer of cuticle, it may bear trichomes & few stomata.
- **<u>Cortex:</u>** Multiple layers of the cells arranged in between epidermis and pericycle. It consists of 3 sub-zones:

- **Hypodermis:** Outer zone. It consists of a few layers of collenchymatous cells just below the epidermis. It provides mechanical strength to the young stem.
- **Cortical layers:** Below hypodermis. They consist of rounded thin walled parenchymatous cells with conspicuous intercellular spaces.
- **Endodermis:** Innermost layer. The cells are rich in starch grains. So the layer is also called as the **starch sheath. Pericycle** is present on the inner side of the endodermis and above the phloem in the form of semi-lunar patches of sclerenchyma.

o **Stele:** Consists of **pericycle, vascular bundles, medullary rays & pith.**
- **Medullary rays:** These are few layers of radially placed parenchymatous cells in between vascular bundles.
- **Vascular bundles:** Large in number. They are arranged in a ring. Ring arrangement is a characteristic of dicot stem. Each vascular bundle is conjoint, open, and with endarch protoxylem.
- **Pith:** Central portion of the stem. It has many rounded, parenchymatous cells with large intercellular spaces.

Monocotyledonous (Monocot) Stem



T.S. of Monocot stem

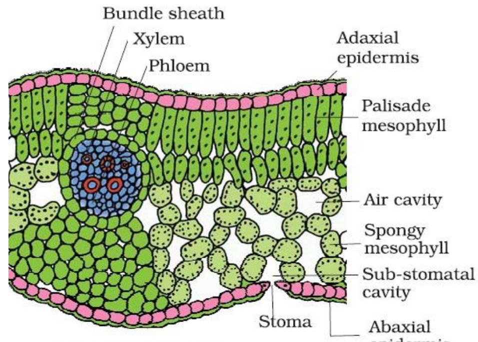
- It has a sclerenchymatous **hypodermis,** many scattered **vascular bundles,** each surrounded by a sclerenchymatous **bundle sheath,** and a large, conspicuous parenchymatous **ground tissue.**
- **Vascular bundles** are **conjoint** & **closed.** Peripheral vascular bundles are smaller than centrally located ones.
- The phloem parenchyma is absent, and water-containing cavities are present within the vascular bundles.

Dicotyledonous (Dorsiventral) Leaf

The vertical section of a dicot leaf through lamina shows 3 main parts: **Epidermis, mesophyll & vascular system.**

o **Epidermis:** It covers both the upper surface **(adaxial epidermis)** and lower surface **(abaxial epidermis)** of the leaf. It has a conspicuous cuticle.
Abaxial epidermis generally bears more stomata than the adaxial epidermis. The latter may even lack stomata.

o **Mesophyll:** The tissue between the upper and the lower epidermis. It is made up of parenchyma. They contain chloroplasts for photosynthesis. It has 2 types of cells:



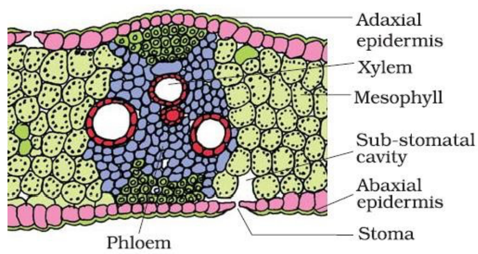
T.S. of Dicot leaf

- **Palisade parenchyma:** It is adaxially placed. Made up of elongated cells arranged vertically and parallel to each other.
- **Spongy parenchyma:** The oval or round and loosely arranged. It is situated below the palisade cells and extends to the lower epidermis. There are numerous large spaces and air cavities between these cells.

o **Vascular system:** It includes vascular bundles. They can be seen in the veins and midrib.
Size of vascular bundles is dependent on the size of the veins. The veins vary in thickness in the reticulate venation of dicot leaves. Vascular bundles are surrounded by a layer of thick walled **bundle sheath cells**.

Monocotyledonous (Isobilateral) Leaf

The anatomy of monocot leaf is like that of the dicot leaf in many ways. It shows following differences:



T.S. of Monocot leaf

o Stomata are present on both surfaces of the epidermis.
o Mesophyll is not differentiated into palisade and spongy parenchyma.
o In grasses, certain adaxial epidermal cells along the veins modify themselves into large, empty, colourless cells. These are called **bulliform cells.** When the bulliform cells have absorbed water and are turgid, the leaf surface is exposed. When they are flaccid due to water stress, they make the leaves curl inwards to minimise water loss.
o Parallel venation is reflected in the near similar sizes of vascular bundles (except in main veins).

SECONDARY GROWTH

- The growth of the roots and stems in length with the help of apical meristem is called the **primary growth.**
- **Secondary growth** is the increase in girth of dicot plants.
- Tissues involved in secondary growth are the two **lateral meristems: Vascular cambium & cork cambium**.

Vascular Cambium

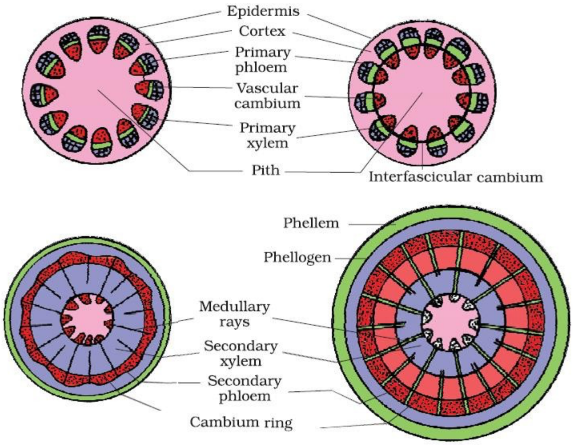
- It is the meristematic layer responsible for cutting off vascular tissues (xylem and phloem).
- In the young stem, it is present in patches as a single layer between xylem & phloem. Later it forms a complete ring.

Formation of cambial ring

- In dicot stems, cells of cambium present between primary xylem & primary phloem is **intrafascicular cambium**.
- Cells of medullary cells, adjoining this intrafascicular cambium become meristematic and form **interfascicular cambium**. Thus, a continuous ring of cambium is formed.

Activity of the cambial ring

- The cambial ring becomes active and cut off new cells, both towards the inner and outer sides. The cells cut off towards pith, mature into **secondary xylem.** The cells cut off towards periphery mature into **secondary phloem**.
- Cambium is more active on the inner side than on the outer. As a result, more secondary xylem is produced than secondary phloem and soon forms a compact mass.
- Primary and secondary phloems get gradually crushed due to the continued formation and accumulation of secondary xylem. However, primary xylem remains intact, in or around the centre. At some places, cambium forms a narrow band of parenchyma, which passes through the secondary xylem and the secondary phloem in the radial directions. These are the **secondary medullary rays.**



Secondary growth in a dicot stem – stages in transverse views

Spring wood and autumn wood

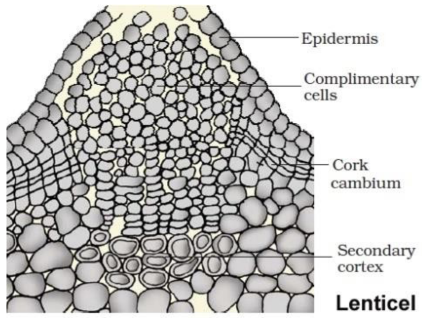
- Many physiological & environmental factors control the activity of cambium.
- In spring season, cambium is very active and produces many xylary elements having vessels with wider cavities. This wood is called **spring wood (early wood)**. It is lighter in colour and has a lower density.
- In winter, cambium is less active and forms fewer xylary elements having narrow vessels. This wood is called **autumn wood (late wood)**. It is darker and has higher density.
- These two kinds of woods that appear as alternate concentric rings constitute an **annual ring.** This is used to estimate the age of tree (Dendrochronology).

Heartwood and sapwood

- **Heartwood:** It is the hard, dead, dark brown-coloured, highly lignified and non-functional central part of the secondary xylem of old trees. The dark colour is due to deposition of organic compounds (tannins, resins, oils, gums, aromatic substances, essential oils etc). These substances make it hard, durable and resistant to the attacks of microorganisms and insects.
  Function: It gives mechanical support to stem.
- **Sapwood:** It is the peripheral region of secondary xylem. It is living and lighter in colour. It is involved in the conduction of water and minerals from root to leaf.

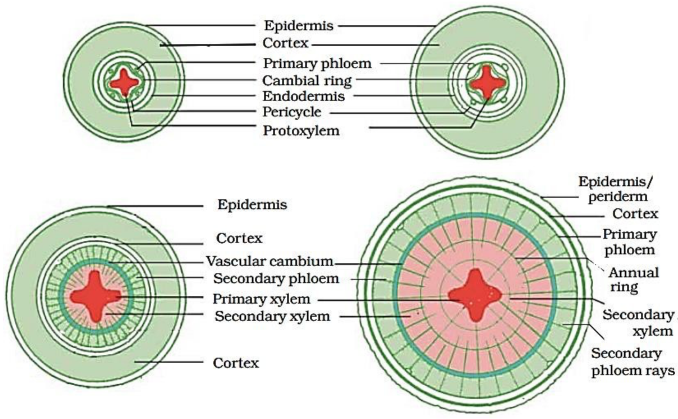
Cork Cambium

- As the stem continues to increase in girth due to the activity of vascular cambium, the outer cortical & epidermis layers get broken. It is to be replaced to provide new protective cell layers. Hence another meristematic tissue called **cork cambium (phellogen)** develops, usually in the cortex.
- Phellogen is a couple of layers thick. It is made of narrow, thin-walled and nearly rectangular cells.
- Phellogen cuts off cells on both sides. The outer cells differentiate into **cork (phellem)** while the inner cells differentiate into **secondary cortex (phelloderm).** Cells of secondary cortex are parenchymatous.
- The cork is impervious to water due to suberin deposition in the cell wall.
- Phellogen, phellem, and phelloderm are collectively known as **periderm**. Due to activity of cork cambium, pressure builds up on the remaining layers peripheral to phellogen and ultimately these layers die and slough off.
- **Bark** is a non-technical term that refers to all tissues (such as periderm & secondary phloem) exterior to the vascular cambium. It is 2 types:
  - ○ **Early (soft) bark:** It is formed early in the season**.**
  - ○ **Late (hard) bark:** It is formed towards end of season.
- **Lenticels:** At certain regions, phellogen cuts off closely arranged parenchymatous cells on outer side. These cells rupture epidermis, forming a lens shaped openings called **lenticels.** They occur in most woody trees.



  Function: Lenticels permit gas exchange of between the outer atmosphere and the internal tissue of the stem.

Secondary Growth in Roots



Different stages of the secondary growth in a typical dicot root

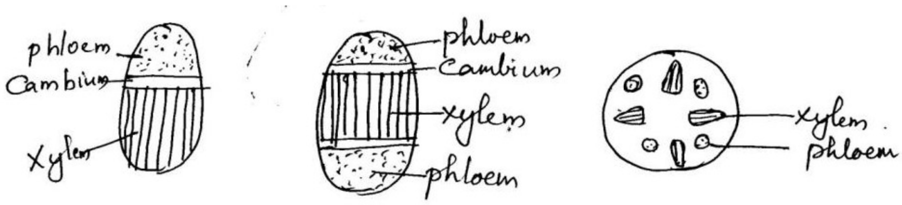
- In dicot root, vascular cambium is completely secondary in origin. It originates from the tissue located just below the phloem bundles (a portion of pericycle) above the protoxylem forming a complete and continuous wavy ring. It later becomes circular. Further events are similar to those of a dicotyledon stem.
- Secondary growth also occurs in stems and roots of gymnosperms. However, secondary growth does not occur in monocotyledons.

MODEL QUESTIONS

1. Find out the odd one
    a. Parenchyma, Xylem, Collenchyma, Sclerenchyma
    b. Sieve tubes, companion cells, tracheids, bast fibre
2. Analyze the table and arrange them in an appropriate order

A	B	C
Monocot Stem	Bulliform cells	Bean shaped guard cells
Isobilateral leaf	Endarch Xylem	Secondary thickening
Dorsiventral leaf	Closed Vascular bundle	Dumble shaped guard cells
Dicot stem	Palisade and spongy parenchyma	Proto xylem and lacunae

3. Give reasons.
    a. Conduction of the food through the sieve tube is under the control of companion cell.
    b. Annual rings are not found in coconut tree.
4. Identify the type of vascular bundle.



5. Vascular bundles of a plant are conjoint, collateral and open.
    a. In which part of a plant this kind of vascular bundles are seen?
    b. Is it possible for this part of plant to undergo secondary thickening? Give reasons.
6. Some anatomical characters are given in brackets. Arrange them in three columns under root, stem and leaves. (Conjoint open bundles, mesophyll cells, endarch xylem, radial bundles, bulliform cells on epidermis, casparian thickenings in endodermis, exarch xylem)