COURSE TITLE: WOOD ANATOMY

COURSE No. : FPR-121

CREDITE HOURS : 3(2+1)

COURSE CONTENTS

Sl. No.	TOPIC
1.	Introduction to wood anatomy. Classification of plant kingdom, Gymnosperms versus angiosperms. Kinds of woody plants.
2.	The plant body ; a tree and its various parts. Meristems, promeristem, primary meristem, secondary meristem, apical and intercalary meristems.
3.	Simple tissues – Parenchyma, collenchyma, sclerenchyma and the vascular tissues.
4.	Parts of the primary body; typical stems and roots of dicots and monocots
5.	Secondary growth in woody plants.
6.	Mechanism of Wood formation in general, and with special reference to typical dicot stem.

COURSE CONTENTS

Sl. No.	TOPIC
7.	Ray initials and fusiform initials; anticlinal and periclinal division.
8.	Physiological significance of wood formation. (Formation of early and late wood, Growth rings, Transformation of sapwood to heartwood).
9.	Macroscopic features of wood, sapwood ,heart wood, pith, early wood, late wood, growth rings, wood rays etc.
10.	Sapwood versus heart wood, anatomocal differences. Transformation of sapwood to heart wood; factors affecting transformation.
11.	Microscopic feature of wood.
12.	Prosenchymatous elements, tracheids, vessels, fibers. Parenchymatous elements, parenchyma and rays, resin canals, gum canals, latex canals, infiltrants in wood.
13.	Three dimensional features of wood; transverse, tangential and radial surfaces. Elements of wood cell walls.
14.	The structure and arrangement of simple pit, bordered pits. Extractives in wood.

COURSE CONTENTS

Sl. No.	TOPIC
15	Comparative anatomy of gymnosperms and angiosperms.
16	Anatomical features of common Indian timbers; classification into porous and non-porous woods, ring porous and diffuse porouswoods.
17	Effect of growth rate on wood properties. Juvenile wood and mature wood.

PRACTICAL	
1	Study of primary growth in stems of typical dicot and monocots.
2	Study of wood formation in typical dicot stem
2	Study of vascular bundles in monocots
3	Parts of the logs (woody trunks), and three distinctive surfaces of wood (i.ecross,radial and tangential planes)
4	Timber identification and its importance. Procedures for field identification of timbers.
	Study of physical features of wood, pores or vessels, different types.
5	Study of anatomical features of different types of wood pores/vessels; differen types.
6	Study of soft tissues in timbers and their different types distributions.
7	Study of wood rays and their types.
8	Study of non – porous wood, their physical and anatomical description.
9	Study of infiltration and inclusions in wood.
10	Anatomical keys and methods to use them. Dichotomous keys, punched card keys and computer aided identification. Field identification of important timber species.

BOOKS:

1. Botany (For degree Students): By A C Dutta.
2. Plant Anatomy: By A Fahn
3. Biology Botany : By Dr Mujeera Fahima, Nalini P Rajagovindan and N Shantha
4. Principles of Wood Science & Technology Vol. I- Solid Wood By Franz F.P. Kollmann & Wilfred A.
5. Guide to Plant Anatomy By Ratikant Mati, Dasari Rajkumar and Allam Ramaswamy

BOOKS:

6. Field Identification of Fifty Important Timbers of India By K. Ramesh Rao and KBS Juneja

7. Indian Forest Utilization Vol.-I & II , Complied and written Forest research Institute & College, Dehradun.

8. A Hand book Forest Utilization By Tribhawan Mehta

9. A textbook of Plant Anatomy By Dr. PC Vasisht

- The study of gross internal structure of plant organs by the technique of section cutting is called anatomy .

- The term anatomy was derived from two words ‘ ana’ means as under and ‘temmein’ meaning to cut.

- Anatomy is the branch of science which deals with internal structures and organization of the organism. It is also known as internal morphology. Plant anatomy also describes tissue and tissue systems of the plant body.

HISTORY/INTRODUCTION OF PLANT ANATOMY

DATE	INVESTIGATOR	MAJOR CONTRIBUTIONS	CONCEPTS
369 -262BC	**Theophrastus of Eresus** "Father of Botanical Science" Greek Philosopher	Descriptive morphology of types of organs, relation of organ to organ, and of type of organ to type of organ. Described gross internal anatomy of stems, roots, and leaves.	Recognized normal sequence of root, stem, branch, leaf, flower, and fruit in trees. Plants are made up of bark (phloios), wood (zylon), and pith (metra), when pith is present.
1519 - 1603	Andrea Caesalpino Italian Philosopher	Initiated idealistic morphology in studies on plant "souls".	Postulated canals for conduction. Observed that roots lack in pith.
1635 - 1703	Robert Hooke English mathematician & architect	Examined many objects with newly invented magnifying lens. (*Micrographica*. 1665).	Cell coined in reference to cavities in cork cambium and charcoal.
1628 - 1694	Marcello Malpighi Italian physician and professor	Searched independently of Grew for similarities between structures of animals and plants.	Discovered Spiral Vessels and Stomata.

1641 - 1712	Nehemia Grew "Founder of Plant Anatomy" English physician	Presented classification of plant tissues as consisting of two different "bodies" (woody parts, strings, and fibers vs. barques, piths, parenchymas, and pulps). Recognized vertical and horizontal systems of tissues. Described secondary growth of bark and wood. *The Anatomy of Vegetables Begun.* 1672.	"...Parenchyma of the Barque is much the same thing, as to its conformation, which the Froth of Beer or Eggs is, as a fluid..." Vessel coined in reference to spiral vessels.
1632 - 1723	Antony van Leeuwenhoek Dutch		Described pitted vessels.
1700 - 1781	Du Hamel French Arboriculturist		Coined Cambium in reference to gelatinous generative zone in the inner cortex.
1733 -1794	Caspar Friedrich Wolff German	Theorized that tissue is a homogeneous matrix filled with bubbles, as is rising dough.	

1776 - 1854	Charles Francois Mirbel French	Elaborated Wolff theory. Theorized that new cells appear in a homogeneous matrix as cavities with openings between them for the passage of sap.
1766 - 1833	Kurt Sprengel	Opposed Mirbel's theory. Proposed new cells arise within the contents of old cells as small vesicles (starch grains?) that get larger by uptake of water.
1779 - 1864	Ludolph Christian Treviranus	Discovered vessels formed by disappearance of cross-walls between series of cells. Observed development of spiral thickenings in protoxylem.
1774 - 1850	Johann Jakob Bernhardi	Discovered annular thickenings in vessels. Observed primary wall binding annular and spiral thickenings together. Recognized that vessel elements don't metamorphize.

1766 - 1827	Johann Jakob Paul Moldenhawer	Demonstrated each cell had its own wall, so cavities are separated by two walls.	
1773 - 1858	Robert Brown	Cell anatomy	Discovered cell nucleus (1831)
1804 - 1840	Franz Julius Ferdinand Meyen	Suggested new cell arise through cell division rather than free cell formation.	
1805 -1872	Hugo von Mohl	Proposed that the vacuolated body (primordial utricle) within the cell wall was the living component. Proposed cell wall thickening occurs by apposition.	Coined term protoplasm in reference to cell contents. Described relation of primary and secondary cell wall layers and nature of pits.
1805 - 1880	Theodor Hartig		Discovered sieve tube and its perforated nature in phloem.
1804 -1881	Matthias Jacob Schleiden	Studied protoplasm of plants.	

1810 - 1882	Theodor Schwann	Studied protoplasm of animals.	The Cell Theory (1838) there is one universal principle of development for the elementary parts of organisms, however different, and that this principle is the formation of cells.
1817 - 1891	Wilhelm von Nageli	Studied ontogeny of apical meristems. Distinquished primary and secondary meristems. Proposed cell wall thickening occurs by intussusception.	Described development of vascular bundles from procambial strands. Applied terms xylem and phloem to different parts of vascular bundle.
1832 - 1891	Carl Sanio Prussian school teacher	Described how vascular cambium originates and functions. Described secondary development of periderm.	Described details of bordered pits.
1822 - 1880	Johannes von Hanstein	Proposed theory of histogen apical meristem organization.	Dermatogen Periblem. Cal

1831 - 1888	Heinrich Anton De Bary mycologist	Demonstrated Hanstein's histogens could not be universally applied and lacked morphological value.	
1832 - 1897	Julius von Sachs	Proposed first physiological classification of plant tissue that were derived from uniform meristem.	Epidermal. Fibrovascular. Fundametal.
1884	Gottlieb Haberlandt	*Physiologische Pflanzenanatomie.* . Grouped tissues according to functional systems, disregarding morphological classification and arrangements.	
1924	Schmidt	Proposed method of apical organization on basis of planes of cell division.	Tunica. Corpus. Kappe.
1943	Foster.	Proposed zones of growth description of gymnosperms apical meristems.	Apical Initials. Mantle Layer. Central Mother Cell Zone.
1961	Clowes.	Described quiescent center in root apical meristems.	

CLASSIFICATION OF PLANT KINGDOM

- Arrangement of plants and animals into groups according to their close resemblance, naming and describing them is called classification. Classifying the plants into groups is called systematic botany.

- The main aim of classification is to name the plant to describe them and to bring out their resemblances in order to throw light on their relationship and common ancestor. It is to indicate primitive and advanced plants systematically.

Need for Classification

It is not possible for any one to study all the organisms. But if they are grouped in some convenient way the study would become easier as the characters of a particular group or a family would apply to all the individuals of that group. Classification allows us to understand diversity better.

Classification of plants:

Entire plant kingdom is divided into four main groups.

1. Thallophyta 2. Bryophyta 3. Pteridophyta 4. Spermatophyta or Phenerogams

1. THALLOPHYTA:

- These are simplest and primitive unicellular or filamentous (thread like) plants.
- They are green as well as non green and their body is not differentiated into root stem and leaves. Such a plant body is called thallus and hence is the name of the group. It consists of three sub-groups:-

  a) Bacteria b) Algae c) Fungi

a) BACTERIA:

- These are minute microscopic unicellular, non-green round or rod like structures. They are either saprophytes or parasites.
- They are harmful because they cause many diseases of plants and animals.
- They are useful also in industries such as alcohol and vinegar production in tea, leather and dairy industries. Reproduction is by spores e.g. *Bacillus* (Hay bacteria) and *Lactic bacteria*.

b) ALGAE.

- Unicallular (e. g. Chlamydomonas) or filamentous (Spirogyra) and ribbon like, many hundred feet in length (Laminaria).
- Algae may be green, brown or red. Reproduction is vegetative as well as sexual.

C) FUNGI.

- These are all non green plants and their thallus is called *mycellium* consisting of white threads called *hyphae*.
- Each hypha is a tube with protoplasm, vacuoles and many nuclei and oil drops.
- There is no chlorophyll. Mode of nutrition is *saprophytic* and thallus is saprophyte, i.e. it absorbs food material in solution form by its hyphae from dead and decomposed organic remains of animals and vegetables. Reproduction is a asexual by spores and sexual by *gametes*. Rhizopus, mucor.
- Some higher forms of fungi grow erecton soil with big stemlike structure. They are edible also e.g. Morchell (Guchhi) and Agaricus (Khumb)

2. BRYOPHYTA:

- They are land plants and plant body is thallus and green in colour being rich in chloroplasts.
- They are moisture and shade lovers and are found attached to substratum (rocks and banks of streams) by thread like structures called rhizoides. It has following two sub-groups.

a) LIVERWROTS:

They have flat thallus like the palm of hand. Dorsal side is green with vegetatively ventral side is pale yellow with rhizoids attached to substratum e.g. Marchantia and Riccia.

b) MOSSES:

They are plants with errect green leafy shoots. They can tolerate drought very well. Separate male and female shoots are present on the same plant. Reproduction is vegetative as well as sexual e.g. Funaria

3. PTERIDOPHYTA:

- These are land plants with well developed roots, stem and leaves. They are also shade and moisture lovers.
- They have tracheides for conduction of water. Some have underground stem called rhizome, others have erect aerial stem as in ferns.
- Many have stem creeping above the soil e.g. Selaginella. Some are aqatic plants e.g. water fern (Marsilea). Reproduction is vegetative by tubers as well as sexual.
- All the avobe mentiones three groups of plants are also called Cryptogams or non flowering plants.

4. SPERMATOPHYTA OR PHENEROGAMS:

i) This group of plants is very advanced group than all the non-flowering plants or crytograms because they bear flower and reproduce by seeds.

ii) They may be naked or enclosed in ovary

iii) Vascular system is advanced and contain well developed xylem and phloem. Xylem has tracheids (gymnosperm) and vessels (Angiosperm).

iv) They all have definite root stems and leaves and occurs in different habitats .

v) They are herbs, shrubs, or tall trees ,

vi) Methods of pollinations and sexual reproduction are complicated and advanced. They are divided into two groups.

a) GYMNOSPERM **B) ANGIOSPERMS**

a) GYMNOSPERM:

- The gymnosperms (*gymnos : naked, sperma : seeds) are plants in which* the ovules are not enclosed by any ovary wall and remain exposed, both before and after fertilisation.

- The seeds that develop post-fertilisation, are not covered, i.e., are naked. Gymnosperms include medium-sized trees or tall trees and shrubs. One of the gymnosperms, the giant redwood tree *Sequoia is one of the tallest tree species.*

- *The roots are* generally tap roots. Roots in some genera have fungal association in the form of **mycorrhiza *(Pinus), while in some others (Cycas) small specialised*** roots called coralloid roots are associated with N2- fixing cyanobacteria.

- The stems are unbranched (*Cycas) or branched (Pinus, Cedrus). The leaves* may be simple or compound.

- In *Cycas the pinnate leaves persist for a few* years. The leaves in gymnosperms are well-adapted to withstand extremes of temperature, humidity and wind.

- In conifers, the needle-like leaves reduce the surface area. Their thick cuticle and sunken stomata also help to reduce water loss.

- The gymnosperms are heterosporous; they produce haploid microspores and megaspores.

- The two kinds of spores are produced within sporangia that are borne on sporophylls which are arranged spirally along an axis to form lax or compact strobili or **cones.**

- **The strobili bearing microsporophylls and microsporangia are called** microsporangiate or **male strobili.**

- **The microspores** develop into a male gametophytic generation which is highly reduced and is confined to only a limited number of cells.This reduced gametophyte is called a **pollen grain.**
- **The development of pollen grains take place within** the microsporangia.

- The cones bearing megasporophylls with ovules or **megasporangia are called** macrosporangiate or **female strobili.**

- **The male or female** cones or strobili may be borne on the same tree (*Pinus).*

- However, in *cycas male*
- *cones and megasporophylls are* borne on different trees. The megaspore mother cell is differentiated from one of the cells of the nucellus.

- The nucellus is protected by envelopes and the composite structure is called an **ovule.**
- **The ovules are borne on** megasporophylls which may be clustered to form the female cones. The megaspore mother cell divides meiotically to form four megaspores.

- One of the megaspores enclosed within the **megasporangium** develops into a multicellular female gametophyte that bears two or more **archegonia or female sex organs. The** multicellular female gametophyte is also retained within megasporangium.

- Unlike bryophytes and pteridophytes, in gymnosperms the male and the female gametophytes do not have an independent free-living existence.

- They remain within the sporangia retained on the sporophytes. The pollen grain is released from the microsporangium. They are carried in air currents and come in contact with the opening of the ovules borne on megasporophylls.

- The pollen tube carrying the male gametes grows towards archegonia in the ovules and discharge their contents near the mouth of the archegonia. Following fertilisation, zygote develops into an embryo and the ovules into seeds. These seeds are not covered.

b) ANGIOSPERMS

- Unlike the gymnosperms where the ovules are naked, in the angiosperms or flowering plants, the pollen grains and ovules are developed in specialised structures called **flowers.**
- **In angiosperms, the seeds are enclosed by fruits.**
- The angiosperms are an exceptionally large group of plants occurring in wide range of habitats. They range in size from tiny, almost microscopic *Wolfia to tall trees of Eucalyptus (over 100 metres). They provide us with* food, fodder, fuel, medicines and several other commercially important products.
- They are divided into two classes : the **dicotyledons and the monocotyledons .**
- **The dicotyledons are characterised by** having two cotyledons in their seeds while the monocolyledons have only one.
- The male sex organ in a flower is the stamen. Each stamen consists of a slender filament with an anther at the tip. The anthers, following meiosis, produce pollen grains.

- The female sex organ in a flower is the pistil or the carpel. Pistil consists of an ovary enclosing one to many ovules. Within ovules are present highly reduced female gametophytes termed **embryosacs.**

- The embryo-sac formation is preceded by meiosis. Hence, each of the cells of an embryo-sac is haploid.

- Each embryo-sac has a three-celled **egg apparatus – one egg cell and two synergids, three antipodal cells and** two **polar nuclei.**

- **The polar nuclei eventually fuse to produce a diploid** secondary nucleus. Pollen grain, after dispersal from the anthers, are carried by wind or various other agencies to the stigma of a pistil. This is termed as pollination.

- The pollen grains germinate on the stigma and the resulting pollen tubes grow through the tissues of stigma and style and reach the ovule.
- The pollen tubes enter the embryo-sac where two male gametes are discharged.
- One of the male gametes fuses with the egg cell to form a zygote (syngamy). The other male gamete fuses with the diploid secondary nucleus to produce the triploid primary endosperm nucleus (PEN).
- Because of the involvement of two fusions, this event is termed as **double fertilisation,** an event unique to angiosperms.
- The zygote develops into an embryo (with one or two cotyledons) and the PEN develops into endosperm which provides nourishment to the developing embryo.
- The synergids and antipodals degenerate after fertilisation. During these events the ovules develop into seeds and the ovaries develop into fruit.

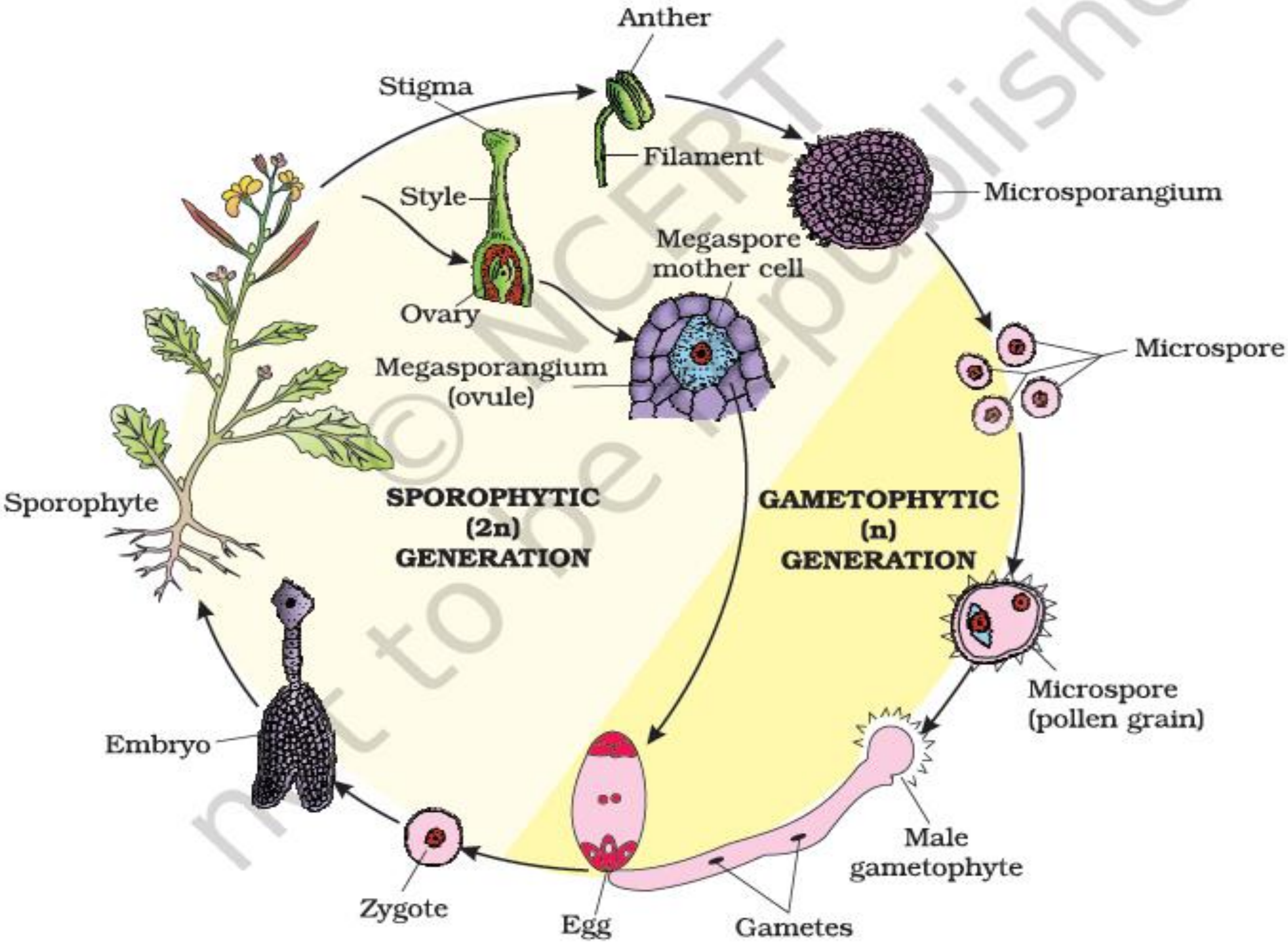


Figure 3.6 Life cycle of an angiosperm

KINDS OF WOODY PLANTS

A woody plant is a plant that produces wood as its structural tissue. Woody plants are usually either **trees**, **shrubs**, or **lianas**. These are usually **perennial** plants whose stems and larger roots are reinforced with wood produced from secondary xylem.

1) Trees:

A woody perennial plant, typically having a single stem or trunk growing to a considerable height and bearing lateral branches at some distance from the ground.

2) Shrubs:

Woody plants without a single main stem, occurring well below the forest canopy. For Examples *Lantana camera, Daphanae cannabina, Carissa carandus, Woodfordia spp* etc.

3) Linas :

- A **liana** is any of various long-stemmed, woody vines that are rooted in the soil at ground level and use trees, as well as other means of vertical support, to climb up to the canopy to get access to well-lit areas of the forest.

- Lianas are characteristic of tropical moist deciduous forests (especially seasonal forests), but may be found in temperate rainforests. There are also temperate lianas, for example *Clematis or vitis* ,*Calamus spp. Capparis spp, Dioscorea spp*

DEVELOPMENT OF PLANT BODY

- **A vascular plant begins in existence as a morphologically simple unicellular zygote (2n).**

- **The zygote develops into the embryo which in the long run develops into the mature sporophyte.**

- **The development of the sporophyte (2n) involves division and differentiation of cells and organization of cells into the tissue systems.**

- **The embryo of the seed plant possesses relatively simple structure as compared to the mature sporophyte.**

- **The embryo bears a limited number of parts containing generally only axis bearing one or more cotyledons.**
-
- **The cells and the tissues of this structure are less differentiated.**

- **However, the embryo grows further, because of the presence of the meristems, at two opposite ends of the axis, of future shoot and root.**

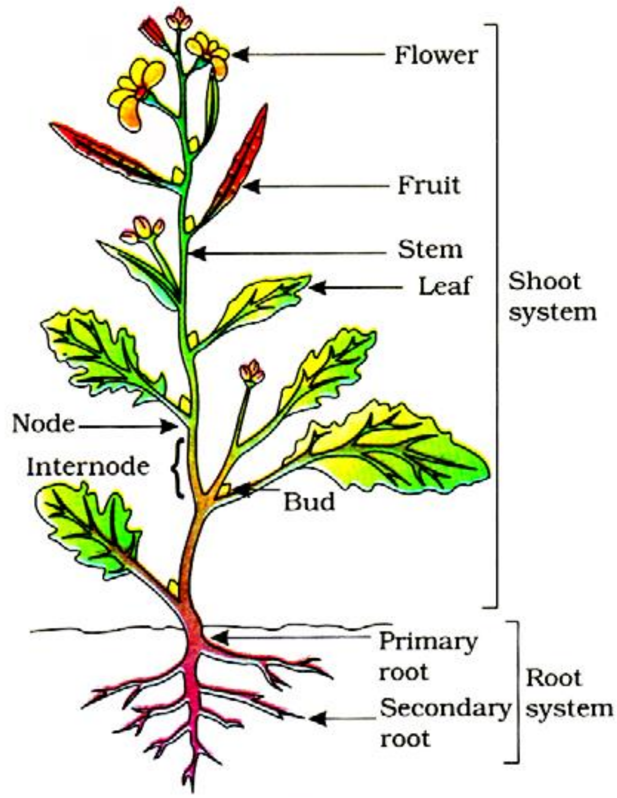
- **After germination of the seed during development of the shoot and root new apical meristems appear which cause a vegetative growth and reproductive stage of the plant attained.**

FUNDAMENTAL PARTS OF THE PLANT BODY

- The plant body consists of a number of organ *i.e.*, root, stem, leaf and flower. Each part has different functions for plant growth.

- Flower consists of sepal, petals, stamens, carpels and sometimes also sterile members. Each organ is made up of number of tissue systems; each tissue system consists of number of tissues.

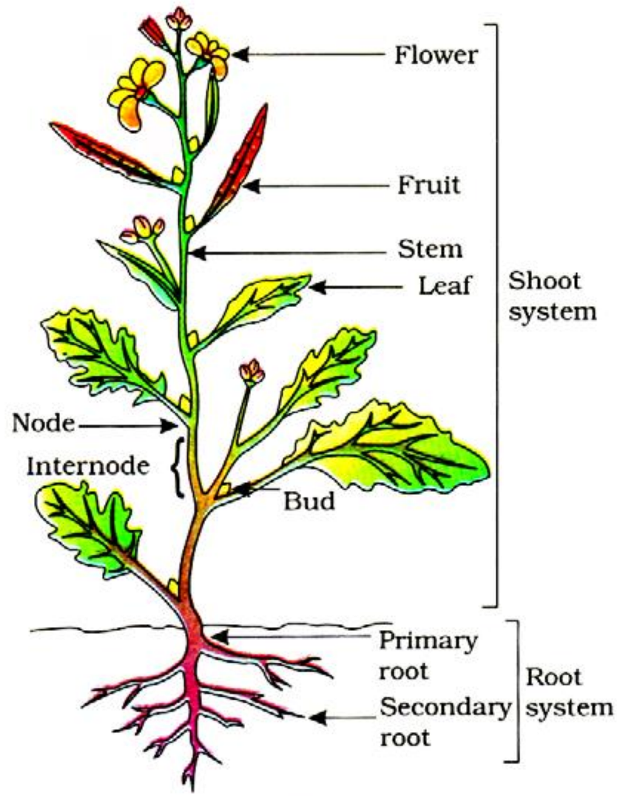
- Tissue consists of group of cells that are alike in origin, structure and function.



- The plant body consists of two main systems namely, root system and shoot system. Both of these systems have a common axis.

- Root system is generally underground and positively geotropic. Roots are non green brown in colour. They are not differentiated into nodes and internodes.

- The chief functions of root system includes fixation of the plant in soil, absorption of mineral water and conduction of mineral water to the root system.



- Shoot system is aerial part of the plant and it is negatively geotropic.

- Main axis of the shoot system is called stem. The stem bears branches, leaves, buds and flower etc. The stem is distinguished into nodes and internodes.

- The leaves develop over the stem at the nodes only. The part of the stem between two successive nodes is called internod.

- The main stem and its branches end with terminal bud or apical bud.
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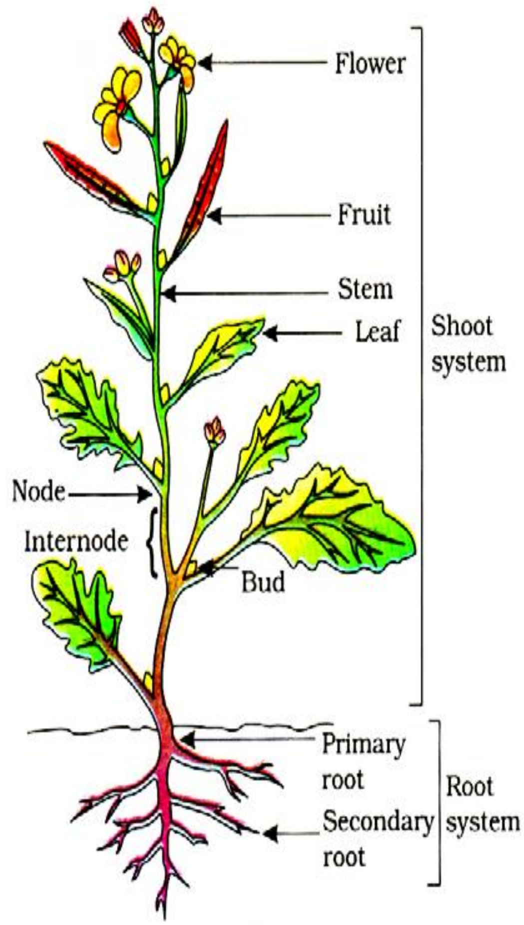
- The main functions of shoot system includes display the foliage by branches, conducts mineral water from the root system and food material to the root system, and gives mechanical strength to the plant body.



GROWTH OF THE PLANT BODY:

- The growth of plant occurs from the embryo is called primary growth. The tissues formed from the embryo are called primary tissues. Examples: primary xylem.
- Generally constant growth in monocots occurs due to the primary growth. Secondary growth is absent in monocots. In the most vascular cryptogams and monocotyledons, the entire life cycle of the sporophyte is completed in primary plant body.
- The gymnosperms, most dicotyledons and some monocotyledons show an increase in thickness of the stem and root by means of secondary growth.
- The tissues formed as a result of secondary growth are called secondary tissues.
- A special meristem, the cambium, is concerned with the secondary thickening. The cambium arises between the primary xylem and the primary phloem, and lays down the new xylem and phloem adjacent to these.

- The bulk of the plant increases because of secondary growth. Especially the vascular tissues are developed which provide new conducting calls and additional support and protection.

- In addition, a cork cambium or phellogen commonly develops in the peripheral region of the axis and produces a periderm in the stem, a secondary tissue system assuming a protective function when the primary epidermal layer is disrupted during the secondary growth in thickness.

- The primary growth of an axis is completed in relatively short period, whereas the secondary growth persists for a longer period, and in a perennial axis the secondary growth continues indefinitely. The plant body consists of a number of small, microscopic, boxes like compartments called cells. Fundamental basis of the life is cell.

THANK YOU

MERISTEMATIC TISSUES:

These are composed of cells that are in state of division or retain the power of dividing. These cells are essentially alike and isodiametric. They may be spherical, oval or polygonal and their walls thin and homogeneous; the protoplasm in them abundant and active with large nuclei, and the vacuoles small or absent.

Classification of meristems:

Meristems are classified in different ways on the basis of certain factors.

A) **According to their origin and development**

1. Promeristem or primordial meristem 2. Primary meristem and
   3. Secondary meristem.

B) According to their position in the plant body

1. Apical 2. intercalary and 3. lateral meristem.

C) According to their functions

1. Protoderm 2. Procambium and 3. Ground or fundamental meristem.

A) According to their origin and development

1. Promeristem or primordial meristem:

- These consists of a group of meristematic cells representing the earliest or youngest stage of a growing organ.

- It is, in fact the stage from which differentiation of later meristems and finally, of permanent tissue, takes place.

- It occupies a small area at the tip of the stem and the root.

- The **promeristem or primordial meristem** gives rise to the primary meristem by cell division and is therefore the earliest stage or originator of the latter.

2. Primary meristem:

- It is derived from the **promeristem or primordial meristem,** and still fully retains its meristematic activity.

- As a matter of fact, its cells divide rapidly and become differentiated into distinct tissues – the primary permanent tissues which make up the fundamental structure of the plant body.

- It is primarily the growing apical region of the root and stem.

- It should also be noted that the cambium of the stem is also a primary meristem although it gives rise to the secondary permanent tissues.

- Another fact to be noted in this connection is that the cambium cells divided in one plane (tangential), while those of the primary meristem divide in 3 planes.

3. Secondary meristem:

- These appear later, at a certain stage of the development of an organ of a plant. It is always lateral, lying along the side of the stem and root.

- The primary permanent tissues become meristematic, e.i. they acquire the power of division and constitute the secondary meristem e.g, the cambium of root, the interfascicular cambium of the stem and the cork – cambium of both.

- All lateral meristems (primary & secondary) give rise to the secondary permanent tissues and are responsible for growth in the thickness of the plant body.

B. According to their position in the plant body

1. Apical meristem

- Apical meristem is found at the tips of roots, stem and branches.
- It includes the promeristem and the primary meristem, to give rise the primary permanent tissues and is responsible for increase in length of plant body.
- It is divided into three zones – protoderm, procambium and ground meristem.
- Protoderm gives rise to epidermal tissue;
- Procambium gives rise to primary vascular tissues and Ground meristem gives rise to cortex and pith.

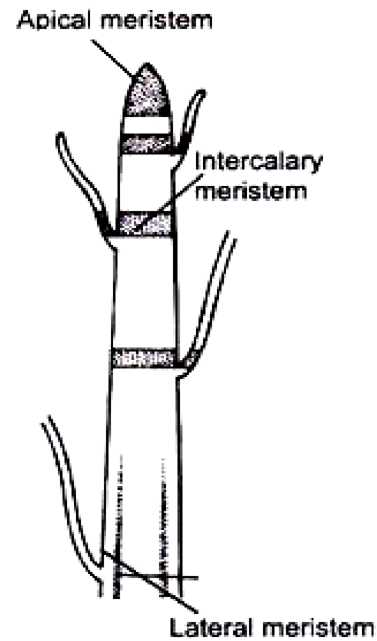


Fig. 3.1 Schematic representation of position of different meristems

2. Intercalary meristem:

- It is present in the nodal region and is prominently found in monocotyledons, *e.g.* grasses. Sometimes below the node, as in mint (Mentha).

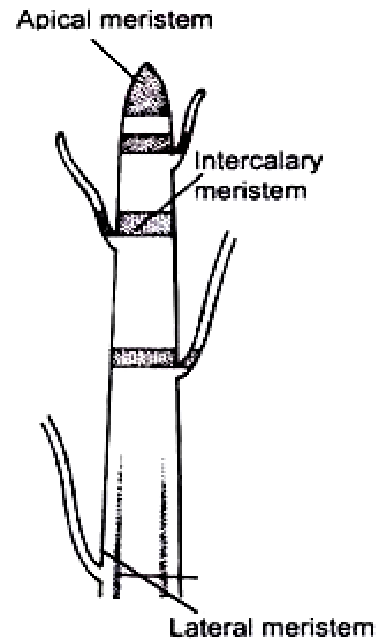


Fig. 3.1 Schematic representation of position of different meristems

- It is detached portion of the apical meristem, separted from the latter due to growth of the organ.

- As the name indicates, it is present in between the permanent tissues.
- It is derived from the apical meristem and is responsible for the elongation of internodes.

- It is generally short – lived, either disappearing soon or becoming transformed into permanent tissues.

3. Lateral meristem:

- The meristem that is present along the longitudinal axis of stem and root is called lateral meristem.

- Vascular cambium and cork cambium (phellogen) are examples for lateral meristem.

- It divides mainly in the tangential direction and giving rise to the secondary permanent tissues to the inside and outside of it, which result in the thickening of stem and root.

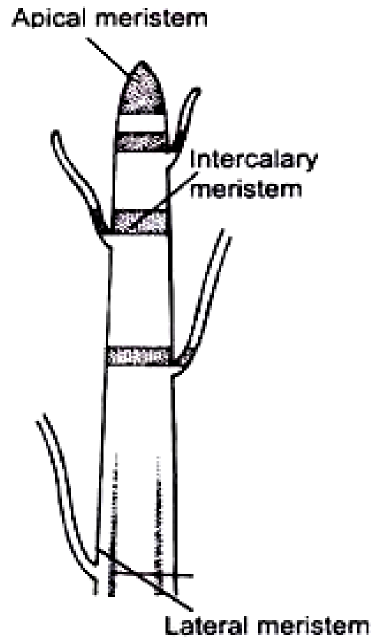


Fig. 3.1 Schematic representation of position of different meristems

C. According to their functions (Haberlandt, 1914)

1. **Protoderm :** Give rise to the epidermal tissue system

2. **Procambium :** Give rise to vascular tissue system

3. **Ground or fundamental meristem:** Ground tissue system

Permanent tissues

The cells, which are formed by apical meristem, are differentiated into different types of permanent tissues. These tissues have lost the power of dividing either permanently or temporarily.

Classification of permanent tissue:

Based on the constituent cells, the permanent tissue is classified into two types:

1. Simple tissue 2.complex tissue.

1. SIMPLE TISSUE:

A tissue with the cells of similar structure and function is called simple tissue. It is of three types –

A. Parenchyma
B. Collenchyma
C. Sclerenchyma

Parenchyma

- It is generally present in all organs of the plant.
- It constitutes the ground tissue in a plant. Parenchyma is the precursor of all the other tissues.
- Its main function is to storage of food.
- Parenchyma is a living tissue and made up of thin walled cells. The cell wall is made up of cellulose.
- Parenchyma cells may be oval, spherical, rectangular, cylindrical or stellate. The cells are usually polyhedral with 10 to12 facets. Parenchyma is of different types and some of them are discussed as follows.

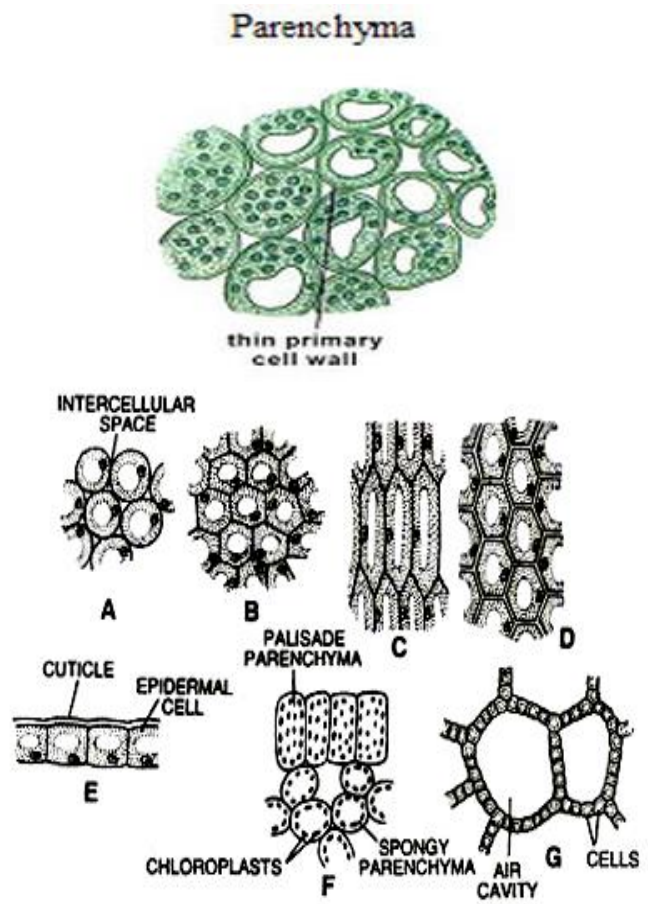
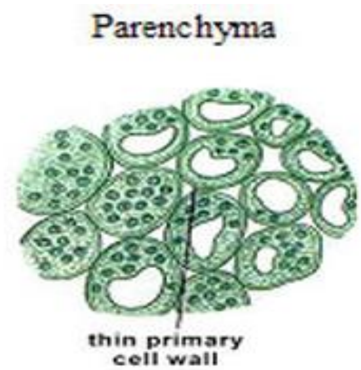


Fig. 6.7. Types of Parenchyma Cells. A–B, normal parenchyma cells; A, rounded; B, angular; C, prosenchyma; D, xylem parenchyma; E, epidermal cells; F, mesophyll; G, aerenchyma

- In water plants, the parenchyma found in the cortex region possesses well-developed large intercellular spaces called air spaces. This air filled parenchyma tissue is called **aerenchyma.**
- It helps the plant to float in water. eg. Nymphaea and Hydrilla.
- The parenchyma cells that are stored with starch grains are called **storage parenchyma**. eg. stem and root tubers. In the petioles of banana and Canna, star shaped parenchyma cells are found. These cells are called **stellate parenchyma**.
- In green parts of the plants, the parenchymatous cells have chloroplasts. These cells are called chlorenchyma. It's important function is photosynthesis.



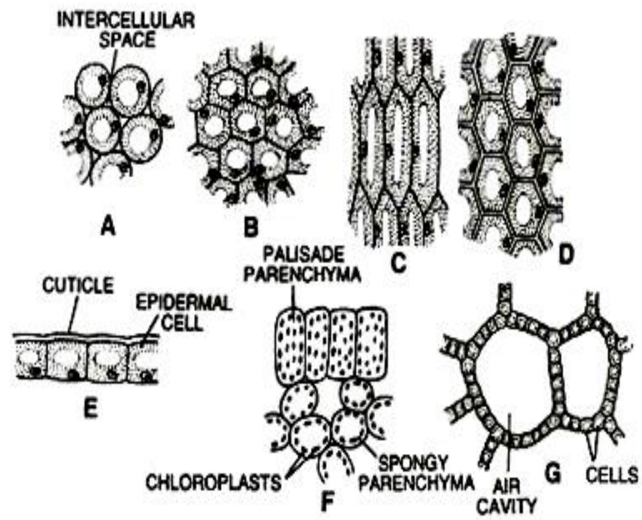
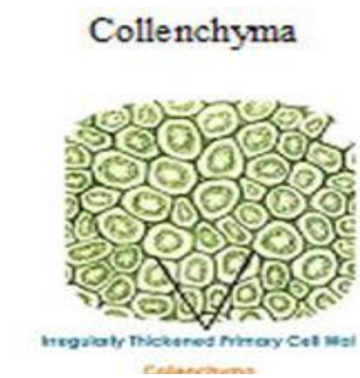


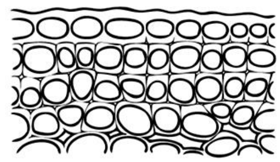
Fig. 6.7. Types of Parenchyma Cells. A–B, normal parenchyma cells; A, rounded; B, angular; C, prosenchyma; D, xylem parenchyma; E, epidermal cells; F, mesophyll; G, aerenchyma

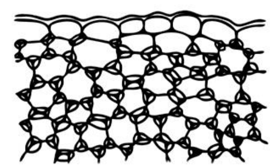
Collenchyma:

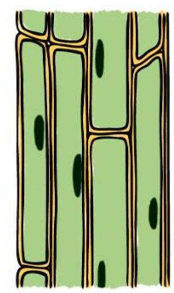
- Collenchyma generally occurs in the dicot stems in two or more layers below the epidermis.
- These layers constitute the hypodermis. It is absent in the roots of land plants. It also occurs in petiole and pedicel.It gives strength to young organs. Collenchyma is a living tissue.
- It consists of more or less elongated cells, which are polygonal in cross section.
- The cell wall is unevenly thickened. The thickening is confined to the corners of the cells.
- Besides cellulose, the cell wall contains high amounts of hemicellulose and pectin Collenchyma may contain chloroplasts and carry out photosynthesis.



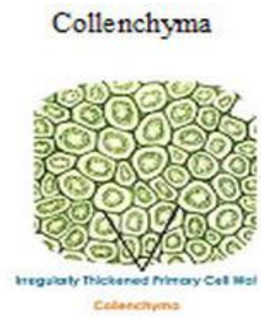
collenchyma


lamellar

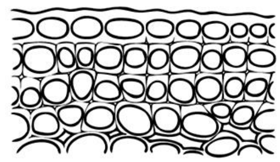

angular



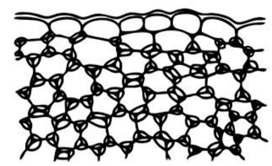
- Collenchyma is divided into three types – lamellar, angular and lacunate collenchyma.
- Its functions are, therefore, both mechanical and vital.
- In the hypodermis of Helianthus, only the tangential walls of collenchyma are thickened and the radial walls are devoid of thickening. This type of collenchyma is called lamellar collenchyma.
- In the hypodermis of Datura and Nicotiana, the cell walls of collenchyma are thickened at their angles. This type is called angular collenchyma.
- In the hypodermis of Ipomoea, the cell wall thickening materials are deposited on the walls bordering the intercellular spaces. This type is called lacunate collenchyma.



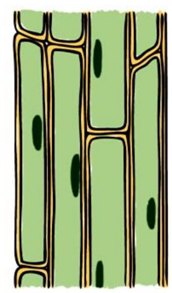
collenchyma



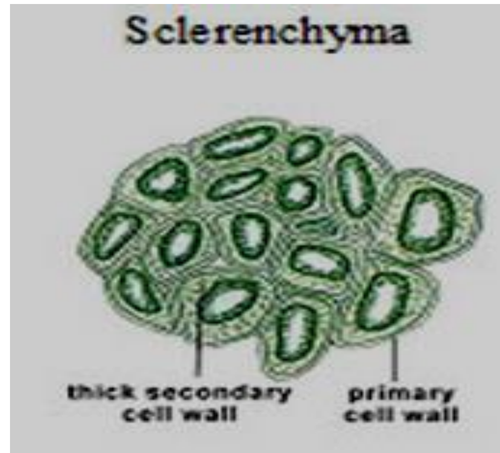
lamellar



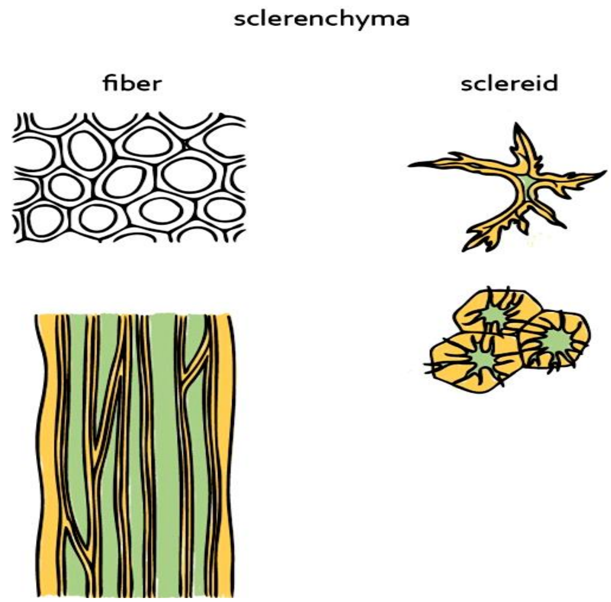
angular



Sclerenchyma:



- Sclerenchyma is a dead tissue. The cells have lignified secondary walls. They lack protoplasts.
- On the basis of origin, structure and function, sclerenchyma is divided into two types – sclereids and fibres.
- The sclereids are different from fibres in the following respects. Sclereids are shorter whereas fibres are longer. Sclereids possess numerous pits as compared to the fibres.

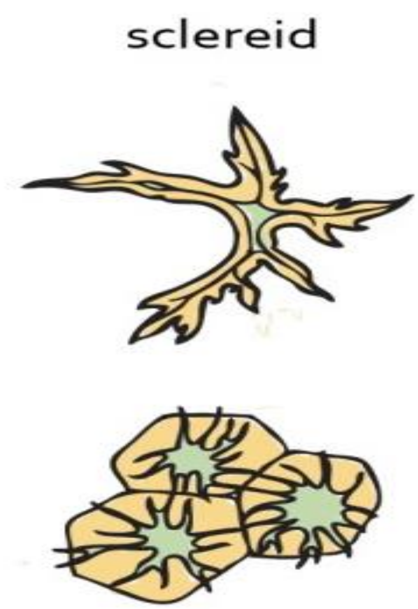


Sclereids:

- Sclereids are dead cells. They vary greatly in shape and thickness. The cell wall is very thick due to lignification. Lumen is very much reduced.

- The pits may be simple or branched.

- Usually sclereids are isodiametric, but in some plants they are elongated. They are responsible for the rigidity of the seed-coat.



Types of sclereids:

a. Brachysclereids

The isodiametric sclereids are called **brachy-sclereids** (stone cells). They are found in bark, pith, cortex, hard endocarp and fleshy portions of some fruits. eg. pulp of Pyrus.

Brachysclereids

b. Macrosclereids

Elongated rod shaped sclereids are called **macrosclereids** (rod cells). They are found in the outer seed coat. eg. Crotalaria.

Macrosclereids

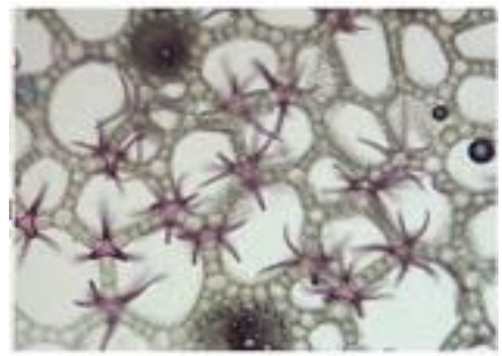
c. Osteosclereids

The rod shaped sclereids with dilated ends are called osteosclereids (bone cells). eg. Seed coat of Pisum (Pea).

Osteosclerieds

d. Astrosclereids

- They are irregular stone cells, i.e. they are branched in an irregular way, with radiating arms of varying lengths, giving a stellate or star –like appearance.
- They are found in leaves of certain dicotyledons, as in tea leaf and also in *Tsuga* and *Gnetum.* They also found in the bark of certain conifers, as in *Abies* and *Larix*.



Astrosclereids

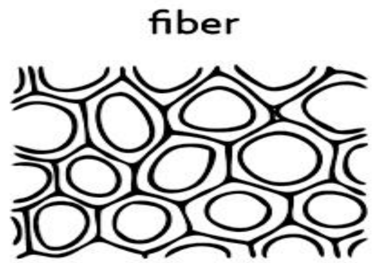
Fibres:

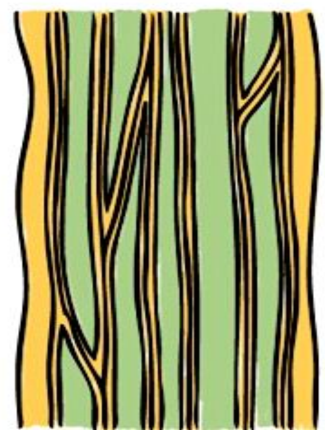
- Fibre cells are dead cells. They are very long and narrow with pointed ends. In transverse section, the fibres are polygonal with narrow lumen.

- The secondary wall is evenly thickened with lignin. It possesses simple pits.

- Fibres are supporting tissues. They provide mechanical strength to the plants and protect them from the strong winds.

- The fibres that are found in the seed coat of some seeds are called surface fibres. eg. Cotton.





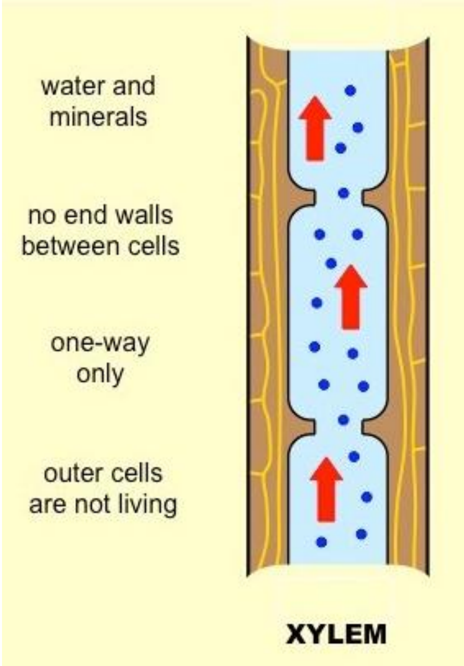
Difference between Fibres and Sclereids:

Fibre	Sclereids
Elongated and narrow like thread	Usually broad
End walls tapering	End walls blunt in unbranched **Sclereids**
Usually unbranched	May be branched
Pits narrow and unbranched	Pits deep and commonly branched
Fibres are formed directly from derivatives of meristematic cells	Sclereids arise by secondary thickening of parenchyma cells

COMPLEX TISSUES :

A tissue that consists of several kinds of cells but all of them function together as a single unit is called complex tissue. It is of two types :

A. Xylem B. Phloem.

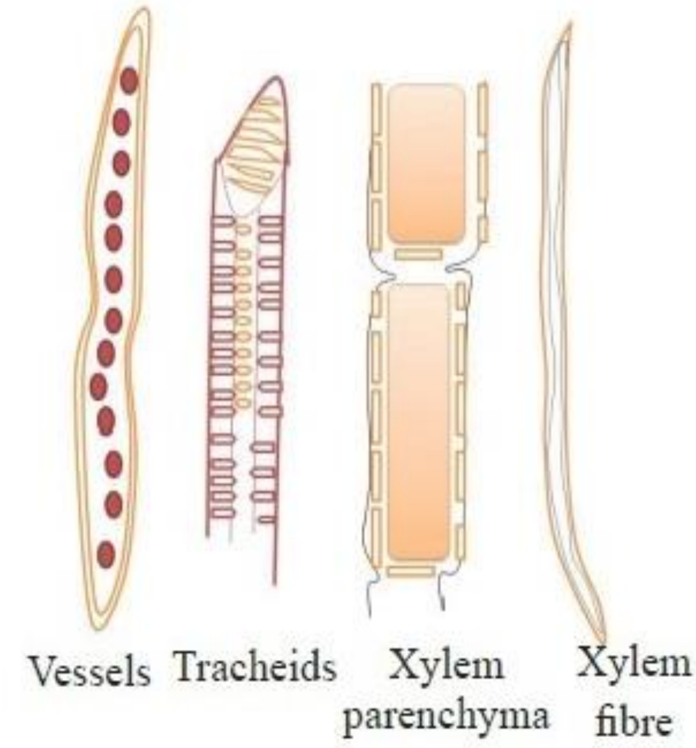


A. Xylem:

- Xylem (Greek word ‘xylos’= wood) is a complex tissue that is mainly responsible for the conduction of water and mineral salts from roots to other parts of the plant.

- The xylem, which is derived from procambium, is called primary xylem and the xylem, which is derived from vascular cambium, is called secondary xylem.

- Earlier formed xylem elements are called protoxylem, whereas the later formed xylem elements are called metaxylem.



Xylem is made up of four kinds of cells:

a. Tracheids b. vessels or tracheae c. xylem fibres d. xylem parenchyma

a. Tracheids:

- Tracheids are elongated with blunt ends. Its lumen is broader than that of fibres.
- Their secondary wall is lignified.
- In cross section, the tracheids appear polygonal and thick walled. The pits are simple or bordered.
- There are different types of cell wall thickening due to deposition of secondary wall substances.
- They are annular (ring like), spiral (spring like), scalariform (ladder like), reticulate (net like) and pitted (uniformly thick except at pits).

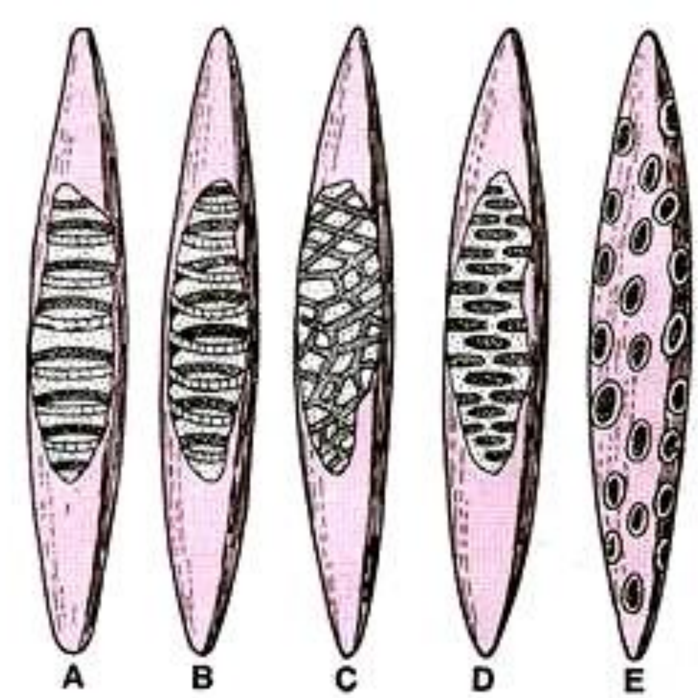


Fig. 6.12. Types of thickenings found in tracheids. A, annular; B, spiral; C, reticulate; D, scalariform; E, pitted.

- Tracheids are imperforate cells with bordered pits on their end walls. They are arranged one above the other.

- Tracheids are chief water conducting elements in gymnosperms and pteridophytes.

- Here, the conduction of water and mineral salts takes place through the bordered pits. They also offer mechanical support to the plants.

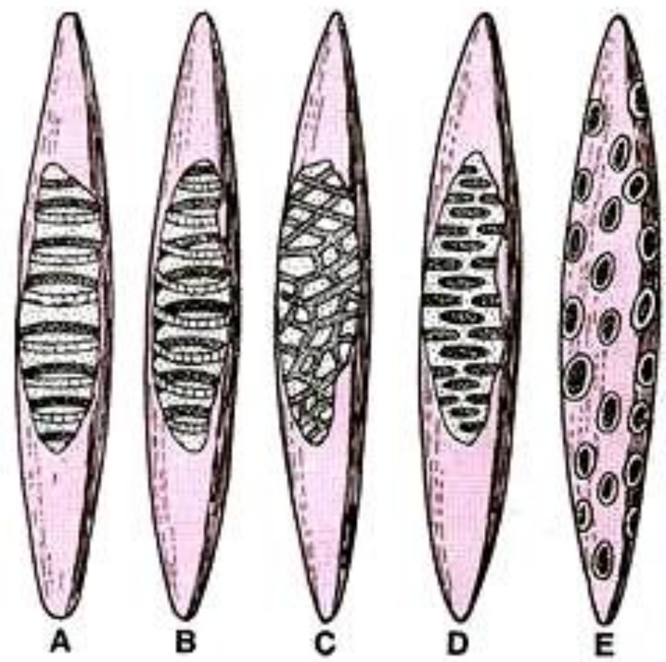


Fig. 6.12. Types of thickenings found in tracheids. A, annular; B, spiral; C, reticulate; D, scalariform; E, pitted.

b. Vessels or Tracheae

- Vessels are perforated at the end walls. Its lumen is wider than that of tracheids.
- The perforated plates at the end wall separate the vessels. They occur parallel to the long axis of the plant body.
- Due to dissolution of entire end wall, a single pore is formed at the perforation plate.
- It is called simple perforation plate eg. Mangifera.
- If the perforation plate has many pores, then it is called multiple perforation plate. eg. Liriodendron.

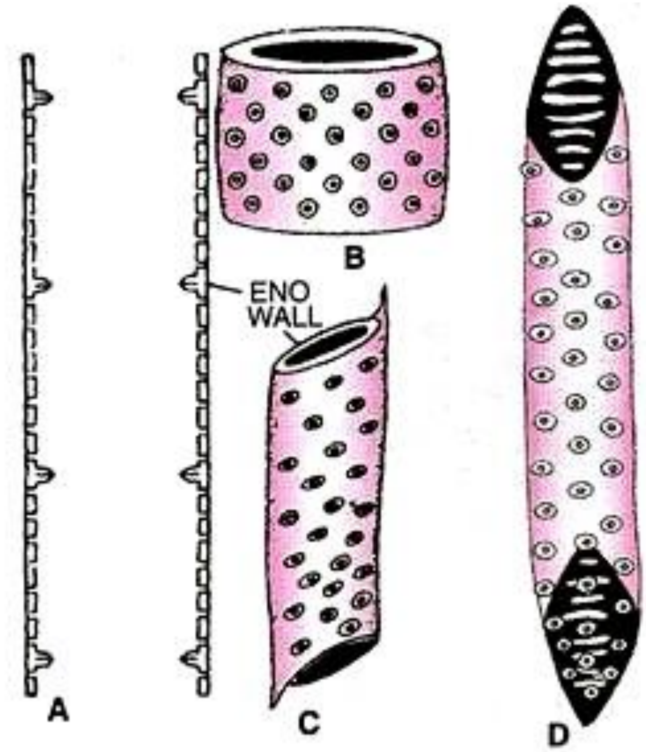


Fig. 6.13. Vessels. A, vessel in L.S. B–C, vessel elements with simple perforation plates. D, a vessel element with multiple perforation plate.

- The secondary wall thickenings of vessels are annular, spiral, scalariform, reticulate, or pitted as in tracheids.

- Vessels are chief water conducting elements in angiosperms and they are absent in pteridophytes and gymnosperms.

- However, in Gnetum of gymnosperms, vessels occur.

- The main function of vessel is conduction of water and minerals. It also offers mechanical strength to the plant.

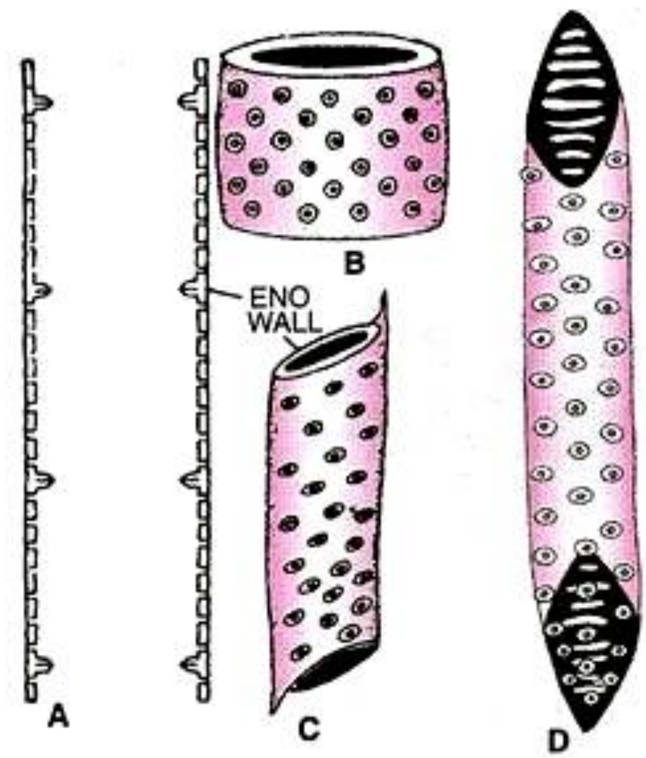


Fig. 6.13. Vessels. A, vessel in L.S. B–C, vessel elements with simple perforation plates. D, a vessel element with multiple perforation plate.

c. Xylem fibres:

- The fibres of sclerenchyma associated with the xylem are known as xylem fibres or wood fires.
- They give additional mechanical support to the plant body.
- They are present both in primary and secondary xylem.
- Xylem fibres are dead cells and have lignified walls with narrow lumen. Xylem fibres are also called libriform fibres.

d. Xylem (wood) parenchyma

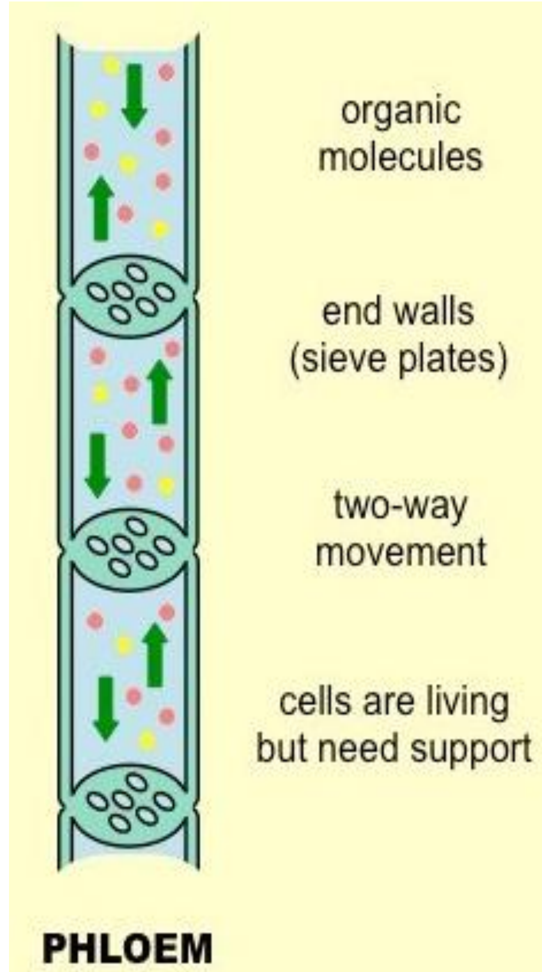
- The parenchyma cells associated with the xylem are known as xylem parenchyma.
- Xylem parenchyma is the only living tissue amongst the constituents of xylem. The cell wall is thin and made up of cellulose.
- The xylem parenchyma cells store food reserves in the form of starch andfat. They also assist in conduction of water.

Difference between vessels and tracheids:

A vessel is made of a number of cells.	A tracheid is formed from a single cell.
The ends are rounded or transverse.	The ends are generally oblique and tapering.
A vessel is several centimeters in length.	A tracheid is only a fraction of a centimeter
The septa between adjacent cells get dissolves to produce a vassel.	The end walls or septa remain intact.
They are comparatively wider.	Tracheids are comparatively narrow.
The wall is less thickened	The wall is more thickened.
The lumen is wide	The lumen is comparatively narrow.

B. Phloem:

- Like xylem, phloem is also a complex tissue. It conducts food materials to various parts of the plant.
- The phloem elements which are formed from the procambium of apical meristem are called primary phloem. The phloem elements which are produced by the vascular cambium are called secondary phloem.
- The primary phloem elements that develop first from the procambium are smaller in size called the protophloem, whereas those develop later are larger in size called metaphloem.

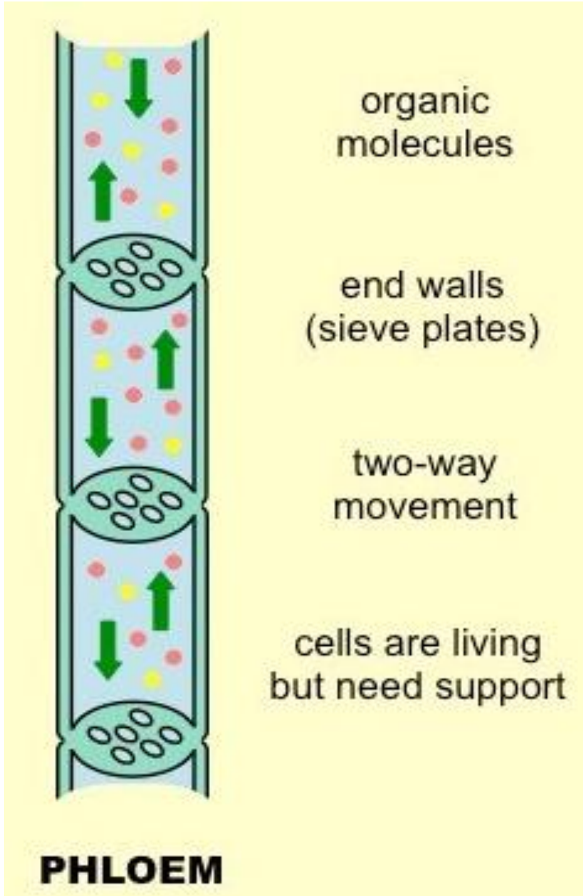


- The protophloem is short lived. It is crushed by the developing metaphloem.

- Phloem is composed of four kinds of cells: sieve elements, companion cells, phloem parenchyma and phloem fibres.

- Companion cells are present only in angiosperms. Companion cells are absent in pteridophytes and gymnosperms.

- Phloem fibres are absent in the primary phloem of most of the angiosperms. But they are usually present in the secondary phloem.



a. Sieve elements

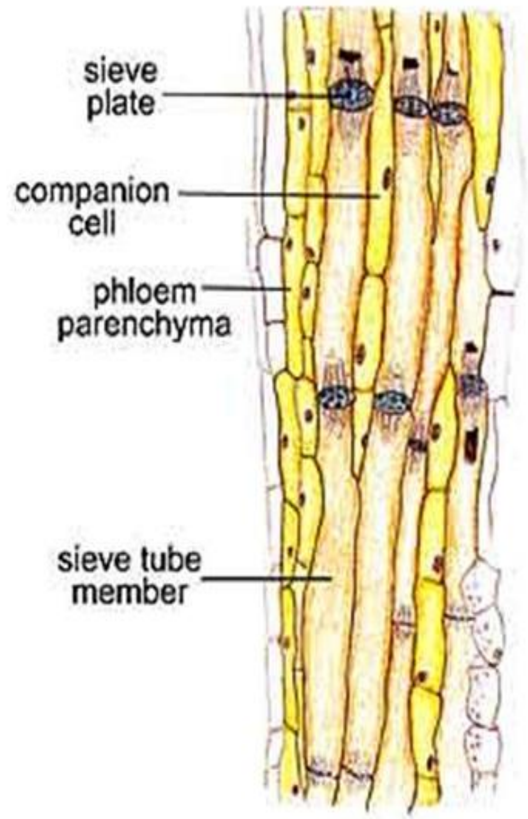
- Sieve elements are the conducting elements of the phloem. They have thick primary walls. Their end walls are transverse or oblique. The end wall contains a number of pores and it looks like a sieve. So it is called a sieve plate.
- The sieve elements are arranged one above the other and form vertical sieve tubes. In matured sieve tube, nucleus is absent. It contains a lining layer of cytoplasm. This is an important feature of sieve elements.
- A special protein called slime body is seen in it.
- The conduction of food material takes place through cytoplasmic strands. They are distinguished into sieve cells and sieve tubes.
- Sieve cells occur in pteridophytes and gymnosperms, while sieve tubes occur in angiosperms.
- Sieve cells have sieve areas on their lateral walls only and are not arranged one above the other in linear rows. They are not associated with companion cells.
- Sieve tubes are arranged one above the other in linear rows and have sieve plates on their end walls.
- They are associated with the companion cells. In mature sieve elements, sometimes the pores in the sieve plate are blocked by a substance called calluose.

b. Companion cells:

- The thin-walled, elongated, specialised parenchyma cells, which are associated with the sieve elements, are called companion cells.

- In contrast to sieve elements, the companion cells have cytoplasm and a prominent nucleus. They are connected to the sieve tubes through pits found in the lateral walls.

- The companion cells are present only in angiosperms and absent in gymnosperms and pteridophytes. They assist the sieve tubes in the conduction of food materials.



c. Phloem parenchyma:

- The parenchyma cells associated with the phloem are called phloem parenchyma. These are living cells. They store starch and fats.

- They also contain resins and tannins in some plants. They are present in all, pteridophytes, gymnosperms and dicots.

- In monocots, usually phloem parenchyma is absent.

d. Phloem or bast fibres:

- The fibres of sclerenchyma associated with phloem are called phloem fibres or bast fibres.

- They are narrow, vertically elongated cells with very thick walls and a small lumen (the cell cavity).

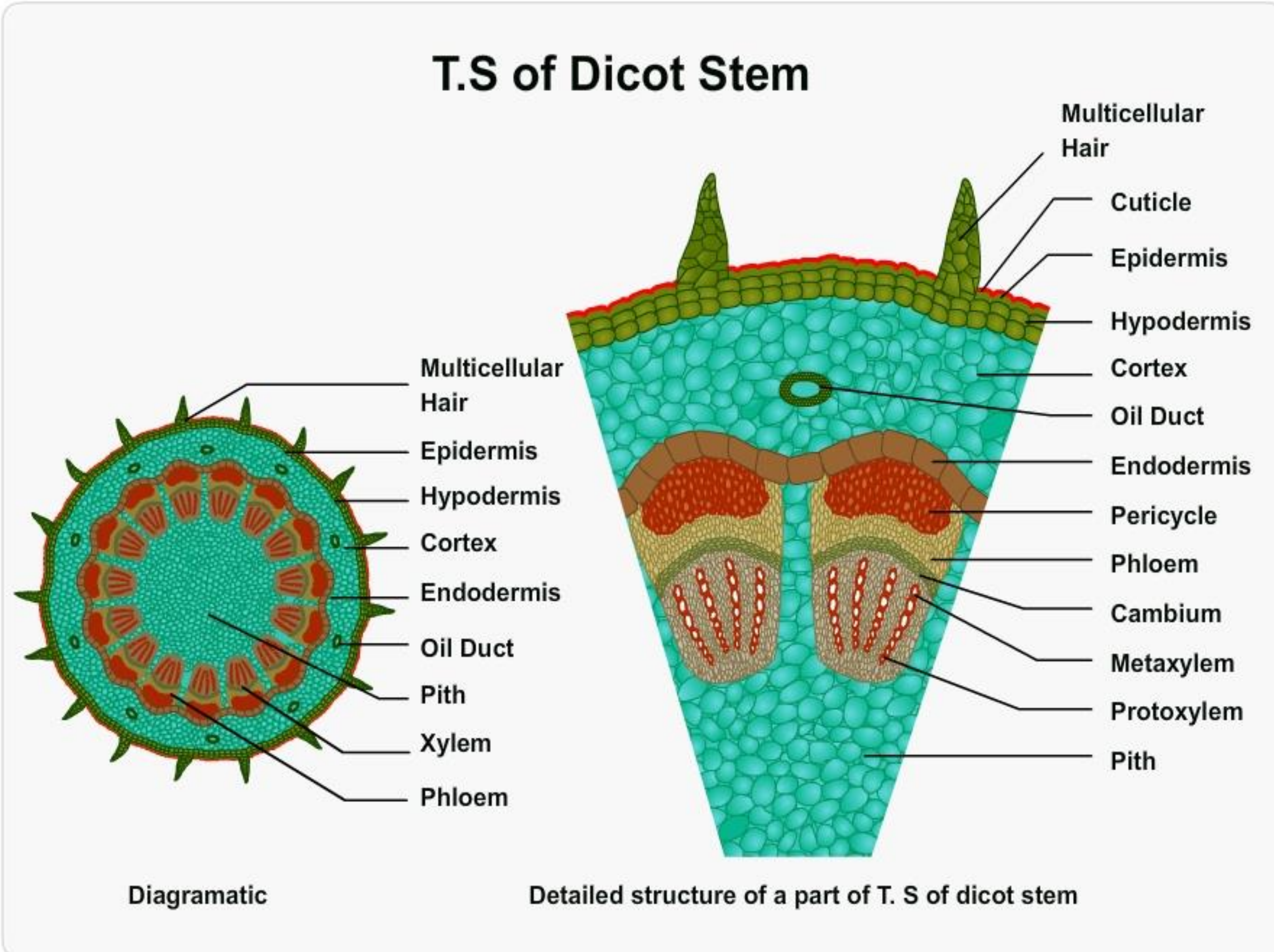
- Among the four kinds of phloem elements, phloem fibres are the only dead tissue.

- These are the strengthening and supporting cells. These are generally absent in the primary phloem, but occur frequently in the secondary phloem.

Vascular tissue is a complex conducting **tissue**, formed of more than one cell type, found in **vascular**plants. The primary components of **vascular tissue**are the xylem and phloem. These two **tissues**transport fluid and nutrients internally.

ANATOMY OF STEM

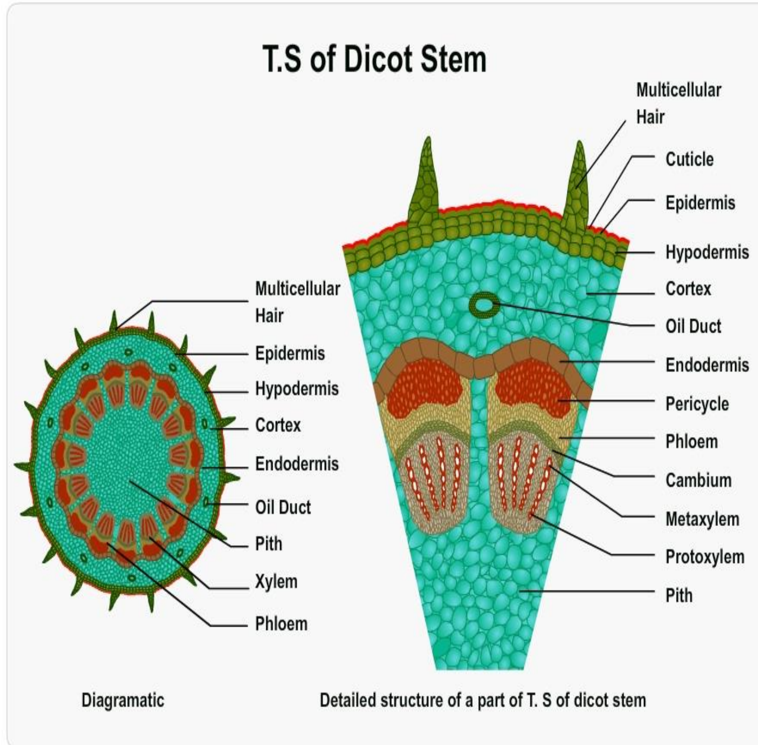
PRIMARY DICOT STEM:



ANATOMY OF STEM

PRIMARY DICOT STEM:

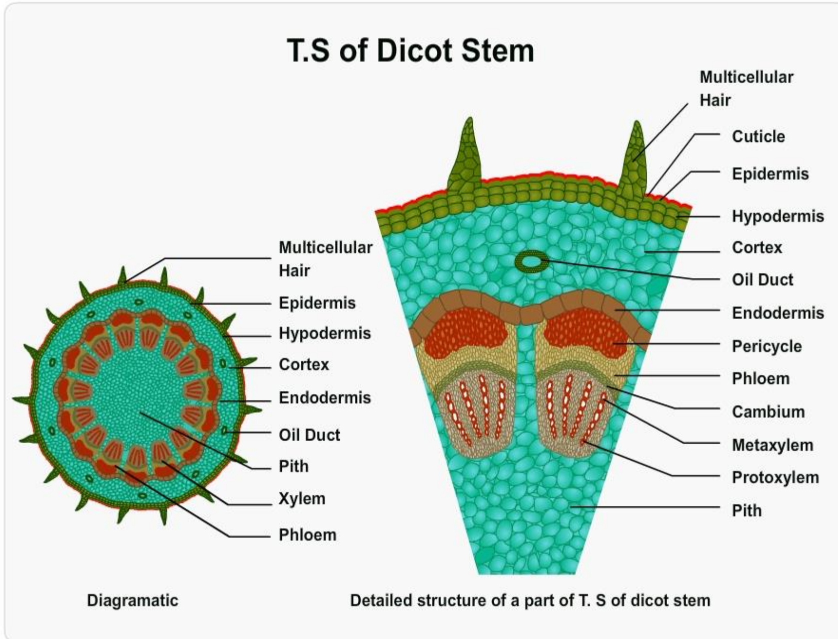
A stem with only primary permanent tissues is called primary stem. It represents a young stem. The different tissues present in dicot stem are arranged in concentric layers. e.g. (Sunflower)



I) Epidermis:

➢ Epidermis is the outermost layer of the stem. It is made up of compactly arranged parenchymatous cell, which look rectangular in transverse section.

- The cells are transparent and devoid of chloroplasts.
- The outer walls are convex, thickened and cutinized. On the outer side they possess a layer of cuticle.
- The internal walls of the epidermal cells are thin. The radial walls are thick towards the outer side and gradually become thin towards the inner side.
- Pits occur in the radial walls.



- The epidermis of sunflower bears several unbranched multicellular hair.
- At place the epidermis contains minute pores called stomata or stomates.
- Each stomate or stoma has a pair of specialized kidney shaped cells called guard cells.
- The guard cells have a few chloroplasts. By their swelling, the two guard cells can form a pore between them.

Functions of epidermis:

i) Protection of internal tissues

ii) Prevention of entry of harmful organisms

iii) Minimizing surface transpiration by having thick cuticle

iv) Exchange of gases through the stomata

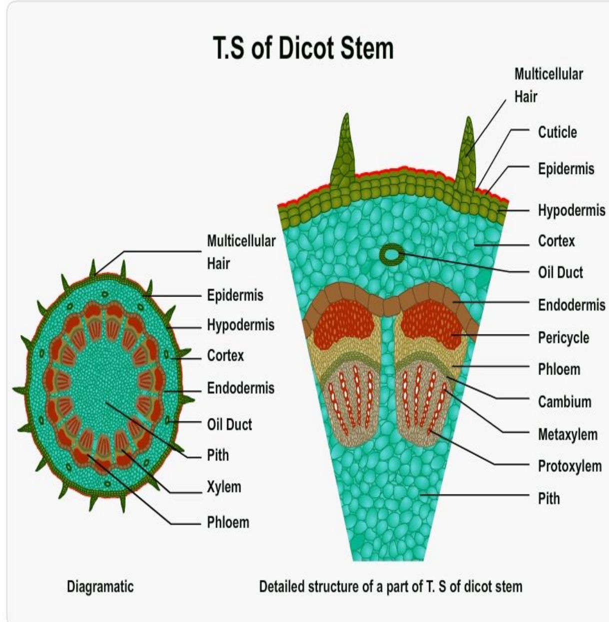
v) Protection against excessive heating up and sudden changes in temperature with the help of hair

II) Hypodermis:

- The hypodermis is made of a new layered sub-epidermal collenchyma tissue.

- Its cell possess cellulose thickenings either on the tangential walls (Lamellate collenchyma) or at the angles (angular collenchyma).

- The collenchyma cells are green and enclose small inter-cellular spaces.



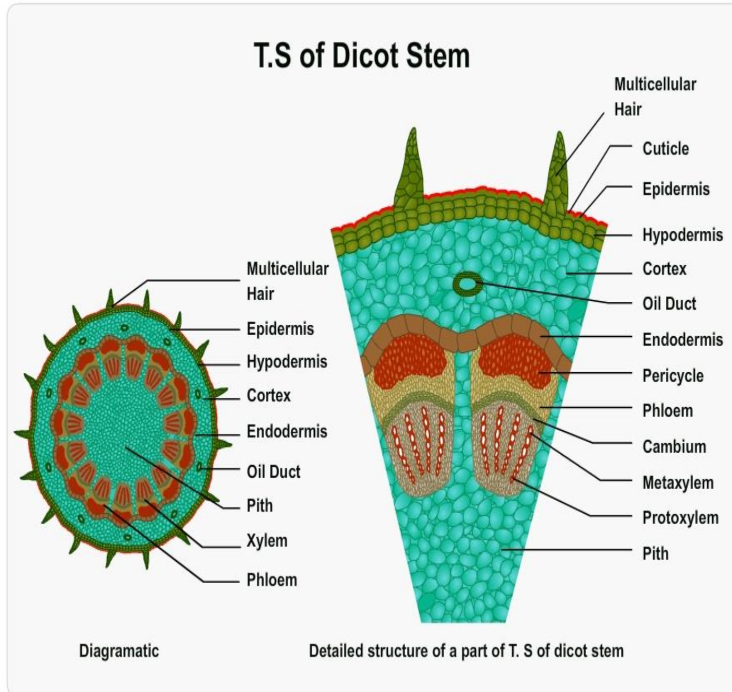
Functions of hypodermis :

i) Providing mechanical strength

i) Storage of food

i) Manufacture of food with the help of chloroplast

III) Cortex:



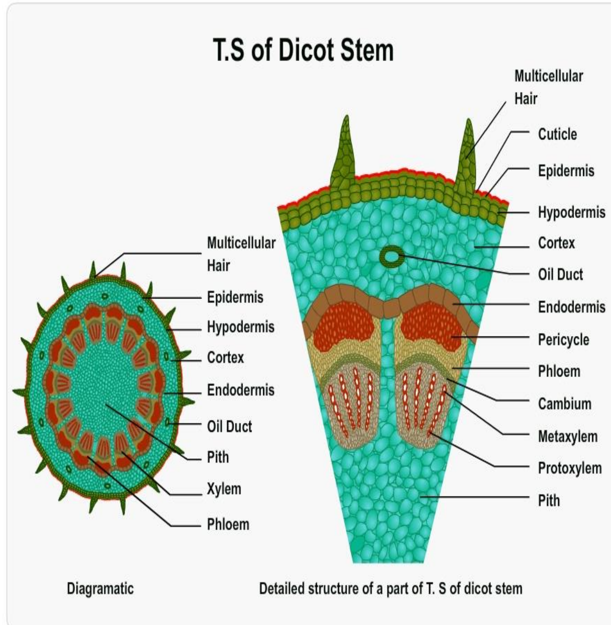
- It is few to several cells in thickness. The cortex is made up of thin walled angular, oval or rounded parenchymatous cells. They enclose intercellular spaces.

- The cortical cells may possess chloroplasts. The major function of the cortex is storage of food.

- Cortex contains a number of longitudinally running oil ducts. Each oil duct has a channel which is lined by an epithelium of small glandular cells.

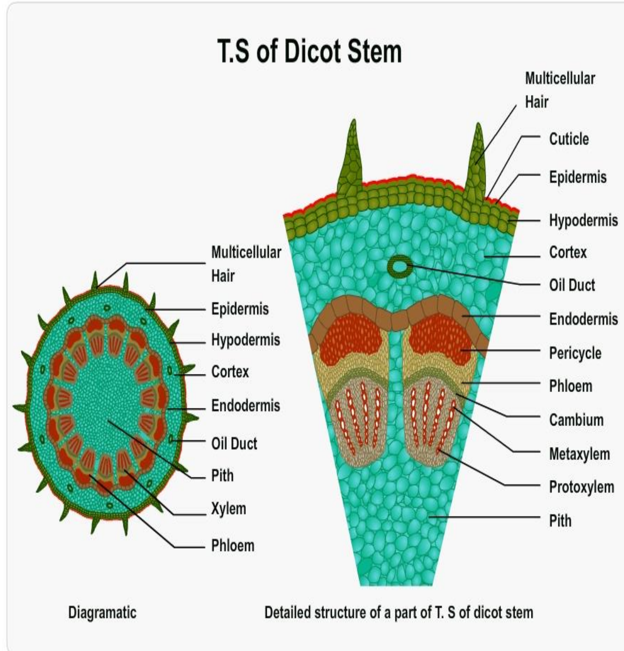
IV) Endodermis:

- It is a wavy layer of one cell in thickness. The endodermis lies at the innermost boundary of cortex.
- It is made up of barrel – shaped cells which do not enclose intercellular spaces.
- The endodermal cells contain conspicuous starch grains as food reserve.
- Therefore, the endodermis is also called starch sheath.



V) Pericycle:

- It is a few layered thick tissues. It lies inner to the endodermis and the outside the vascular strand.



- The pericycle is made up of both parenchyma and sclerenchyma fibres. sclerenchyma lies on the outside of the vascular bundles in the form of semicircular patches called bundle caps.

- Paremchymatous pericycle is present outside medulary rays. The sclerenchymatous pericycle provides mechanical strength to the young tem.

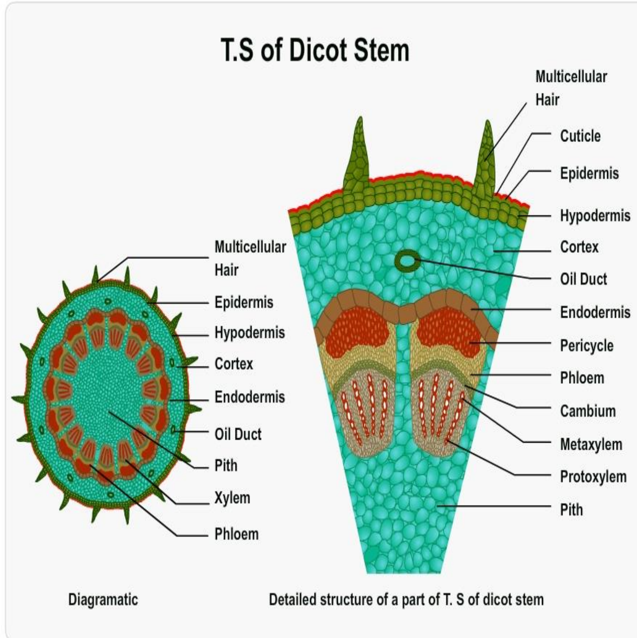
- The parenchymatous pericycle stores food.

VI) Vascular Strand:

- The vascular strand is in the form of ring of vascular bundles present around the central pith and inner to the pericycle.

- The vascular bundles are wedge shapped. Each vascular bundle consists of phloem (Primary) on the outside, xylem towards the inside and a strip of cambium in between the two.

- Phloem and xylem tissues lie on the same radius. Such vascular bundles are known as conjoint (with both phloem and xylem), collateral (phloem and xylem on the same radius) and open (with a strip of cambium in between phloem and xylem)



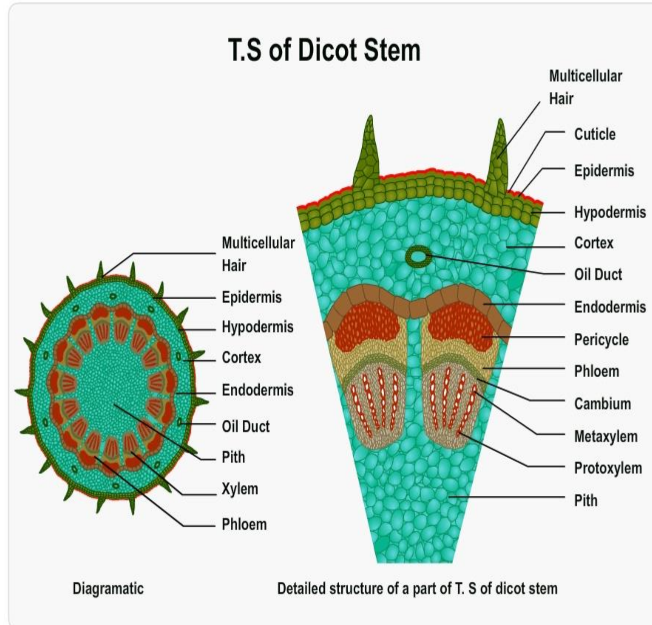
a) Phloem:

- It lies towards the pericycle on the outer side of vascular bundle.

- Phloem consists of sieve tubes, companion cells, phloem parenchyma and some phloem fibres.

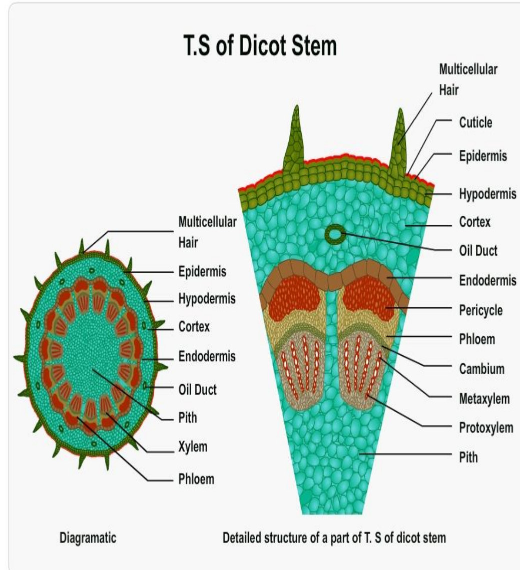
- The companion cells and phloem parenchyma are connected with sieve tubes through pits.

- They help in the lateral flow of the organic food. The companion cells also control the functions of the sieve tubes. The sieve tubes conduct organic food longitudinally.

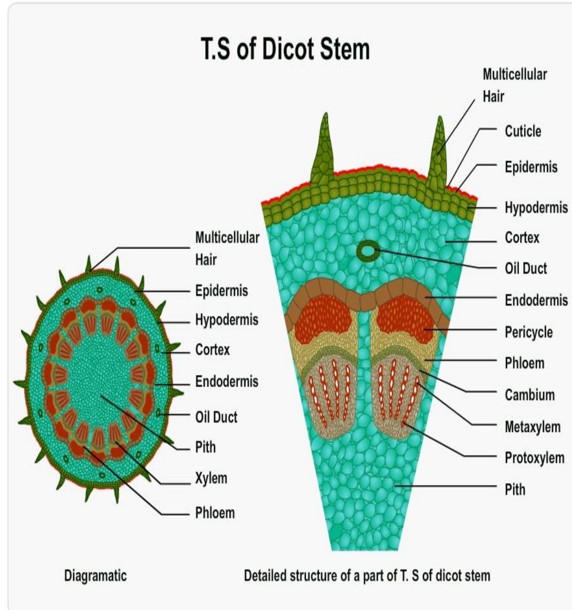


b) Xylem:

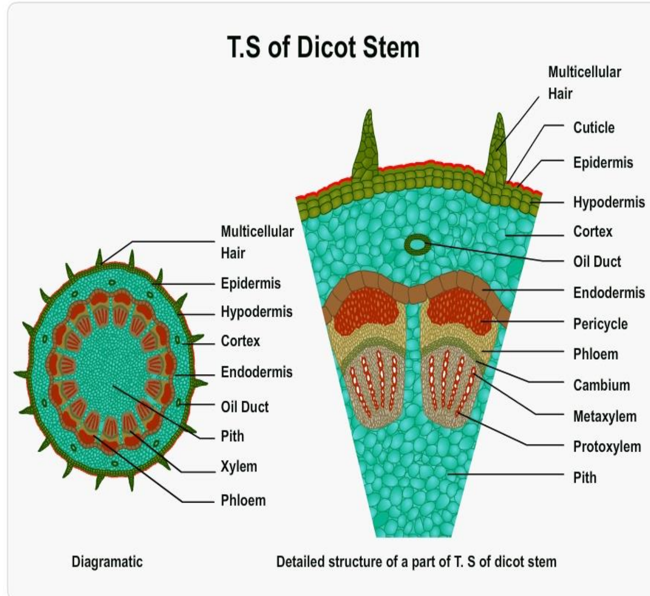
- It is found towards the pith or the inner portion of the vascular bundles. Xylem consists of two parts, smaller protoxylem (of narrow elements) and larger metaxylem (of broader elements).
- Protoxylem or first formed xylem lies at the tip of metaxylem towards the pith or centre of stem. Therefore, the xylem is endarch.
- **Xylem** consists of tracheids, vessels, xylem parenchyma and xylem fibres.
- Out of these only the xylem parenchyma cells are living. They are smaller in size than the parenchyma cells found outside the bundles.
- Most of the xylem parenchyma is found around the protoxylem region.
- Parenchyma cells store food and help in the lateral conduction of sap. For this their walls have simple pits.



- **Vessels** are present in the form of a few radial rows. They are angular in outline.
- The vessels of the protoxylem region are smaller and possess annular or spiral thickenings.
- These thickenings make the protoxylem vessels elastic and capable of stretching during the elongation of stem. The vessels of the metaxylem have pitted thickenings.
- **Tracheids** are present in between and around the radial rows of vessels especially of the metaxylem region.
- Xylem fibres lie scattered amongst the tracheids.
- The vessels, tracheids and xylem fibres, all provide mechanical strength to stem. However, the most important function of xylem is the conduction of water and mineral substances. This is carried out by vessels and tracheids.



iii) Cambium:



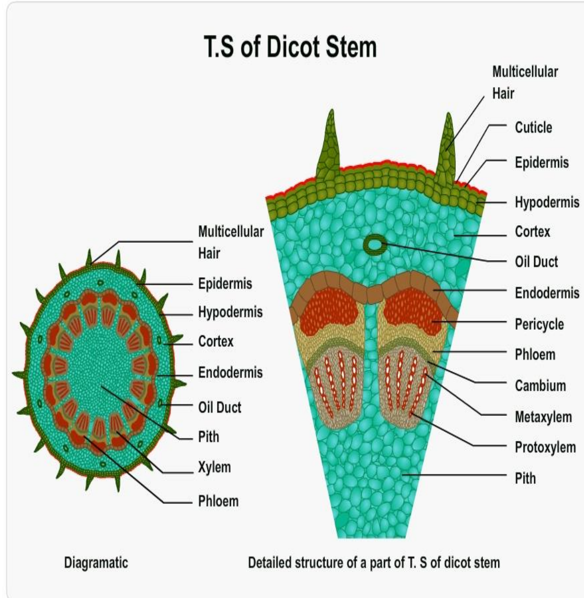
- Cambium is in the form a narrow strip of primary meristematic cells that lies between the phloem and the xylem of a vascular bundle. It is called intrafascicular or fascicular cambium.

- The cell are thin walled and rectangular in out line. They possess prominent nuclei.

- It increases the girth of stem by producing secondary phloem towards the outside and secondary xylem towards the inner side

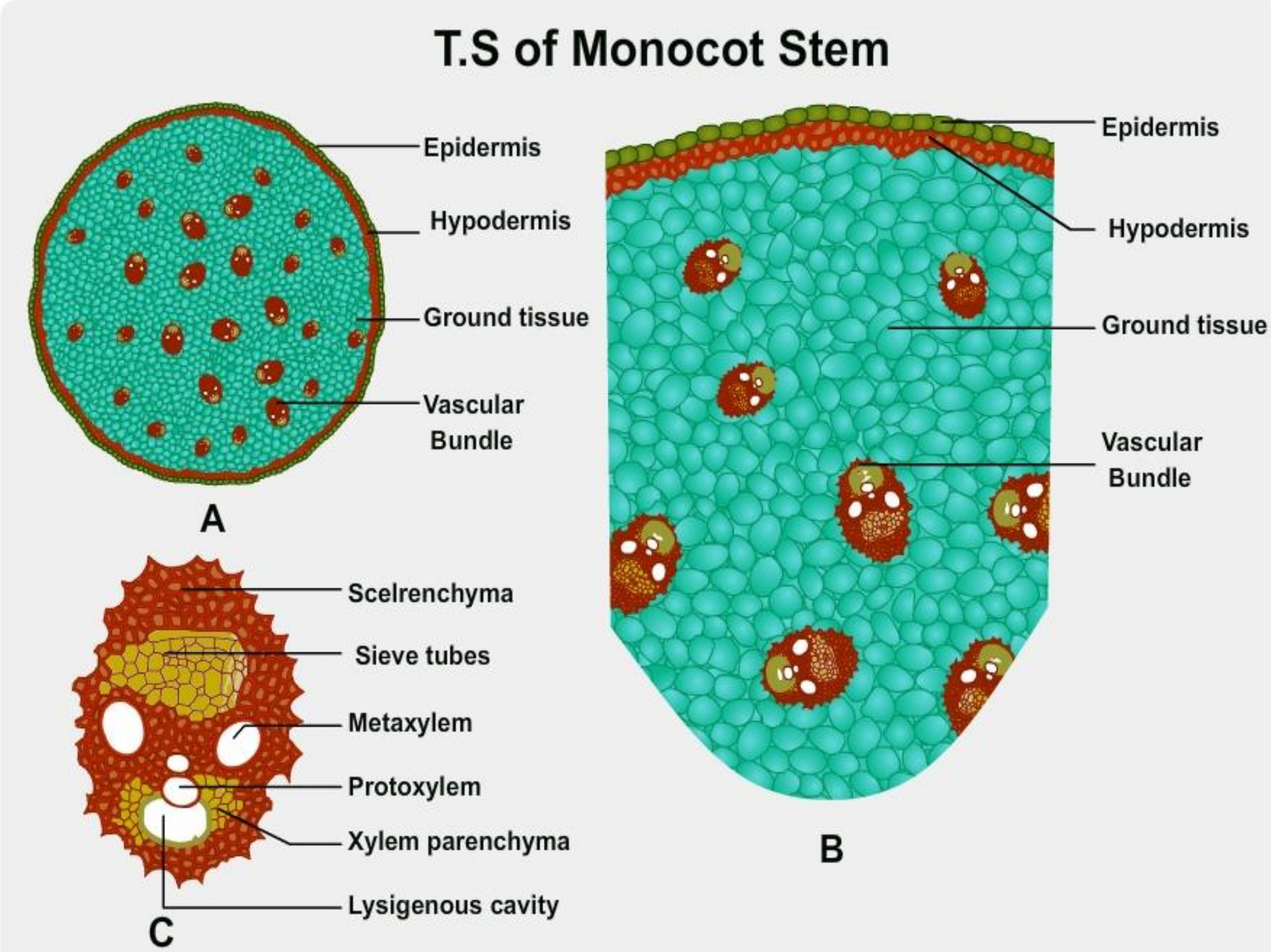
VII) Medullary or pith rays:

- They are radial strips of parenchyma which are present between adjacent vascular bundles.
- The medullary rays connect the pith with pericycle and cortex. The cells are radially elongated.
- The ray cells make intimate contact with the conducting cells of both phloem and xylem through pits.
- The medulary rays help in the radial conduction of food and water. They also transport gases from pith to cortex and vice versa.



VIII) Pith or medulla:

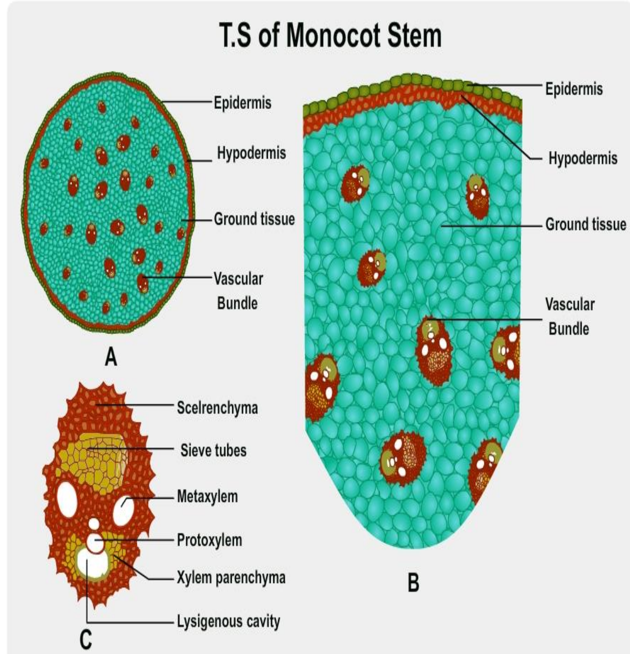
- It forms the centre of the stem. The pith is made up of oval or rounded parenchyma cells which enclose intercellular spaces. The pith cells store food.



A. Diagrammatic; B. Detailed structure of a part of T.S. of monocot stem; C. Single vascular bundle

PRIMARY MONOCOT STEM:

- A monocot stem is lack of secondary growth. It, therefore, possesses only the primary permanent tissues.
- The various tisues, unlike a dicot stem, are not arranged in concentric rings.
- The stem can be solid, or fistular. A typical monocot stem consists of the following tissues.

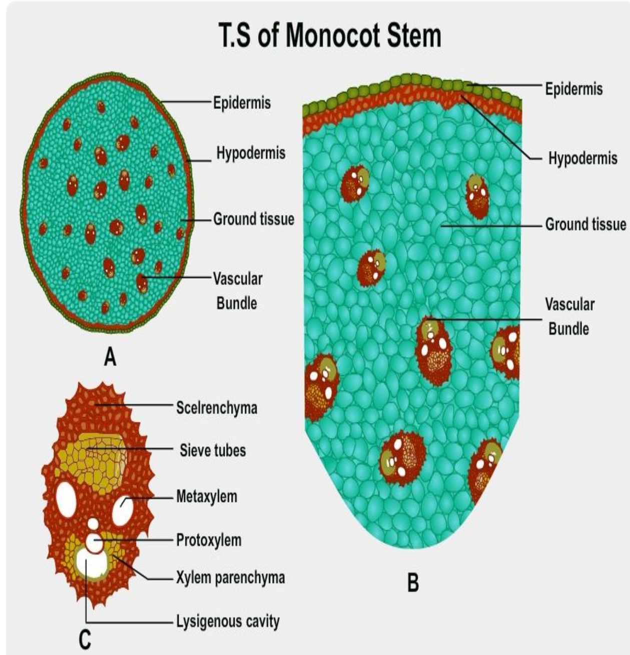


A. Diagrammatic; B. Detailed structure of a part of T.S. of monocot stem; C. Single vascular bundle

I) Epidermis:

- It is the outermost layer of the stem which is made up of compactly arranged transparent elongated and rectangular or barrel shaped parenchyama cells.
- The outer walls of epidermil cells possess deposition of silica and cutin.

- A separate layer of cuticle also occurs on the outside, the cuticle and cutinized epidermal cells prevent the evaporation of water from the stema. Slica provides stiffness.
- At places the epidermis possesses stomata for gaseous exchange. Each stoma or stomata has two dumble shaped guard cells.
- The guard cells can open or close the stoma. They contain a few chloroplasts.



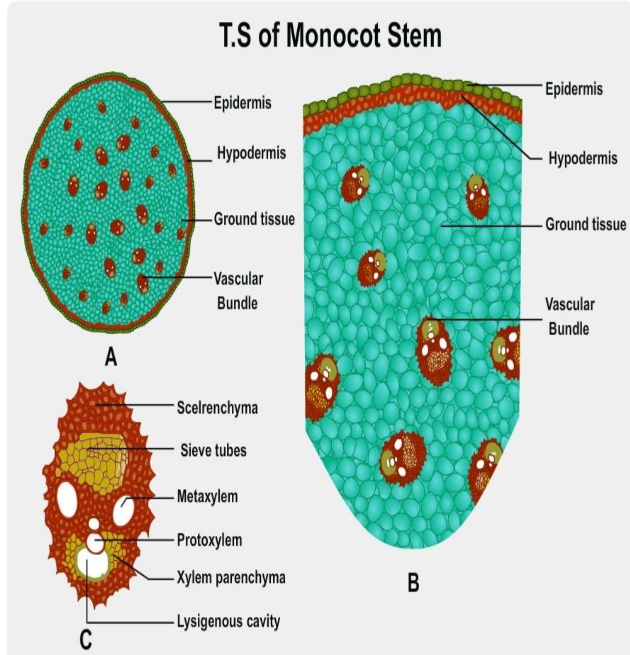
A. Diagrammatic; B. Detailed structure of a part of T.S. of monocot stem; C. Single vascular bundle

II) Hypodermis:

- It is 2 – 3 layered thick and lies below the epidermis.
- The hypodermis is made up of thick walled sclerenchyma fibres.
- It acts as a heat screen and provides the rigidity and mechanical strength to stem

III) Ground Tissue:

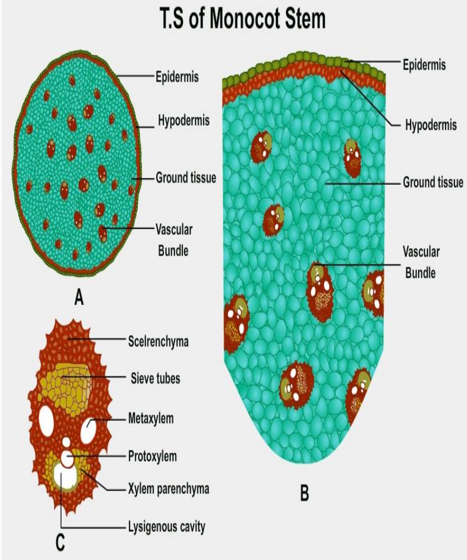
- It is parenchymatous and occupies the whole stem interior. In the stem of maize the cells are small and angular towards the hypodermis but become large anf oval in the inner region.
- The ground tissue stores food.
- Some of the outer cells may also synthesize food due to the presence of chloroplasts in them. Abundant inter – cellular spaces are present in the ground tissue. These spaces communicate with exterior through the stomata present in the epidermis.
- In some monocots a centeral cavity is formed in the ground tissue by the disintegration of cells during growth (e.g. grass). A band or cylinder of sclerenchyma occurs in the ground tissue of grass stem.



A. Diagrammatic; B. Detailed structure of a part of T.S. of monocot stem; C. Single vascular bundle

IV) Vascular Strand:

- The vascular strand is in the form of large number of vascular bundles. They lie scattered throughout the ground tissue (atactostele).
- Vascular bundles are smaller but more numerous towards the outside than towards the centre.
- The vascular bundles are oval or round in outline.
- They contain both phloem and xylem.
- Phloem lies towards the outside and the xylem on the inner side. Cambium is absent. The vascular bundles are, therefore, conjoint, collateral but closed. Each vascular bundlis surrounded by a sheath of sclerenchyma known as bundle sheath.



A. Diagrammatic; B. Detailed structure of a part of T.S. of monocot stem; C. Single vascular bundle

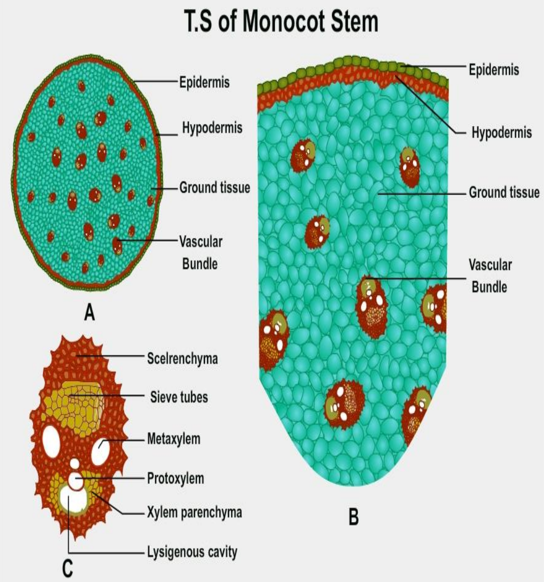
- The bundle sheath is more developed on outer and the inner sides.
- The hypodermis and bundle sheath coalesce in some of the outer vascular bundles. The bundle sheath is absent in ***Asparagus.***

- Phloem consists of sieve tubes, companion cells and a few phloem fibres. Phloem parenchyma is absent.

- The sieve tubes conducts organic food. In maize the phloem is distinguished into outer protophloem and inner metaphloem. The protophloem gets crushed in the latter stages.

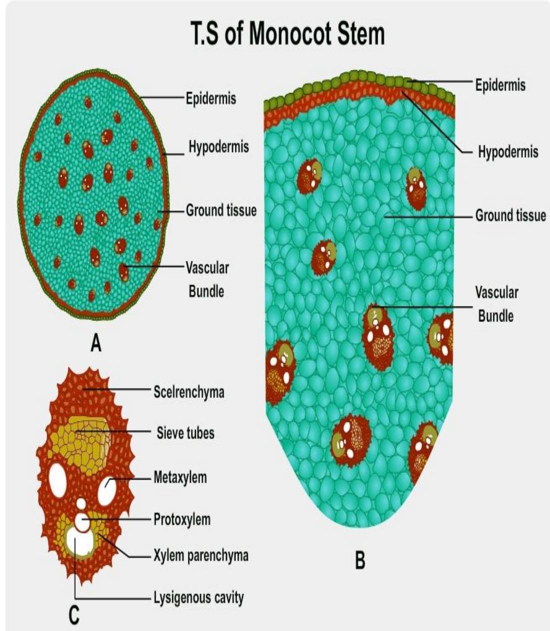
- Xylem is in the form of letter Y. It is endarch, i.e., protoxylem lies towards the centre of the stem.

- Xylem is made up of vessels, tracheids, xylem parenchyma and a few xylem fibres. Metaxylem generally consists of two large oval or rounded vessels is lying at the upper two angles of xylem.



A. Diagrammatic; B. Detailed structure of a part of T.S. of monocot stem; C. Single vascular bundle

- The metaxylem vessels have pitted walls. The two vessels are connected with each other by polygonal tracheids having pitted thickenings
- Protoxylem has a few small oval vessels. They lie at the lower angle of xylem. The vessels of the protoxylem show spiral and annular thickenings. Xylem parenchyma and a few fibres are found just outside them.
- Some of the protoxylem vessels and xylem parenchyma cells dissolved or separate during the rapid growth of the stem to form a cavity of maize is schizo – lysigenous in origin. It generally stores water.
- The tracheids and vessels help in the conduction of sap as well as mechanical support.
- In maize the protoxylem cavity and protophloem can be absent in the smaller vascular bundles.



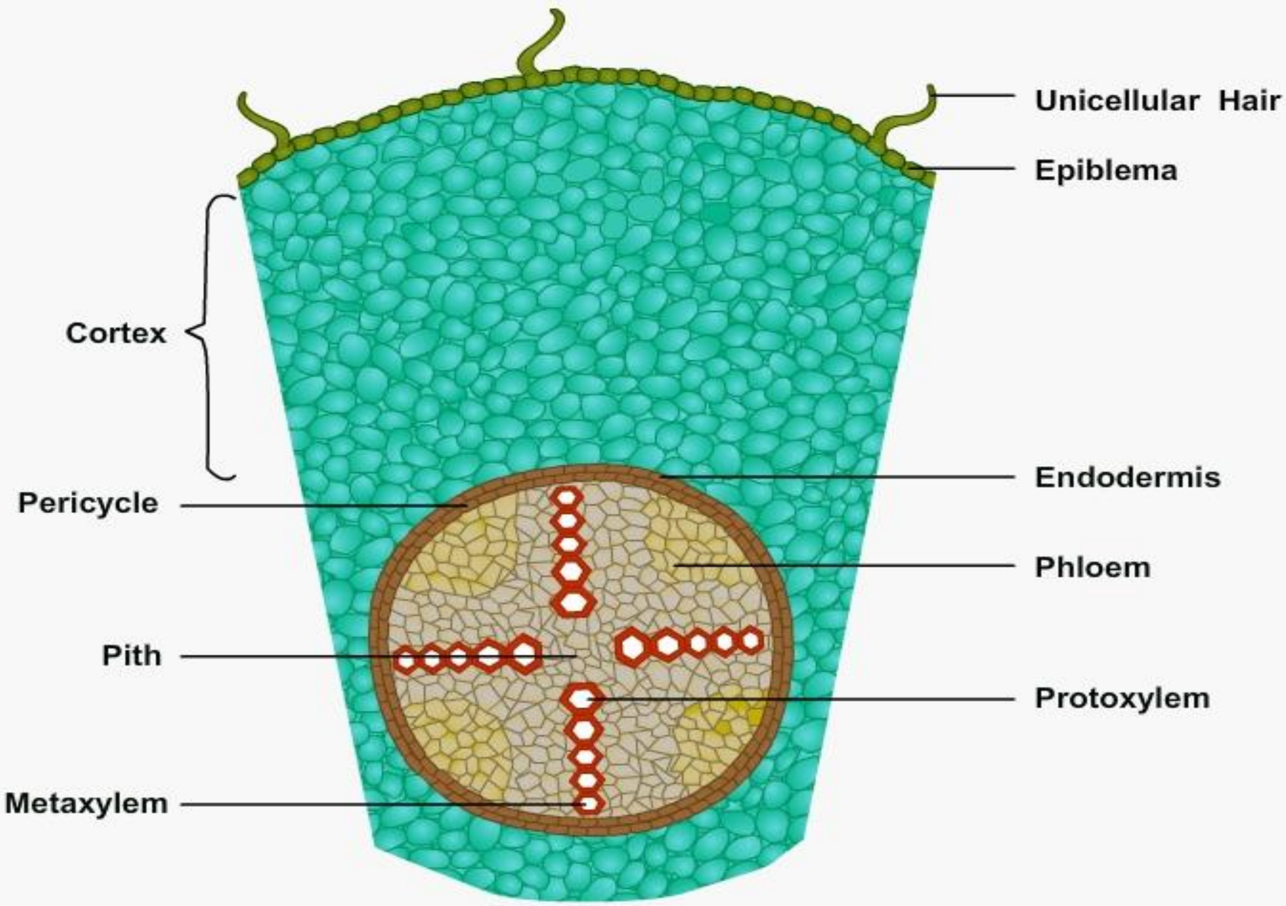
A. Diagrammatic; B. Detailed structure of a part of T.S. of monocot stem; C. Single vascular bundle

Difference between Dicot and Monocot stem:

Sl.No.	**Dicot Stem**	**Monocot Stem**
1	Stomata have kidney –shaped guard cells.	Stomata usually possess dumbel shaped guard cells.
2	The hypodermis is made up of collenchymas which may be green	The hypodermis is formed of non green sclerenchyma fibres.
3	The internal tissues are arranged in concentric layers.	The concentric arrangement of tissues is absent.
4	The ground tissue is differentiated into cortex, endodermis, pericycle, pith, etc.	The ground tissue is a mass of similar cells
5	The stem is almost always solid.	The stem is generally hollow in the centre (exception in maize)
6	The vascular bundles are arranged in ring around the pith.	The vascular bundles are scattered throughout the ground tissue.
7	The vascular bundles are few in number and are of similar size	The vascular bundles are numerous and are of different size –smaller towards the outside and larger towards the centre
8	The vascular bundles are wedge shaped in outline.	They are oval or rounded in outline.
9	No bundle sheath is present on the outside of a vascular bundle	A sclerenchymatous bundle sheath is generally present on the outside of each vascular bundle.

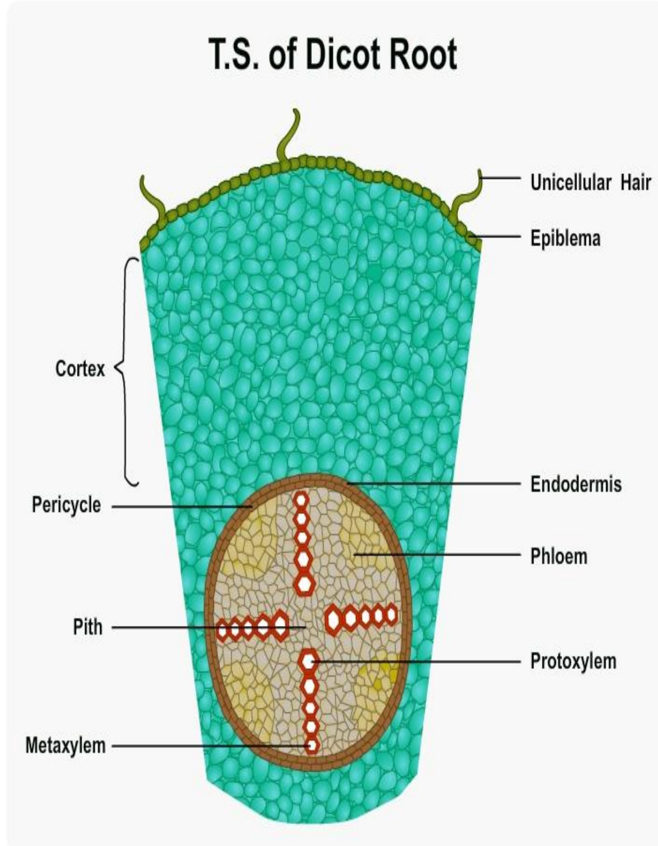
10	The vascular bundles are open due to the presence of cambium in between phloem and xylem.	The vascular bundles are closed.
11	The stem shows secondary growth due to the formation of secondary vascular tissues and periderm.	Secondary growth is usually absent.
12	Phloem parenchyma is present in the phloem alongwith other elements.	Phloem parenchyma is absent.
13	The vessels are polygonal in outline.	The vessels are oval or rounded.
14	The vessels are usually arranged in chains or rows	The vessels are arranged in a Y- shapped manner.
15	Metaxylem vessels are generally numerous.	Metaxylem vessels are few in number.
16	Medullary rays are found in between the vascular bundles	Medullary rays are absent.
17	A cavity is not found in the vascular bundle.	A cavity containing water is found in vascular bundle be the dissolution or separation of some protoxylem vessels and parenchyma lying nearby.
18	The older vascular tissues stop functioning after some time. They are replaces by younger vascular tissues.	The first formed vascular tissues continue functioning throughout the life of the plant.

T.S. of Dicot Root



PRIMARY DICOT ROOT:

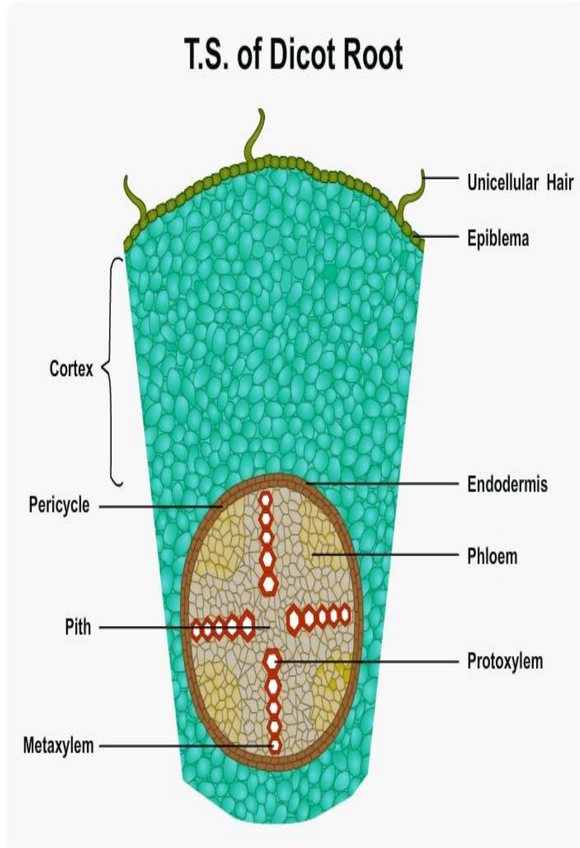
A young dicot root which does not possess secondary tissues but only the primary permanent tissues (tissues derived from the apical growing point) is called primary dicot root. It is generally cylindrical in outline and possesses the following tissues.



I) Epiblema or Piliferous Layer:

- It is the outermost layer of the root. It is made of compactly arranged thin walled and slightly elongated parenchymatous cells.
- Epiblema of a root differs from the epidermis of the stem in being devoid of distinct cuticle and stomata.
- Some cells of the epiblema give rise to thin – walled tubular outgrowths called root hairs.

- In some plants the root hair mother cells are shorter in comparison to other epiblema cells. The root hairs and piliferous layer (pilus – hair, ferre to carry). The root hair and thin walled epiblema cells absorb water and mineral salts from the soil.
- Root hairs commonly do not live for more than one week. With their death the epiblema cells become suberised and cutinised.



II) Cortex:

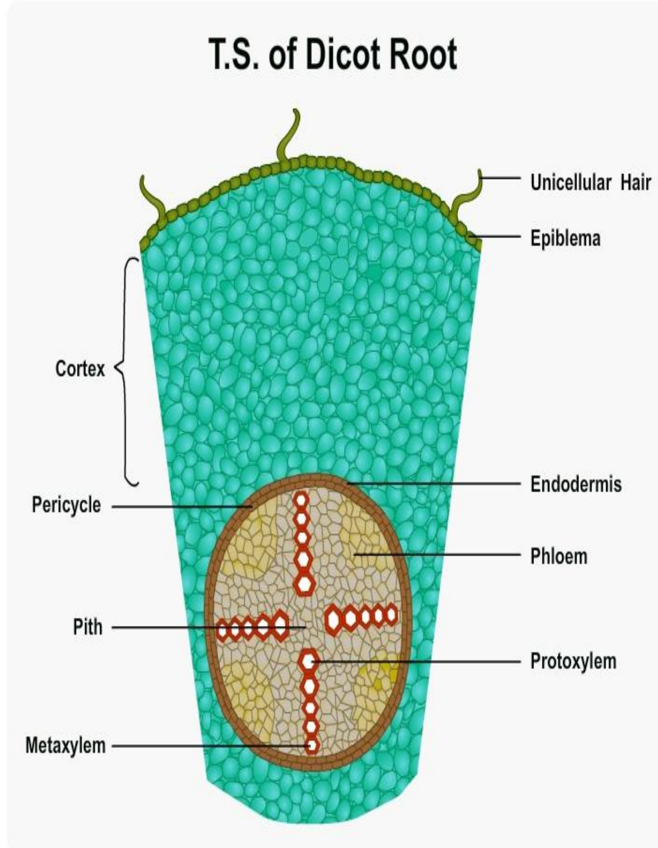
- It lies below the epiblema.
- The cortex is made up of many layers of thin walled parenchyma cells. The parenchyma cells may be rounded or angular. They enclose inter-cellular spaces for diffusion of gases.
- The cells of the cortex store food. They also conduct water from the epiblema to the inner tissues.

III) Endodermis:

- It is made up of single layer of barrel – shaped cells which do not enclose inter-cellular spaces. The cells are rich in starch grains.

- The young endodermal cells possess a band of thickening which runs along their radial and tangential walls. This band of thickening is called casparian strip. It is made up of both suberin and lignin.

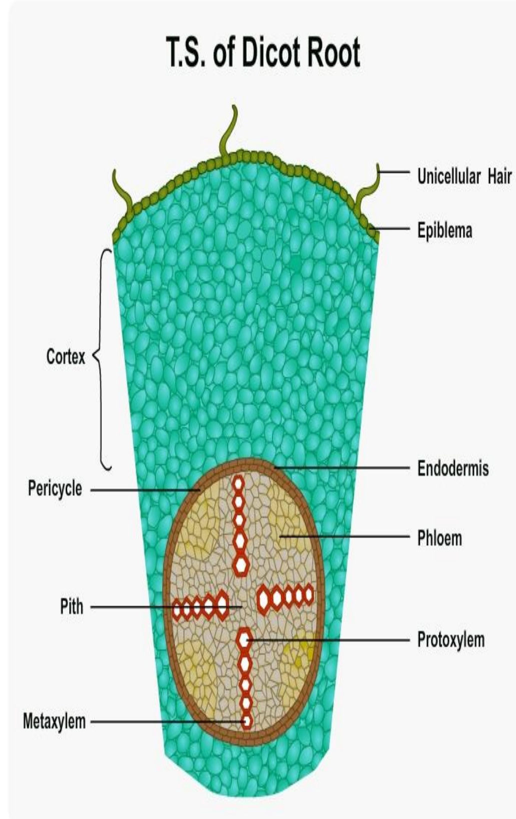
- In a transverse section, the casparian strip appears in the form of small lenticular swellings on the radial walls only.



- The casparian strip may become faint due to deposition of additional wall thickening of lignin. In such cases small unthickened areas called pits are left in the cell walls.
- The endodermis probably controls the movement of fluid and air from outside to the interior and vice versa.

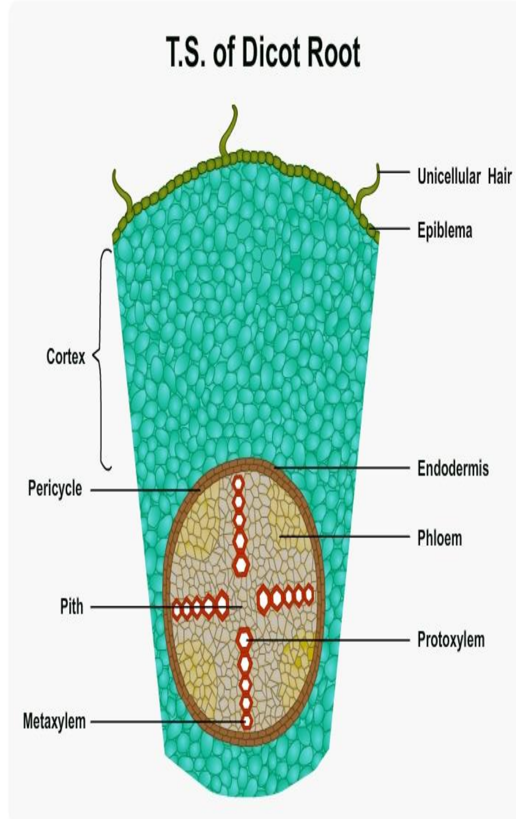
IV) Pericycle:

- Endodermis is followed by one or more layers of pericycle.
- The cell of the pericycle are thin walled and parenchymatous.
- The pericycle is a very important layer. A part of the vascular cambium is formed by the pericycle.
- The cork cambium also develops from it. All lateral roots originate from the pericycle.



V) Vascular Strand:

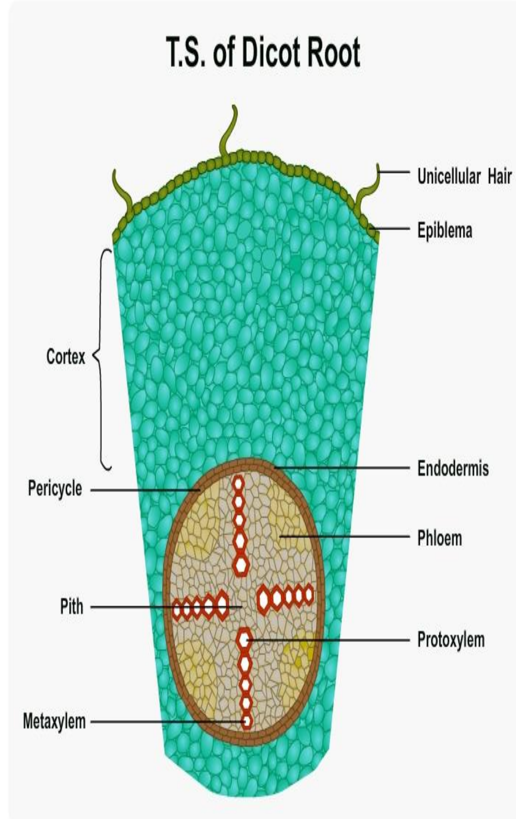
- Inner to the pericycle are found a few alternately arranged bundles of xylem and phloem. They are equal in number and lie on different radii. Such vascular bundles are called radial bundles.
- The various xylem bundles put together give a stellate or star shaped appearance. The number of rays is equivalent to the number of xylem bundles (and phloem bundles).
- According to the number of rays, the root may be diarch (with 2 Xylem bundles e.g. Tomato), triach (Pea, tetrarch (Sunflower), pentarch (with 5 xylem bundles) or polyarch (with more than 5 xylem bundles)
- Protoxylem or the first formed xylem lies at the tip of the rays while metaxylem or later formed xylem is present towards the centre of the root.



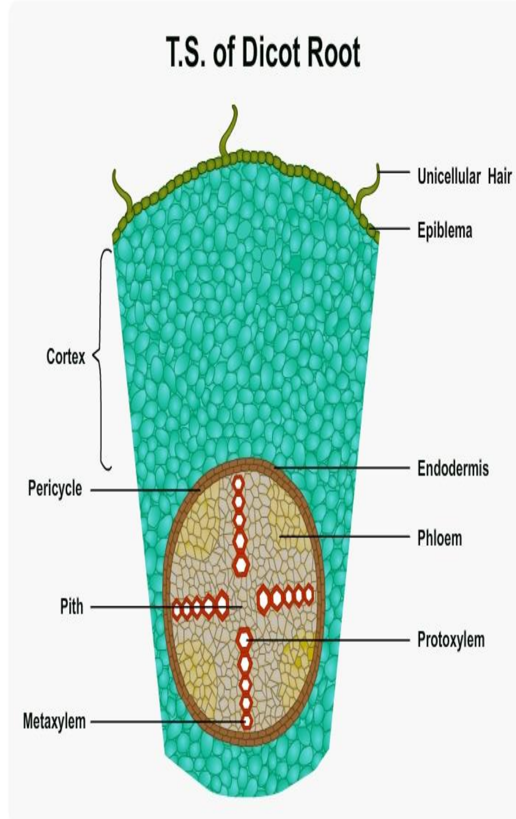
- Such a xylem is called exarch (ex- outside, arche – beginning). The metaxylem of different xylem bundles may lie separate from one another so that a pith is present in the centre of the root (e.g. Bean).
- However, usually the metaxylem elements of different bundles meet in the centre to form a solid star shaped structure. In such case the pith is absent.
- **Xylem** is made up of vessels and few tracheids. Vessels and tracheids are polygonal in outline.
- Protoxylem elements are fewer, smaller and narrower. The metaxylem elements are larger and wider. They have pitted thickenings while protoxylem possesss spiral, annular, reticulate or scalariform thickenings.

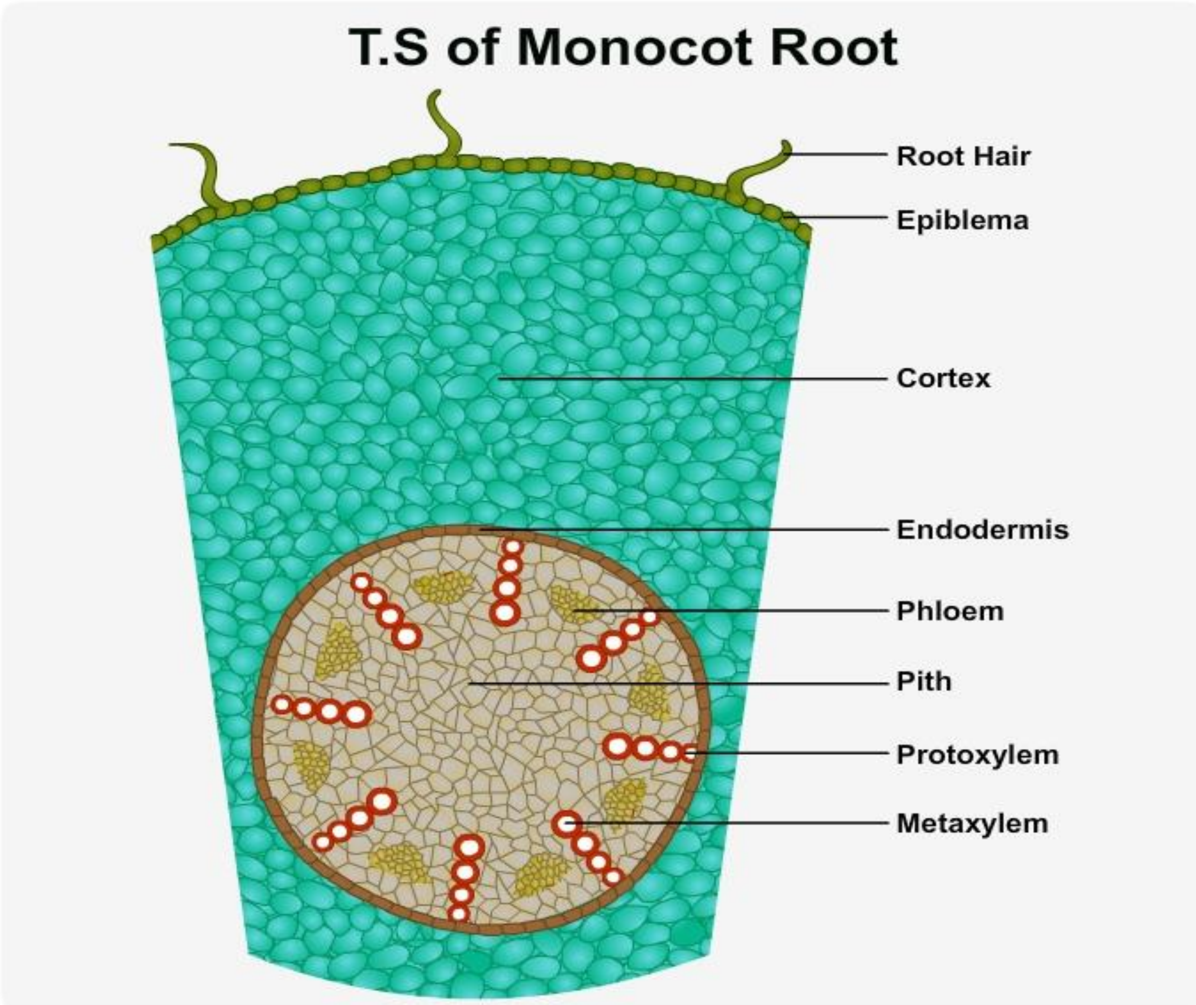
Xylem performs two important functions:

- Mechanical strength
- Conduction of water and mineral salts to the shoot



- In between the two adjacent xylem bundles is found a phloem bundle.
- Phloem and xylem bundles are separated from each other by one or more layers of small thin walled cells called conjunctive parenchyma or tissue. Latter on the conjunctive tissue becomes meristematic to form vascular cambium.
- In some roots the phloem bundle bear a cap of sclerenchyma towards the outer side, below the pericycle.
- **Phloem** consists of sieve tubes, companion cells and phloem parenchyma. It conducts organic food from shoot to the root and its branches.




T.S of Monocot Root
Root Hair
Epiblema
Cortex
Endodermis
Phloem
Pith
Protoxylem
Metaxylem

PRIMARY MONOCOT ROOT:

There is no distinction between a young and an old root of monocotyledonous plant. This is due to the absence of secondary growth in monocot roots. Typical monocot root consists of the following parts.

I) Epiblem or piliferous layer:

- It is the outermost layer of young root which has thin walled cells. Some of the cells give rise to root hairs.
- Root hairs are tubular in outline and lie in contact with soil water.
- Both epiblema and root hairs are devoid of cuticle.
- They take part in the absorption of water and mineral salts. In older parts the epiblema is shed or become impervious.

II) Cortex:

- It is very wide region of parenchymatous cells that enclose intercellular spaces for the exchange of gases. The cells are store food.
- In older roots the outer one or more layers of the cortex become thick walled and suberised. They constitute the exodermis.
- It is protective and to some extent absorptive in function.

The cortex of a monocot root has, therefore, three functions:

- Storage of food
- Conduction of water from the root hairs to the inner tissues
- The outermost layer or layers of the cortex produce protective exodermis in the older roots.

III) Endodermis:

- It is a single layered structure that lies on the inner boundary of the cortex. It is made up of barrel-shaped cells which do not enclose intercellular spaces.

- The young endodermal cell possess an internal strip of suberin and lignin which is known as casparian strip.

- However, it soon disappears due to the additional thickening of the endodermal cells.

- Endodermal cells lying opposite the protoxylem groups, however, remain in the primary stage with the usual casparian strip. These unthickened cells are called passage cells.

- The passage cells are ment for the conduction of fluids inwardly from the cortex and outwardly from the interior into the cortex. The thickened cells can also allow transport through plasmodesmata of pits.

- The endodermis regulates the flow of fluid both inwardly as well as outwardly.

IV) Pericycle:

- It lies below the endodermis. The pericycle is made up of parenchymatous cells which store abundant food.

- In monocots the pericycle does not form cambia. It, however, produces lateral roots.

V) Vascular strand:

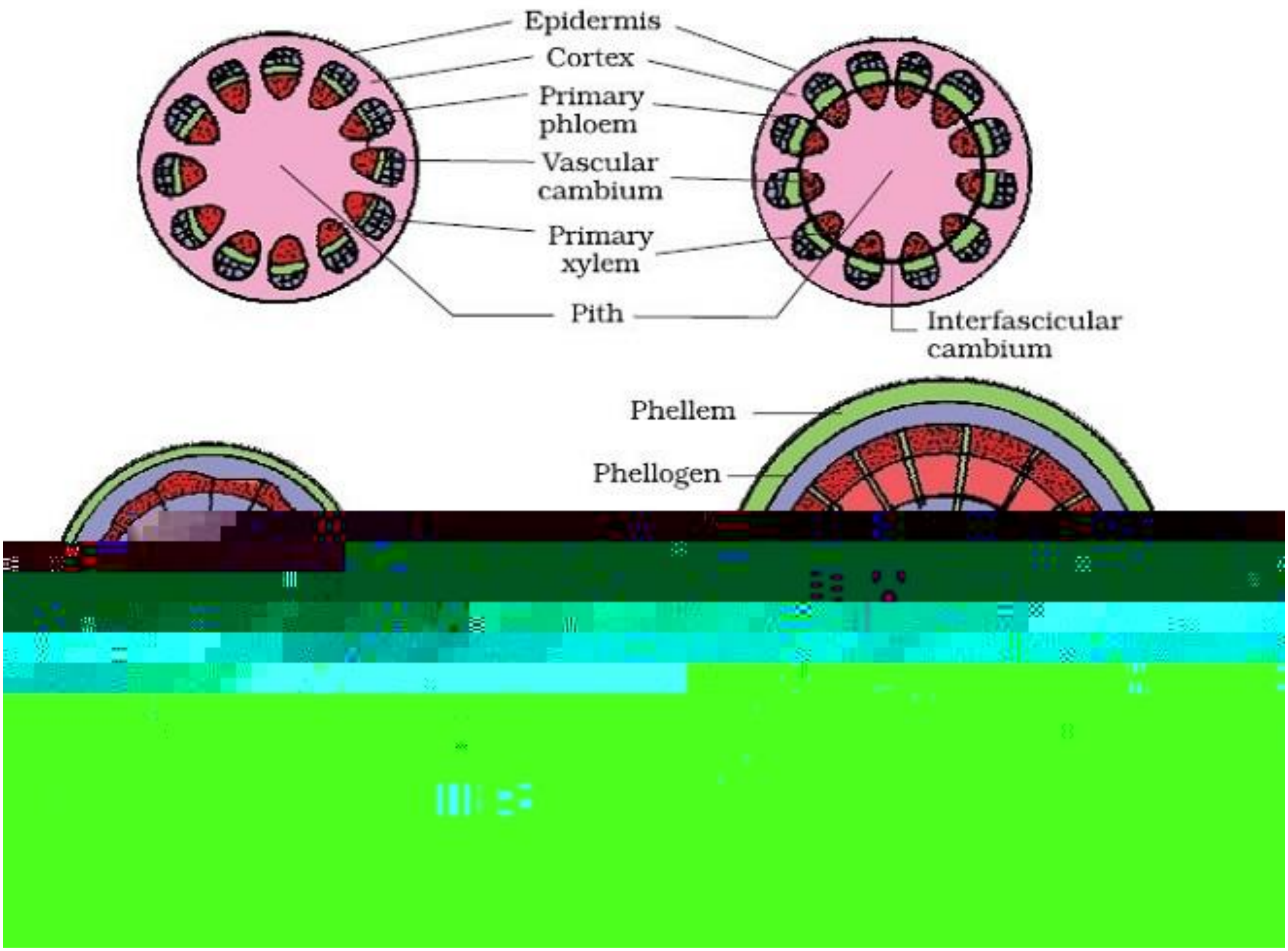
- It is in the form of several alternate and radial xylem and phloem bundles. The number is 100 or more of each type in *Pandanus* and palms.
- In many cases the vascular bundles are embedded in a cylinder of sclerenchyma. The vascular bundles are arranged in the form of ring around a central pith.
- The xylem bundles are exarch, i.e., protoxylem lies towards the outside while the metaxylem faces inwards.
- Xylem is made up of rounded or oval vessels and xylem parenchyma. Xylem provides mechanical strength and helps in the conduction of water and mineral salts.
- Phloem bundles alternate with the xylem bundles.
- These two are separated from each other by means of narrow strip of parenchyma called conjunctive tissue. The cells of this tissue simply store food. They do not take part in the formation of cambium.
- Phloem consists of sieve tubes, companion cells and phloem parenchyma, it helps in the conduction of organic food.

VI) Pith:

- The centre of monocot root is occupied by the pith.
- It consists of parenchymatous cells which may be rounded or angular. Intercellular spaces are present amongst the pith cells.
- The pith cells store food.

Difference between Dicot and Monocot Root:

Sr. No.	Dicot Root	Monocot Root
1	Cortex is comparatively narrow	Cortex wider
2	The epiblema, the cortex and even the endodermis are peeled off and replaces by cork.	Cork is not formed. The cortex and the endodermis persist. Only the epiblema is peeled off.
3	Endodermis is less thickened and casparian strips are more prominent.	Casparian strips are visible only in young root. The endodermal cells later become highly thickened
4	Passage cells are generally sbsent in endodermis.	Thin walled passage cells generally occur in the endodermis opposite the protoxylem points.
5	Pericycle produces lateral roots cork cambium and part of the vascular cambium.	Pericycle produces lateral roots only.
6	The number of xylem and phloem bundles varies from 2- 5 or some times 8.	Xylem and phloem bundles are numerous and are 8 or more in number.
7	Xylem vessels are generally angular.	Xylem vessels are oval or rounded.
8	Conjunctive tissue is parenchymatous.	Conjunctive tissue may parenchymatous or sclerenchymatous.
9	Conjunctive parenchyma forms the cambium.	Conjunctive parenchyma does not produce cambium.
10	Secondary growth takes place with the help of vascular and cork cambium.	Secondary growth is absent.
11	Pith is either absent or very small.	A well – developed pith is present in the centre of the root.


Epidermis
Cortex
Primary phloem
Vascular cambium
Primary xylem
Pith
Interfascicular cambium
Phellem
Phellogen

SECONDARY GROWTH IN DICOT STEM

- The formation of secondary tissue from the lateral meristem is called secondary growth.

- It increase in diameter of the stem. A stem with secondary tissues is called secondary stem.

- Secondary tissues are formed by two types of lateral meristem, vascular cambium and cork cambium or phellogen.

- Vascular cmbium produces secondary vascular tissues while phellogen form periderm.

- Secondary growth occurs in perennial dicots such as trees and shrubs.

- It is also found in the woody stems of herbs. In such cases, the secondary growth is equivalent to one annual ring, e.g. sunflower.

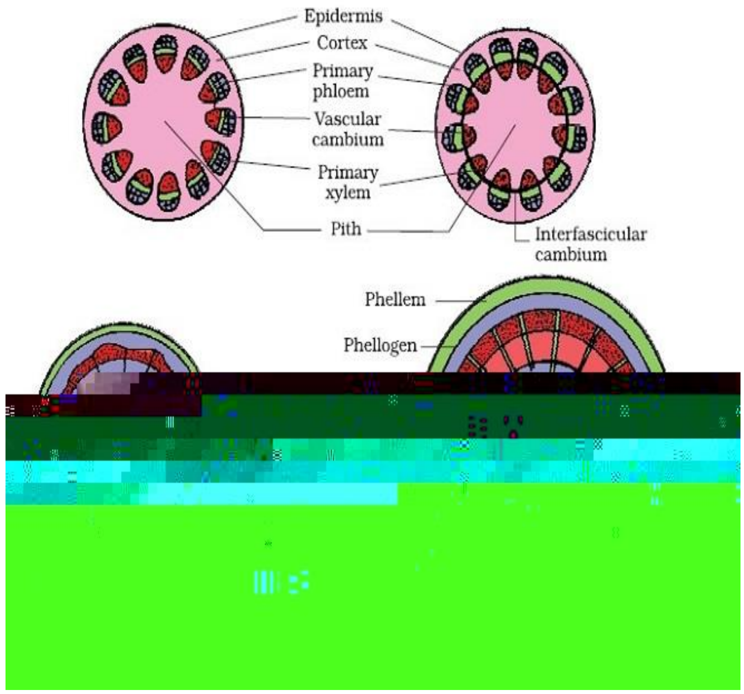
Formation of secondary vascular tissues:

- They are formed by the vascular cambium. Vascular cambium is produces by two types of meristems, intrafascicular and interfascicular cambium.

- Interafascicular cambium is a primary meristem which occurs as strips in vascular bundles.

- Interfascicular cambium arises secondarily from the cells of medullary rays which occur at the level of intrafascicular strips.

- These two types of meristematic tissues get connected to form a ring of vascular cambium

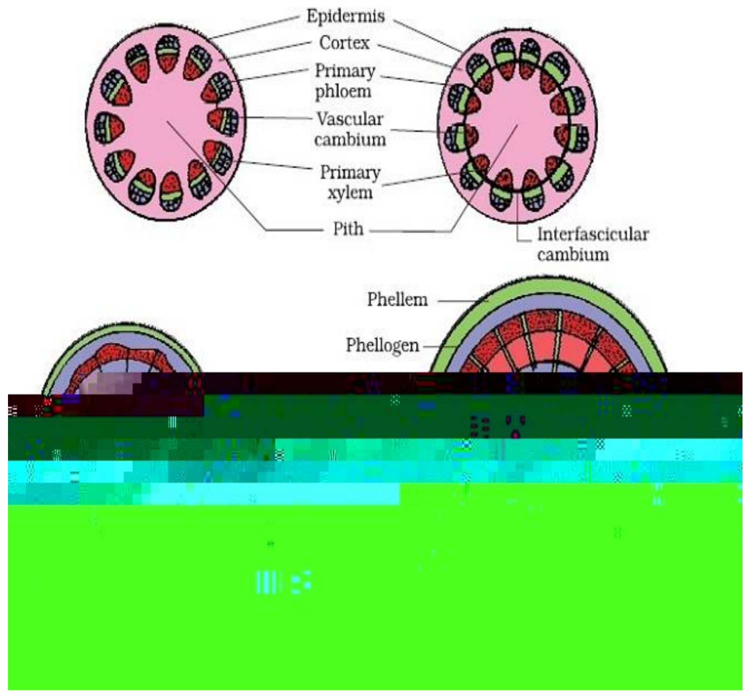


- The cells of vascular cambium are of two types, fusiform initials and ray initials.

- The ray initials are smaller and are found in groups they give rise to vascular rays.

- The fusiform initials are elongated ant taper at their ends. They divide both on the outer and inner sides to form tissue mother cells.

- The tissue mother cells, formed outside the ring of vascular cambium, give rise to secondary phloem while those of the inner side produce secondary xylem.



- With the formation of secondary xylem on the inner side, the vascular cambium moves gradually to the outside by adding new cells.

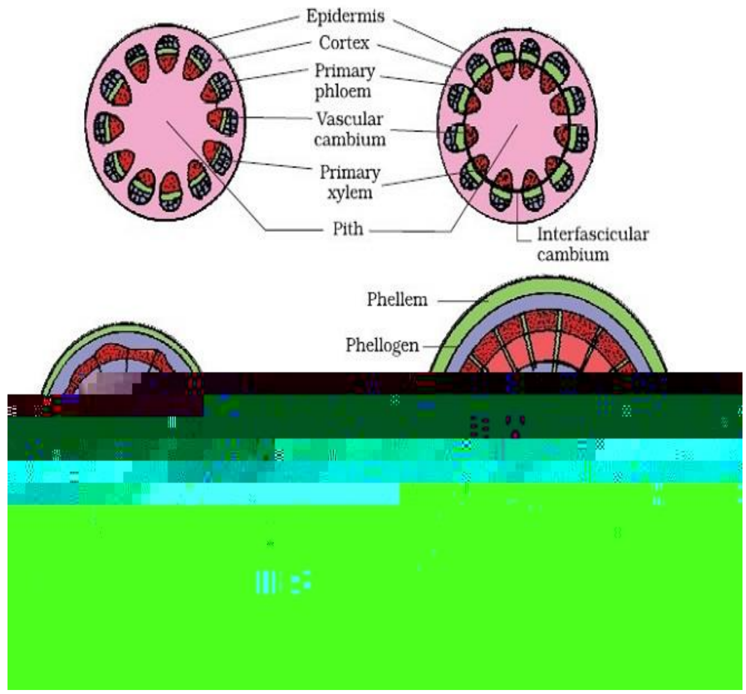
- The phenomenon is called dilatation. New ray cells form additional rays every year.

a) Vascular rays:

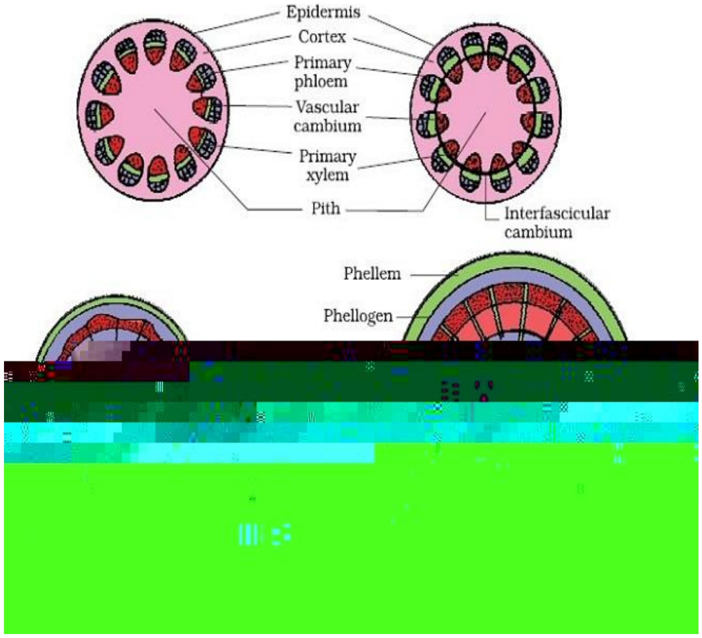
- The vascular rays or secondary medullary rays are rows of radially arranged cells which are formed in the secondary vascular tissues. They are a few cells in height.

- Depending upon their breadth, the vascular rays are uniseriate (one cell breadth) or multiseriate (two or ore cells in breadth).

- Vascular rays may be homocellular (having one type of cells) or heterocellular (with more than one type of cells).



- These cells of the vascular rays enclose intercellular spaces.
- The part of the vascular ray present in the secondary xylem is called wood or xylem ray while the part present in the secondary phloem is known as phloem ray.
- The vascular rays conduct water and organic food and permit diffusion of gases in the radial direction. Besides, their cells store food.

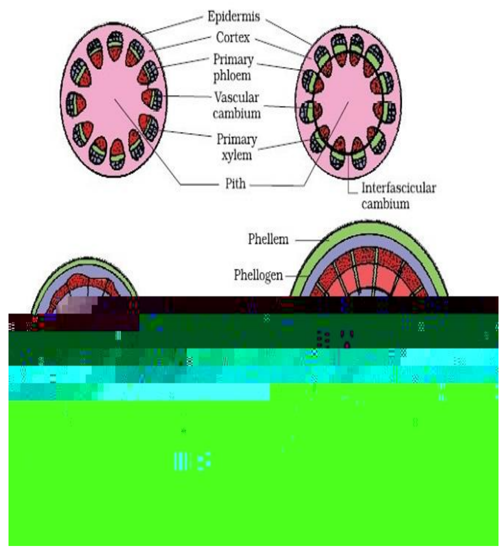


b) Secondary phloem:

- The secondary phloem forms a ring on the outside of cambium. It is made up of the same types of cells as are found in the primary phloem.
- Fibres commonly occur either in patches or bands. The primary or older phloem present on the outside gets crushed.

c) Secondary xylem:

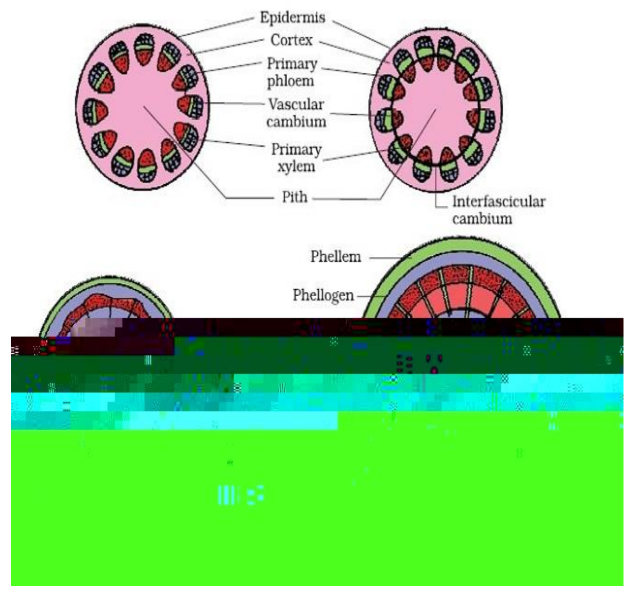
- It forms the bulk of the stem and is commonly called wood. Its width grows with the age of plant.
- The primary xylem persists as conical projection on its inner side.
- The yearly growth of secondary xylem is distinct in the ares which experience two seasons, one favourable (spring or rainy season) and the other unfavourable (autumn, winter or summer).
- Here the annual or yearly growth appears in the form of distinct rings which are called annual rings.



Annual ring:

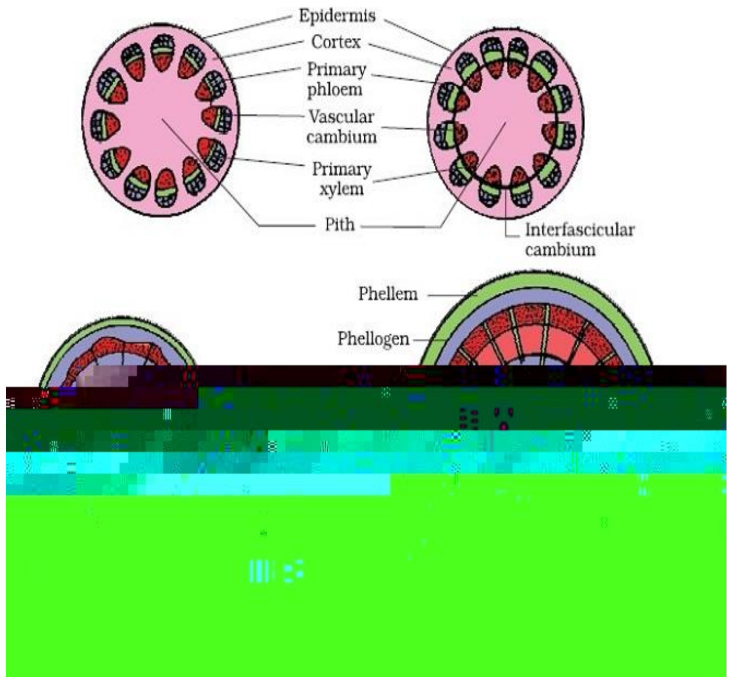
- It is the wood formed in a single year. It consists of two types of wood, spring wood and autumn wood.
- The spring or early wood is much wider than the autumn wood. It consists of large xylem elements.

- The autumn or late wood contains compactly arranged smaller elements which have comparatively thicker walls. In autumn wood, tracheids and fibers are more abundant than those found in the spring wood.
- The transition from spring to autumn wood in an annual ring is gradual but the transition from autumn wood to the spring wood of the next year is sudden.
- Therefore, each year's growth is quite distinct.
- The number of annual rings correspond to the age of that part of the stem (They can be counted by increment borer). Besides giving the age of the plant, the annual rings also give some clue about the climatic conditions of the past through which the plant has passed.
- Ring like markings occur in wood of some plants growing in uniform climate, e.g., Mango. They represent tangential bands of xylem parenchyma.

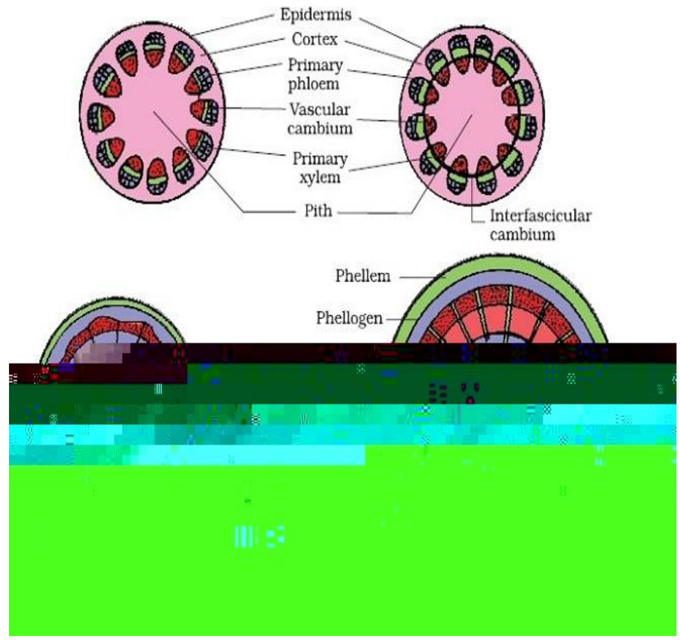


Sapwood and heartwood:

- The wood of the older stems gets differentiated into two zones, the outer lighter and functional sapwood or alburnum and the inner darker and nonfunctional heartwood or duramen.
- The tracheids and vessels of the heartwood get plugged by the in growth of the adjacent parenchyma cells into their cavities through the pits. These ingrowths are called tyloses.
- Ultimately, the parenchyma cells become lignified and dead.
- Various types of plant products like oils, resins, gums and tannins are deposited in the cells of the heartwood. These substances provide colour to the heartwood. They are also antiseptic.



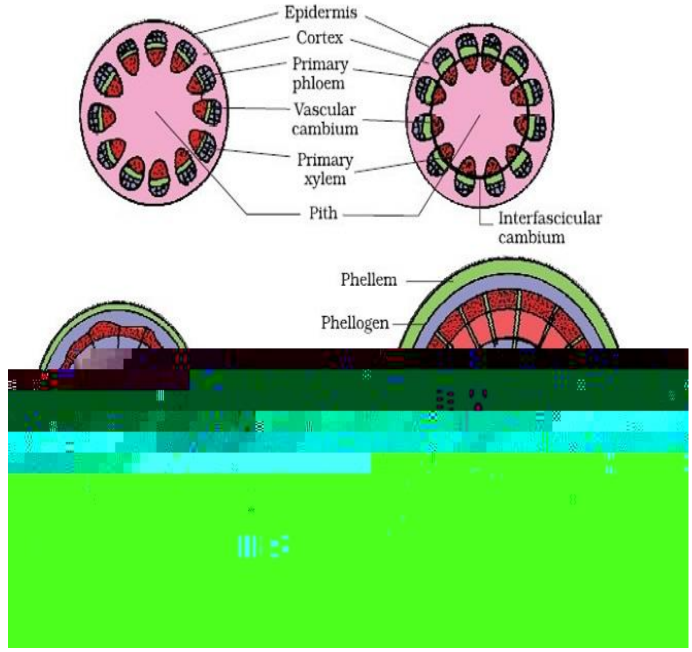
- The heartwood is, therefore, stronger and more durable than sapwood.
- It is however, liable to be attacked by wood rotting fungi. Hollow tree trunks are due to their activity.



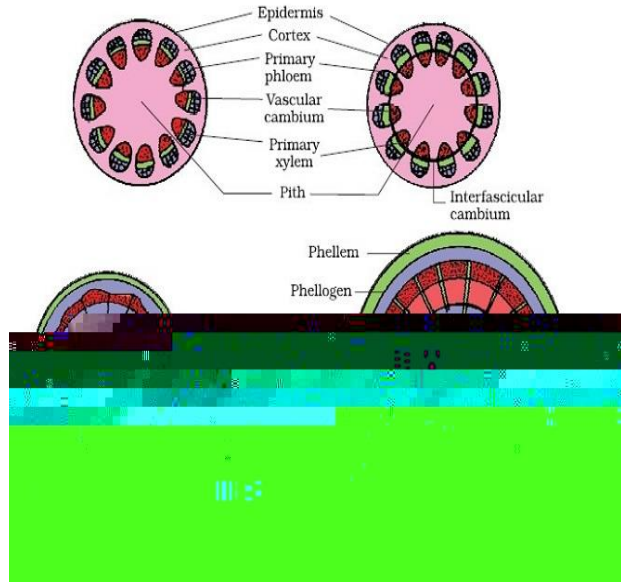
Formation of periderm:

- In order to provide for increase in girth and prevent harm on the rupturing of the outer ground tissue due to the formation of secondary vascular tissues, dicot stems produce a cork cambium pr phellogen in the outer cortical cells.
- Rarely it may arise from the epidermis (e.g. Teak, Olender), hypodermis (e.g., Pear) or phloem parenchyma.
- Phellogen cells divide on both the outer as well as the inner side (Bipolar) to form secondary tissues.

- The secondary tissue produced on the inner side of the phellogen is parenchymatous or collenchymatous. It is called secondary cortex or phelloderm. Its cells show radial arrangement
- Phellogen produces cork or phellogen on the outer side. It consists of dead and compactly arranged cells that possess lignified and suberised cell walls.
- The cork cells contain tannins. Hence they appear brown or dark brown in colour.
- The cork cells of some plants are filled with air (e.g. Bottle Cork). The phelloderm, phellogen and phellem together constitute the periderm.
- Cork prevent the loss of water by evaporation.



- It also protect the interior against entry of harmful micro-organisms, mechanical injury and extremes of temperature. At places phellogen produces aerating pores instead of cork.
- These pores are called lenticels. Each lanticel is filled by mass of somewhat loosely arranged subrised cells called complementary cells.

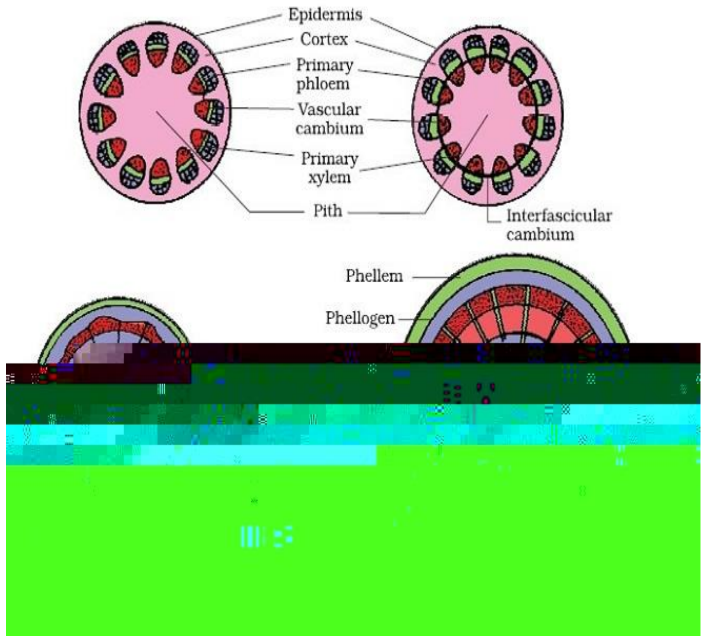


Bark:

- All the dead cells lying outside phellogen are collectively called bark. The outer layers of the bark are being constantly peeled off on account of the formation of new secondary vascular tissues in the interior.
- The peeling of the bark may occur in sheets (sheets or ring bark, e.g. eucalyptus) or in irregular strips (Scaly bark). The scaly bark is formed when phellogen arise in strips instead of ring, e.g., *Acacia*

➢ Bark is insect repellent, decay proof, fire – proof and acts as a heat screen. Commercially it is employed in tanning (e.g., *Acacia*), drugs (e.g., Cinchona quinine) or as spice (e.g., Cinnamon).

➢ The cork of quercus suber is employed in the manufacture of bottle stoppers, insulators, flots, sound proofing and linoleum

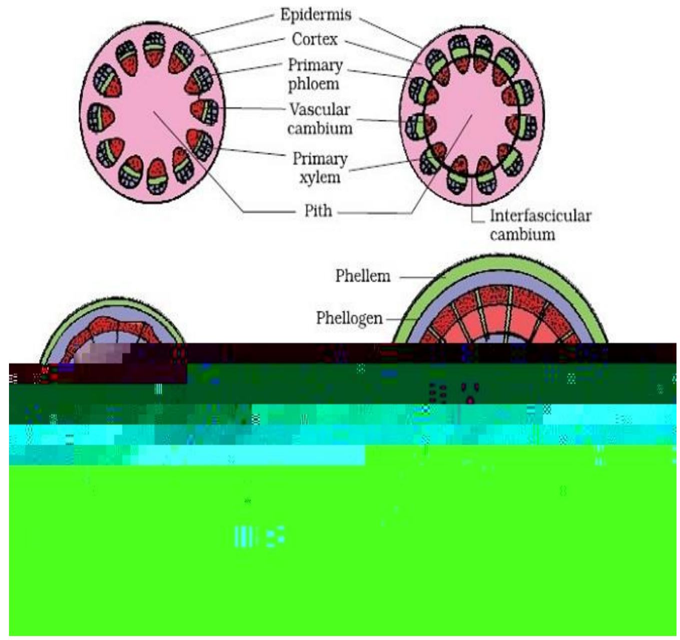


Lanticels:

➢ Lenticels are aerating pores in the bark of plants. They appear on the surface of the bark as raised scars containing oval, rounded or oblong depressions.

➢ A lanticel is commonly produced beneath a former stomata or stoma of the epidermis. Its margin is raised and is formed by surrounding cork cells.

- The lenticels is filled up by loosely or compactly arranged thin walled rounded and suberised or unsuberised cells called complementary cells. They enclose intercellular spaces for gaseous exchange.



- The complementary cells are formed from loosely arranged phellogen cell and division of sub-stomatal parenchyma cells.

- The suberised nature of complementary cells checks excessive evaporation of water.

- In temperate plants the lenticels get closed during winter by the formation of compactly arranged closing cells over the complementary cells.

Difference between primary and secondary xylem:

Sr.No.	**Primary xylem**	**Secondary xylem**
1	It is formed from apical meristem	Secondary xylem is produced from a lateral meristem.
2	Primary xylem occurs in all types of stems and root	It is found only in dicots with the exception of some annuals.
3	The xylem is differentiated into two parts, protoxylem and metaxylem.	There is no distinction.
4	A radial system is absent.	It is traversed by a radial system of xylem rays
5	Annual rings are absent	It may show annual rings.
6	There is no distinction into sapwood and heartwood	A distinction into sapwood and heartwood is found in large woody plants.
7	Fibres are few or absent.	Fibres are generally abundant.
8	The tracheids and vessels are long and comparatively thin walled	The tracheids and vessels are long and comparatively shorter and more thick walled.
9	Tyloses are absent	The tracheids and vessels of older xylem get blocked by the development of Tyloses.

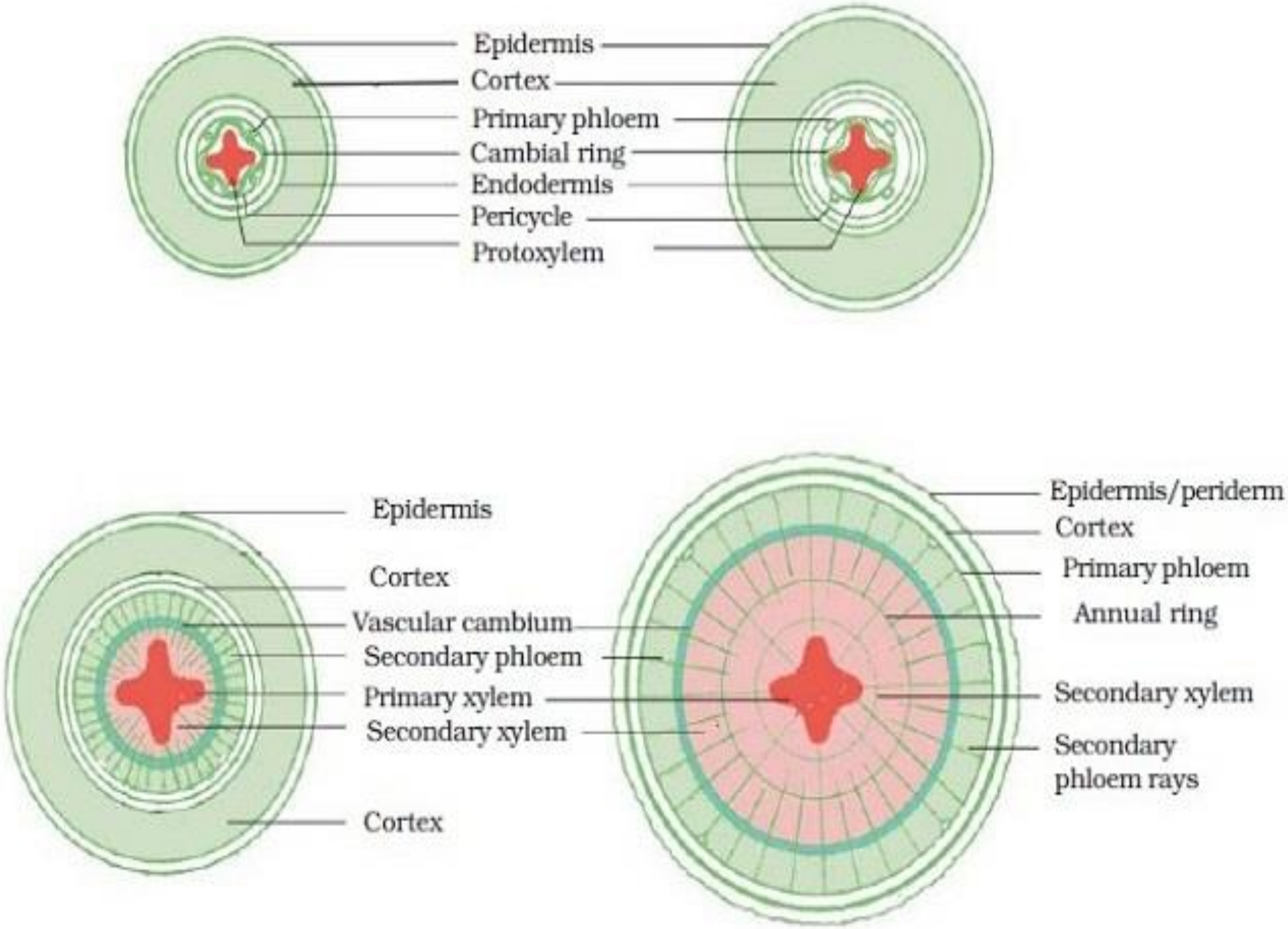


Figure 11. Different stages of the secondary growth in a typical dicot root

SECONDARY GROWTH IN DICOT ROOT:

- Secondary growth is the production of secondary tissues. Secondary tissues increase the thickness of the root. With the exception of some annuals, most of the dicots show secondary growth in their roots.

- It takes place by the production of two types of secondary tissues.

- They are secondary vascular tissue and epiderm. These tissues are formed by meristems, vascular cambium and cork cambium respectively.

Secondary vascular tissues:

- The conjunctive parenchyma cells lying around each phloem bundle become meristematic to produce a strip of cambium.

- These strips are soon joined by cambial strips arising from pericycle cells lying opposite the protoxylem points.

- Wavy band of vascular cambium is, therefore, formed the cambium of the root is a secondary meristem.

- The vascular cambium becomes active first below the phloem bundles. The vascular cells formed by it push the primary phloem to outside. The cambium also moves outwardly and becomes circular in outline.

- The ring of vascular cambium produces secondary xylem on the inner side and phloem to the outside.

- Both of them are in the form of rings (primary vascular bundles). The primary phloem gets crushed by the growth of secondary vascular tissues.

- The older secondary phloem is also partially destroyed as the new phloem becomes functional. The primary and secondary xylems persist.

- Primary xylem is distinguishable by its exarch nature and central position.

- As compared to the primary xylem, the vessels of the secondary xylem are broader and thinner.

- Annual rings are not very sharp because unlike aerial climate, the climate of the soil does not vary much during different seasons.

- **The secondary phloem** is made up of sieve tubes, companion cells and phloem parenchyma. Sclerenchyma fibres are rare.

- The secondary xylem is formed of vessels trachieds and xylem parenchyma.

- At place the vascular cambium possesses ray initials. They produce vascular rays.

- The rays are made up of two parts, xylem or wood ray and phloem ray.

- They help in radial conduction of substances.

- Very prominent vascular rays are produces opposite the protoxylem point. They are many cells in which in width (multiseriate)

Secondary ground tissues or Periderm

- The pericycle layer either directly or after a few divisions, becomes converted into a secondary meristem called cork cambium or phellogen.

- Rarely phellogen appears in the cortex.

- The cells of phellogen divide both towards, the outside as well as inside.

- The tissue formed towards the inner side is parenchymatous and known as secondary cortes or phelloderm. It is only a few layers in thickness.

- The cells formed on the outside by the phellogen become dead.

- The cavities get filled up with tannin and their walls become suberised. They are described as cork cell.

- The tissue of cork cell is spoken as cork or phellem. The cork is impervious to water. It protecy the interior from mechanical injury and entry of bacteria.

- Primary tissues present outside the cork undergo starvation and get shriveled.

- Under the impact of secondary growth in the interior, the outer layers of the cork are also peeled off occasionally.

- The phellem the phellogen and the phelloderm are collectively called secondary ground tissue or periderm.

- At places the phellem or cork bears lenticels for exchange of gases.

Origin of lateral roots:

- The root branches are endogenous (endon within, genes – produces) in origin. It is aprotective mechanism.
- The lateral roots arise from pericycle (endodermis in case of seedless vascular plants) opposite the protoxylem points , a little distance behind the tip.
- Two or more cells of the pericycle become meristematic.
- They develop into the growing point of the lateral root. This soon produces root cap, protoderm, ground meristem and procambium. Latter these give rise to epiblems, ground tissue and vascular strand respectively.
- The vascular strand of lateral root gets connected with that of the parent root.
- Some of the cells present at the tip of the lateral root may act as digestive cells for destroying the outlying cells.
- The endodermis, the cortex and the epiblem of the parent root ultimately break and the lateral root comes out.

Thank you

The tissue system:

- A group of tissues performing a similar function irrespective of its position in the plant body is called a tissue system.

- In 1875, Sachs recognized three tissue systems in the plants.

a) **Epidermal tissue system b) Vascular tissue system c) Fundamental tissue system**.

a) Epidermal tissue system:

- Epidermal tissue system is the outermost covering of plants.

- It consists of epidermis, stomata and epidermal outgrowths.

- Epidermis is generally composed of single layer of parenchymatous cells compactly arranged without intercellular spaces.

- But it is interrupted by stomata. In leaves some specialized cells which surround the stomata are called the guard cells.

- Chloroplasts are present only in the guard cells of the epidermis.

- Other epidermal cells usually do not have chloroplasts. The outer wall of epidermis is usually covered by cuticle.

- Stoma is a minute pore surrounded by two guard cells. The stomata occur mainly in the epidermis of leaves.

- In some plants such as sugarcane, the guard cells are bounded by some special cells. They are distinct from other epidermal cells. These cells are called subsidiary or accessory cells.

- Trichomes and root hairs are some epidermal outgrowths. The unicellular or multicellular appendages that originate from the epidermal cells are called trichomes.

- Trichomes may be branched or unbranched.

- Rhizodermis has two types of epidermal cells - long cells and short cells.

- The short cells are called trichoblasts. Root hairs are produced from these trichoblasts.

Functions of epidermal tissue system:

1. This tissue system in the shoot checks excessive loss of water due to the presence of cuticle.

2. Epidermis protects the underlying tissues.

3. Stomata involve in transpiration and gaseous exchange.

4. Trichomes are also helpful in the dispersal of seeds and fruits.

5. Root hairs absorb water and mineral salts from the soil.

b. Vascular tissue system:

- The vascular tissue system consists of xylem and phloem.

- The elements of xylem and phloem are always organized in groups. They are called vascular bundles.

- In dicot stem, the vascular bundle consists of cambial tissue in between xylem and phloem. Such vascular bundle is called **open vascular bundle.**

- In monocot stem, cambium is absent in the vascular bundle, hence it is known as **closed vascular bundle** In roots, xylem and phloem are arranged in an alternate manner on different radii. It is called **radial arrangement**.

- In stems and leaves, xylem and phloem are arranged at the same radius and form a vascular bundle together. Such vascular bundle is called conjoint vascular bundle.

- Depending upon the mutual relationship of xylem and phloem, conjoint vascular bundles are divided into three types. They are **collateral, bicollateral and concentric.**

- If xylem and phloem in a vascular bundle are arranged along the same radius with phloem towards the outside, such vascular bundle is called collateral vascular bundle.
- If phloem occurs on both the outer and inner sides of xylem, the bundle is called bicollateral. Bicollateral vascular bundles are most typically seen in Cucurbitaceae.
- The bundle in which either phloem surrounds the xylem or xylem surrounds the phloem completely is known as concentric vascular bundle.
- This is of two types amphicribral and amphivasal. In amphicribral concentric vascular bundles, the phloem completely surrounds the xylem. eg. Polypodium.
- In amphivasal concentric vascular bundles, the xylem completely surrounds the phloem. eg. Acorus.
- In roots, protoxylem vessels are present towards the periphery and the metaxylem vessels towards the centre. This arrangement of xylem is called exarch.
- In stem, protoxylem vessels are towards the centre, while metaxylem towards the periphery. This condition is known as endarch.

c. Ground or fundamental tissue system:

- The ground or fundamental tissue system constitutes the main body of the plants.
- It includes all the tissues except epidermis and vascular bundles.
- In monocot stem, ground tissue system is a continuous mass of parenchymatous tissue in which vascular bundles are found scattered.
- Here ground tissue is not differentiated into **cortex, endodermis, pericycle and pith**.
- Generally in dicot stem, ground tissue system is differentiated into three main zones **- cortex, pericycle and pith**.
- The cortex occurs between the epidermis and pericycle. Cortex may be a few to many layers in thickness.
- In most cases, cortex is made up of parenchyma tissues.
- Intercellular spaces may or may not be present. Cortical cells may contain non-living inclusions like starch grains, oils, tannins and crystal.

- In the leaves, the ground tissue consists of chlorenchyma tissues. This region is called mesophyll.

- The inner most layer of the cortex is called endodermis. Generally endodermis is made up of barrel shaped parenchyma cells. These cells are arranged in a single layer without intercellular spaces.

- Pericycle occurs between the endodermis and the vascular bundles. It is generally made up of parenchyma cells. Lateral roots originate from the pericycle. Thus their origin is endogenous.

- The central part of the ground tissue is known as pith or medulla. Generally this is made up of thin walled parenchyma cells which may be with or without intercellular spaces. The cells in the pith generally store starch, fatty substances, tannins, phenols, calciumoxalate crystals, etc.

The mechanism of wood formation

- The growth of the tree is the result of production of new cells by tissues termed meristems.
- Meristems consist of cells that are undifferentiated and retain the ability to divide and produce new cells.
- The increase in the height of tree stem is designated as *primary growth* and is the result of cell production by *apical meristems* located at the tip of the stem.
- Just below the apical meristems, some of the cells form a *lateral meristem* called the c*ambium*. *Secondary growth* (to diameter), begins with formation of the cambium.
- Longitudial cells of wood are produced by cambial cells designed as *fusiform initials* and transverse by r*ay initials*. Cambium initials divide periclinally, namely with walls parallel to the cambium layer, and produce *xylem* and *phloem* mother cells.

- The phases of development of wood cells are: *cell division*, *cell enlargement*, *cell wall thickening*, *lignification* and *death*.

- The first phase, cell division, occurs when a cambial initial divides, forming two cells.

- The outermost cell remains meristematis and the innermost cell develops into a mature wood cell.

- During the enlargement phase, the cell grows in length and diameter. Softwood cells increases only in radial direction.

- During the enlargement phase, a very thin and plastic cell wall (primary wall) encases the protoplasm. During next phase, wall thickness is increased by the addition of secondary wall

- lignification involves the formation of lignin between the newly formed cells and within their cell walls.

- For most wood cells, death occurs immediately after lignification. However, for those wood cells that perform the function of storage, this step is postponed for an indefinite period.

- Cells performing the support and conduction roles usually pass through the five phases of cell development in 14 to 21 days.

FORMATION OF EARLYWOOD AND LATEWOOD

- The transition from earlywood to latewood formation is a conspicuous developmental in trees.
- Latewood is induced during the later part of the growing season, when cell division activity in the cambial meristem declines.
- It involves a reduction in radial expansion and an increase in wall thickening of the cambial derivatives.
- Thus, earlywood is characterized by large-diameter and thin-walled tracheids/vessels, whereas latewood is composed of narrow diameter tracheids/vessels with thick cell walls.
- The process of earlywood and latewood formation, that is the frequency of division of cambial cells, the enlargement of newly formed xylem cells, and cell wall thicken are controlled by photosynthate activity and plant hormones.

- In active season IAA **(Indole-acetic acid)** is largely synthesized by buds in the tree crown, developing leaves shoots and in the dormant period in winter, IAA is synthesized by dormant buds and old leaves.
- The occurrence of small amounts of endogenous IAA in the cambial zone suggests the formation of IAA by cambial cells.
- IAA synthesized by the tree crown is basipetally transported mainly to cambial cells and their differentiating cells.
- Concentration of endogenous IAA in the cambial zone of a tree stem exhibits a seasonal change.
- The concentration of IAA increased from spring to early summer, and then decreased toward the autumn to the level found in the spring.
- In winter, IAA was present at a low level.

- The stage of rapid decrease of IAA coincides well with the change from earlywood to latewood formation.
- IAA is a major factor in the control of elongation of xylem-differentiating cells, the formation of earlywood and latewood, and the transition of earlywood to latewood.
- Even if IAA is supplied, cambial activity ceased at a certain time of the season. For termination of cambial activity (dormancy), other factors may be involved.
- A change in the sensitivity of cambial cells to IAA has been suggested to be one of the factors involved. When IAA was supplied to tree stems cambial activity increased, but the effect changed seasonally, and after summer the effect was very small.
- The extract natural of any cambial sensitivity to IAA is scarcely known, but it seems that the change is induced by a change of temperature and day length, and is related to structural and histochemical changes in the cambial cells

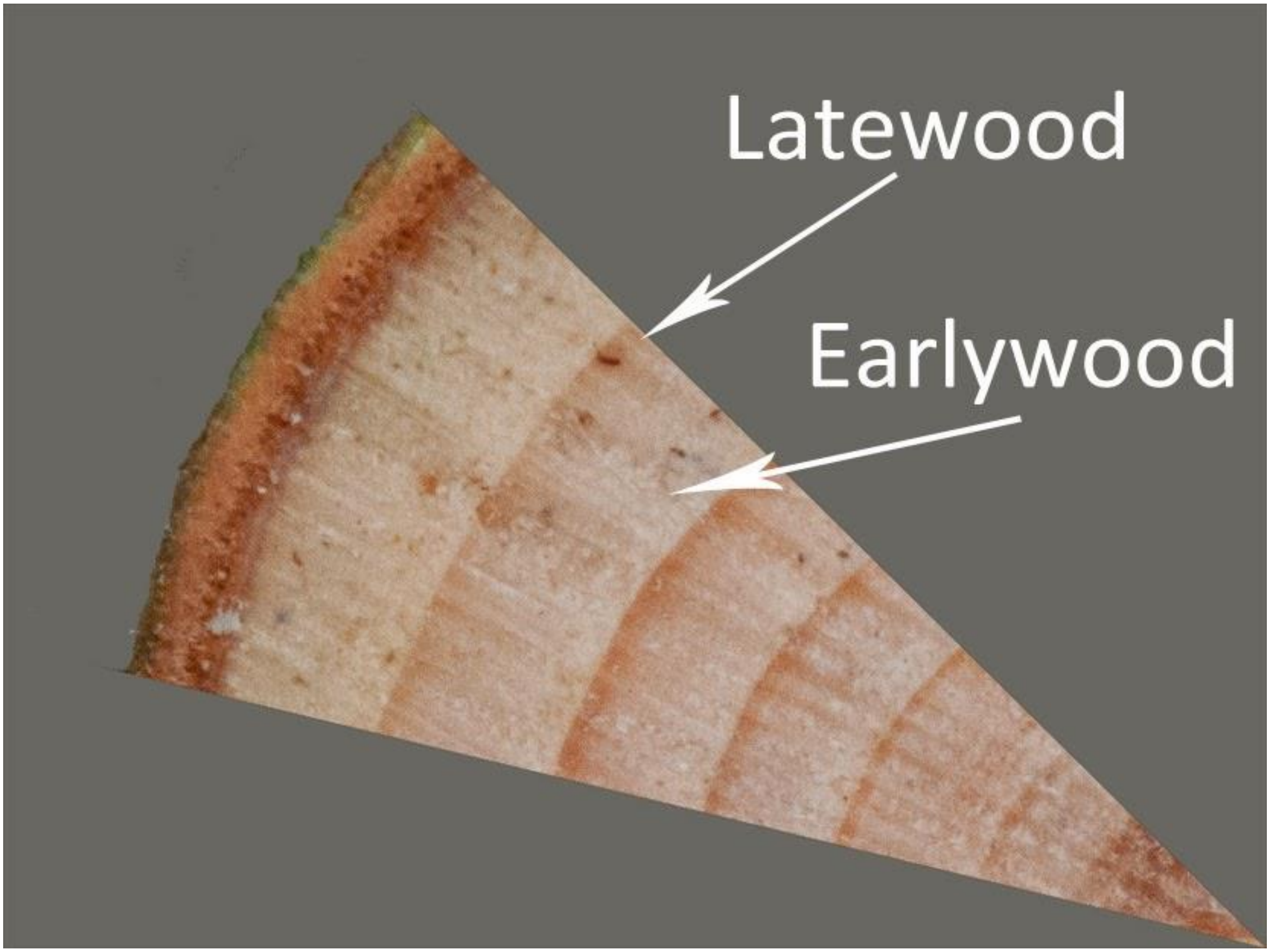
- It was found that a reconstructure of cell membrane occurred before dormancy.

- If IAA receptor or carrier proteins are present on the plasma membranes these proteins may tentatively be transported of decreased, thus inducing a low sensitivity for IAA.

- Other hormones like abscisic Acid (ABA) and cytokinins also play a role in the formation of early and late wood.

- Other factors responsible for the formation of early and late wood are abundance of soil moisture, nutrients.

- Water deficit conditions induce the early formation of the late wood. But, continued moisture deficit are reported to shorter period of latewood formation.


Latewood
Earlywood

Difference between early wood and late wood:

Sr. No.	Early wood or Spring wood	Late wood or Autumn wood
1.	Formed during spring season.	Formed during winter season
2.	Formed early in a year.	Formed after the early wood.
3.	Consists of xylem tissues with wider vessels	Consists of xylem elements with narrow vessels.
4.	Produced more in amount.	Produced less in amount.
5.	Less dense.	More dense.
6.	A broad zone of wood.	A narrow zone of wood.
7.	Not as strong as late wood.	Stronger than early wood due to larger Volume of wall materials.

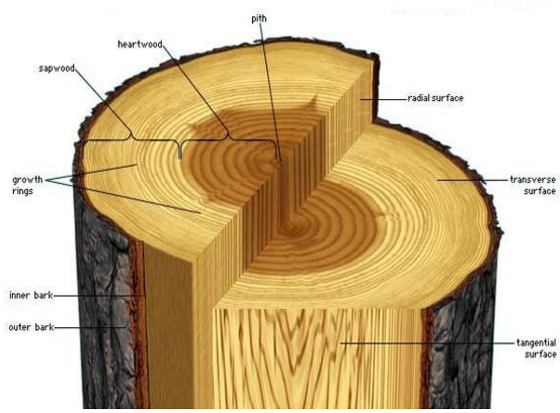
Growth Ring Formation

- The activity of vascular cambium is markedly effected by variation in the climate.
- Growth rings are the result of new growth in the vascular cambium, a layer of cells near the bark that is classified as a lateral meristem; this growth in diameter is known as secondary growth.
- Visible rings result from the change in growth speed through the seasons of the year; one ring generally marks the passage of one year in the life of the tree.
- During winter the cambium stop dividing. In spring season it regains its activity and starts dividing.

- During the season vegetative growth of the trees is pronounced, more leaves appear and there is dire need of effective transport of water and minerals dissolved in it and food material so that plant can cope with its increasing requirements.
- The cambium becomes more active because of favourable environments and divides activity producing a large number of vessels that have wider lumens.
- The secondary xylem formed during this period of pronounced activity is called spring wood.
- During the autumn season the activity of the cambium is lessened and the vessels produced are generally of smaller size and have narrow limens.
- Tracheids and wood fibres are produced in large numbers.

- The secondary wood formed during this season of the year is called autumn wood or summer wood. In transverse section of the stem these two types of woods appear in the form of distinct concentric circles known as the annual or growth rings.

- Spring wood circle and autumn wood circle constitute annual rings. Like this, year after year such rings appear and their identity is well marked.



- The number of annual rings in the old parts of the tree corresponds to its age.
- In some woody trees e.g. Tilia , Black ash and Tamarix dioca , the vessels in the springs woods are large and arranged in a ring and narrow vessels of the summer or autumn wood are scattered. Such a wood said to be ring porous.
- In *Eugenia* and *Azadiracta indica* the vessels are more or less uniformly distributed through the spring wood and autumn wood such wood is called diffuse porous wood
- The growth rings are not well marked in the trees growing in the tropical region of the world. Here the number of growing rings does not correspond to the age of the tree.

- The thickness of the annual rings is greatly influenced by fluctuation in the environmental conditions.

- It has been found that the annual rings remain thin during low rainfall and became thick if the rainfall is heavy.

- Sometimes permanent changes are brought about in he environment by chopping down the trees or by draining away water.

- In such cases the thickness of the ring produced before and after the change is remarkable and it has been possible to exactly judge the year when such a change was brought about.

Ray initial and fusiform initials, anticlinal and periclinal division

The vascular cambium produces secondary xylem on the inside of the ring, and secondary phloem on the outside, pushing the primary xylem and phloem apart. The vascular cambium usually consists of two types of cells: **Fusiform initials** (tall, axially oriented) **Ray initials** (smaller and round to angular in shape)

Functions:

- Fusiform initials are helpful in the formation of secondary xylem and secondary phloem components and thereby contributes in secondary growth.

- Ray initials are helpful in the formation of xylem rays and phloem rays and helps in lateral conduction of water and mineral salts through these ray initials.

Fusiform Initial Cells:

- These cells are highly elongated and tapering, and give rise to the vertical system of a plant.

- They are prismatic in the centre and wedge-shaped towards the ends.

- In TLS(Transverse longitudinal section) they appear flat and prism shaped. The derivatives of fusiform initials always divide periclinally and give rise to the axial system.

- Maturation of fusiform initials show characteristic growth patterns, wherein their elongation keeps on increasing, reaches a plateau and eventually dies. However in some species of Pinusplateau has not been reached even after 2200 years.

- Mean length of fusiform initial is higher in angiosperms with primitive vessel members than those with advance vessels. Storied cambia have shorter fusiform initials than non-storied cambia.

- Fusiform initials are the only cell types that divide along their longitudinal axis.

- The products formed by division of fusiform initials are: tracheids, vessel members, xylem fibres, xylem parenchyma, which together forms the secondary xylem.

- They also gives rise to components of secondary phloem namely, phloem parenchyma, phloem fibres, sieve cells,albuminous cells (strasbuger’s cells), sieve tube members along with companion cells.

- Number of vessel members is equal to the number of fusiform initials. Every contagious, adjoining neighboring vessel member has a common perforation plate.

Ray initials:

- Ray cells are isodiametric and upon division lead to formation of the radial system of secondary growth.
- They run parallel to the radii which pass through the centre of the organ.
- They affect the transport efficiency of water, mineral nutrients and photo-assimilates and ultimately plant height.
- Transformation of ray initials into fusiform initials and vice versa.
- Fusiform and ray initial cells may interconvert into the other.
- Formation of ray initial from fusiform initial may be brought about by lateral partitioning, direct partitioning and septation.
- Reverse pattern of transformation of ray-initial to fusiform initial is although present, but uncommon.

Anticlinal and Periclinal Cell Division:

- All living things, including plants and living creatures are made up of one cell or multiple cells. **Cell division** is the process by which the parent cell divides into two or multiple daughter cells.
- Anticlinal and periclinal cell division are both different ways of cell division

Periclinal cell division:

- **Periclinal** cell divisions are the ones that occur parallel to the tissue or organ surface. As a result, we get rows of cells stacked one over the other.

- Periclinal is parallel to the surface. Such a division results in an increase in girth of the organ thus adding length. In cylindrical organs, such as stems and roots, the term tangential may also be used in place of periclinal.

Anticlinal cell division:

- **Anticlinal** cell divisions are perpendicular to the adjacent layer of cells. So, what you get is columns of cells adjacent to one another.

- Anticlinal division is at right angles to the surface. The anticlinal wall of a cell is arranged perpendicular to the surface of the plant body.

- An anticlinal division leads to the formation of anticlinal walls between daughter cells. Such a division allows the tissue to increase its circumference, thus increasing the girth of the organ.

In simple words, anticlinal division adds more thickness and periclinal division adds length.

Physiological significance of wood formation

Wood formation is an all-inclusive term for a series of biological processes that can be arbitrarily divided into four developmental phases :

i. Awakening of the cambium from dormancy
ii. Cell division of cambial initials and mother cells,
iii. Differentiation of cambial derivatives,
iv. Maturation.

- Sapwood is physiologically important because it serves as the principal avenue/role for transformation of water and minerals, while the living cells carry on metabolic process and store food.

- In contrast the dead heart wood is physiologically inactive.

- The function of heart wood is no longer conduction of water, but simply to give the mechanical support to the stem

- The most critical change during conversion of sap wood to heartwood is the death of ray and axil parenchyma cells other important change include a decrease in the metabolic rate and enzymatic activity, starch depletion, darkening of xylem.

- Anatomical changes such as an increase in aspiration of pits in gymnosperm and formation of tyloses in angiosperms and changes in moisture content

MACROSCOPIC FEATURES OF WOOD

Wood have two types of features: A) Macroscopic or Gross feature
B) Minute structure feature

A) Gross features of wood: Features can be easily seen with unaided eye may be considered as gross features.

1. Bark
2. Sap wood & Heart wood
3. Pith
4. Growth rings
5. Wood rays
6. Resin or gum canals
7. Early wood and late wood

Bark

- Bark varies in thickness, colour and appearance in different species.

- It usually show two distinct regions: an outer protective zone of croky nature consisting of dead and dying cells, and an inner living portion which is actively associated with conduction and storage of food materials required for growth.

- The outer bark may be smooth as in Ficus, or it may show fissures or cracks, as in Shorea.

- Sometime the general appearance of the external bark due to fissuring or exfoliation may be distinctive as to be of some diagnostic value in the identification of trees or logs.

Sap wood & Heart wood

- The woody cylinder show, as a rule , two well marked zones: an outer, lighter coloured portion known as sapwood and an inner or central dark-coloured portion known as heartwood.

- Colour distinction, however, is not always a true criterion.

- For example, in fir (*Abies pindrow*) and spruce (*Picea smithiana*), there is no colour distinction between the heartwood and sapwood, although, physiologically, hrartwood is always present in mature wood of any tree species.

- Some trees like Mango (*Mangifera indica*), Semul (*Bombex ceiba*) and Fig (*Ficus spp*.) do not always show any distinct heartwood in Sal (*Shorea robusta*) show a clear cut distinct between sapwood and heartwood.

- Physiologically, heartwood is dead and does not take any active part in the life of tree except to give it rigidity.

- All cell in heartwood are dead or skeleton cell, consisting of cell walls only without living contents.

- The sapwood however is composed mostly of licing cell and as its name implies, is primarily concerned with conduction of sap.

- The sapwood is also rich in starch and other food materials and is not durable, being easily attacked by insects and rot in the felled trees. Heartwood , on the other hand is comparatively more durable.

Sr.No	Heart wood	Sap wood
1	Heartwood is produced after of a few years of secondary growth.	This is also produced due to secondary growth.
2	Most of the heartwood nears the center of the axis forms a dark coloured region is called heartwood or duramen.	There is a small outer region, however, remains light coloured is known as sapwood or alburamen.
3	Heartwood is formed due to accumulation of organic compounds, such as oils gums, and resins, etc.	Sapwood is lighter coloured and it is the outer region of the secondary xylem. It is formed due to the cambial activity of the secondary xylem.
4	The Heartwood is dark coloured and non-functional. The major function of this wood is mechanical support.	The cells of the sapwood are functionally active. So it helps in conduction of water.
5	Amount of heartwood increases as the tree grows older.	The amount of sapwood, however, remains almost constant.

Sr.No	Heart wood	Sap wood
6	The tracheary elements are plugged by tyloses	The tracheary elements are not plugged by tyloses.
7	Tracheary elements have deposition of tannins, resins, gums, etc.	Tracheary elements do not possess any deposition in their lumen.

Pith

- Pith is the soft core found near about the centre of the log.

- It may be round, oval, triangular or squarish in shape and is usually not more than 0.6 cm in diameter.

- The colour is commonly some shade of brown, though in some trees it may be pinkish, grayish or yellowish.

- The pith does not seem to have any specific function to perform in the mature tree. The squarish pith with concave sides is found teak (*Tectona grandis)*.

Growth rings

- These are concentric ring which usually represent the wood formed during one growing season; also called, though less aptly, annual rings.
- These vary greatly in width, being 5 to 25 mm in fast grown timber and narrow in slow grown timber, 8 rings or more per cm.
- In many timbers these are not distinct because there is little variation in their growth, throughout the growing season and a year' s growth, imperceptibly merges into the next year 's growth.
- The greater the difference between the late wood and early wood the more prominent is the growth ring, as in temperate region

Wood rays or medullary rays

- These are group of horizontally arranged cells, running radially from bark towards the centre of the tree on radial and tangential surface often too fine to be visible.
- Their function is to take up the rising sap and descending food which is elaborated in the leaves, in driblets and pass it radially to the growing layer where it is required.
- Wood rays are organs for radial conduction and for storage of food in the trees.
- On the transverse section they appear as radial lines; in tangential section short as vertical line and on the radial section as narrow horizontal ribbons.
- The rays appear, as small plates and produce the decorative effect of Sliver grain.

Intercellular canal (Resin canals and gum ducts)

- Intercellular canals are long tubular cavities found in wood, which serve as repositories for waste products of metabolic activity like resin or gums.

- They are therefore, commonly referred to as resin canals or gum ducts. They may run either vertically or in the horizontal direction and are found in both porous and non-porous woods.

- The vertical canals can be distinguished from the vessels by the fact that they are fewer and have no walls of their own.

- The horizontal canals are similar to the vertical ones but run in a horizontal manner through the rays.

- Resin cavities are intercellular spaces which arise, through pulling apart of cells and or by liquefication of cell wall substance.

- Pine and Spruce have both vertical and horizontal canals. The dark streak on the faces of pine boards are due to these.

- In sal (*Shorea robusta*) and toon (*Toona ciliate*) gum ducts are found in bands of variable length at irregular intervals.

Transformation of Sapwood to Heartwood

- Wood cells are produced by a layer of cells between living bark (phloem) and the wood.
- This layer is called the cambium and can be seen only with a microscope.
- Cells which form on the inside of the cambium become wood and those on the outside becomes phloem.
- Once wood cells are laid down by the cambium, they rapidly differentiate in size and shape until finally a thickened wall is formed, the process being completed within a milli metre or so from the outer wood layers.
- After the thickened wall is produced, the cells remain largely unaltered in shape for the life of the tree.
- The wood cells thus produced by the cambium become the sapwood.

- The ray and axial parenchyma cells remain alive in the sapwood, while the more specialized wood cells, the fibres, vessels and tracheids, lose their living contents soon after differentiation and thickening of the cells are completed.
- Changes in the nature of the sapwood occur with the death of the parenchyma cells and with the completion of these changes heartwood is produced.
- These changes occur gradually through a layer of cells of variable width known as the transition zone.
- In this zone increased amounts of so called tannins (polyphenolics) and coloured materials of many types are deposited in the ray and axial parenchyma. These materials diffuse into the surrounding tissue. The development of heartwood colour is due to this deposition.

- The development of heartwood colour is the most spectacular change between sapwood and heartwood.
- While a great number of timbers do not produce coloured heartwood extractives, the large majority of species show some evidence of doing so.
- Heartwood colours range from white to cream as in southern silver ash, alpine ash and European ash, to black in ebony, olive-green in lignum vitae, yellow-orange in osage orange, brown in tallo wood and red in red ironbark.
- Most of the colours undergo a change with age, becoming darker and more brown.
- Frequently the heartwood substances are unevenly distributed giving rise to bands of wood of different colour.
- Such banded or striped effects are evidently related to the growth conditions as they occur concentrically with the growth rings.

- In hard woods, as well as the production of tannins and other materials, changes occur in the vessels which become blocked on heartwood formation.
- This blocking of the vessels takes place by means of the pits.
- Pits occur abundantly in all wood cell walls and are well-defined thin regions in the wall through which solutions can readily diffuse from one cell to another.
- In species with larger pits, blockage of the vessels occurs as a result of the growth of adjacent parenchyma cells through the pit forming balloon-like structures in the vessels.
- These growths are known as tyloses.
- In species with small pits , blockage of the vessels occurs due to the secretion by the ray parenchyma of tannin or gum-like materials through the pits.

- This deposition of materials can also occur in the species with large pits along with tyloses.

- Tyloses are common in the eucalypts and the merantis, whereas tannin-like materials are common in the mahoganies, true Australian red cedar and Queensland maple.

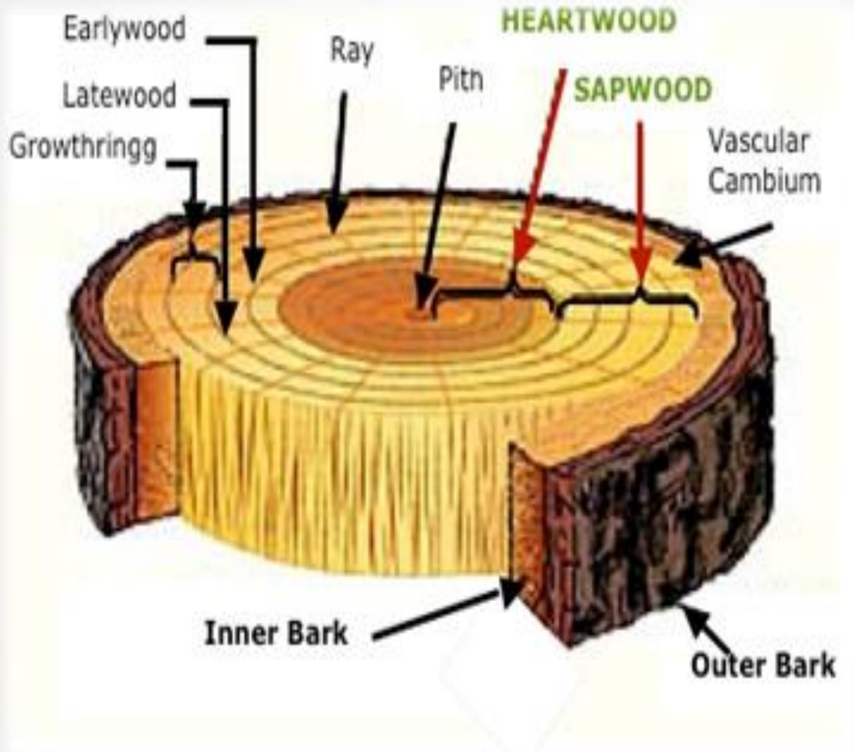
- **In** softwoods, blockage of the tracheids on heartwood formation can occur either by closing of the pits (aspiration) or by the increased deposition of resins and tannins.

- The pit membrane of a tracheid is a specialized structure consisting of a thickened centre (torus)-supported by a cellulose web, the web being flexible and allowing the torus to move and close (aspirate) the pit opening.

- Aspiration is confined to the pits of the earlywood tracheids, latewood pits remaining open.

- Latewood tracheids appear to be specialised structural cells not conducting cells. They have narrow lumens and thick cell walls and are formed near the end of the growing season.

- Earlywood tracheids have wide lumens and thin cell walls and are formed in the first part of the growing season .



Earlywood
Latewood
Growthringg
Ray
Pith
HEARTWOOD
SAPWOOD
Vascular
Cambium
Inner Bark
Outer Bark

Factors affecting transformation

- The width of the sapwood depends primarily on the longevity of the parenchyma cells.
- It is subject to great variation between species and minor variation between individuals of the one species and even within the individual.
- While the sapwood width seems regular along the grain , it is apt to show fluctuations around the growth ring.
- Variation in sapwood width within a species has been related to many factors, some of which are:

Rate of growth

- It seems fairly evident that the width of sapwood would be wider in dominant than in suppressed trees.

Environment

- It also seems fairly evident that the width of sapwood would be wider in the more favourable environment; however, it has been suggested that heartwood formation is encouraged by favourable water relations in rad iata pin

Position in tree

- Sapwood widths remain fairly constant with height.
- It can be seen therefore, due to the natural taper of a tree, that the proportion of sapwood to heartwood increases with height.

Age

- Young trees have wider sapwood than old trees.
- It is important to note that once the tree has commenced to lay down heartwood the volume of sapwood in proportion to heartwood becomes less as the tree becomes older.
- The amount and rate of heartwood formation vary greatly with species, tree age, rate of growth, environment and silvicultural practices.

Microscopic features of wood

- The minute structure of wood can be studied under a compound microscope.

- When so examined, wood is seen to be cellular in structure that is made up of minute components or cells, each with a distinct wall of its own, which consists mostly of cellulose and lignin.

- When these cells are first formed, either at the growing points or from cambium, they are all similar in shape and size , with thin wall and living protoplasmic contents.

- Very soon, as a result of growth, differentiation and cell wall thickening, they become modified in size, shape and structure according to the function they have to perform.

- Though man in his ingenuity has found many uses for wood, in nature it has only three main functions, conduction, mechanical support and storage.

- Depends upon their function and structure, the various types of cells that go to make up wood are classified as bellow:

Prosenchymatous elements: Tracheids, vessels, fibers.

Parenchymatous elements: Parenchyma and rays, resin canals, gum canals, latex canals, infiltrants in wood.

Vessels or Pores:

- Vessels are vertical series of cells with open ends place one above the other, forming a continuous tube, like the section of a drain pipe, running in the direction of the long axis of the tree.
- Their function is to conduct sap (Water & mineral nutrients) from the soil and roots to the crown for which they structurally well adapted.
- On the longitudinal surfaces or board faces of timber, the vessels frequently show up as long fine scratches or grooves, especially in coarse-textured wood (Kokko & Mango).
- When cut across, they appear on the end surface of wood as small, circular or somewhat oval opening or holes, usually visible to the eye or hand lens and are therefore also known as pores.

- The occurrence of pores or vessels is a constant feature of all broad-leaved trees, and it is for this reason that the wood of broad-leaved species is described as porous.

- On the other hand, in conifers (Softwood), vessels or pores are entirely absent and the wood is accordingly classified as nonporous.

- The arrangement and size of vessels vary in different species which fact is of diagnostic value in the identification of hardwoods.

Fibres:

- Fibres are vertically aligned, narrow, elongated and thick-walled cells with pointed tapering ends, which make up the bulk of the wood by weight in most hardwoods.

- Their main function is to give mechanical support to the tree, and like the vessel, they are absent in non-porous or coniferous woods.

- The fibres are individually indistinct even under a lens, but collectively they form, as it were, the darker coloured ground mass in which the vessels and other lighter-coloured wood elements are arranged, giving rise to various pattern.

Tracheids:

- These are longitudinal elements, hollow, needle-shaped, resembling fibres and characterized by the presence of large bordered pits on their walls.

- Tracheid cells are minute, narrow thick walled with closed tapering ends, closely packed together so that a cross section through them resembles a honey-comb.

- These are the main longitudinal elements of conifers or non-porous wood.

- Their main function is to conduct sap and to give rigidity to the tree.

B. Parenchymatous elements:

Parenchyma or soft tissues:

- ➢ These are short, rectangular or brick-shaped cells, which comparatively thin walls and simple pits, whose main function is storage and conduction of food material.
- ➢ They are oriented in the same direction as fibres and vessels, with their long axis parallel to the grain.
- ➢ Therefore, sometimes they are also referred to as longitudinal parenchyma whereas the parenchyma cells of the rays are arranged horizontally.
- ➢ They are found in both porous and non-porous woods.
- ➢ Individually the longitudinal parenchyma cells are too small to be seen under a hand lens, but collectively they form various patterns which are often very distinctive and of considerable importance in the classification and identification of timber.

Parenchyma described under two classes

1. **Apotracheal:**

These are independent of the distribution of the pore

Terminal or initial:

- In some hardwoods, the parenchyma cells are arranged in a continuous line or narrow band, which may be formed either at the beginning or at the end of the growth season.
- Such bands of soft tissue, which are usually lighter coloured than the background, are classified as initial or terminal, depending upon as they are formed.

Diffuse:

- when soft tissues occur as isolated cells or small groups of 2-3 cells scattered throughout the ground mass of the wood.

Reticulate or net-like:

- In some wood the parenchyma cells, instead of being scattered, may form fine, more or less evenly spaced, tangential lines, which together with the rays give rise to a characteristic pattern somewhat resembling the meshes of a net. Such a distribution is described as Reticulate or net-like.

- The parenchyma lines may be broken or continuous, closely to somewhat widely-spaced and of varying of thickness, giving rise to further variation in reticulate pattern.

2. Paratracheal:

In these soft tissues are closely associated with the vessels

Vasicentric:

- The soft tissues form a narrow but complete sheath, more or less of uniform thickness all around, surrounding the pores. The parenchyma sheath is distinctly visible under lens, appearing as a light- coloured border or halo round the pores as in Babul (*Acacia nilotica*).

Aliform or eyelet type:

- The parenchyma surrounding the pores, instead of being uniformly thick and narrow, may extend sideways as wing like lateral extensions. Such a distribution of parenchyma round the pores is described as Alifom or eyelet eg. *Acrocarpus fraxinifolius* & *Mangifera indica*.

- A further development of the Alifom type, in which the wing-like extensions of adjacent pores become confluent of connected together, is known as Aliform confluent eg. *Dalbergia sissoo* & *Ougeinia oojeinensis*.

Banded:

- When soft tissues are arranged in continuous tangential bands, alternating with fibre layers throughout the growth ring.

- The bands may be relatively broad or narrow, straight or wavy, and confluent or independent of the pores eg. *Butea monosperma* & *Ficus spp*.

Resin canals:

- **Resin canals** or **resin ducts** are elongated, tube-shaped intercellular spaces surrounded by epithelial cells which secrete resin into the canal.
- These canals are orientated longitudinally and radially in between fusiform rays.
- They are usually found in late wood: denser wood grown later in the season. Resin is antiseptic and aromatic and prevents the development of fungi and deters insects

Types :

Normal resin canals:

- Normal resin canals exist naturally in the wood of the genera *Picea. Larix, Pinus,Pseudotsuga and Shorea.*

Traumatic resin canals:

- Traumatic resin canals may be formed in wounded trees that don't have normal resin canals.
- Wounding occurs from either fire, freezing or mechanical damage. These canals are irregularly shaped compared to normal resin canals

Gum Ducts (Canals):

- Gum ducts are produced as a result of wounding in many hardwoods and such canals are said to be traumatic; they may be distinguished from the normal type because they are invariably in tangential series, are irregular in outline, contain no epithelial cells and usually have dark-coloured, more-or-less viscus, gum like deposits.

- Further, traumatic canals are usually larger than the vessels and typically wider tangentially.

- In some species, such as African walnut, traumatic canals are sufficiently frequent in occurrence to be regarded almost as a characteristic feature of the timber.

Latex canals or tubes:

- Special cells, containing latex and called latex tubes, occur in the ray tissue of certain timbers.

- They are usually invisible to the naked eye, but where they can be detected they are a helpful feature in identification.

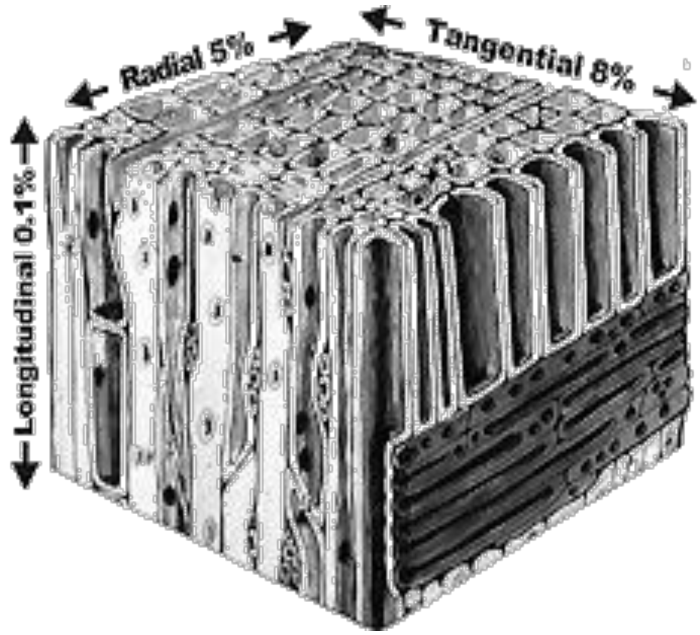
- In a few timbers (jelutong and mujwa) specialised parenchymatous tissue, containg numerous latex tubes, develops from leaf-traces and continues outwards during the subsequent growth of the bole, such latex traces, as seen on the tangential surfaces, are up to 20 mm high and lens-shaped section.

- As the leaf –traces occur in whorls, the latex traces are found in tangential series up the tree at intervals of 0.6-0.8 metres, disfiguring long lengths of timber, and rendering it unsuitable for many purposes.

- Long splits can develop from the latex traces during seasoning.

Three dimensional features of wood; transverse, tangential and radial surfaces.

- Because of the arrangement of the layers of growth in the tree, as well as the vertical or horizontal orientation of the individual cells, it is appropriate to consider the structure of wood is three-dimensional .



PLANES OF SECTION

- Although wood can be cut in any direction for examination, the organization and interrelationship between the axial and radial systems give rise to three main perspectives from which they can be viewed to glean the most information.

- These three perspectives are the transverse plane of section (the cross section), the radial plane of section, and the tangential plane of section.

- Radial and tangential sections are referred to as longitudinal sections because they extend parallel to the axial system (along the grain).

TRANSVERSE PLANE OF SECTION

- The transverse plane of section is the face that is exposed when a tree is cut down.

- Looking down at the stump one sees the transverse section cutting a board across the grain exposes the transverse section.

- The transverse plane of section provides information about features that vary both in the pith to bark direction (called the radial direction) and also those that vary in the circumferential direction (called the tangential direction).

- It does not provide information about variations up and down the trunk.

Radial plane of section

- The radial plane of section runs in a pith-to-bark direction and it is parallel to the axial system, so it provides information about longitudinal changes in the stem and from pith to bark along the radial system.

- To describe it geometrically, it is parallel to the radius of a cylinder, and extending up and down the length of the cylinder.

- In a practical sense, it is the face or plane that is exposed when a log is split exactly from pith to bark.

- It does not provide any information about features that vary in a tangential direction.

TANGENTIAL PLANE

- The tangential plane is at a right angle to the radial plane.

- Geometrically, it is parallel to any tangent line that would touch the cylinder, and it extends along the length of the cylinder.

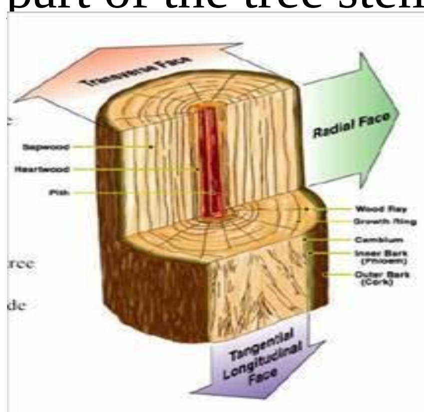
- One way in which the tangential plane would be exposed is if the bark were peeled from a log; the exposed face is the tangential plane.

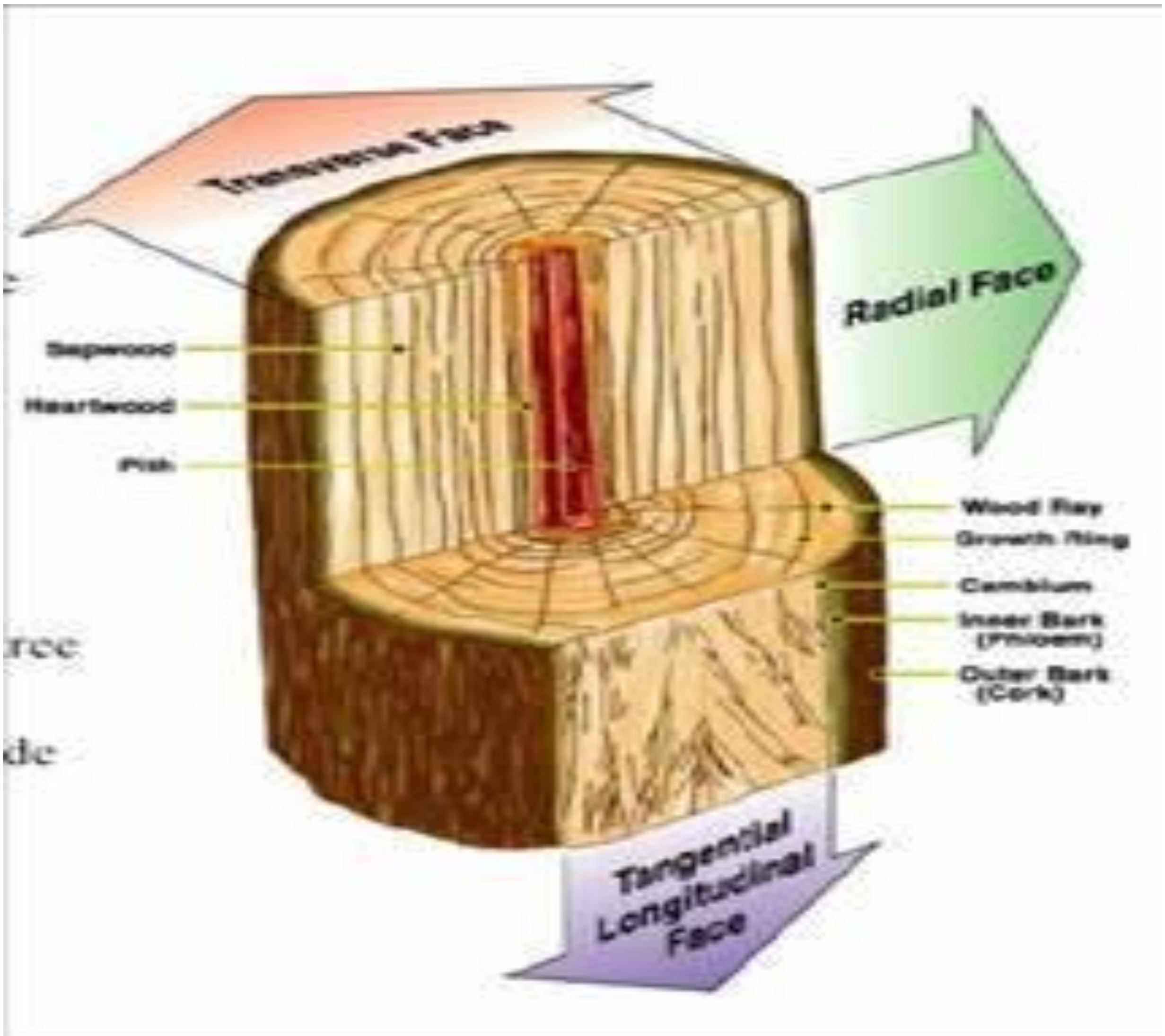
- The tangential plane of section does not provide any information about features that vary in the radial direction, but it does provide information about the tangential dimensions of features.

- All three planes of section are important to the proper observation of wood, and only by looking at each can a holistic and accurate understanding of the three-dimensional structure of wood be gleaned.

- The three planes of section are determined by the structure of wood and the way in which the cells in wood are arrayed.

- The topology of wood and the distribution of the cells are accomplished by a specific part of the tree stem




Radial Face
Sapwood
Heartwood
Pith
Wood Ray
Growth Ring
Cambium
Inner Bark
(Phloem)
Outer Bark
(Cork)
Tangential
Longitudinal
Face

1) CROSS SECTION:

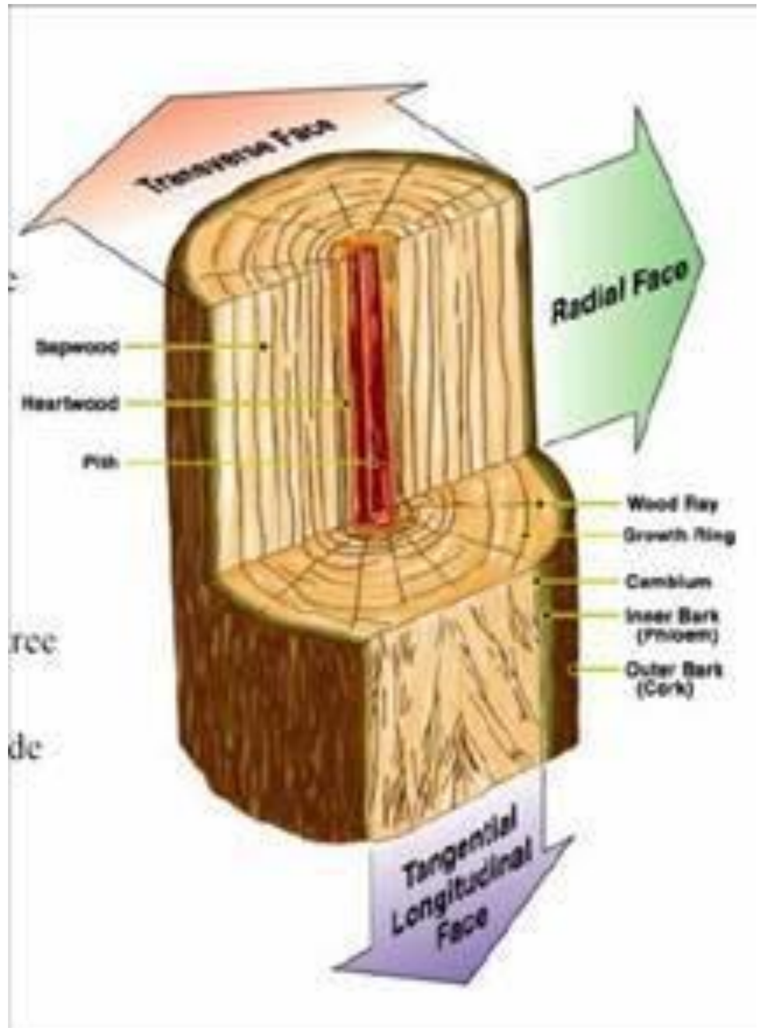
When a section is cut at right angle to the long axis then it is a cross / transverse section .

2) RADIAL SECTION:

When a section is cut parallel to the long axis and it passes through the radius of the axis then it is radial section OR radial longitudinal section .

3)TANGENTIAL SECTION

A tangential section is a longitudinal section of a stem where the section is perpendicular to the tangent or radius of the stem.



Elements of wood cell walls:

- Cell walls mainly consist of **cellulose**, **hemicellulose**, and **lignin** in a 4:3:3 ratio. This ratio differs from sources such as hardwood, softwood, and herbs.

- Besides these three components, **natural lignocellulosic materials** contain a small amount of **pectin**, nitrogenous **compounds**, and the secret ash.

1. **Cellulose**

2. **Hemicellulose**

3. **Ligninn**

CELLULOSE.

- Cellulose is a glucan polymer consisting of linear chains of 1,4-ß -bonded anhydroglucose units.
- Cellulose is the structural component of the primary cell wall of the green plants.
- About 33% of all plant matter is cellulose (the cellulose content of cotton fiber is 90%, that of wood is 40-50% and that of dried hemp is approximately 45%)
- Cellulose is a straight chain polymer.
- The number of sugar units in one molecular chain is referred to as the degree of polymerization (DP).
- Cellulose is insoluble in most solvents including strong alkali. It is difficult to isolate from wood in pure form because it is intimately associated with the lignin and hemicelluloses.

HEMCELLULOSES

- Hemicelluloses are mixtures of polysaccharides synthesized in wood almost entirely from glucose, mannose, galactose, xylose, arabinose, 4-O methylglucuronic acid, and galacturonic acid residues.
- Some hardwoods contain trace amounts of rhamnose.
- Generally, hemicelluloses are of much lower molecular weight than cellulose and some are branched.
- They are intimately associated with cellulose and appear to contribute as a structural component in the plant.
- Some hemicelluloses are present in abnormally large amounts when the plant is under stress; e.g., compression wood has a higher than normal galactose content as well as a higher lignin content.
- Hemicelluloses are soluble in alkali and easily hydrolyzed by acids

Lignin

- Lignin is a phenolic substance consisting of an irregular array of variously bonded hydroxy- and methoxy-substituted phenylpropane units.
- The precursors of lignin biosynthesis are
  - p-coumaryl alcohol (I),
  - Coniferyl alcohol (II), and
  - Sinapyl alcohol (III).
- I is a minor precursor of softwood and hardwood lignins;
- II is the predominant precursor of softwood lignin;
- and II and III are both precursors of hardwood lignin.
- These alcohols are linked in lignin by carbon–carbon bonds.

The structure and arrangement of simple pit, bordered pits.

- Pits are the characteristic depressions on the cell walls of plant cells. They act as the channels for the transport of water and minerals between adjacent cells.

- Pits of two neighboring cells are usually located opposite to each other and these opposite pits together are called **pit pair**. Each pit has a cavity called **pit cavity**.

- Pit cavity opens internally to the lumen of the cells.

- The pit cavities of a pit pair are separated by a thin membrane called **pit membrane**. Pit membrane composed of the middle lamella and the primary cell wall of corresponding cells.

- Usually two types of pits are met within the cells of various plants, viz., simple pits and bordered pits.

- Two bordered pits make up a bordered pit pair, two simple pits form a simple pit pair.

- A bordered pit and a simple pit lying opposite to each other in contiguous cells, constitute a half bordered pit pair.

- A pit occurs opposite an intercellular space has no complementary pit and is known as blind pit.

- Fundamentally the bordered pit differentiates from a simple pit in having a secondary wall arching over the pit cavity, which constitutes the actual border and becomes narrow like a funnel towards the lumen of the cell.

- In the simple pit, no such arching of the secondary wall and narrowing of the pit towards the lumen of the cell occurs.

- In Angiosperms, the pit membrane is **homogenous** where as in Gymnosperms, the pit membrane is **heterogenous**.

Simple pits:

- Simple pit pairs occur in parenchyma cells, in medullary rays, in phloem fibres, companion cells, and in tracheids of several flowering plants.
- In the simple pits, the pit cavity remains of the same diameter and the pit or closing membrane also remains simple and uniform in its structure.
- The simple pit may be circular, oval, polygonal, elongated or somewhat irregular in its facial view.
- The simple pits occurring in the thin walls are shallow, whereas in thick wall the pit cavity may have the form of a canal passing from the lumen of the cell towards the closing or common pit membrane.
- The diffusion of protoplasm takes place through these pits.

Bordered pits:

- They are abundantly found in the vessels of many angiosperms and in the tracheids of many conifers.
- They are more complex and variable in their structure than simple pits.
- The overarching secondary wall which encloses a part of the pit cavity is called, the pit border, which opens outside by a small rounded mouth known as pit aperture.
- The overarching rim forms a border around the aperture and thus named ‘bordered pits’.
- The pit aperture may be of various shapes in the facial view. It may be circular, lenticular, linear or oval.
- In the case of relatively thick secondary walls, the border divides the cavity into two parts.

- The space between the closing membrane and the pit aperture may be called the pit chamber and the canal leading from pit chamber to the lumen of the cell may be termed as pit canal.

- The pit canal opens in the pit chamber by an outer aperture and at the same time it opens in the lumen of the cell by an inner aperture.

- The closing membrane of a bordered pit pair which consists of the parts of two primary walls and the intercellular substance or middle lamella, is somewhat thickened in its central part.

- This thickening is called torus which remains surrounded by a delicate margin.

- In many bordered pits, the closing membrane may change its position within pit cavities.
- The torus may remain in central position or it may shift to the lateral position.
- As the torus is shifted to the lateral position the pit aperture closes, and the passage of the protoplasm may take place only by diffusion through torus.

Distribution of pits

Pits are distributed differently in different types of cells. Pattern of distribution may vary in the same cell.

In tracheary cells, the bordered pits are arranged in following patterns.

Half bordered pits: When a bordered pit is opposed by a simple pit

Blind pit: if a pit has not opposing pit, occurs if pit opens into intercellular space

Ramified pits: branched pits, formed by the fusion of may pits due to the increase in thickness of cell wall

Unilateral compound pitting: a large pit is opposed by two or more small pits

Vestured pits: pits with minute outgrowth from wall surface of pit chamber

Scalariform pitting: If pits are elongate and are arranged in a ladder like series

Opposite pitting: Pits are arranged in horizontal rows or pairs. In opposite pitting, the pits are so closely placed and hence the outline of the pits become rectangular in surface view

Alternate pitting: Pits are arranged in diagonal rows, in alternate pitting, the pits are so closely placed and hence the outline of the pits become hexagonal

Sieve pitting: small pits seen in clusters, looks like sieves

Extractives in wood

- Wood extractives, or wood extracts, can be regards as non-structural wood constituents and usually represent a minor fraction in wood or tiny molecules that are extracted from wood using solvents or other extraction methods.

- The extractives comprise both inorganic and organic components.

- The extractives are the waxes, fatty acids, resin acids, and terpenes of a tree. They are classified as phenolic, aliphatic, alicyclic , terpenoids, terpenes compounds, or other lesser compounds.

- The overall composition of the extracts varies dramatically from tree species to tree species and various parts of the same tree, e.g. stem, branches, roots, bark and needles, differ markedly with respect to both their amount and composition of extractives.

- Generally, content of extractives is higher in bark, leaves and roots, than that in stem wood.

- The growth environment that the tree grows within also has an effect on the composition and levels of wood extractives.

- Wood extracts are considered to have a low molecular weight, and do not have an effect on the growth rate of the plant. Therefore, they are not vital to plant growth.

Role of extractives:

a. Extractives can effect the density and strength of the wood species. The more extractives that are embedded in the fibers, the denser and stronger the wood.

b. Many extractives are minerals. These act as fine abrasives, dulling your cutting tools as you work.

c. Some are resinous and waxy substances. These build up as pitch on the cutting surfaces of power tools and interfere with the cutting action. They can also make a wood difficult to glue or finish.

d. Many are antibiotics, killing molds and bacteria that would cause disease and rot. Woods high in these chemicals are resistant to decay.

e. A few of these antibiotic chemicals are toxic to humans as well as microbes and have been known to cause or aggravate allergic reactions, respiratory ailments, and other health problems.

Comparative anatomy of gymnosperms and angiosperms.

- Since gymnosperms and angiosperms are both vascular plants, they have a sporophyte-dominant life-cycle.
- Tissue formation in angiosperms exceeds the amount and complexity found in gymnosperms.
- Angiosperms have a triploid vascular tissue, flat leaves in numerous shapes and hardwood stems.
- Because of the innumerable varieties of the fruit and/or flower-bearing plants, they have variegated colors and shapes of leaves, flowers and fruits.
- Gymnosperms are haploid, have spiky, needle-like leaves and are softwood.
- Gymnosperms are "simpler" anatomically because they do not bear flowers or fruit, and although of different species, are usually only tall evergreens with brown cones

	Angiosperms	**Gymnosperms**
Definition	Seed-producing flowering plants whose seeds are enclosed within an ovary.	Seed-producing non-flowering plants whose seeds are unenclosed or “naked.”
Seeds	Enclosed inside an ovary, usually in a fruit.	Bare, not enclosed; found on scales, leaves or as cones.
Life Cycle	Seasonal (die during autumn/fall).	Evergreen
Tissue	Triploid (endosperm produced during triple fusion)	Haploid (endosperm produced before fertilization)
Reproductive system	Present in flowers; can be unisexual or bisexual	Cones; unisexual
Leaves	Flat	scalelike , needle-like
Cotyledons	Present; single (monocots) or in a pair (dicots)	Absent

Wood	Hardwood	Softwood
Periniality	Non-perinnial	Perinnial
Kingdom	Plantae	Plantae
Domain	Eukarya	Eukarya
Reproduction	Mostly rely on animals.	Mostly rely on wind.
Uses	Medications , food, clothing, etc...	Paper, Lumber , etc

Anatomical features of common Indian timbers:

Ring Porous

- having vessels more numerous and usually larger in cross section in the springwood with a resulting more or less distinct line between the springwood and the last season's **wood**— compare **diffuse-porous**.
- **In some species** (e.g. oak (**red oak**, **white oak) Teak** and ash **elm**, **hickory**,), the largest pores are in the earlywood while those in the latewood are more evenly distributed and uniform in size.
- These woods typically have distinct figures and patterns, and the uneven uptake of stain (the large pores soak up more color) make the figure more pronounced.
- These are also known as open-grain woods

Se mi-ringPorou s orSemi-d iffusePorous

- In some species (e.g. Butternut, **Black cherry**, **black walnut**, **pecan**, **tanoak**), pores are large in the earlywood and smaller toward the latewood, but without the distinct zoning seen in ring-porous woods.

- Also, some species that are usually ring-porous (e.g. cottonwood) occasionally tend toward semi-ring porous.

Diffuse Porous

- In some species (e.g. maple, cherry and yellow poplar **Basswood**, **red alder**, **sugar maple**, **sycamore**, **yellow birch**, **yellow poplar**.) the pores are distributed fairly evenly across the earlywood and latewood.

- Most domestic diffuse-porous woods have relatively small-diameter pores, but some tropical woods of this type (e.g. mahogany) have rather large pores.

- These woods usually have even uptake of stain (there seems to be no scientifically proven explanation of the cause of blotching). These are also known as closed-grain woods.

Non-porous

- Softwoods don’t have vessel cells (water is conducted in the living tree in tracheid cells).

- Different softwoods have different growth-ring characteristics however.

- In white pine, the rings are non-distinct, and stain uptake is fairly even, as in diffuse porous woods.

- In yellow pine, where the rings are clearly visible, stain uptake in earlywood is more pronounced than in latewood, as in ring-porous woods.

Effect of growth rate on wood properties:

Juvenile wood and mature wood:

Juvenile wood:

- Wood formed near the pith, characterized by progressive increases in dimensions and
- changes in the cell characteristics, and the pattern of cell arrangement; also called core wood.
- Secondary xylem at the center of a tree formed throughout the life of the tree.
- Pith plus the wood produced for the first 2 to 20 year
- The juvenile wood zone is conically shaped area that narrows from a broad base toward the top of the tree.

Mature Wood:

- Wood which is characterized by relatively constant cell size, well-developed structural
- patterns, and stable physical behavior, also called adult wood.
- Occurs as the cambium becomes farther from and less influenced by the apical meristems.

Juvenile wood is lower in quality than mature wood:

- Juvenile wood cells are shorter than those of mature wood.
- There are relatively few latewood cells in the juvenile zone and a high proportion of cells have thin wall layers. As a result, Juvenile Wood Has:
  - Up to 30% less density for DF, 76% less for SYP.
  - About 15-50% less strength.
  - Only 39% of the stiffness (MOE) in SYP
  - 54% of the bending strength in SYP
- Juvenile wood has a greater tendency for spiral grain
- The microfibril angle in the S-2 part of the secondary wall is greater in juvenile wood.
  - Juvenile wood may have 3-10 times more shrinkage along the grain.
  - Large microfibril angles are also associated with low tensile strength.
  - Veneer produced from juvenile wood is rougher and contains more splits and deeper lathe checks

Thank You

Physical properties of wood:

1. Colour 2. Hardness 3. Weight

4. Texture 5. Grain 6. Lustre

7. Odour 8. Figure

COLOUR:

- The unique color of a wood species is determined by the chemical extractives embedded in the cell walls.
- But the initial color of the raw, freshly cut wood doesn't remain unchanged.
- This color darkens somewhat when you apply a finish, even if that finish appears clear and colorless.
- Most finishes also change the hue, making it more amber. Craftsmen describe this as "warming up" the wood color.
- In the chart of "Physical Properties of Wood," you can see how common finishes affect colour.
- Unfortunately, what you can't see is that the wood also changes color with age.

- As the surface of the wood is exposed to air, it slowly oxidizes. Some woods are photosensitive — exposure to ultraviolet light alters the extractives.

- Both reactions change the wood colour at the surface. This thin layer of color-changed wood, sometimes only a few thousandths of an inch thick, is the patina.

Hardness

It signifies the resistance offered by a wood specimen to penetration by another body i.e. resistance to indentation and not cutting which depends on nature of grain, presence of silica and other substances. The hardness of wood depends on:

i) Anatomical structure:

The degree of cohesion of fibres determines the hardness. Heartwood is harder than sapwood.

ii) Specific gravity:

Generally hardness increases the specific gravity i.e. slow grown coniferous timber is harder than fast grown wood of the same species.

iii) Moisture content:

Dry wood is harder than green wood.

iv) Presence of resinous material:

These increase the hardness.

v) Soundness:

The decay wood softens by disintegrating tissues.

Extremely hard: *Shorea robusta, Acacia nilotica, Acacia catechu, Dalbergia latifolia*

Very hard: *Dalbergia sissoo, Morus alba, Terminalia alata, Syzygium cuminii*

Hard: *Albizia lebbeck, Tectona grandis, Adina cordifolia, Churasia tabularis*

Moderately soft: *Mangifera indica*

Soft: *Lannea coromandelica, Cedrus deodara, Abies pindrow*

Very soft: *Boswellia serrata, Pinus roxburghii, picea smithiana, Pinus wallichiana*

Extremely soft: *Bombax ceiba, Cryptomeria japonica*

Weight (Specific gravity)

- Weight of wood varies with species and even in different parts of the same tree.
- The density of any material is defined as the weight of an unit volume of the material and is expressed as Kg/cum.
- The specific gravity, is the ratio of the weight of material to the weight of an equal volume of water at 4^o c. Specific gravity in itself is only of secondary importance; but it is closely connected with other properties such as strength, durability, soundness, combustibility and seasoning power.
- Specific gravity of wood depends on:

Anatomical structure: The thicker the cell walls, the greater the specific gravity. Slow grown wood is heavier than fast grown wood.

Soil and locality:	The weight depends on conditions of soil fertility, moisture, heat and light. Excess of moisture renders wood porous, and spongy hence reduce specific gravity. Insufficient light produces similar results. Soil fertility also increase the weight.
Age of the tree:	The formation of heavy heartwood during middle age may render the average specific gravity of wood of older tress higher than of young trees.

TEXTURE

- Texture pertains to the relative size of cells and their proportion in unit volume**.**
- Texture may be fine, coarse, even or uneven and with intermediate shade.
- Fine textured wood take polish easily, even textured wood are less decorative than uneven textured one.
- Texture depends on the size of the longitudinal cells.
- In hardwoods, this refers to the size of the **fibers** and the **vessel elements**; in softwoods, it's the **tracheids**.
- Fine-textured woods have small cells, while coarse woods have larger ones.

GRAIN

- Grain pertains to alignment of cells or direction of fibres with regards to vertical axis of the tree .

- When the vessel elements in hardwoods are sliced open, they create depressions called **pores**.

- Woods with large pores that are easily visible to the naked eye are said to have an **open grain**.

- Those with smaller pores, to small to see clearly, have a **closed grain**.

Note: Because softwoods do not have vessel elements, these terms don't apply. For practical purposes – such as preparing and finishing the surface – softwood grain is closed.

GRAINPATTERN

The normal orientation of the longitudinal cells determines a species' characteristic grain pattern. There are four categories.

Straight grain: The longitudinal cells grow fairly straight and parallel to the axis of the trunk.

Wavy grain: The cells undulate in short, even waves. This sometimes produces curly figure.

Irregular grain: The cells undulate around knots or in no discernible pattern.

Interlocked grain: The cells spiral around the trunk, reversing direction every few growth rings. This produces ribbon figure.

Diagonal: The direction of fibres is not parallel with the longitudinal axis of the board or plank.

Sprial: Fibres follow a spiral course.

LUSTRE

- Lustre or sheen depends on the ability of the cell walls to reflect light. This property is not present in all timbers.
- Lustre is conspicuous on longitudinal and radial section where maximum width of ray is exposed eg. *Picea smithiana*, *Quercus spp*. *Albizia lebbek etc*.

ODOUR

- Tannins, fatty acids, act as bearers of scent in wood. Many timbers have characteristics odour, particularly when freshly cut.
- Odour is more pronounced in heartwood than sapwood. Resinous odour in pines, spicy aroma of sandalwood (*Santalum album*), unmistakable odour of deodar (*Cedrus deodara*), Camphor (*Cinnamomum camphora*) Teak (*Tectona grandis*).

Figure

- Figure refers to the distinctive pattern produced on longitudinal surfaces of timber as a result of arrangement of different tissues and direction of the grain.

- Figure may be attractive due to differences in the reflective property of different surfaces.

C)According to condition:

Live knot: a knot free from decay and other defects, firmly intergrown with surrounding wood. (intergrown knot, tight knot, sound knot)

Decayed knot: a knot soften than the surrounding wood and containing decay (unsound knot, punk knot, rotten knot)

Loose knot: a knot which is not held firmly in place by growth or position.

Dead knot: a knot in which the wood elements are not comptletely intergrown wit those of the surrounding wood (encased knot, black knot)

Pith: a sound knot with a pith hole not over ¼ inch (0.6cm) in diameter (hollow knot:

Enclosed knot : a knot that does not appear on the surface of timber.

(a hole left as a result of the removal of a knot is called a knot hole)

Pith

- The pith is an essential part of the living tree, but from a wood utilization point of view it is defect.

- Its presence in wood products may reduce both strength and durability.

- This is primarily due to the different cellular structure of the pith in comparison to the surrounding wood.

- In addition the wood immediately around the pith often contains small checks and knots of various size, and may also develop shakes.

- In sawing logs to lumber, the pith is left enclosed within (boxed-heat) timbers or it may be sawn through and removed.

Pith flecks

- Certain timber may often show irregular batches of soft tissue, which seem to have no relation whatsoever to the general arrangement of parenchyma.

- These abnormal patches of parenchyma are formed as a result of injury to the cambium due to insect attack and known as pith flecks.

- On the board face, they show up clearly against the natural colour of the wood, but do not constitute a serious defect unless of very large size and numerous.

- Some species may be more liable to form pith flecks than others.