Chapter -1

PLANT ANATOMY

- *Plant anatomy deals with the study of gross internal structure of plant.*
- *Basic unit of anatomy is tissue.*
- *Term tissue was used by N. Grew (known as father of plant anatomy).*
- *A group of structurally similar or dissimilar cells that perform or help to perform a common function and have a common origin is called a tissue.*
- Tissues can be conveniently grouped in two headings:

  A. Meristematic tissues

  B. Permanent tissues

Meristematic Tissue

- Meristematic tissue is made up of group of immature cells that are preparing to divide or are in continuous state of division.
- Term meristem was coined by C. **Nageli**, (Gr. Meristos = divisible).
- Meristem are found in growing regions of plants.
- Meristem are ultimate source of all tissue in plant.
- Chief characteristics of meristem are:

- Cells may be round, oval, polygonal or rectangular but isodiametric (equal size)
- Have thin cellulosic wall with dense cytoplasm & conspicuous nuclei.
- Do not have intercellular spaces and reserve food material.
- Cells are in active state of metabolism.
- Chloroplast and chromoplasts are absent but leucoplast may be present.
- Vacuoles are either small or absent.
- ER is small and nucleocytoplasmic ratio is very high.

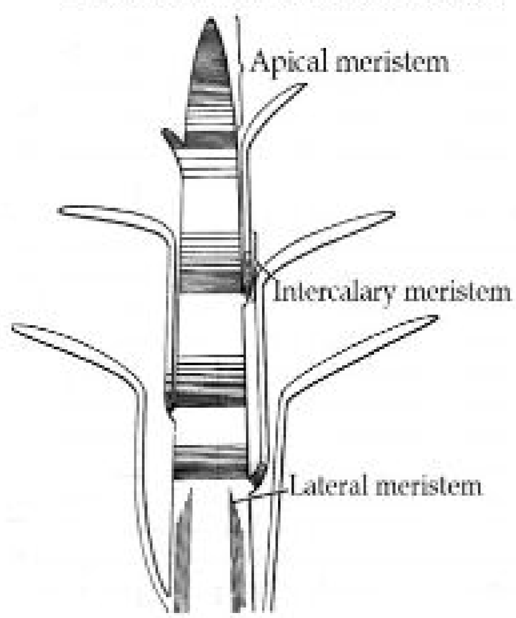
Types of meristem

A. On the basis of origin and development, meristems can be promeristem, primary meristem and secondary meristem.

1. **Promeristem** (= Primordial meristem or Ur-meristem or Embryonic meristem):
   - Represent primary stages of meristematic cells.
   - Plant embryo truly represents this kind of meristem. [Ind. Emb]
   - They give rise to primary meristems.
2. **Primary meristems:**
   - **Cells** are always in active state of division and give rise to primary permanent tissues.
   - They are found below the promeristem at shoot and root apices, at the apex of leaves, in intercalary parts and intrafascicular cambium in dicot stems.
3. **Secondary meristems:**
   - Develops from primary permanent tissue at a later stage and give rise to secondary permanent tissues.
   - Examples: cambium of roots, interfascicular cambium of stem, wound cambium and cork cambium in stem as well as root.

B. On the basis of position on plant body; meristematic tissues can be divided into apical, intercalary & lateral meristem.

Figure: Meristem based on position



1. **Apical meristems:**
   - These tissues are found at apices of stem and root.
   - Responsible for increase in length, *i.e.*, they form growing points at the apices of roots and stems.
2. **Intercalary meristems:**
   - These tissue are intercalated in between the permanent tissues.
   - Originate from the apical meristems during development [Ind Emb, IOM 1997].
   - May be present at the base of internodes (*i.e.*, above node) e.g. in grasses (Gramineae) or at the base of leaves e.g. in monocots and *Pinus* or at the base of node e.g. mint or *Mentha* .
   - Aactivity of these meristems also add to the length of the plant or its organs.

Quick Digest

- Axillary and terminal bud are formed from apical meristem.

- Leaf of pinus is evergreen due to intercalary meristem on leaf base.
- Increase in length in grass is due to intercalary meristem
- The process of conversion of meristematic tissue into permanent tissue is called **differentiation** and the reverse process is called **de-differentiation**.
- **Example of de-differentiation:** Formation of cambium (2^0 meristem) from medullary ray (permanent tissue)
- **Plastochoron:** time gap between two successive primordia

3. **Lateral meristem:**
   - Present along the lateral sides of stem and roots.
   - Responsible for increase in girth of stem and roots.
   - Example: intrafascicular, interfascicular cambium and cork cambium (phellogen).

Root and shoot apex organization:

- Several theories have been put forward to explain the activity of apical meristems:

1. **Apical cell theory (By Nageli)**
   - According to this theory, activity of single apical cell leads to development of entire plant body.
   - Applicable to higher algal forms, bryophytes and some pteridophytes but is certainly not applicable to the seed plants (spermatophytes).
2. **Histogen theory (By Hanstein)**
   - According to this theory, cells of root and shoot apices organized into three distinct zones(called histogen).

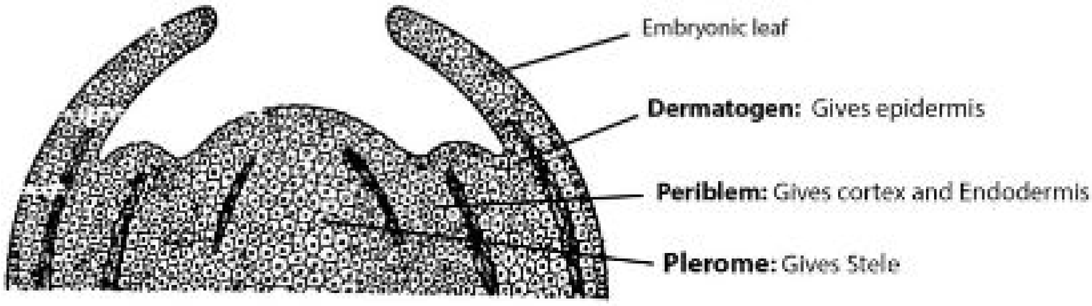


Figure: Types of Histogen on Shoot apex

a. **Plerome** (central core): form stele.
b. **Periblem (several layer surrounding plerome): form hypodermis, cortex and endodermis.**
c. **Dermatogen** (outermost single layer): **form epidermis.**

Note:

- In case of root apex Hanstein proposed one more histogen, *i.e.*, **Calyptrogen** which is responsible for the formation of root cap.

3. **Tunica-corpus theory (By Schmidt)**
   - This theory recognizes only two zones in the apical meristems, *i.e.*, outer **tunica** and central **corpus.**
   - According to this view epidermis is derived from outer layer of tunica and the remaining tissues are derived from remaining layer of **tunica** and entire **corpus.**
   - Cells of the tunica divide anticlinally only and help to increase the extent of surface.
   - Cells of corpus divide in all planes and contribute to the depth and mass of inner tissues.

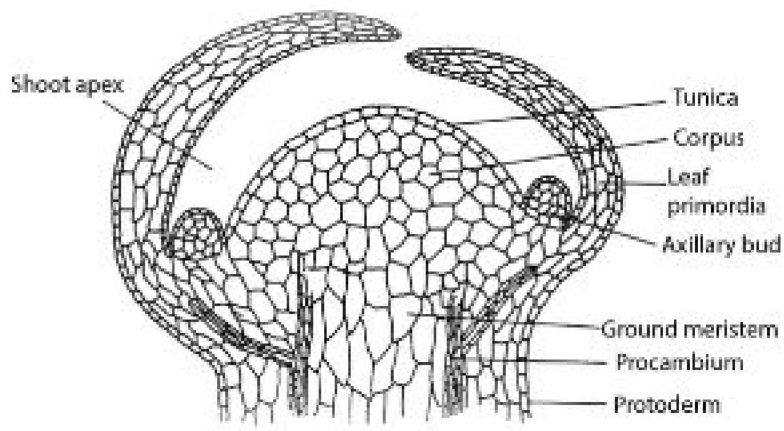


Figure: Diagram showing organization of shoot apical cells as Tunica and Corpus

4. **Quiescent centre concept (By** Clowes)
   - Discovered by Clowes in root tip of *Zeamays.*
   - It is cup like region of passive cells lying between the root cap and active root meristem.
   - Cells of this region normally remain inactive and serve as reservoir to meristematic zone.
   - Cells of quiescent centre are characterized by having low DNA, RNA and protein contents.

C. Based on function; meristematic tissue can be divided into following three types.

1. **Protoderm**: makes epidermal tissue system.
2. **Ground**: makes ground tissue and pith.
3. **Procambium**: makes primary vascular tissues.

D. Based on plane of division, meristem can be divided into following types.

1. **Mass meristem: cells divides in three plane increasing volume and growth, e.g. early growth of embryo, cortex, pith etc.**
2. **Plate meristem: cells divides in two plane so that plate like area is increased, e.g. formation of epidermis, endodermis**
3. **Rib or file meristem: cells divides in one plane to form row of cells causing increase in length, e.g. lateral root formation**

PERMANENT TISSUES

- Formed as a result of division and differentiation in meristematic tissues.
- Cells of these tissues are living or dead, thin-walled or thick-walled.

Permanent Tissue
- Simple Permanent Tissue
  - Parenchyma
  - Collenchyma
  - Sclerenchyma
- Complex Permanent Tissue
  - Xylem
  - Phloem
- Special Permanent Tissue
  - Glandular Tissue
  - Laticiferous Tissue

Simple Permanent Tissues

- Formed of structurally similar cells (homogenous group of cells) that perform a common function.
- 3 types: Parenchyma, Collenchyma & Sclerenchyma

Parenchyma

- Consists of living, isodiametric and thin-walled cells with intercellular space.
- Cell wall is made up of cellulose and calcium pectate.

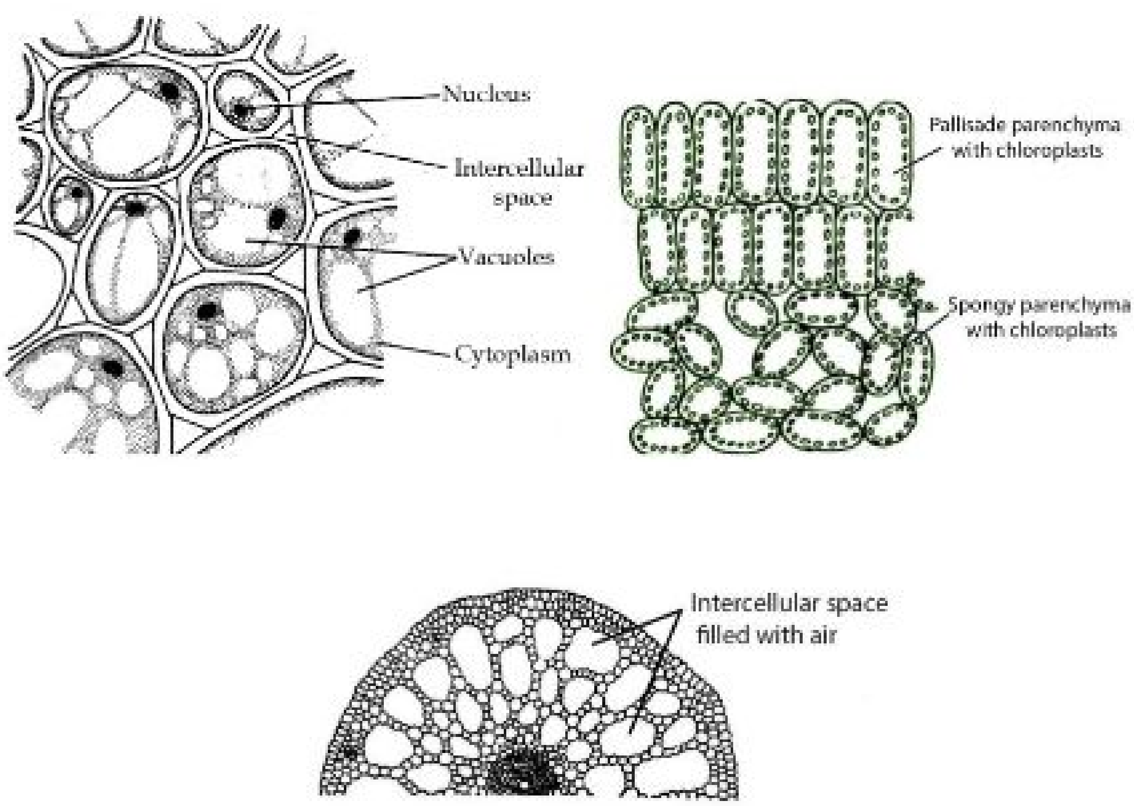


Figure: Storage Parenchyma, Cholerenchyma and Aerenchyma

Quick Digest:

- Parenchyma is commonest, simplest, unspecialized, most primitive, most abundant permanent tissue that evolved first. [IE 2005]
- Most widely distributed tissue in plant is parenchyma.
- A conspicuous feature of parenchyma is presence of **intercellular spaces.**
- Number of facets in parenchymal cell is **14.**

- It is the fundamental tissue as all other tissues are derived from it.
- Most abundant tissue; present in all organs of the plant, *e.g.* roots, stems, leaves, flowers, fruits and seeds.
- Main function of parenchyma is storage of food.

Special type of parenchyma:

- **Prosenchyma:** Parenchyma with pointed and tapering ends, found in **pericycle of roots.**
- **Aerenchyma:** Parenchyma with **air sacs**, found in hydrophytes like *Eichhornia* for **buoyancy. [BPKIHS 1995]**
- **Chlorenchyma:** Parenchyma containing **chloroplast,** example; **palisade tissue** (highest no. of chloroplasts is present).
- **Mucilage Parenchyma:** Parenchyma with large vacuoles and mucilage, found in succulent xerophytic plants (for storage of water).
- **Idioblastic parenchyma**: Parenchyma cells storing waste materials like oils, tannin and crystal of calcium oxalates in the form of food.

Collenchyma (=Living mechanical tissue)

- It is living mechanical tissue. [MOE 2008]
- Cell wall possesses uneven thickening of pectin, hemicellulose and cellulose.
- Intercellular spaces are absent due to deposition of pectocellulose (pectin is dominant) at the corner of cells.
- Hydrophilic nature of **pectocellulose** makes the cells of collenchyma **flexible.**
- Sometimes collenchyma develops chloroplasts and helps in photosynthesis.
- Collenchyma has unique nature of distribution:

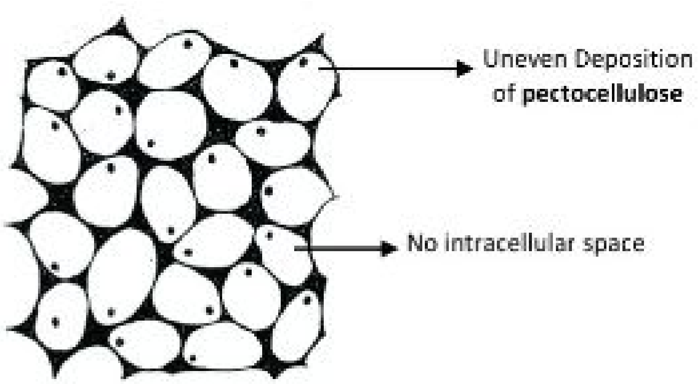


Figure: Collenchyma

  - Present only in hypodermis of dicot stem.
  - Never found in monocot and roots
- Based upon the thickening of the cell walls, collenchyma is of three types :

1. **Angular collenchyma**: Most common type.
   - Thickening occurs only at the corners of the cells and the side walls remain thin.
   - Without intercellular space, *e.g. Vitis,Tagetes, Ficus.*
2. **Lamellar collenchyma**: Thickening occurs at tangential wall.
   - Without intercellular space, *e.g. hypodermis of sunflower stem*
3. **Lacunate or tubular type**: Thickenings occur in cell wall bordering the intercellular space.
   - With intercellular space, *e.g. hypodermis of cucurbita stem.*

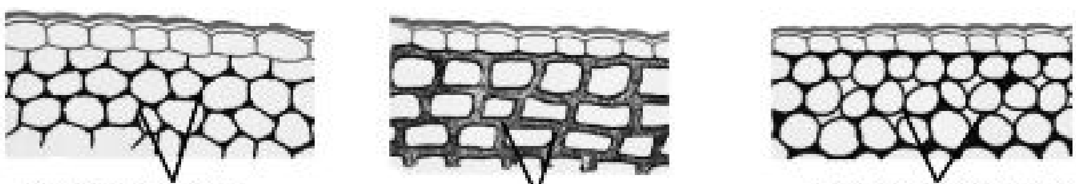


Figure: Types of wall thickening in Collenchyma

- **Collenchyma** provides mechanical support (tensile strength). It resists bending and pulling action of wind.
- In some cases, collenchyma cells contain chloroplast and help in photosynthesis.

Sclerenchyma (Gr; Scleros: Hard)

- Differs from parenchyma and collenchyma in having thickened secondary walls which are lignified.
- On maturation the cells become dead, loses protoplasm and forms lumen.
- Possesses simple or bordered pits.
- Pits are non-lignified area on lignified wall.
- Sclerenchyma is usually found in hypodermis of monocot stem. [MOE 2009, IOM 2006]
- Main function of sclerenchyma is to provide the mechanical strength.
- Can be divided into two types, *i.e.*, sclerenchymatous fibers and stone cells.

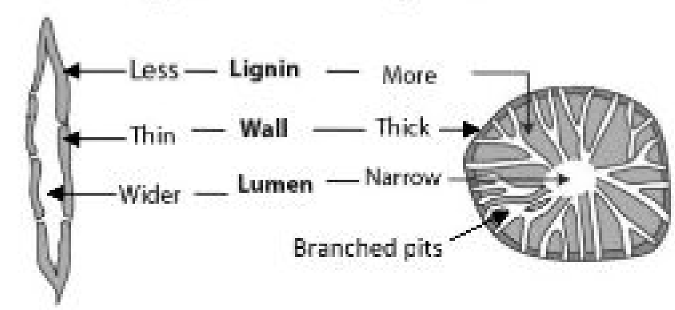


Figure: Fibre and Sclereids

Sclerenchyma fibres:

- Elongated and tapering at both ends, spindle-shaped.
- Longest cell in plant (2-1000mm in angiosperms and 1-12 mm in gymnosperms).
- Pits are narrow and unbranched.
- Fibres are arranged in bundles and provides mechanical strength.
- Unlike sclereids, they are directly derived from meristematic cells.
- Fibre obtained from xylem are called **xylary or wood fibre** e.g. Libriform fibre, fibre tracheids etc.

- Fibre obtained from any other part than xylem are called **extraxylary or bast fibre.**
  - **Bast fibre from secondary phloem** e.g., Jute (Corchorus capsularis), *Crotolaria juncea* (Sun hemp). **[IOM 2004, 2016]**
  - **Bast fibre from pericycle (perivascular fibre)** e.g. *Canabis* (Hemp fibre), *Linum* (Flax fibre)

Sclereids or stone cells:

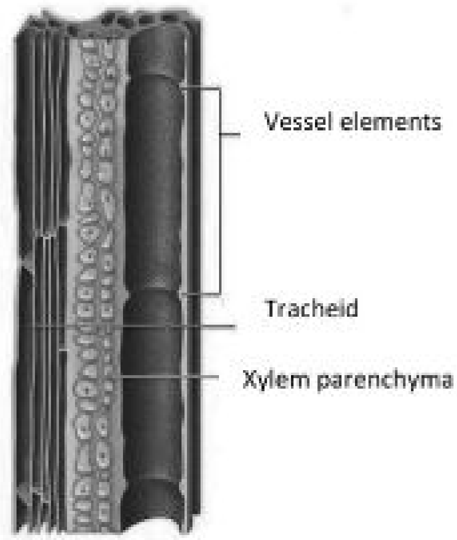
- Derived from secondary thickening of parenchymal cells.
- Shorter, highly thickened with **narrow cavities**.
- Stone cells are present in hard parts like **endocarp of coconut**, **hard seed coats** and also in some **fruit pulp of guava, pear** etc.
- Hardness of seed coat is due to stone cells. **[BPKIHS]**
- Based on shape, sclereids are of following types:
  1. Brachysclereids: Irregular shape
     - Brachysclereids is commonly known as **stone cells.**
     - Most common.
     - It is generally found in pulp of some fruits, **e.g.** pear, guava.
     - Endocarp of coconut fruit is also produced from **Brachysclereids**.
  2. **Macrosclereids** (rod shaped): Found in hard seed coat of Leguminosae family.
  3. **Osteosclereids** (Bone shaped): Found in subepidermis of legume seeds
  4. **Astrosclereids** (Star shaped): Branched like a **star**. e.g. tea leaves, petiole of Lotus

Complex permanent tissue

- A complex tissue is made up of structurally dissimilar cells performing a common function.
- The different elements of complex permanent tissue may have different forms and function but their origin is always same.
- It is of 2 types, i.e., xylem and phloem

Xylem or Hadrome

- Term xylem (Gr; Xylos= wood) was used by **Nageli.**
- Mainly responsible for **ascent of sap** (water + minerals) only in upward direction i.e., **unidirectional** and also provides **mechanical strength**. **[NEET 2019]**
- Xylem conducts water and mineral nutrients from the root to the leaves. **[MOE]**
- It forms bulk of root and stem of vascular plants.
- **Secondary xylem** is also known as **wood**.
- Composed up of **4 types of cell**.



- Out of four element; xylem (wood) parenchyma is only living [MOE] and remaining three *i.e.*, vessels, tracheid and xylem fibre are dead.
- Vessels and tracheids together are called **tracheary elements** because they conduct
- Functional part of xylem is called Hadrome (by Haberlandt).

Figure: Structure of Xylem

Tracheids:

- Long, tubular with tapering, chisel-like ends and are dead.
- **Most primitive** type of conducting elements in xylem.
- Thickening of cell wall occurs due to deposition **of lignin**.
- It is found in **all vascular plants** (including angiosperms).
- Only tracheids form xylem of **pteridophytes (fern)** and **gymnosperms**.
- Main function is **conduction of H_2O** and **minerals** (Ascent of sap) but due to their hard and lignified walls, they **also provide mechanical support**.
- Bordered pits present.
- Depending on the thickening, tracheids are classified into **annular, spiral, scalariform, reticulate and pitted.**

Quick Digest:

- Bordered pits is common in metaxylem of Gymnosperms
- Vessel differ from tracheid in having broader lumen
- "Tyloses" are balloon like ingrowths through pits in the lumens of vessels and tracheids which plug them. **[IOM 2005]**
- Some non-angiosperms with vessels:
    - Some species of *Selaginella*,
    - Two species of *Pteridium* (pteridophytes): Equisetum and *Marsilea*
    - Order Gnetales of gymnosperm: *Gnetum*, *Welwitschia* and *Ephedra*.

Vessels or Trachea:

- Formed by end to end arrangement of cells resulting on cells **syncytes** (dissolution of end walls).
- Most **advanced type of conducting elements** of xylem present only in Angiosperms
- Walls of vessels **lignified** but not so thick as tracheids.
- Bordered pits present.
- Diameter of lumen of **vessels > tracheids.**
- Vessels are generally **upto 10 cm** in length but **longest vessels** are found in **Eucalyptus** and **oak** (***Quercus***), which are from 2 m to 5 m.
- Vessels are **characteristic features of angiosperms**. But, there are certain angiosperms where vessels are absent.
- **Angiospermic families without vessels are;** Winteraceae, Tetracentraceae, Trochodendraceae.
- **Besides**, vessels are absent in stem and leaves of ***Yucca*** and ***Dracaena.***
- Net like thickening of vessels is called **reticulate thickening**. **[MOE 2014]**

Xylem parenchyma:

- It is parenchyma cells associated with xylem which helps in storage and lateral conduction of water and minerals.

Xylem fibre/wood fibres:

- It is the sclerenchyma fibre associated with xylem.

Types of xylem:

- Based on origin; 2 types:

Protoxylem	Metaxylem
First formed primary xylem from procambium during formation of primary plant body.	Later formed primary xylem during plant life
Vessels and tracheids are **smaller** and has **spiral** or **annular thickening** on secondary wall.	Vessels and tracheids are **bigger** and has **reticulate** or **pitted** or **spiral thickening** on their secondary wall.

Note: Protoxylem is more mature than metaxylem because protoxylem is 1st formed xylem.

- **Based on position of protoxylem:**
    1. **Exarch:** protoxylem outside, metaxylem central, e.g. **Root** (dicots and monocots). **[BPKIHS 2001, IOM 1999]**
    2. **<u>End</u>arch:** protoxylem central, metaxylem peripheral, e.g. **<u>S</u>tem** (dicot and monocot). @ <u>S</u> <u>End</u>
    3. **Mesarch:** protoxylem is sandwiched between metaxylem i.e. protoxylem is surrounded by metaxylem from both sides e.g. **Fern**, leaf

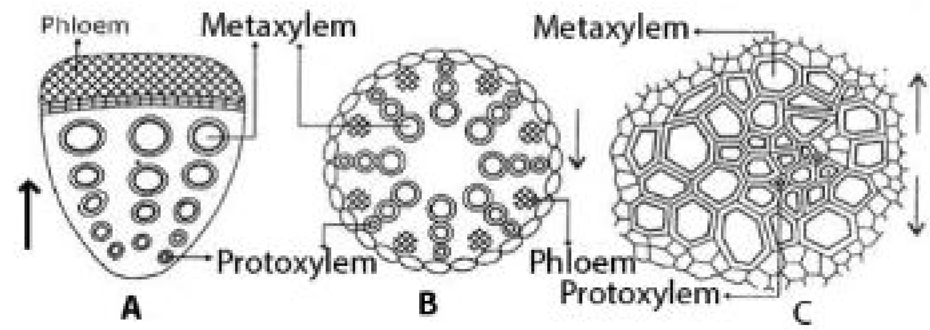


Figure: Order of development of primary vascular tissue; **A. Endarch xylem** (Centrifugal development), **B. Exarch xylem** (=Centripetal development) and **C. Mesarch xylem** (=Both centripetal and centrifugal development

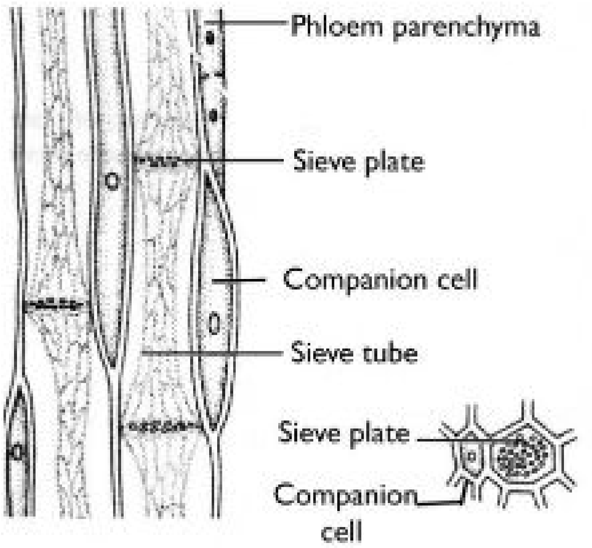
Phloem or Leptome

- Phloem is complex tissue meant for **conduction/translocation** of food/organic solute (sucrose and protein) in both **upward** and **downward direction** (=bidirectional). **[MOE 2007, NEET 2019]**
- Term phloem was given by **Nageli**.
- Phloem consists of 4 types of cells.
  1. Sieve elements
  2. Companion cells
  3. Phloem parenchyma

  } Living cells with cellulosic wall
  4. Phloem fibres → Dead cell with lignified wall

Sieve elements:

- Sieve elements in angiosperms are **sieve tubes** which are made up of sieve cells arranged one after other in distinct linear rows and have **perforated sieve plate** (oblique or transverse perforated septa) on their end walls.
- Sieve tube is **thin walled**, **living cells** which contain nuclei when young but become **enucleated** at maturity.
- In **gymnosperm** and **pteridophyte**, there is no distinct arrangement of sieve cells in linear rows and such elements are called **sieve cells.**
- Sieve cell can be differentiated from sieve tube in having perforation on **lateral wall**.
- Sieve pores in temperate plant get temporarily plugged during **winter** by insoluble carbohydrate called **callose.**
- Callose controls the translocation of food during winter and get dissolved during summer (active period).
- ***p*-Protein** (phloem protein) which is on central portion lumen of sieve tube controls movement of materials.
- Cell wall of sieve tube and sieve cell have **simple pit**.



- Conducting part of phloem is called called **Leptome**; term given by **Haberlandt**.
- Activity of xylem is unidirectional whereas activity of phloem is bidirectional.
- Border of sieve pore surrounded by **Callose carbhohydrate**.
- Starch grain is absent in **companion cells** for which it is dependent on sieve tube.

Figure: A. TS of phloem, B. LS of phloem

Companion cells:

- Thin walled, living cells (with all functional organelle) attached to lateral side of sieve tube.
- Companion cells and seive tubes are originated from same mother cell so called **sister cells**.
- Nucleus of companion cell regulate the function of sieve tube.
- Companion cells occur only in Angiosperms and are absent in the phloem of Pteridophyte and Gymnosperm. **[MOE 1999]**
- Instead of companion cells, modified parenchymal cells called **albuminous cells** (protein rich) are present in **Pteridophytes** and **Gymnosperms**.
- ***Daucus*** (carrot) has many companion cells associated with one sieve tube.

Quick Digest

- Mammalian RBCs, Prokaryotic cell, Platelet, Sieve tube are example of some living cells without nucleus.
- Sieve tube is characteristic of Angiosperm **[NEET 2019]**
- Sieve cells are present in Gymnosperm & Pteridophyte.
- Companion cells contains all functional cell organelle.

Phloem parenchyma:

- Living parenchymal cells associated with phloem and that helps in storage and lateral conduction of food.
- Phloem parenchyma is absent in most of the monocots and few dicots like *Ranunculus*.

Phloem fibres:

- Commonly called **bast fibres** (=to bind) because phloem fibres are used in binding articles.
- These are sclerenchymatous fibre associated with phloem.
- They provide mechanical support.
- The textile fibres of flax, hemp and jute are phloem fibres.

SPECIAL TISSUES

- These tissue perform special function in the plants, *e.g.* secretion of resin gum, oil and latex.

- Manny of these tissues contains cavities for storing their secretion.
  a. Lysigenous cavity: formed by cell disintegration e.g. oil cavity of citrus, eucalyptus etc.
  b. Schizogenous cavity: Formed by separation of cells, e.g. Resin duct of *Pinus*, mucilage canal of cycas
  c. Schizolysigenous cavity: is formed by both separation and disintegration of cells, e.g. protoxylem cavity of maize

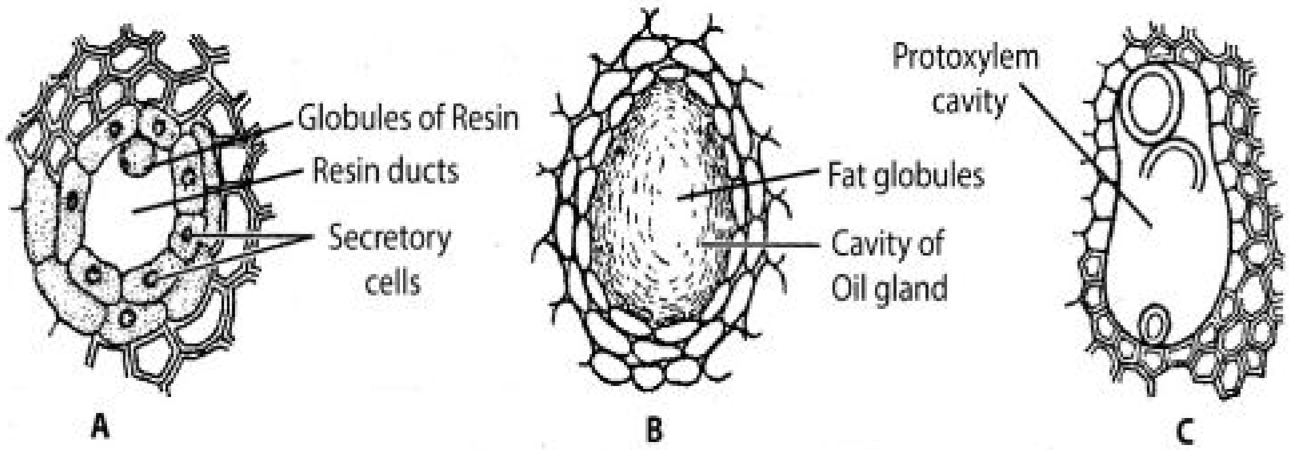


Figure: A. Schizogenous (in Pinus), B. Lysigenous (in Citrus) and C. Schizolysigenous (in Protoxylem of Maize) cavity

- Two types, *i.e.*, Glandular tissue and Laticiferous tissue.

Glandular tissues

- This tissue is present in the form of glands in or on various parts of plants.
- A gland is a **specialized group of cells** that are endowed with the capacity to secrete or excrete products.
- Two types of glandular tissue : External glands and Internal glands

External glands**:**

- Occur on epidermis of stem and leaves as glandular outgrowth, *e.g.* glandular hair, nectar secreting and enzyme secreting glands.
- **Glandular hair**: Present in epidermal layers of leaves e.g. stinging hairs in *Urtica dioica.*
- **Nectar secreting glands (nectaries)**: Present in flowers or leaves.
- **Digestive glands or Enzyme secreting glands:** Insectivorous plants possess the power of digesting proteins from bodies of insects by secreting some digestive enzymes by means of glands or glandular hair, *e.g. Drosera* (Sundew).

Internal glands :

- **Oil secreting glands**: In all *Citrus* sp. the internal glands secrete a volatile oil into a central reservoir. They represent lysigenous cavities.
  - **Osmophores are gland-secreting volatile oil of terpene nature.**
- **Resin secreting glands**: In *Pinus* the resin secreting cells form one or two peripheral layers that surround a schizogenously developed canal or duct in the leaves and stem.
- **Water secreting glands (Hydathodes = water stomata)**: These excrete water in the form of drops.
  - Hydathodes are present at the tip and margins of leaves of some herbaceous plants that generally grow in humid places, *e.g. Colocasia, Tropaeoleum.*

- Hydathode have an aperture guarded by guard cells. Below the aperture is an air cavity, below which a loose tissue called epithem is present.

Laticiferous tissue

- Composed of thin-walled elongated, branched and multinucleate tube-like structures that contain colourless milky or yellow coloured fluid called latex.
- Latex may be watery (e.g. banana), milky (e.g. euphorbia, banyan) or colored (e.g. poppy)
- Laticiferous tissue is of two types, i.e., latex cells and latex vessels.
- **Latex cells:** Differ from latex vessels in that they do not fuse together to form a network.
  - May be branched or unbranched.
  - Do not anastamose, *e.g. Calotropis, Nerium, Euphorbia, Ficus.*
- **Latex vessels**: Composed of a large number of cells placed end to end with their transverse walls dissolved so as to form long vessels.
  - Two or more latex vessels fuse with each other forming a network, *e.g. Papaver, Argemone etc.*

Quick Digest:

- Latex of poppy plant is source of alkaloid Opium or Morphine
- Natural rubber is obtained from *Hevea brasiliensis*
- Latex of Papaya contain enzyme papain (digestive enzyme)
- Insectivorous plant digest insect to obtain nitrogen from their chitinous exoskeleton.

Plant Tissue System

- Plant tissues are divided into three main tissue systems (by Sachs):
  1. Epidermal tissue system.
  2. Fundamental or ground tissue system.
  3. Vascular or fascicular tissue system.

The Epidermal Tissue system

Epidermis:

- Forms the outer covering of the plant. It is in direct contact with the external environment.
- Generally uniseriate (single layer) and living, but multilayered and dead epidermis (=velamen) is present in epiphytic root of *Vanda.*
- Epidermal cells do not contain chloroplasts except shade plants, water plants and some ferns.
- Epidermal cells may have deposition of **cutin** or **suberin.**
- Epidermal cells in some monocot leaves, become larger thin-walled, having vacuoles and are called **bulliform** (bubble-like) **cells.** These cells bring about rolling of leaves during dry season. [BPKIHS 2002]
- Root epidermis is termed as epiblema or rhizodermis or piliferous layer, which develop unicellular root hairs in the zone of maturation. [KU 2010]
- Epiblema does not have cuticle.

Stomata**:**

- Minute apertures in the epidermis. Each aperture is bounded by two kidney shaped cells, called **guard cells.** Stomata are absent in roots.

- In xerophytes the stomata are sunken in grooves due to which rate of transpiration is greatly reduced.
- In monocots, guard cells are dumb-bell shaped while in dicots, they are kidney or rennin shaped.
- Guard's cells are living and have chloroplasts (only epidermal cell with chloroplasts).
- In dicotyledons leaves stomata are scattered but in monocotyledons they are arranged in straight rows. In bifacial (dorsiventral) leaves, stomata generally occur on the lower epidermis and only a few occur on the upper epidermis.
- In sub erect (isobilateral) leaves of monocotyledons they are found in equal numbers on both the surface of leaves.
- In floating leaves stomata are found on upper epidermis only. In submerged plants they are vestigial.
- The function of stomata is exchange of gases and control of transpiration.

Trichomes:

- Represents various unicellular and multicellular appendages that originate from epidermal cells. [KU 2006]
- **Unicellular in root and multicellular in stem.**
- **T**richomes serve for checking excess loss of water and for protection.

Ground (Fundamental) Tissue System

- Tissue that do not come under epidermal tissue system or vascular (fascicular) tissue system are regarded to constitute the fundamental or the ground tissue system. It constitute the main body of plant.
- Except monocot stems where vascular bundles are scattered throughout ground tissue, all dicot stems and roots exhibit clear differentiation of the ground tissue into an outer cortex and central pith.

Hypodermis:

- One or more layered continuous tissue below the epidermis.
- Collenchymatous in dicot stem while in grasses and xerophytic stems, it is sclerenchymatous.
- Absent in root

Cortex:

- It may be few to many layered in thickness.
- Cells are thin-walled and parenchymatous and may be rounded or polygonal or cylindrical.
- Cells have prominent intercellular spaces.
- General cortex provides mechanical support and stores food material.

Endodermis (=Starch sheath) :

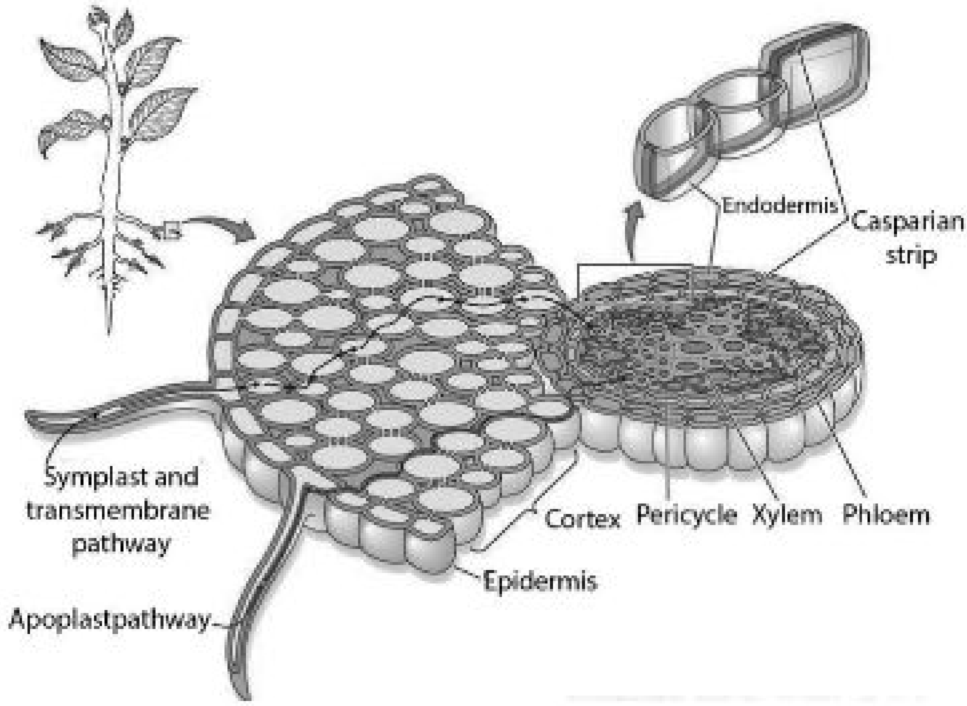


Figure: T.S. of dicot root showing endodermis

- Endodermis is the border between cortex and stele.
- It is a single layer made up of compactly arranged living cells.
- Cells of endodermis are **barrel shaped,** without intercellular space.
- A special thickened band is present on radial and tangential walls of endodermal cells. This is called **casparian strip, which** made up of lignin, suberin and cutin. [NEET 2018]
- A distinct endodermis is a constant feature of roots of all plants but in stem.
- In roots, thick-walled endodermal cells are interrupted by thin-walled cells just outside the protoxylem patches called **passage cells** or transfusion cells.
- Passage cells help in passage of water from cortex to xylem.
- Endodermis acts as a water dam between vascular and non-vascular regions.

Pericycle:

- It is the outermost layer of stele. [IOM 2008]
- It is thin-walled parenchymatous or sometimes thick-walled sclerenchymatous tissue.
- May be single layer or multi-layer.
- In Sunflower, the pericycle is composed of alternating bands of thin-walled and thick-walled cells (heterogenous pericycle).
- In dicot roots the pericycle cells become meristematic and forms part of the cambium ring.
- In angiosperms pericycle give rises to lateral roots so they are endogenous in origin. [IE 2009]

Medulla or pith**:**

- It occupies the central part in dicot stem and dicot and monocot roots.
- It is generally composed of large parenchymatous cells.
- Extensions are called **pith rays** or **medullary rays.**

Vascular (Fascicular) Tissue System

- Central cylinder of the shoot or root surrounded by cortex is called stele. The varying number of vascular bundles formed inside the stele constitute **vascular tissue system.**
- Each vascular bundle is made up of xylem and phloem with or without cambium.
- Vascular bundles in dicotyledonous stem and in roots of dicots as well as monocots are arranged in a ring while in monocotyledonous stem they are scattered in general ground tissue.

Types of vascular bundle:

1. **Radial**: Separate and alternate strands of phloem and xylem present on different radii.
   - Present in Roots. @ [Radial = Root]
2. **Conjoint**: Xylem and phloem are united and are present on the same radius, e.g. Stem.
   i. **Collateral**: Xylem lies towards the inner side and phloem towards the periphery.
      - Open type: Cambium is present between xylem and phloem, e.g. Dicot stem.
      - Closed type: Cambium is absent, e.g. Monocot stem. [MOE 2058, NEET 2011]

   ii. **Bicollateral**: There are two patches of phloem one on each side of xylem, e.g. stem of Cucurbitaceae. [KU 2000, IOM 2007]
3. **Concentric**: Either xylem surrounds the phloem or phloem surrounds the xylem.
   i. Amphicribral (hadrocentric): The xylem is surrounded by phloem *e.g. Hydrilla,* Rhizome of Ferns. @ [Am ph icri ba l= Ph loem ba hira] [KU 2014]

   ii. **Amphivasal** (leptocentric): The phloem is surrounded by xylem. *e.g.* stems of *Dracaena* and *Yucca. @ [Am ph ivasal= Phloem vitra]*

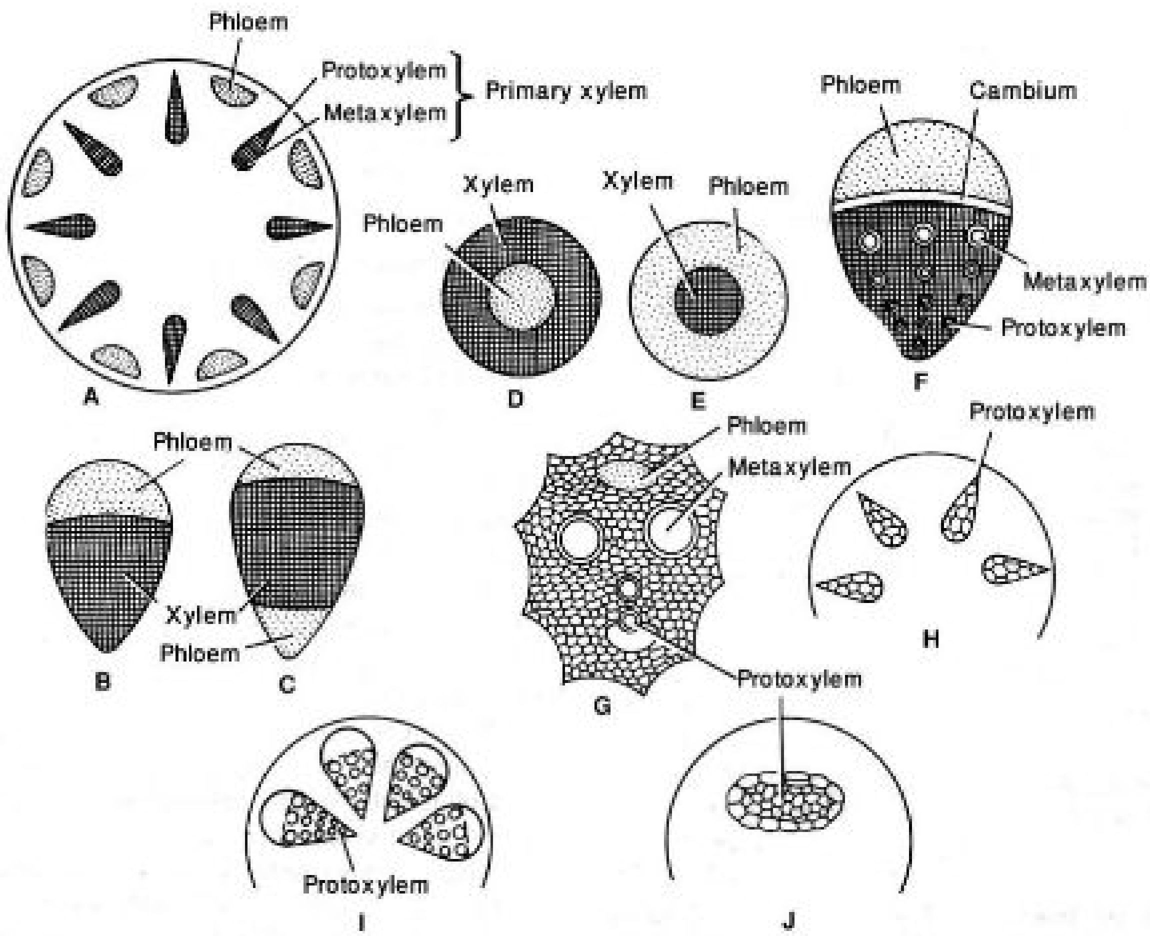


Figure: Different types of vascular bundles A. Radial B. Conjoint collateral C. Conjoint bicollateral D. Amphivasal, E. Amphicribal F. Open VB G. Closed VB H. Hexarch or centripetal xylem I. Endarch or centrifugal xylem J. Mesarch xylem

Internal structure of Dicot and Monocot stem:

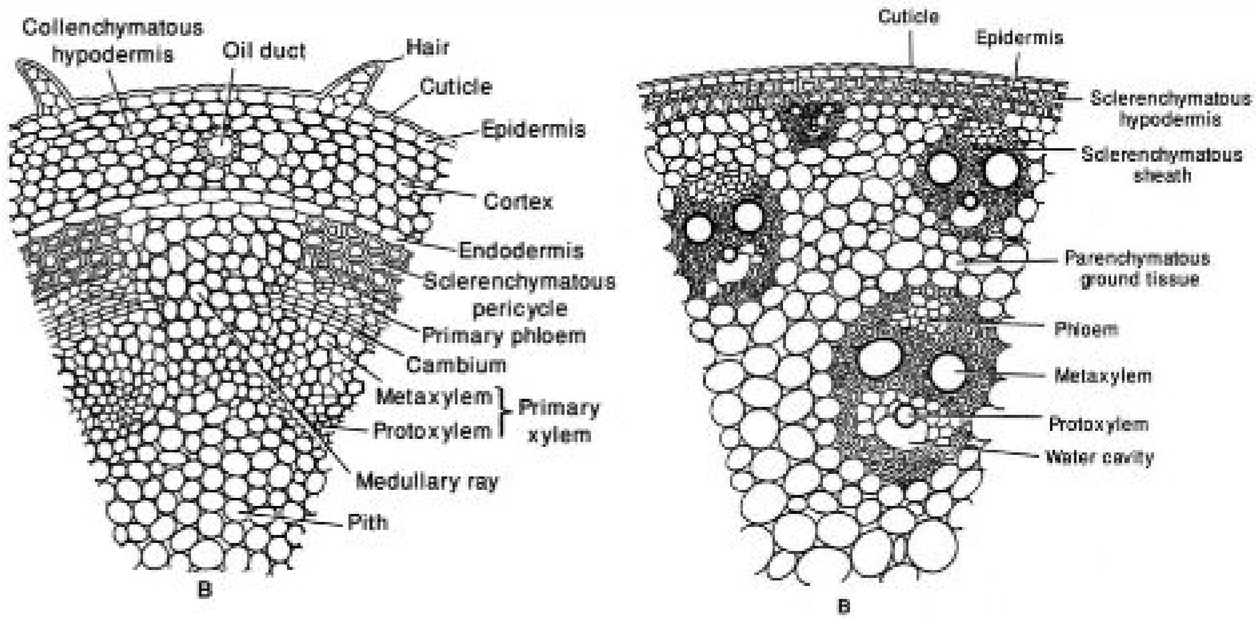


Figure: Anatomy of Monocot stem and Dicot stem

	Dicot stem	**Monocot stem**
1. Epidermis:	• Multicellular hairs are present. • Cutinised	• Hairs are generally absent. • Cutinised
2. Hypodermis:	• **Collenchymatous**	• **Sclerenchymatous**
3. Ground tissue system:	• Differentiated into hypodermis, general cortex, endodermis, pericycle, pith. etc	• Not differentiated into cortex, endodermis and pith.
4. Stele:	• Dictyostele or Eustele	• **Atactostele (most advanced** type) **[IOM 1998]**
5. Vascular bundles:	• Conjoint, collateral and open type • Xylem is **endarch. @ SEnd- Stem; Endarch.** • No. is **2-6 (diarch to hexarch)** and arranged in the form of **ring** around pith. • Wedge or V-shaped • Bundle sheath is absent. • Phloem parenchyma present • Protoxylem cavity is absent • Vessels are arranged in rows of chains, *ie,* in linear manner.	• Conjoint, collateral and closed. • Xylem is **exarch**. • No. is **8-many (Polyarch)** and are **scattered** throughout the ground tissue • Oval shaped. **@MO**nocot- **M**any and **O**val shaped. • Enclosed within a **sclerenchymatous bundle sheath.** • **Phloem parenchyma is absent.** • **Protoxylem cavity is present.** • **Vessels are arranged in Y**-shaped manner

	Dicot stem	Monocot stem
6. Pith:	• Present	• Absent
7. Sec. growth	• Present	• Absent except Yucca, Agave & Aloe

Internal structure of root:

Important characters of both dicot and monocot roots:

- Vascular bundle is radial with exarch xylem.
- Distinct endodermis and passage cells.
- Lateral roots arise opposite the protoxylem points from pericycle, *ie*, endogenously.

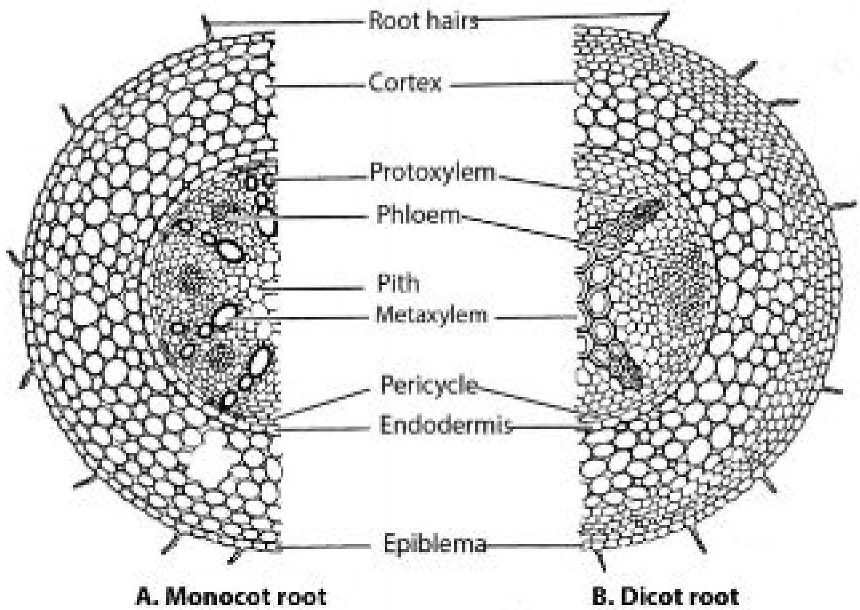


Figure: T.S. of Root

- Difference between anatomy of dicot root and monocot root are:

	Dicot Root	Monocot Root
1. Cortex	• Narrow	• Very wide
2. Cork	• Epiblema, cortex and even endodermis are peeled off and replaced by cork.	• Corks not formed. Only epiblema is peeled off, cortex and endodermis persist
3. Endodermiss	• Less thickened and **casparian stripes are more prominent [NEET 2018]** • Passage cells are generally absent	• Casparian stripes are visible only in young roots. Endodermal cells later become highly thickened. • Passage cells generally occur in endodermis opposite to protoxylem
4. Pericycle	• Produces lateral roots, cork cambium and vascular cambium	• Produces lateral roots only

	Dicot Root	Monocot Root
5. Vascular bundles	• Xylem and phloem bundles are **diarch to hexarch (*ie.* 2 – 6)** • Conjunctive tissue is parenchymatous • Conjunctive parenchyma forms the cambium	• Xylem and phloem bundles are **polyarch *i.e.,* > 8.** • Conjunctive tissue may be parenchymatous or sclerenchymatous • Conjunctive parenchyma does not form the cambium
6. Pith	• Pith small or absent	• Pith is well developed
7. Secondary growth	• Secondary growth present	• Absent

Difference between Anatomy of Root and Stem:

	Stem	Root
1. Epidermis:	• Have outer cutinized walls • Protective in function • Stomata are present • Stem hairs: - Do not arise as outgrowth of epidermal cells. - Generally **multicellular** - Spreads all over the stem - **Heavily cutinized** - **Reduce loss of water**	• Functional epiblema is without any cuticle or cutinized outer walls. • Absorptive in function • Absent • Root hairs: - Arise as tubular outgrowths of epidermal cells - **Unicellular** - Found in clusters in root hair zone - **Not cutinized** - Helps in absorption.
2. Hypodermis:	• Collenchymatous (dicot) or sclerenchymatous (monocot) hypodermis present	• Hypodermis absent. In some cases, thick walled exodermis present
3. Cortex:	• Cortex is narrow	• Cortex is broad
4. Pericycle:	• Pericycle when present is usually multilayered • Does not take part in the formation of branches and secondary growth	• Pericycle is commonly 1-2 layered • Takes part in the formation of root branches and secondary growth
5. Vascular bundles:	• Vascular bundles are **conjoint** and **collateral** • Xylem is **endarch**	• Vascular bundles are **radial** • Xylem is **exarch**
6. Secondary growth:	• Secondary growth when present is by cambium which is mostly intrafascicular	• Secondary growth when present arises from conjunctive parenchyma and pericycle

Anatomy of leaf:

- In dicots is dorsiventral and monocot leaf isobilateral.

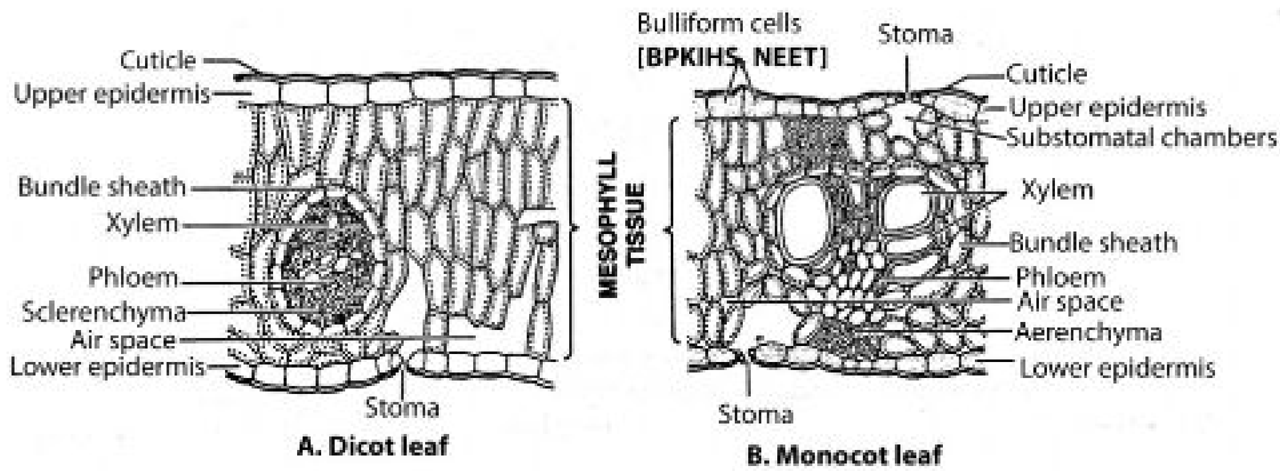


Figure: T.S. of leaf

- Leaf has upper and lower epidermis, mesophyll and vascular bundle.

	Dicot leaf	Monocot leaf
1. Epidermis:	• Deposition of cuticle is thicker in upper than in lower epidermis. • **Bulliform or motor** cells absent • **Hypostomatic,** i.e., no of stomata are maximum in lower surface and few on upper surface. • Stomata guarded by **kidney**-shaped guard cells	• Deposition of cuticle is same in both surfaces. • Bulliform or motor cells present. **[BPKIHS, NEET]** • **Amphistomatic** i.e. no of stomata are equal on both surface. • Stomata guarded by **dumb bell s**haped guard cells
2. Mesophyll tissue:	• Divided into upper tightly packed **palisade parenchyma** and lower loosely arranged **spongy parenchyma.** • Bundle sheath cells are colourless.	• Not differentiated into spongy and palisade parenchyma. • Bundle sheaths are green and help in C_4 cycle. This type is known as **Kranz anatomy**
3. Vascular bundles:	• Conjoint, collateral with mesarch xylem • Inverted vascular bundles, *i.e.*, xylem in the upper part and phloem in the lower part.	• Conjoint, collateral with mesarch xylem. • Inverted vascular bundles, *i.e.*, xylem in the upper part and phloem in the lower part.

Secondary Growth:

- Increase in diameter (girth) of the axis (shoot and root) **due to formation of new tissues as a result of activity of lateral meristems, i.e., intrastelar cambium (=vascular cambium) and extrastelar cambium (=cork cambium=phellogen) is called secondary growth.**
- Present in dicots & gymnosperms.
- Absent in monocot (due to the lack of vascular cambium), however, abnormal secondary growth takes place in some monocot stems, *e.g. Dracaena, Yucca.*

❖ **Stelar secondary growth** results in the formation of secondary xylem and secondary phloem, **cortical secondary** growth results in the formation of protective periderm.

SECONDARY GROWTH IN DICOT STEMS

Stellar secondary growth

❖ **Formation of cambium Ring:**
  - A typical dicot stem has conjoint collateral, open vascular bundles arranged in a ring.
  - Fascicular or intra fascicular cambium is present in between the xylem and phloem.
  - Some medullary ray cells become active forming **inter fascicular cambium. [NEET 2013]**
  - Inter fascicular and intra fascicular cambia join together forming a **ring of cambium**.

❖ **Formation of secondary tissues by stelar cambium** (=Vascular cambium):

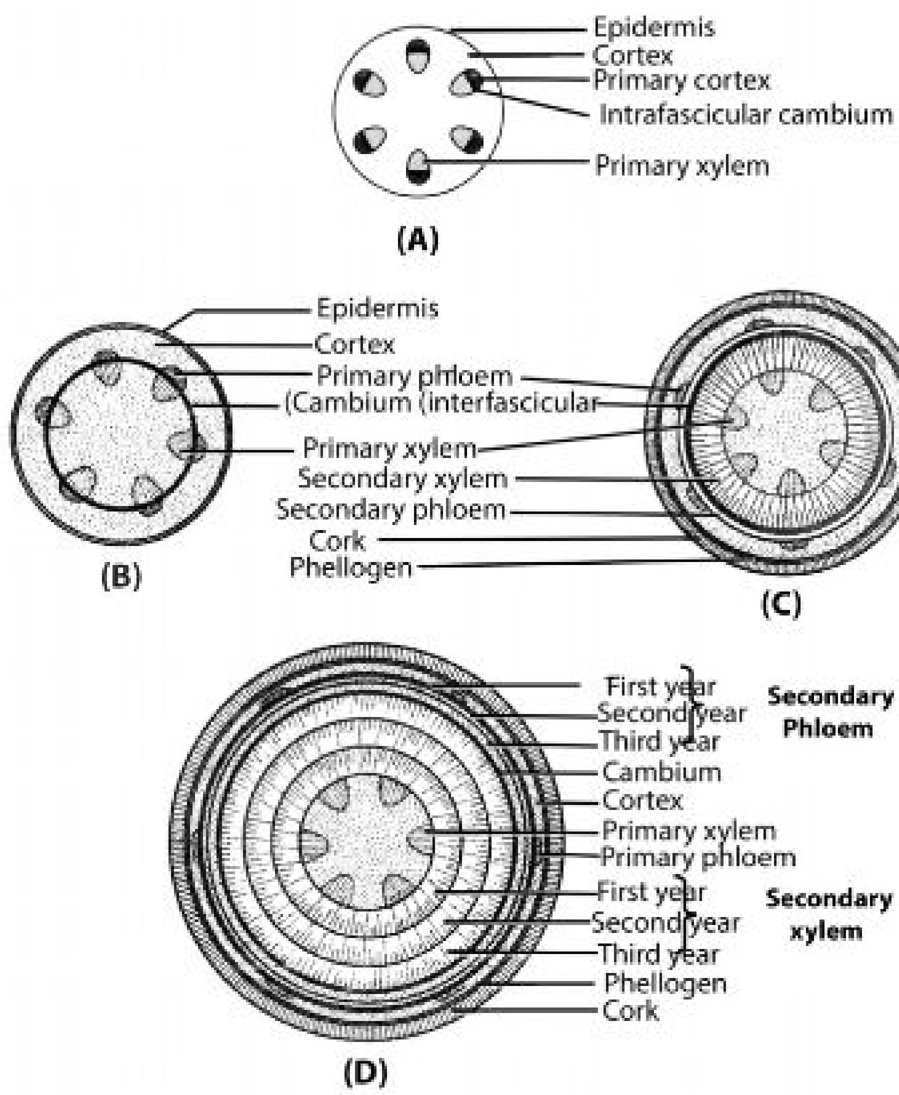


Figure: Stage of secondary growth in dicot stem:

A. Primary structure, B. Formation of cambial ring,

C. Formation of secondary xylem and secondary phloem **[NEET 2018]**

  - Cambial cells are of two **types-fusiform initials** and **ray initials.**
  - **Fusiform initials** form vascular elements, *i.e.,* tracheids, vessels, fibres, sieve tubes.
  - **Ray initials** give rise to parenchyma cells, all or most of which elongate in the horizontal direction forming vascular rays, which extend both inwards (xylem rays) and outwards (phloem rays).

- Of the two cells formed in this way one daughter cell remains meristematic while the other daughter cell becomes permanent.
- Permanent cell formed on the outer side will develop into **secondary phloem** and inner side will develop into **secondary xylem. [NEET 2017]**
- Cambium ring is more active towards inner side so more secondary xylem cells are formed towards the centre due to which the cambium ring moves towards the periphery.
- Due to newly formed secondary xylem and secondary phloem, the primary xylem and primary phloem which were near to one another earlier, get separated far apart.

Annual rings (growth rings):

- There is a marked difference in activity of cambium with change in season.

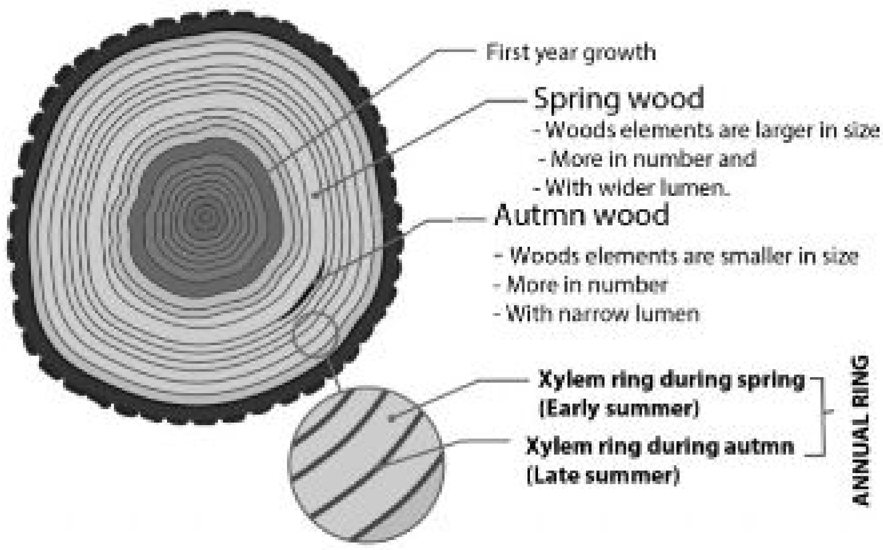


Figure: Annual ring

- In **spring,** the activity of cambium is **more** and hence the woods elements are larger in size, more in number and with wider lumen.
- Secondary xylem or woods formed during spring is called **spring woods**.
- Activity of cambium is **less** during **winter** or **autumn** and the woods elements are smaller in size, lesser in amount and with narrow lumen.
- Woods formed during winter or autumn is called **winter or autumn woods**.
- In a transverse section of the stem; these two types of wood appear in the form of distinct concentric circles known as **annual rings**
- Spring woods + Autumn woods of a year constitute Annual ring.
- Annual rings are conspicuous in temperate (cold) regions. **[IOM 2012, NEET 2019]**
- **The** age of tree can be determined by counting annual rings in **oldest or basal portion of** tree trunk. **Calculation of age of** the tree by **counting annual rings** is called **Dendrochronology.[NEET 2013]**
- In some woody trees, *e.g. Tilia, Dalbergia sissoo* the vessels in the spring wood are large and arranged in a ring and narrow vessels of the autumn wood are scattered such a wood is said to be **ring porous.**
- In *Eugenia jambolana* and Rose, the vessels are more or less uniformly distributed throughout the spring wood and autumn wood. Such a wood is called **diffuse porous wood.**

Heart woods and sap woods

- Heart wood is the **central hard**, **tough** and **darker region** in perennial woody trees.
- Heart wood is hard and tough due to deposition of **resins, tannins, gums** and **formation of tyloses.**

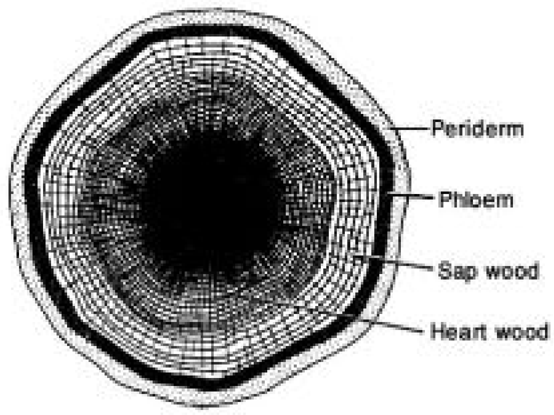


Figure: Heart wood and sap wood in T.S. of old dicot stem

Quick Digest:

- With the passage of time and addition of new outer rings of secondary xylem more rings of the sap wood are changed into heart wood whereas the sap wood remains of about the same thickness. **[MOE 2056, BPKIHS 2001]**
- Tyloses are **balloon-like** structures which are produced due to ingrowth of adjacent xylem parenchyma cells into the lumen of xylem vessels **through pits. [IOM 2005]**
- Bark of Cinchona is source of Quinine (antimalarial drug)
- Heart wood of Hematoxylon is source of Hematoxylin (a nuclear dye)
- Heart wood of Acacia catechu is source of cutch (katha) used in coloring clothes and paan.

- Conduction function of heart woods stops due to formation of tyloses in vessels and hence heart woods is **mechanical in function. [NEEt2017]**
- **Sap wood** or **alburnum** is the outer, soft and lighter portion of the trunk.
- Sap wood performs the function of conduction of water and minerals.

Cortical secondary growth

- As a matter of fact cortical secondary growth is the consequence of stelar secondary growth because latter causes rupture of epidermis and hence **periderm** formation become essential.

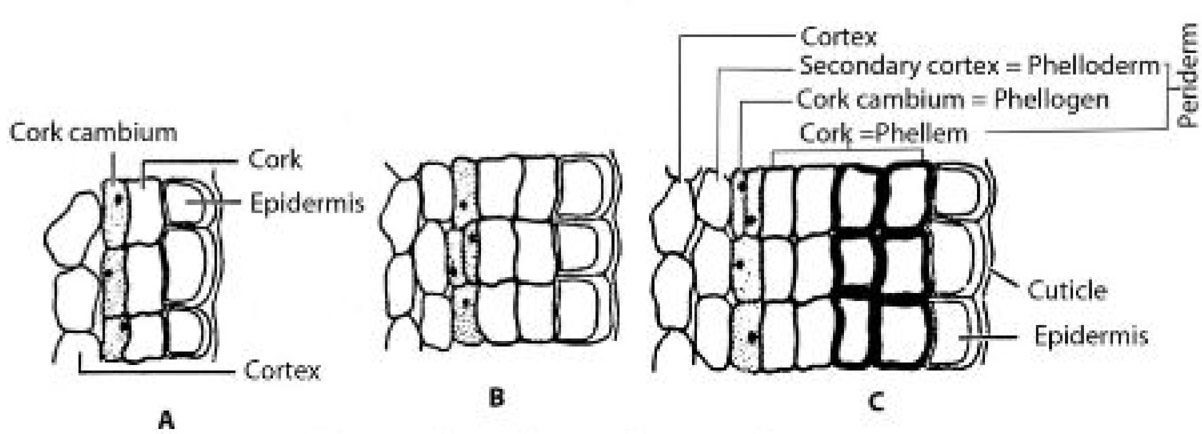


Figure: Cortical secondary growth

- **Periderm is made up of three tissues.**
  1. **Phellogen** (=Cork cambium): It is a secondary lateral meristem that may arise from hypodermis or outer cortex. **[IE 2008]**
     - Composed of a single layer of meristematic cells.
     - Divide in a tangential plane cutting cells towards its inner as well as outer face.
  2. **Phellem** (=Cork): **[IE 2009, NEET 2017]** These cells are formed as a result divisions of phellogen cells towards the outer face.
     - Cell walls become thick due to deposition of **suberin. [BPKIHS 2004]**
     - It is impervious to water.
  3. **Phelloderm** (=Secondary cortex): Layers of thin walled cells cut-off towards the inner side of the phellogen form phelloderm.
- **Bark:** All tissues outside the vascular cambium constitute the bark.
- Bark is a loose term and is used to define all the **tissues, outside vascular cambium.**
- **Bark** = Periderm + Cortex + Pericycle + Primary and secondary phloem
- **Rhytidome (**outer bark) consists of outer, dead portion of bark outside the cork cambium.

Secondary growth in dicot root

- Cambium is completely secondary in origin.
- Conjunctive tissue beneath each phloem becomes meristematic tissue to produce cambium opposite each phloem.
- Pericycle underlying xylem produces new cells of cambium behind xylem.
- All these patches of cambium join to form a wavy cambium ring (vascular cambium ring).
- This cambium ring produces secondary xylem inwardly and secondary phloem outwardly **[NEET 2018, IOM, MOE, BPKIHS, IE]**
- Cork cambium on the other hand is totally formed by pericycle.
- Cork cambium produces little amount of secondary cortex inwardly and cork cells outwardly.
- Differences in Secondary Growth in Dicot Stem and Dicot Root:

Dicot Stem	Dicot Root
1. Vascular cambium is in the circular or ring form	1. Vascular cambium is wavy in early stages
2. Vascular cambium is made up of both primary (intrafascicular) and secondary (interfascicular) strips of meristematic tissue	2. Vascular cambium is secondary in origin. It is formed of conjunctive parenchyma and pericycle
3. Vascular rays are narrow from the beginning	3. Initially, vascular rays are wide and arise opposite protoxylem points
4. Annual rings are quite common	4. Absent
5. Phellogen arises from superficial layer of the cortex	5. Phellogen usually originates from the pericycle