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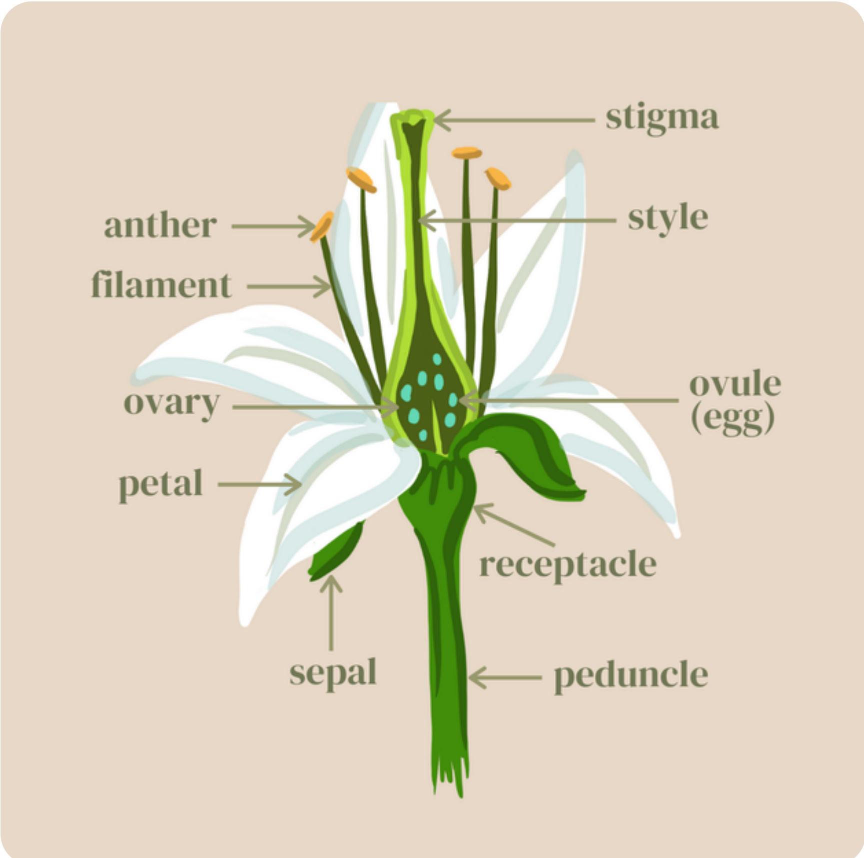

STUDY MATERIAL

Anatomy of Flowering plants

ENGLISH MEDIUM

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Tissues, tissue system, internal structure of root, stem and leaf, secondary growth.

KATHERINE ESAU was **born in Ukraine in 1898**. She studied agriculture in Russia and Germany and received her doctorate in 1931 in United States. She reported in her early publications that the **curly top virus** spreads through a plant via the food conducting or phloem tissue. **Dr Esau's Plant Anatomy published in 1954** took a dynamic, developmental approach designed to enhance one's understanding of plant structure and an enormous impact worldwide, literally bringing about a revival of the discipline.

The **Anatomy of Seed Plants by Katherine Esau was published in 1960**. It was referred to as **Webster's of plant biology – it is encyclopediac.** In 1957 she was elected to the National Academy of Sciences, becoming the sixth woman to receive that honour. In addition to this prestigious award, she received the National Medal of Science from President George Bush in 1989.

When Katherine Esau died in the year 1997, Peter Raven, director of Anatomy and Morphology, Missouri Botanical Garden, remembered that she 'absolutely dominated' the field of plant biology even at the age of 99.

ANATOMY OF FLOWERING PLANTS

01. INTRODUCTION

- Introduction
- The Tissues
- The Tissue System
- Anatomy of Dicotyledonous and Monocotyledonous Plants
- Secondary Growth

- Plant and animals both show the structural similarities and variations in their external morphology as well as in their internal structure (Anatomy)
- Different organs in plants show variations in their internal structures.
- The monocots and dicots are also seen to be anatomically different.
- Internal structure also show adaptations to diverse environments.
- Study of internal structure of plants is called plant anatomy.
- **N.Grew (Nehemiah Grew)** is known as father of plant anatomy.

Note : Book - "The anatomy of seed plants" was written by **Katherine Esau (K. Esau).** It was published in 1960. It was referred to as **Webster's of plant biology – It is encyclopediac.**

02. THE TISSUE

- A group of cells having a **common origin and usually perform a common function** is called **tissue**. A plant is made up of different kinds of tissues. The tissues are classified into two main groups, namely, meristematic and permanent tissue based on whether the cell being formed are capable of dividing or not.

Tissues
↓ On the basis of capability of division

1. Meristematic tissues (undifferentiated)	2. Permanent tissues (fully differentiated)
→ Cells have capacity of division	→ Cells have no capacity of division
→ Composed of immature cells	→ Composed of mature cells

1. MERISTEMATIC TISSUES

- **Meristem :** Growth in plants is largely restricted to specialised regions of active cell division called meristems/A meristem is a localised region in which actual cell division occurs.
- It is derived from a Greek word **meristos** (means **Divided/Divisible**)

(A) Characteristics of Meristematic tissue

- It is an **undifferentiated tissue.**
- Cell cycle of meristem is in continuous state of division. Thus, meristematic tissue is composed of **immature cells.**
- Meristematic cells have only primary cell wall which is thin and flexible (elastic) and made up of cellulose with abundant plasmodesmatal connections.
- Secondary cell wall is absent.
- Cells of meristem are small and generally isodiametric.
- They have dense cytoplasm.
- They have prominent and large nucleus.
- Normally vacuoles are absent in meristematic cells, if present then they are small in size. Meristematic cells are metabolically highly active, so reserve food is absent in these cells.
- Plastids are absent in meristems. If they are present, then only in the proplastid stage.
- They do not have intercellular spaces.
- Ergastic (non living) substances are almost absent.

(B) Classification of Meristematic Tissue/Meristem :

(i) Meristem based on origin and development

On the basis of origin and development meristems can be divided into following three types :-

(a) Promeristem

- This meristem develops at embryonic stage. It forms primary meristem.

  eg. Embryonic meristem

(b) Primary meristem

- Meristematic cells developed from promeristem are known as primary meristem.
- It appears early in the life of a plant & contribute to the formation of the primary plant body.
- Cells are always in division phase and form primary permanent tissue by the process of **differentiation**.

  eg. **Apical meristem** and **intercalary meristem**

(c) Secondary Meristem

- Secondary meristem develops from primary permanent tissue by the process of **dedifferentiation**.
- Secondary meristem appears later than primary meristem.
- By the activity of secondary meristems, **secondary growth** takes place.

  eg. **Interfascicular cambium & cork cambium of dicot stem, vascular cambium & cork cambium of dicot root.**

Promeristem
Division ↓
Primary meristem
↓ **Differentiation**
Primary permanent tissue
↓ **Dedifferentiation**
Secondary meristem
↓ **Redifferentiation**
Secondary permanent tissue

Following divisions of cells in both primary and as well as secondary meristems, the newly formed cells become structurally and functionally specialised and lose the ability to divide. Such cells are termed permanent or mature cells and constitute the permanent tissues.

(ii) Meristem based on Location (Position) in Plant body :-

On the basis of position, meristems are divided into three types :-

(a) Apical Meristem :

It is an example of primary meristem.

- The meristems which occur at the tips of roots and shoots and produce primary tissues are called apical meristems.
- They are responsible for increase in the length of plant organs. It means they are responsible for primary growth. Examples of apical meristem :-
  Root apex/root apical meristem, shoot apex/shoot apical meristem.

HABERLANDT DIVIDED **EUMERISTEM** (It is a primary meristem i.e. apical meristem) into three regions **on the basis of function.**

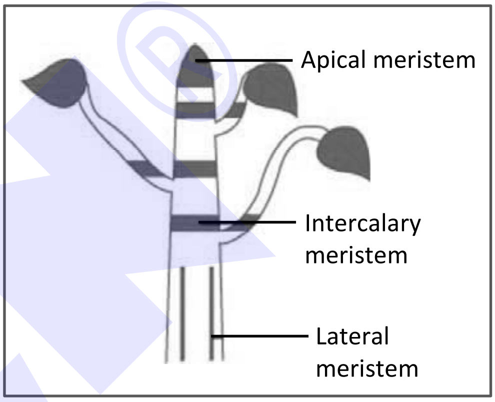
- **Protoderm :** It is the outer most layer of eumeristem. By the activity of protoderm **epidermal tissue system** is formed. E.T.S. includes epidermis, stomata, stem hair(shoot hair/trichomes) etc.
- **Procambium :** It is made up of elongated cells and it gives rise to the **vascular tissue system**.
  V.T.S. includes Xylem, phloem (vascular bundles)
- **Ground Meristem :** The cells of this region are thin walled and isodiametric. **Ground tissue system** is formed by the activity of these cells. G.T.S. includes hypodermis, general cortex, endodermis, pericycle, pith-rays (medullary rays) and pith (medulla).

Note : During the formation of the primary plant body, specific regions of the apical meristem produce dermal tissues, ground tissues and vascular tissues.

(b) Intercalary Meristem :

- It is an example of primary meristem.
- Intercalary meristem occurs between mature tissues.
- It is present at the base of internode of monocots stems e.g. **grasses**, **bamboo**, **sugarcane** etc. It is also present **at the base of leaves**. By the activity of this meristem, length of leaves increases.
- By the activity of this meristem length of the plant organs increases.
- They occur in grasses and regenerate parts removed by the grazing herbivores.

- Both apical meristems & intercalary meristems are primary meristems because they appear early in the life of a plant and contribute to the formation of primary plant body.

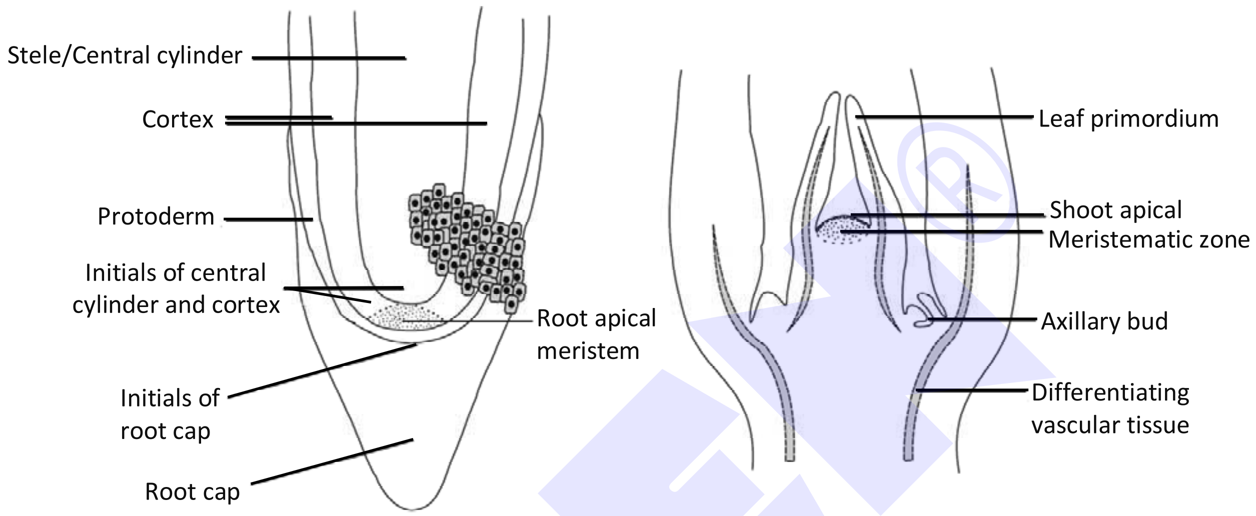


(c) Lateral Meristem :

- Lateral meristem occurs on **lateral side** of plant organs.
- Activity of lateral meristem increases the **circumference/ girth/thickness of plant organ.**
- All secondary meristems are lateral meristems.
- Lateral meristems are both primary and secondary in origin **(mostly secondary in origin)**.
- **Primary lateral meristems :-** Intrafascicular cambium (Fascicular vascular cambium)

  Intrafascicular cambium / fascicular vascular cambium : This cambium occurs inside the vascular bundles of dicot stems and gymnosperms stems.
- **Secondary lateral meristems :- Interfascicular cambium and cork cambium (phellogen) of dicot stem and gymnosperm stem. Cork cambium and vascular cambium of dicot roots**

- Generally **lateral meristems are cylindrical**.
- The meristem that occurs in the mature regions of roots and shoots of many plants, particularly those that produce woody axis and appears later than primary meristem is called the secondary meristem.
- Lateral meristems are responsible for producing the secondary tissues.



(a) Root apical meristem (b) Shoot apical meristem

NCERT XI Page No. 85, Figure No. 6.1

- During the formation of leaves and elongation of stem, some cells "Left behind" from shoot apical meristem, constitute the axillary bud. Such buds are present in the axils of leaves and are capable of forming a branch or a flower.
- Root apical meristem occupies the tip of a root while shoot apical meristem occupies the distant most region of the stem axis

Due to presence of root cap, position of **root apical meristem is sub terminal/sub apical**, so maximum growth in root takes place **behind the apex**.

- In hydrophytes root cap is absent eg. ***Pistia.*** In place of root cap, root **pockets** are present.
- Root cap is living, it contains large number of golgi bodies which secrete mucilage, which makes the root slimy.
- A group of inactive or less active cells present mainly in monocot root apex is called **quiescent centre.**

  Function : The quiescent centre in the root meristem serves as a reserve for replenishment of damaged cells of the meristem.
- Growth of leaf primordium $\rightarrow$ First apical then marginal.

3. PERMANENT TISSUES

- The cells of permanent tissues do not generally divide further.
- Permanent tissues are composed of cells which have lost the power of division temporarily or permanently. They are formed by division and differentiation of meristematic tissues.
- Their cells may be living or dead. Permanent tissues are of following types :-

  (A) Simple permanent tissue (Homogenous tissue)

  (B) Complex permanent tissues (Heterogenous tissue)

(A) Simple permanent Tissue

This tissues is made up of structurally similar type of cells or only one type of cells that perform a common function. Simple tissues are of three types :-

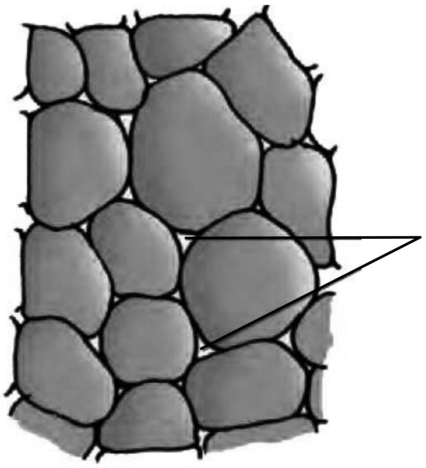
(i) Parenchyma (ii) Collenchyma (iii) Sclerenchyma

(i) PARENCHYMA :

- Parenchyma forms the major component within organs.
- It is **most primitive type of tissue**.
- It is **first evolved tissue** and remaining different types of tissues are derived from this tissue, so it is **precursor of other tissues**.
- It is also called fundamental tissue.
- It is a living tissue.
- It is first differentiated tissue.
- It is a **universal tissue**.
- Pulp of a fruit is mainly composed of parenchyma.
- Body of bryophytes is mainly composed of parenchyma.

(a) Characteristic features :

- The cells of parenchyma are **thin walled.** Cell wall is made up of pectocellulose means pectin and cellulose (**mainly cellulose**).
- Each cell generally contains large central vacuole. So the main function of a parenchyma cell is storage of food.
- Parenchymatous cells may either be closely packed or have small intercellular spaces.
- The cells of parenchyma are generally isodiametric. They may be spherical (rounded), oval, elongated or polygonal in shape.



Parenchyma

NCERT XI Page No. 86, Figure No. 6.2 (a)

(b) Occurrence :-

- It is found in cortex, pericycle, medullary rays, pith, leaf mesophyll etc. It forms major component within organs.

(c) Modifications of Parenchyma :

- **Aerenchyma** :- In this type of parenchyma air chambers are surrounded by rounded parenchymatous cells. Aerenchyma is usually found in cortex region. It provides **buoyancy** to **hydrophytes**.
- **Chlorenchyma** : Such type of parenchyma contains abundant quantity of chloroplasts. It is found in the **mesophyll of leaves.** Its function is to perform **photosynthesis**.

(d) Functions of parenchyma :

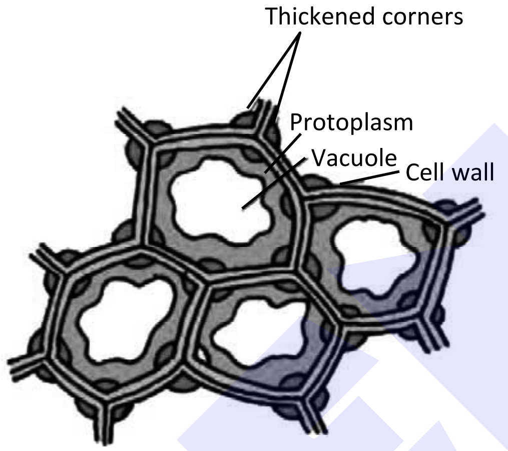
- The parenchyma perfoms various functions like storage, photosynthesis, secretion etc.
- The main function of this tissue is **storage of food.**
- **Photosynthesis** (by chlorenchyma)

(ii) COLLENCHYMA :

(a) Characteristic features :

- Collenchyma is a **living mechanical tissue,** devoid of lignin.
- It is made up of more or less elongated cells (In transverse section cells appear oval, spherical/rounded or polygonal in shape).

- Localized deposition of pectin (mainly), cellulose & hemicellulose occurs mainly at corners.
- Usually intercellular spaces are absent.
- Generally chloroplasts are found in the cells of collenchyma or cells often contain chloroplasts.
- These cells assimilate food when they contain chloroplasts.

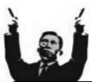


NCERT XI Page No. 86, Figure No. 6.2(b)

Collenchyma

(b) Occurrence :-

- Collenchyma is not a universal tissue. It is found in the **stems of herbaceous dicotyledons (young dicot stem) below the epidermis either as a homogenous layer** (in sunflower stem) or **in patches** (in *Cucurbita* stem).
- Collenchyma forms the **hypodermis of dicotyledon stems**. Cells of collenchyma are **flexible** due to hydrophilic nature of pectocellulose, so flexibility occurs in dicotyledonous/dicot stems.
- **Margins of leaf lamina** and **petiole of leaves** also bear collenchyma. It protects the lamina margins from cracking by the action of wind.



- Collenchyma is absent in mature/woody plant parts (After secondary growth in dicot stem), roots and monocotyledons.

(c) Functions :-

- Collenchyma performs both functions **mechanical** as well as **biological/vital functions**. It provides tensile strength against bending & swaying **(mechanical function)**.
- They provide mechanical support to the growing parts of the plant such as young stem and petiole of a leaf.
- Due to the presence of chloroplast, **photosynthesis** process (assimilation of food) takes place in collenchyma **(vital function)**.

(iii) SCLERENCHYMA :

(a) Characteristic features :

- Sclerenchyma is the main mechanical tissue. It is dead mechanical tissue.
- Cells of sclerenchyma are generally long, narrow, thick walled, lignified without protoplasts and dead (Cells become dead at maturity).
- Various types of pits are formed due to the deposition of lignin on the walls.

(b) Occurrence :-

- Sclerenchyma is found in the **hypodermis of monocot stem**.

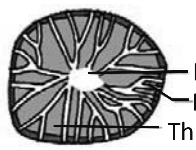
(c) Functions :-

- It provides mechanical support/mechanical strength to plant organs.

(d) Types of sclerenchyma :-

On the basis of variation in form, structure, origin & development sclerenchyma cells are of two types.

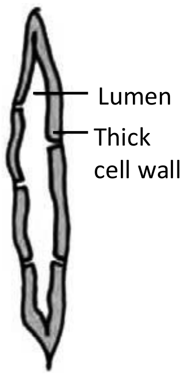
- **Sclereids**
- **Sclerenchymatous fibres**
- **SCLEREIDS :**
- These cells are small, dead extremely thick walled (highly thickened) and generally their ends are not pointed.
- Sclereids are of various shaped (Spherical, oval or cylindrical).
- Sclereid cells have pits and lumen (cavity) is almost very small/very narrow.



A sclereid (Sclerenchyma)
NCERT XI Page No. 86 Figure No. 6.2(c)

- Sclereids are commonly found in fruit walls of nuts, pulp of guava, pear & sapota, seed coats of legumes and leaves of tea etc.

- **SCLERENCHYMATOUS FIBRES :-**
- Fibres are longest cells in plant body.
- The fibres are thick walled, elongated and pointed cells.
- Their both ends are pointed (tapering).
- Due to thick cell wall, lumen is reduced.
- Generally occuring in groups in various parts of the plant.
- Their cell wall contains pits.



A fibre (Sclerenchyma)

NCERT XI Page No. 86
Figure No. 6.2(c)

(B) Complex Permanent Tissue :-

- The complex tissues are made of more than one type of cells or different types of cells and these work together as a unit. Complex tissues are heterogenous.
- Complex tissues are absent in gametophytes.
- During vascularisation in plants differentiation of procambium is followed by the formation of primary phloem and primary xylem simultaneously.
- Complex tissues are also known as vascular tissues or conducting tissues.

Complex tissues are of two types - (i) Xylem (ii) Phloem

(i) XYLEM :

- The function of xylem is to **conduct water & mineral salts** upwards from the roots to stem & leaves and to give **mechanical strength** to the plant parts.
- For efficient conduction of water death of protoplasm is must. Dead tissues are more developed in water scarce conditions.
- In hydrophytes xylem is poorly developed, while in xerophytes xylem is well developed.

- On the basis of **origin**, xylem is divided into primary xylem and secondary xylem.

  Primary xylem originates from procambium during vascularisation. Xylem which is formed early in the life of a plant is known as primary xylem. On the basis of development primary xylem is divided into two parts.

- **Protoxylem**
- **Metaxylem**

- Cells of protoxylem are smaller in diameter as compared to metaxylem. The first formed primary xylem elements are called protoxylem and the later formed primary xylem is called metaxylem.

Secondary xylem originates from vascular cambium during secondary growth. Xylem which is formed during secondary growth is known as secondary xylem. Secondary xylem is not differentiated into protoxylem and metaxylem.

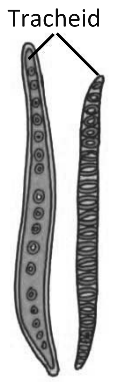
- Xylem is composed of four different kinds of elements. The elements of xylem are

(a) Tracheids, (b) Vessels or tracheae, (c) Xylem fibres → **Dead elements**

(d) Xylem parenchyma → **Living element**

(a) Tracheids :

- Tracheids are **primitive conducting elements of xylem**.
- A single tracheid is elongated or tube like cell with thick and lignified walls and possess a **narrow lumen**. The ends of tracheids are tapering or chisel like.
- The tracheids found one above the other and are separated by cross wall / end wall which bears bordered pits.



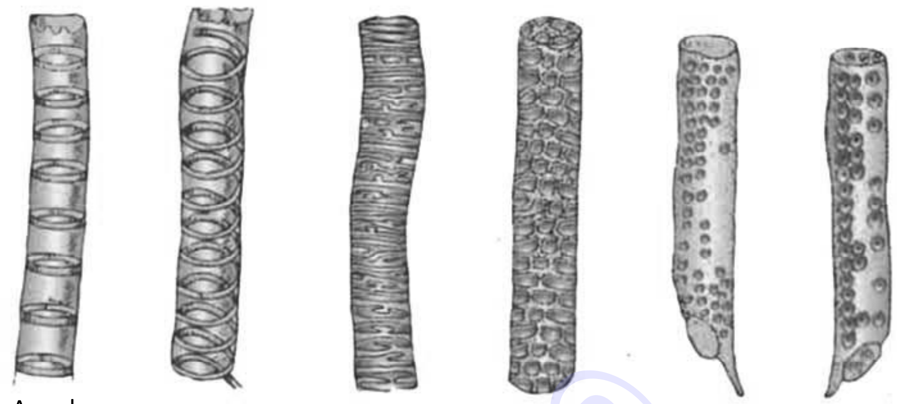
NCERT XI Page No. Figure No. 6.3(a)

- Usually **bordered pits** are present at the end walls of tracheids.

The maximum bordered pits are found in the tracheids of Gymnosperm plants.

- Tracheids are dead (without protoplasm) and lignified cells.
- Tracheids are found in pteridophytes, gymnosperms and angiosperms.
- End walls of tracheids are **imperforated** (not porous) but **pitted** (Pits are present).
- Tracheids are **unicellular**.

- The inner layers of cell walls have thickenings which vary in form.

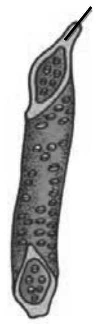


Different types of thickening on the walls of tracheids and vessels

- **Pits** are nonlignified areas on lignified walls

(b) Vessels = Tracheae

- Vessel is an **advanced conducting element of xylem.**
- Vessel is a long cylindrical, tube like structure with lignified walls and **a wide (large) central lumen/cavity**.
- Vessel is multicellular, it is made up of many cells called vessel members or vessel elements.
- Vessel is an example of **dead syncyte.** Vessel cells are also devoid of protoplasm.



NCERT XI Page No. 87 Figure No. 6.3(a)

- The **end wall is perforated.** Thus vessels are more capable for conduction of water and minerals than tracheids.
- Vessel members are interconnected through perforations in their common walls. The perforation may be **simple** (only one pore) or **multiple** (several pores). Vessels contain **usually simple pits** on their lateral walls.

- **Presence of vessels is a characteristic feature of angiosperms. Vessels are usually absent in gymnosperms** but exceptionally vessels are present in **some gymnosperms like *Ephedra, Gnetum*** and ***Welwitschia*** (order Gnetales).
- Vessels are **absent in some** *angiosperm* **plants** such as ***Dracaena, Yucca, Dagenaria, Drimys.*** There are some angiosperm families in which vessel less angiosperms are included. e.g.**Winteraceae**, **Tetracentraceae** and **Trochodendraceae**.
- Tracheids and vessels are called tracheary elements of xylem.
- In flowering plants, tracheids and vessels are the main water transporting elements.
- **Syncyte :** Structure which is formed by fusion of cells is called syncyte.

(c) Xylem fibres / Wood fibres :

- They may either be septate or aseptate.
- Xylem fibres provide strength to the tracheids and vessels.
- They have highly thickened walls and obliterated central lumens.
- They are **abundantly** found in **secondary xylem (wood)**.
- They are generally not found in gymnosperm wood (so gymnosperms are also called soft wood spermatophytes).

(d) Xylem Parenchyma :

- Cells living and thin walled and their cell walls are made up of cellulose.
- **Function : Storage of food materials in the form of starch or fat and storage of other substances like tannins.**

Note : Function of ray parenchymatous cells (xylem rays) - radial conduction of water.

Hadrome : –

Conducting part of xylem is known as hadrome.

Tracheids and **vessels** are collectively known as **water conducting elements** or **"Hadrome".** Hadrome term was proposed by **Haberlandt.**

(ii) PHLOEM :

- The main function of the phloem is **to conduct/trasport food material,** usually from the leaves to other parts of the plant.

On the basis of **origin**, phloem is classified into two categories primary and secondary phloem.

- **Primary phloem** originates from procambium during vascularisation and **secondary phloem** originates from vascular cambium during secondary growth.

On the basis of development primary phloem is categorised into :-

1. **protophloem** 2. **metaphloem**.

- The **protophloem** (first formed primary phloem) has narrow sieve tubes whereas **metaphloem** (later formed primary phloem) has bigger sieve tubes.

- Phloem consists of **four types** of cells / elements:-
- Sieve tube elements, companion cells, phloem parenchyma & phloem fibres (In angiosperms).
- Sieve cells, albuminous cells, phloem parenchyma & phloem fibres (In gymnosperms).

(a) Sieve tube element / Sieve cell :

↓ ↓

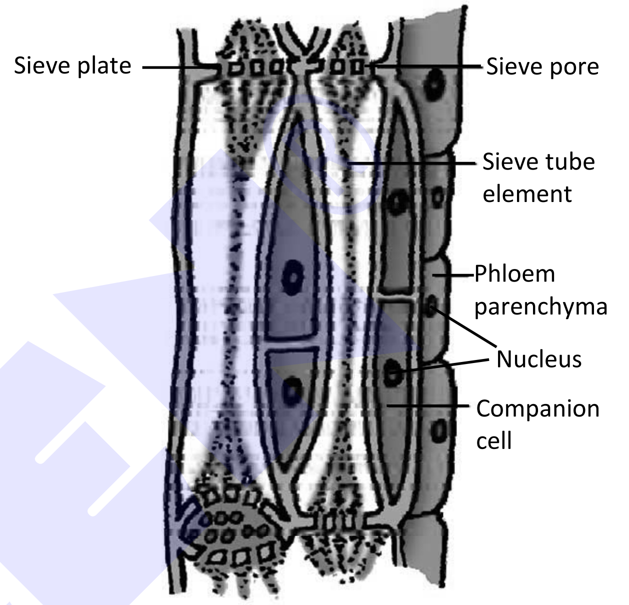
In Angiosperms — **In Gymnosperms and pteridophytes**

- Sieve cells and sieve tube elements are **living** and thin walled.
- **In Angiosperm plants,** sieve tube elements are joined with their ends to form **sieve tube.** Their end walls are perforated (means having sieve pores) in a sieve like manner to form the sieve plates. Translocation of food material takes place through these pores.
- Sieve tube is an example of **living syncyte**.
- Sieve tube elements are long, tube like structures arranged longitudinally and are associated with companion cells.
- A mature sieve tube element possess a peripheral cytoplasm & a large vacuole but lacks a nucleus. (i.e. enucleated)
- The function of sieve tubes are controlled by the nucleus of companion cells.

- Sieve elements contain special type of protein-**P-protein** (p=phloem). Most likely function of p-protein is sealing mechanism on wounding along with callose and it is also related with conduction of food.
- In Pteridophyte and gymnosperms, sieve cells are arranged in zig-zag manner. In sieve cells, less conspicuous sieve areas are usually located laterally. Sieve cells are narrow elongated cells.

(b) Companion cells :

These are thin walled, living, **specialised parenchymatous cells,** which are closely associated with sieve tube elements.



Phloem

NCERT XI Page No. 87, Figure No. 6.3 (b)

- The sieve tube elements and companion cells are connected by **pit fields** present in their common longitudinal walls.
- Companion cell is laterally associated with each sieve tube element in angiospermic plants.
- **Sieve tube element and companion cell** originate together from a single mother cell. So, they are called **sister cells**.
- Companion cell is a **living cell** with **large elongated nucleus**. This nucleus also controls the activity/functions of sieve tube element.
- Companion cells are found only in **angiosperms.**
- The companion cells help in maintaining the pressure gradient in the sieve tubes.

Special type of cells are attached with the sieve cells in **gymnosperm and in pteridophytes** in place of companion cells. These cells are called **Albuminous cells/Strasburger cells**.

(c) Phloem fibres / Bast fibres : These are made up of **sclerenchymatous** cells.

- These are much elongated, unbranched and have pointed needle like apices. The cell wall of phloem fibres is quite thick.
- These fibres are generally not found in primary phloem but are found in the secondary phloem.

- These fibres **provide mechanical support** to sieve elements.
- At maturity fibres lose their protoplasm and become **dead**.
- Phloem fibres of jute, flax and hemp are used commercially.

(d) Phloem Parenchyma :

- It's cells are living, elongated, tapering, cylindrical which have dense cytoplam and nucleus.
- The wall is composed of cellulose and has pit fields through which plasmodesmatal connection exist between the cells.
- It stores food material and other substances like resins, latex, mucilage etc.
- The main function of phloem parenchyma is storage of food material and function of phloem rays (ray parenchyma) is conduction of food in radial direction.
- Phloem parenchyma is absent in most of the monocotyledons.

- The conducting element of phloem is called **Leptome**.
- **Leptome** term was given by **Haberlandt**.

4. TISSUE SYSTEM

In higher plants several tissues work together in the form of a unit to perform a particular function. These tissues have the same origin. Such tissues form a system which is called tissue system. On the basis of **location / position** & **structure / morphology** tissues were categorised by **Von Sachs** (German scientist) into three types of tissue system. Each system usually consist of an association of tissues which perform specific function :-

1. EPIDERMAL/DERMAL TISSUE SYSTEM

- This system forms the outer-most covering of the whole plant body and comprises epidermis, stomata, root hairs, trichomes.

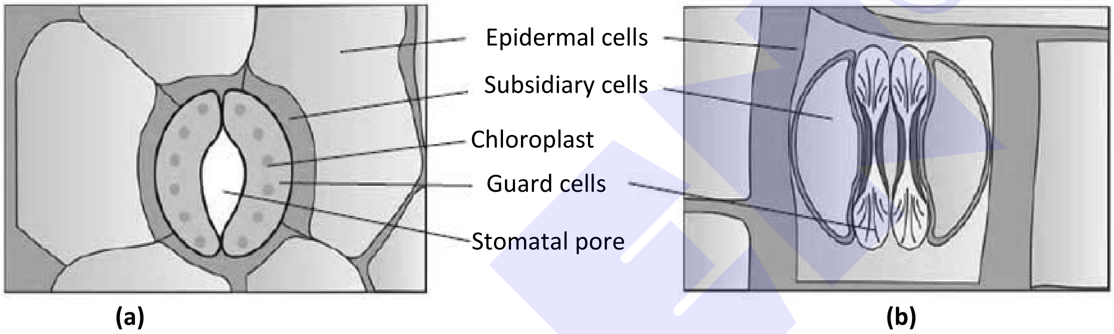
(A) Epidermis :

- It is outermost layer of the primary plant body and made up of elongated, compactly arranged cells.
- It is usually single layered and made up of parenchymatous cells.
- Cuticle (Waxy thick layer) is present on the epidermis which prevents the loss of water.
- Cuticle is absent in roots.
- Epidermal cells are with a small amount of cytoplasm lining the cell wall and a large vacuole.

(B) Stomata :

- These structures are present in the epidermis of leaves.
- Stomata regulate the process of transpiration and gaseous exchange. Each stoma is composed of two bean shaped cells known as guard cells which enclose stomatal pore.
- In grasses, the guard cells are dumb-bell shaped.
- The outer walls of guard cells (away from the stomatal pore) are thin and the inner walls (towards the stomatal pore) are highly thickened. The guard cells possess chloroplasts and regulate the opening and closing of stomata. Sometimes, a few epidermal cells, in the vicinity of the guard cells become specialised in their shape and size and are known as subsidiary cells.

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



Diagrammatic representation : (a) Stomata with bean-shaped guard cells
(b) Stomata with dumb-bell shaped guard cells.

NCERT XI Page No. 89, Figure No. 6.4

(C) Trichomes :

- The cells of the epidermis of dicot stem produce hairs called trichomes.
- The trichomes in the shoot system are usually multicellular.
- They may be branched or unbranched and soft or stiff. They may even be secretory called glandular hairs.
- In shoot system, **trichomes** are **usually multicellular.**

Function : The trichomes help in preventing water loss due to transpiration.

(D) Root hairs

- The root hairs are formed due to the elongation of the epidermal cells. These are ephemeral (short lived) structure.
- **Root hairs** are always **unicellular.**

Function : Root hairs play an important role in absorbing water and minerals from the soil.

2. GROUND TISSUE SYSTEM

- It is the **largest tissue system**. All tissues except epidermis and vascular bundles constitute the ground tissue.
- It includes hypodermis, general cortex, endodermis, pericycle and medullary rays (pith rays), pith. In leaf G.T.S. consists of mesophyll. G.T.S. is also called **fundamental tissue system.**
- G.T.S. is made of simple tissues such as parenchyma, collenchyma & sclerenchyma. The G.T.S. forms the main bulk of the plant.

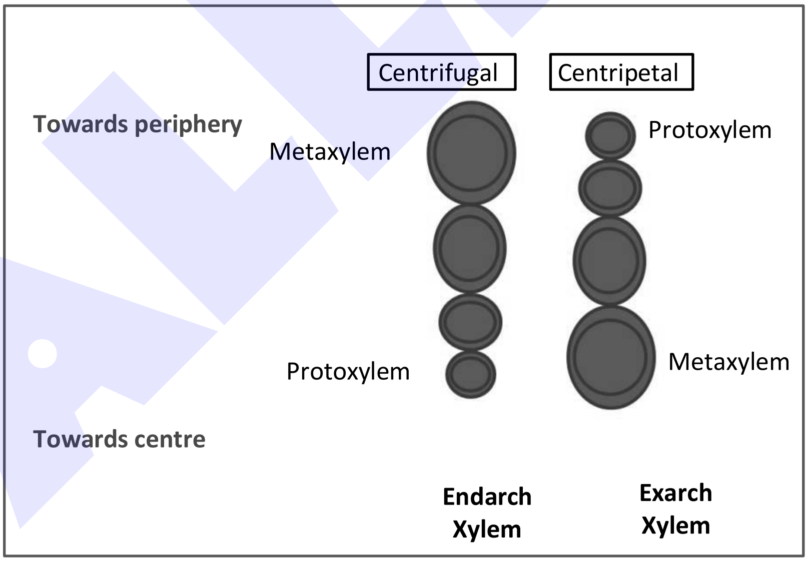
Primary structure of plant organ or primary plant body is mainly composed of parenchyma.

3. VASCULAR/CONDUCTING TISSUE SYSTEM

- The V.T.S. consists of complex tissues, xylem and phloem. It is also called **specific tissue system**.

Types of development of primary xylem :-

- **Centrifugal** :- In this type of development, the protoxylem is formed towards the centre (pith) and metaxylem is formed towards the periphery. In this condition xylem is known as **endarch.** ex. **Stem of angiosperms & gymnosperms**
- **Centripetal** :- In this type of development the protoxylem is formed towards the periphery and metaxylem is formed towards the centre (pith). In this condition xylem is called **exarch.** ex. **Roots.**



05. VASCULAR BUNDLES

- Xylem and phloem are collectively termed as vascular bundles.

Which may or may not have cambium.

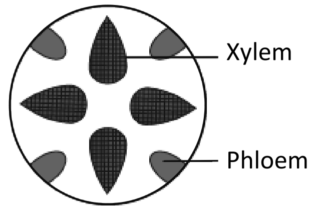
On the basis of arrangement of elements means location of xylem and phloem, vascular bundles are divided into following categories.

(1) Radial (2) Conjoint

1. Radial vascular bundles

- When the xylem and phloem are present separately on different radii in alternate manner, then vascular bundles are called radial vascular bundles.

  Example : Most of the **roots.** (Dicot, monocot, gymnosperm, fern root)



NCERT XI Page No. 90
Figure No. 6.5(a)

2. Conjoint vascular bundles

In these type of vascular bundles xylem and phloem are present on the same radius of vascular bundles. These are of two types -

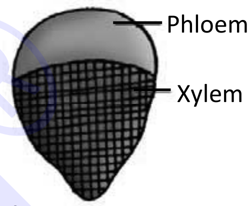
(A) Conjoint Collateral : In this type of vascular bundle xylem and phloem are present on the same radius and phloem is present towards the periphery.

These are two types -

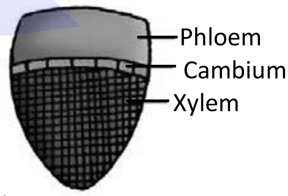
(i) **Closed** - When cambium is absent between the xylem and phloem of conjoint collateral vascular bundle then it is called closed vascular bundle.

Ex. **Monocotyledons stem and leaves of angiosperms.**

(ii) **Open** - If the cambium is present between the xylem and phloem, then it is said to be open vascular bundle. Ex. **stem of dicots/dicotyledons** and **gymnosperms**.



(b) Conjoint collateral closed

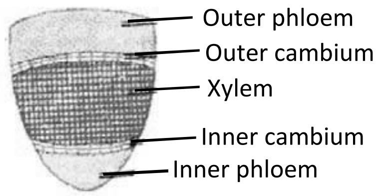


(c) Conjoint collateral open

NCERT XI Page No. 90
Figure No. 6.5

(B) Conjoint, bicollateral and open vascular bundle : In this type of V.B. two patches of phloem, one on each side of xylem, are found. There are two strips of cambium (outer and inner), one on each side of xylem are found.

Ex. **Stem of family cucurbitaceae** and some plants of family solanaceae.



Conjoint bicollateral

STELE

- All the tissues which are present inside the endodermis constitute the stele.
- The stele is the whole central mass of vascular tissue (vascular cylinder) with or without pith surrounded by endodermis. Stele is surrounded by endodermis but endodermis is originally the part of cortex. It is not a part of stele.
- In **eustele**, vascular bundles are **arranged in a ring** e.g. dicot stem
- In **atactostele**, vascular bundles are **scattered in ground tissue** e.g. monocot stem

Golden Key Points

- **Meristos** is a Greek word which means **divided.**
- A simple tissue is made of only one type of cells whereas the complex tissues are made of more than one type of cells.
- Generally gymnosperms lack vessels.
- All tissues except epidermis and vascular bundles constitute the ground tissue.
- When xylem and phloem within a vascular bundle are arranged in an alternate manner along the different radii, the arrangement is called radial such as in roots.
- In conjoint type of vascular bundles, the xylem and phloem are jointly situated along the same radius of vascular bundles.
- In dicotyledonous stems, cambium is present between phloem and xylem. Such vascular bundles because of the presence of cambium possess the ability to form secondary xylem and phloem tissues, and hence are called open vascular bundles.
- In the monocotyledons, the vascular bundles have no cambium, hence they are referred to as closed.

BEGINNER'S BOX — MERISTEM TO VASCULAR BUNDLES

1. The process of formation of secondary meristem from primary permanent tissue is called :-

(1) Differentiation (2) Dedifferentiation

(3) Redifferentiation (4) Secretion

2. Which of the following are examples of primary lateral meristems :-

(1) Cork cambium and vascular cambium

(2) Interfascicular cambium and cork cambium

(3) Interfascicular cambium and vascular cambium

(4) Intrafascicular cambium

3. Which of the following is primitive tissue :-

(1) Parenchyma (2) Collenchyma

(3) Sclerenchyma (4) Xylem

4. Conjoint, collateral vascular bundles are found in :-

(1) Stems (2) Leaves (3) Roots (4) Both (1) & (2)

5. Phloem parenchyma is absent in :-

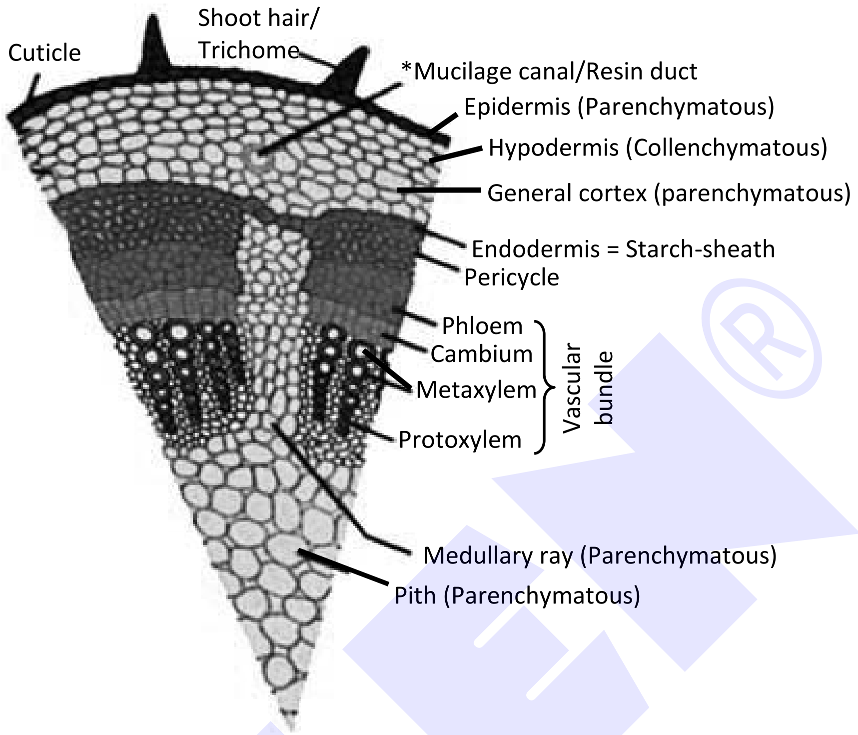
(1) Most of the Monocotyledonous stem (2) Most of the Dicotyledonous stem

(3) All Monocotyledonous stem (4) All Dicotyledonous stem

6. ANATOMY OF DICOTYLEDONOUS AND MONOCOTYLEDONOUS PLANTS

1. DICOTYLEDONOUS STEM

Internal structure of a typical dicotyledonous stem shows following anatomical features:-



T.S. OF SUNFLOWER STEM - [A part of cellular diagram]

(A) Epidermis :

Epidermis is the outermost protective layer of the stem. It is made up of elongated compactly arranged cells. It is **single layered** and lack of chloroplasts.

- Stomata, **multicellular hairs (trichomes)** are present on epidermis. Thin **cuticle** is present on epidermis.
- Epidermis plays a significant role in protection.
- Trichomes help in preventing water loss due to transpiration.

(B) Cortex :

The cells arranged in multiple layers between epidermis and pericycle constitute the cortex. In dicotyledon stem cortex is divided into three parts or sub zones.

(i) Hypodermis (ii) General cortex (iii) Endodermis

(i) **Hypodermis :** It is present just below the epidermis. It is multilayered thick. It is **composed of collenchyma** and cells often contain **chloroplasts**.

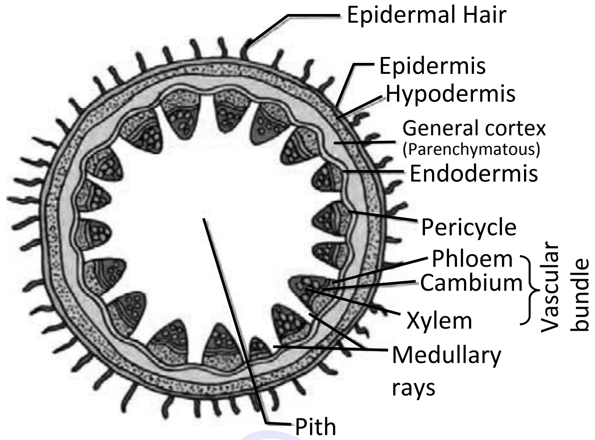
(ii) **General Cortex :** This part is composed of rounded thin walled cells of **parenchyma** with conspicuous intercellular spaces. Storage of food is the main function of the cortex. Resin canals/mucilage canals are present in it. The innermost layer of the cortex is called **endodermis**.

(iii) **Endodermis :** It is single layered. The cells of the endodermis are rich in starch grains and the layer is also referred to as the starch sheath.

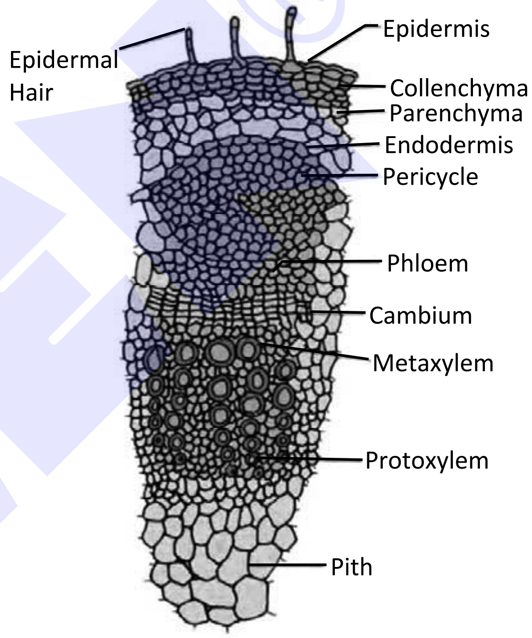
(C) Pericycle :

- Pericycle is situated below the endodermis. The pericycle of stem is **multilayered.**
- In **sunflower** stem, **pericycle** is made of alternate bands of **parenchymatous** & **sclerenchymatous** cells.
- The part of pericycle which is present infront of the vascular bundle is made up of sclerenchyma and remaining part is composed of parenchyma. Part of pericycle which is situated in front of vascular bundle is known as **Bundle cap**.
- In sunflower stem, pericycle is **heterogenous** in nature.

Note :- Pericycle is present above the phloem in the form of semilunar patches of sclerenchyma.



(Outline diagram)



(A part of cellular diagram)

T.S. of Dicotyledonous stem

NCERT XI Page No. 92, Figure No. 6.7 (a)

(D) Vascular Bundles :

The **wedge shaped** vascular bundles are **arranged in a ring**. The ring arrangement of vascular bundles is a characteristic of dicot stem. Each vascular bundle is **conjoint, collateral** and **open** and **xylem is endarch**.

(E) Medullary Rays :

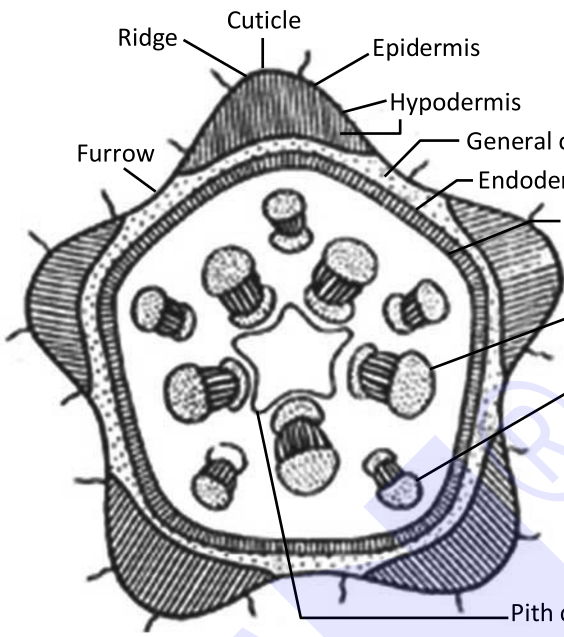
A few layers of radially arranged parenchymatous cells in between the vascular bundles, called **pith rays or medullary rays.** The main function of pith rays is radial conduction of food and water.

(F) Pith :

A large number of rounded, parenchymatous cells with large intercellular spaces which occupy the central portion of the stem constitute the pith.

2. CUCURBITA STEM

Internal structure of Cucurbita stem shows following anatomical features :-



T.S. of *Cucurbita* Stem (Outline Diagram)

- Five ridges and five furrows
- **Collenchymatous** discontinuous hypodermis is present in ridges below the epidermis.
- **No. of vascular bundles** are **ten** and they are arranged in **two** rings.
- Conjoint, bicollateral and open vascular bundles

3. MONOCOTYLEDONOUS STEM

Internal structure of a typical Monocotyledonous stem shows following anatomical features :-

T.S. of Maize Stem - [A part of cellular diagram]

(A) Epidermis :

Epidermis is the outer most single celled thick layer. It is covered with thick cuticle. **Multicellular hairs are absent.**

(B) Hypodermis :-

Hypodermis of monocotyledonous stem is **made up of sclerenchyma**. It is 2-3 layered thick. In monocot stem rigidity is more in hypodermis whereas in dicot stem elasticity is more. It provides **mechanical** support to the plant.

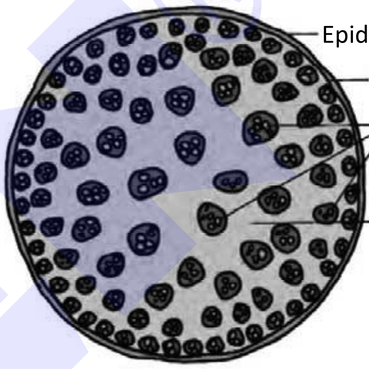
(C) Ground tissue :-

It is large, conspicuous parenchymatous. There is no differentiation of ground tissue in monocotyledonous stem. It means ground tissue is not differentiated into general cortex, endodermis, pericycle, pith & medullary rays.

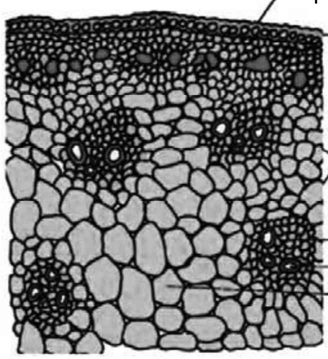
(D) Vascular Bundles :-

- Many vascular bundles are found **scattered** in the ground tissue and V.B. are generally **oval** (egg shaped). Peripheral vascular bundles are generally smaller than the centrally located ones.
- Vascular bundles which are situated towards the **centre** are **large** in size and **less** in number.

  Vascular bundles which are situated towards the **periphery** are **small** in size but **more** in number.
- Each vascular bundle is **conjoint, collateral and closed** and **xylem is endarch**. Each vascular bundle is surrounded by **sclerenchymatous bundle sheath**.
- Water containing cavities are present within the vascular bundles.



(Outline Diagram)



(A part of Cellular Diagram)

T.S. of Monocotyledonous Stem

NCERT XI Page No. 92, Figure No. 6.7(b)

(i) Xylem :- In xylem number of **vessels** is less. In **metaxylem** there occurs **two large vessels** while in **protoxylem** there occurs **one** or **two small vessels**. There occurs a **water cavity** which is **schizolysigenous** in origin. In which major part of water cavity is **lysigenous** in origin (formed due to lysis of protoxylem elements) and few part of water cavity is schizogenous (formed by separation of cells).

(ii) Phloem :- It consists of sieve tube elements and companion cells. **Phloem parenchyma** is absent.

4. DICOTYLEDONOUS ROOT

Internal structure of a typical dicotyledonous root shows following anatomical features :-

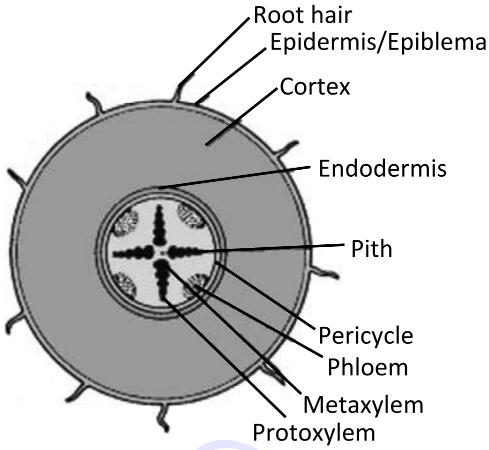
(A) Epiblema/Epidermis :-

- It is **uniseriate** (single layered) outermost layer. **Cuticle and stomata are absent.**
- Many of the epidermal cells protrude in the form of unicellular root hairs means unicellular root hairs are formed due to elongation of cells of epiblema.
- Hypodermis is absent in the roots.

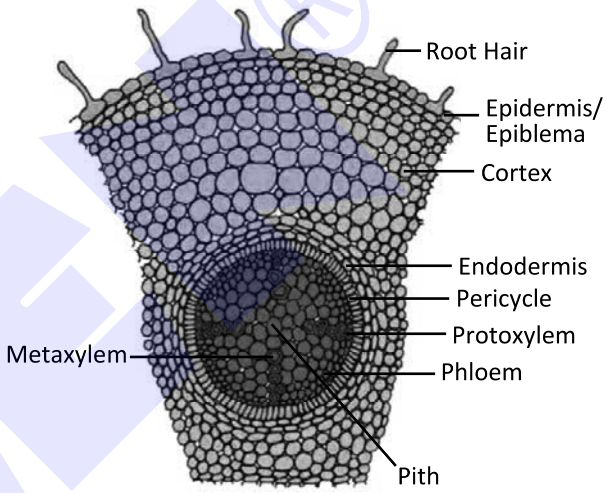
(B) Cortex :-
It is made up of thin walled **parenchymatous** cells with intercellular spaces. Chloroplast is absent, so they are non-photosynthetic.

(C) Endodermis :-

- The innermost layer of the cortex is called endodermis.
- It comprises a single layer of barrel - shaped cells without any intercellular spaces.



(Outline diagram)



(A part of cellular diagram)
T.S. of Primary Dicotyledonous root
NCERT XI Page No. 91, Figure No. 6.6(a)

- This layer of **barrel shaped cells** is situated between the pericycle and cortex. Casparian strips/bands are present on radial and tangential walls of endodermis. These strips are made up of **ligno suberin means lignin & suberin (mainly suberin)**.
- Suberin is water impermeable waxy material.
- Casparian strips were discovered by **Caspari**.
- The cells of endodermis which are situated infront of protoxylem cells are devoid of casparian strips. These are called **passage cells/path cells.**
- Passage cells provide path to absorbed water from cortex to pericycle.
- Intercellular spaces are absent between the cells of endodermis of root.
- **Endodermis** acts as a **water tight jacket** (Dam) which **prevents leakage of water from stele**.

(D) Pericycle :-

- It is a single or **few layers of thick walled parenchymatous cells.**
- Initiation of **lateral roots** occurs from the cells of pericycle. Lateral roots are **endogenous** in origin because they originate from stelar region.

(E) Vascular Bundles :

- Vascular bundles are **radial** and xylem is **exarch.**
- The number of xylem patches and phloem patches are **usually two to four** but they may be two to six (diarch to hexarch).
- Tetrarch condition is found in gram & sunflower.
- Parenchyma which is found between the xylem and phloem is called **conjunctive tissue**.
- In T.S. of dicot root, xylem vessels appear angular in shape.

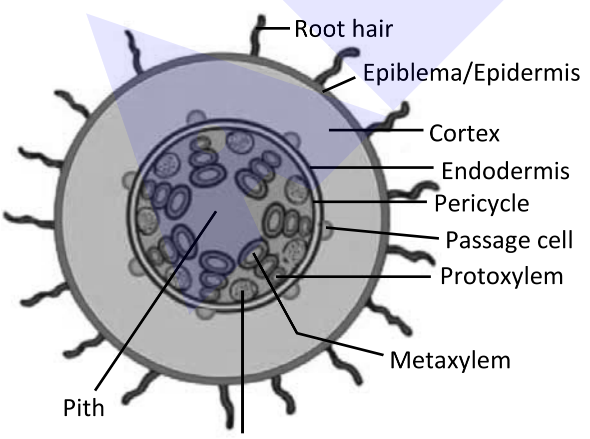
(F) Pith : In dicot root pith is **small (less developed)** or **inconspicuous** or absent.

5. MONOCOTYLEDONOUS ROOT

- The internal structure of a typical monocotyledonous root is similar to dicotyledonous root except some differences which are as follows :-
- Number of **xylem bundles** are **usually more than six (polyarch)** in monocotyledonous root.
- **Pith** is **large and well developed** in monocotyledonous root
- **Xylem vessels** appear **circular or oval shape**.

Velamen :- It is found in aerial roots or hanging roots of epiphytes (eg. **Orchids–*Vanda***)

- It is an example of **multilayered epidermis**
- It **absorbs atmospheric moisture** by imbibition.



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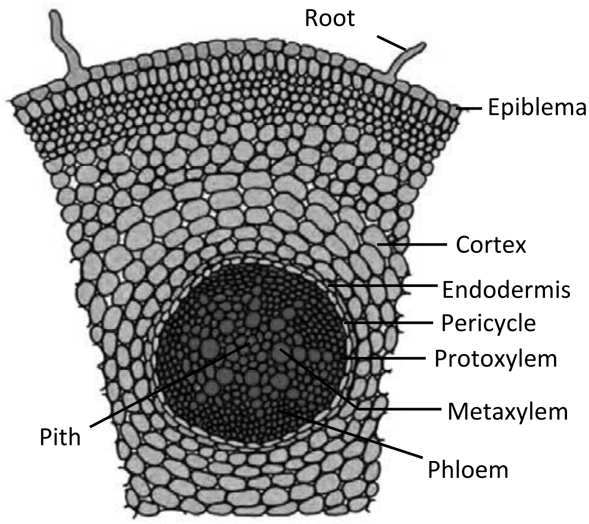


(A part of cellular diagram)
NCERT XI Page No. 91, Figure No. 6.6(b)

T.S. of Monotyledonous root

LEAVES

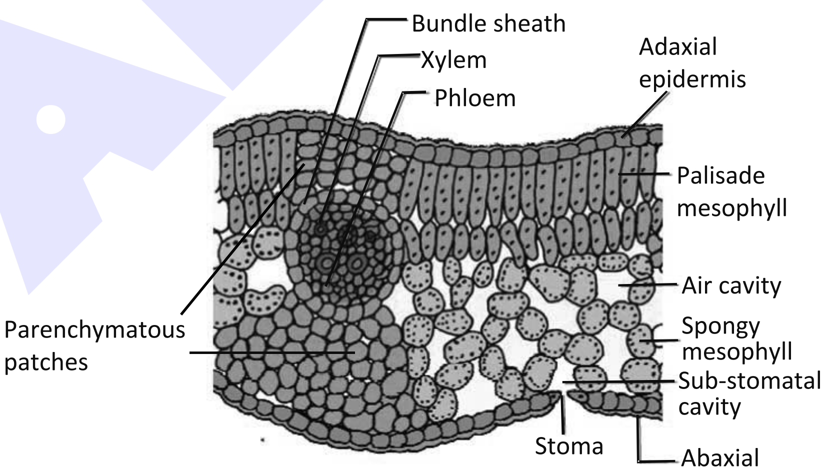
Generally leaves are divided into two categories - Dorsiventral leaves and isobilateral leaves. The differences in between them are as follows :

Dorsiventral or Bi–facial leaf	Iso–bilateral or Equifacial leaf
1. Present at **right angle to stem**	**1.** Arranged **parallel to stem**.
2. Upper surface of leaf receives more sun light as compared to the lower surface, so there occur **difference** between internal structure of upper and lower surfaces Example :- Usually in **Dicots**	**2.** Both surfaces of leaf receive equal amount of sun light so **no difference** occurs between internal structure of upper & lower surfaces. Example :- Usually in **Monocots**

6. DORSIVENTRAL (Dicotyledonous) LEAF

Internal structure of a typical Dorsiventral Leaf shows following anatomical features :-

- Cuticle is present on both surfaces but **cuticle on upper surface is more thick.**
- In dorsiventral leaves **stomata are more on lower surface** and stomata on upper surface may even absent or less in number.
- The tissue between the upper & the lower epidermis is called the mesophyll.
- **In dicot leaf, mesophyll is differentiated** into **palisade** parenchyma (palisade mesophyll or palisade tissue) and **spongy** parenchyma (spongy mesophyll or spongy tissue).
- **Palisade tissue** is situated towards the upper (adaxial or ventral) surface. It is made up of elongated cells which are arranged vertically and parallel to each other and have more chloroplasts.



T.S. of Dorsiventral (Dicotyledonous) Leaf

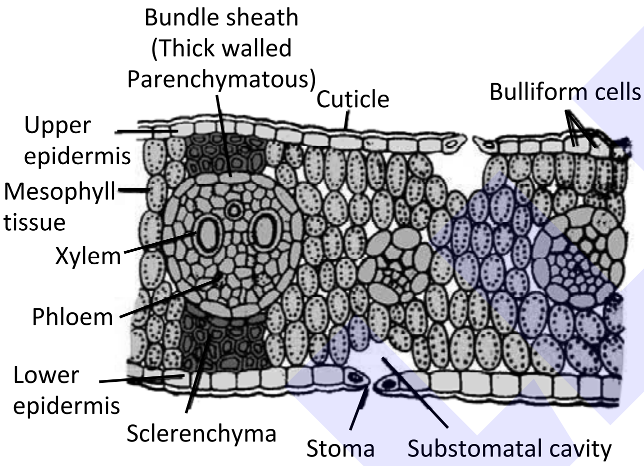
NCERT Page No. 94, Figure No. 6.8(a)

- **Spongy tissue** is situated towards lower (abaxial or dorsal) surface. The cells are oval or rounded and between the cells large air spaces / air cavities are present.
- In **dorsiventral leaf**, two distinct patches of **parenchyma (mainly)/**collenchyma are present above and below the large vascular bundle and extend up to the upper and lower epidermal layers.

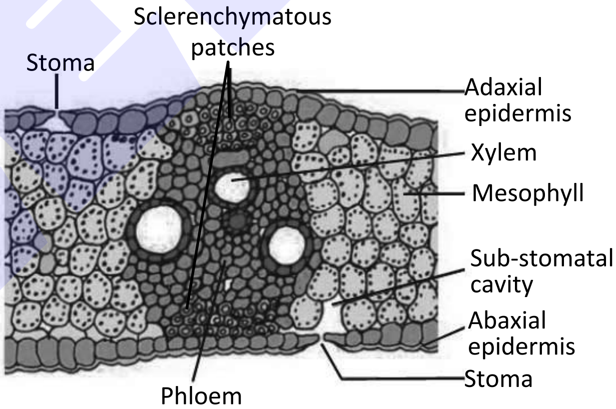
7. ISOBILATERAL (Monocotyledonous) LEAF

Internal structure of a typical Isobilateral Leaf shows following anatomical features :-

- The **thickness of cuticle is equal** on both surfaces.
- Usually **stomata on both surfaces** are **equal** in number.
- **Mesophyll is not differentiated** into palisade and spongy tissues in isobilateral leaves. Mesophyll cells have only a few intercellular spaces.
- In **isobilateral leaf**, two distinct patches of **sclerenchyma** are present above and below the large vascular bundle and extend up to the upper and lower epidermal layers.



T.S. of Isobilateral (Monocotyledonous) leaf



T.S. of Isobilateral (Monocotyledonous) leaf

NCERT XI Page No. 94, Figure No. 6.8(b)

- Similar types of vascular bundles are found in both dorsiventral and isobilateral leaves. Vascular bundles of leaves are **conjoint, collateral** and **closed**.
- **Protoxylem** is situated **towards the adaxial** (upper) surface and **protophloem towards the abaxial** (lower) surface in the vascular bundle. Leaves are **devoid** of **endodermis** and **pericycle**.
- Vascular bundles are surrounded by a **bundle sheath**. It is made up of thick walled **parenchyma.**

- In the leaves of **C_4-plants** (eg. sugarcane, maize etc.) **bundle sheath is chlorenchymatous.**
- **In grasses**, certain adaxial epidermal cells along the veins modify themselves into large, empty, colourless cells. These are called **bulliform cells or motor cells .** When the bulliform cells in the leaves have absorbed water and are turgid, the leaf surface exposed. When they are flaccid due to water stress, they make the leaves curl inwards to minimise water loss.
- The stomatal aperture, guard cells and the surrounding subsidiary cells are together called stomatal apparatus.
- The size of vascular bundles are dependent on the size of the veins. The veins vary in thickness in the reticulate venation of the dicot leaves.
- The parallel venation in monocot leaves is reflected in the near similar sizes of vascular bundles (except in main veins) as seen in vertical sections of the leaves.
- Both upper & lower **epidermis of *Nerium* leaves** are **multilayered** This is an adaptation to reduce transpiration.

Types of leaves	Position of stomata	Examples
Epistomatic leaf	Stomata are present on upper surface of leaf	Floating leaves Examples - Lotus *(Nelumbium)* *Victoria regia, Nymphaea*
Hypostomatic leaf	Stomata are present on lower surface of leaf	Mostly dicot leaves
Amphistomatic leaf	Stomata are present on both surfaces of leaf	Mostly monocot leaves
Astomatic leaf	Stomata are absent or non-functional in leaf	Submerged leaves Examples - *Vallisneria, Hydrilla*

07. SECONDARY GROWTH

- By the activity of laterel meristems (vascular cambium and cork cambium), **increase in the circumference/girth/ thickness** of the plant organs is called secondary growth.
- Normally secondary growth takes place in **roots and stem of dicotyledons** & **gymnosperms**.
- The tissues involved in secondary growth are two lateral meristems : vascular cambium and cork cambium.
- Secondary growth is not found in the leaves and monocots.

- Due to lack of cambium in monocotyledons, secondary growth is absent. But **exceptionally** secondary growth takes place in **some monocotyledons**. Such as - **Palm, Date Palm, Coconut Palm, *Yucca, Dracaena,*** *etc.* These plants show **abnormal secondary growth**.

1. SECONDARY GROWTH IN DICOTYLEDONOUS STEM

(A) Secondary growth in stelar region by vascular cambium :

Secondary growth in stelar region begins earlier than the extrastelar region.

(i) Formation of ring of vascular cambium :- A cambium which is present inside the vascular bundle (means between primary xylem and primary phloem) is called **intrafascicular- cambium**. This is a type of primary lateral meristem.

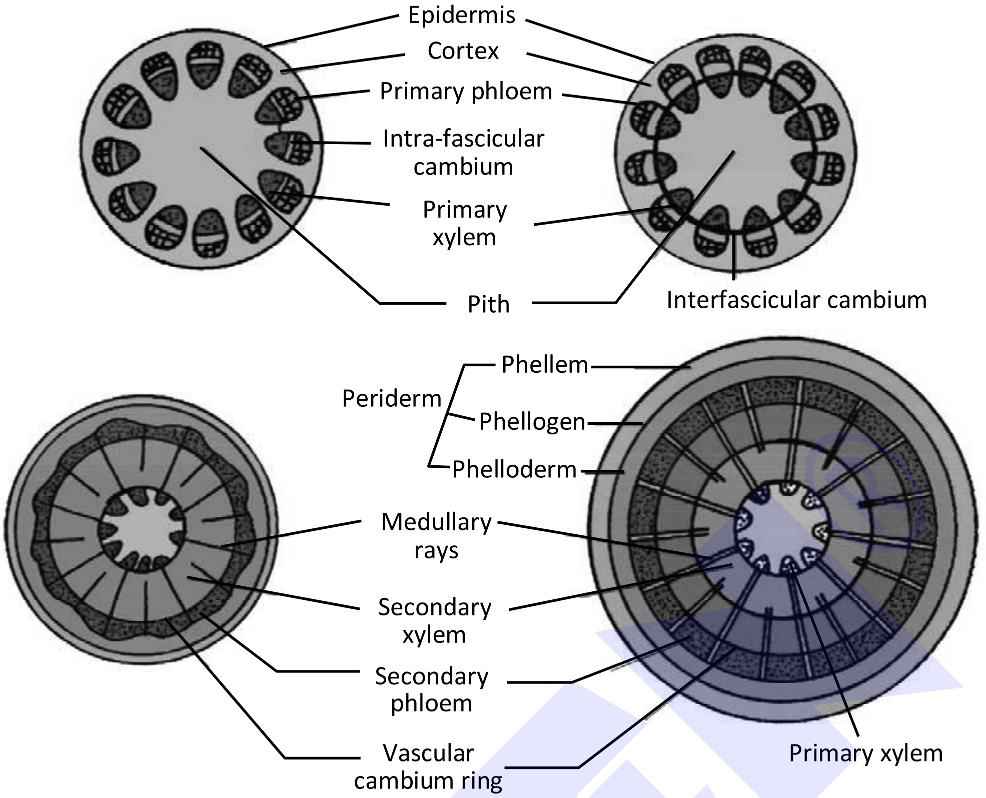
- First of all, cells of medullary rays adjoining intrafascicular cambium become meristamatic to form **interfascicular cambium** which is a secondary lateral meristem.
- Intrafascicular and interfascicular cambium are collectively known as **vascular cambium** or intra stelar cambium. Vascular cambium is formed in the form of a complete ring which is made up of single layer of cells.
- In diocot stem, the **vascular cambium is partly primary and partly secondary** in origin.
- Two types of cells are found in the ring of this vascular cambium.
  - **Fusiform initials**
  - **Ray initials**
- Fusiform initials are long with pointed ends, whereas ray initials are spherical/rounded or oval in shape.
- Fusiform initials are more in number in vascular cambium.

(ii) Activity of vascular cambium :

(a) Activity of fusiform initials :

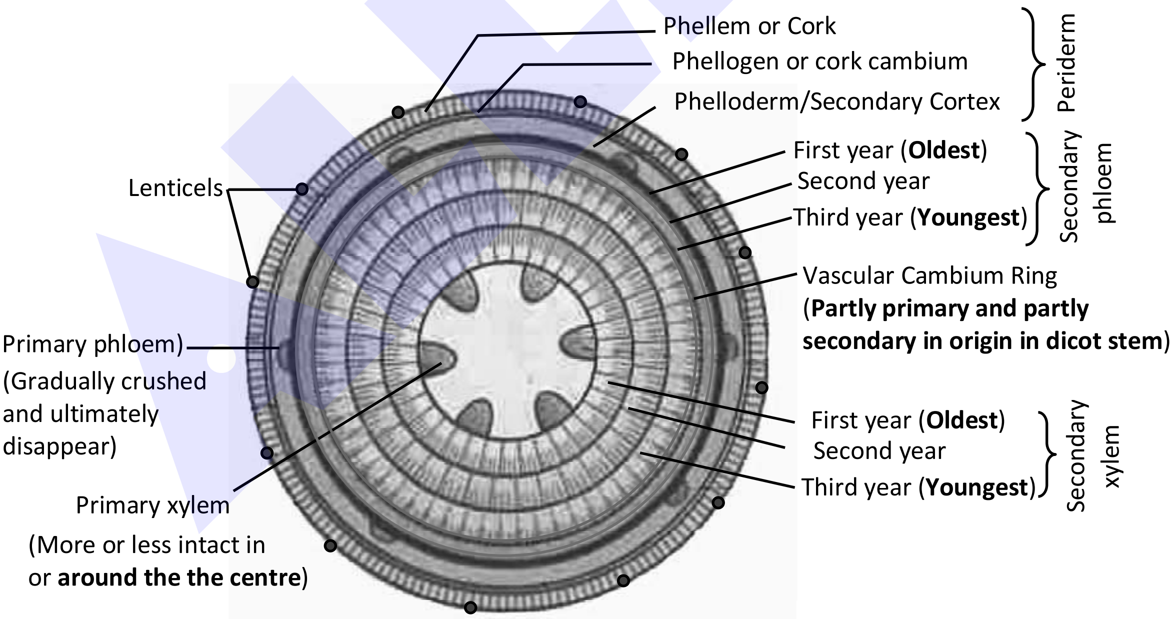
- Continuous periclinal divisions (parallel to longitudinal axis) takes place in fusiform initials, then few cells are formed towards the periphery and these cells are differentiated into **secondary phloem or bast** and the cells which are formed towards the centre (towards pith) are differentiated into **secondary xylem or wood**.
- The cambium is generally more active on the innerside than on the outer.
- Normally **more secondary xylem** is formed as compared to the secondary phloem **due to unequal distribution of hormones**.

  (**Secondary xylem** is formed **8-10 times more** as compared to the secondary phloem).



Secondary growth in a dicot stem (diagrammatic) – stages in transverse views

NCERT XI Page No. 95, Figure No. 6.9



T.s. of Woody dicot stem showing secondary growth in stelar and extra stelar regions

***** Primary phloem and earlier secondary phloem get gradually crushed due to the continued formation and accumulation of secondary xylem.**

- By the pressure of secondary xylem, all the primary tissues- such as **primary xylem, pith** are pushed towards the centre.
- The **primary xylem** however remains **more or less intact** in or around the centre. The primary phloem and earlier secondary phloem (old secondary phloem) get gradually crushed due to the continued formation and accumulation of secondary xylem.

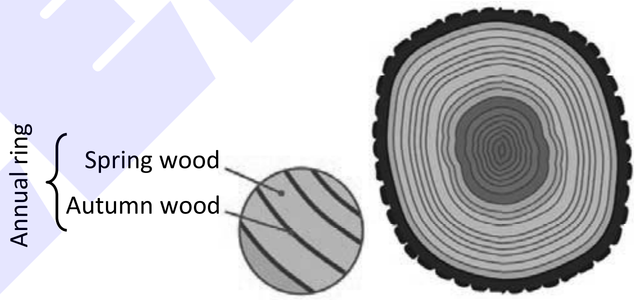
(b) Activity of Ray initials :-

- Periclinal divisions take place in ray initials.
- Ray initials cuts off (form) parenchymatous cells. These are called **vascular rays** (Xylem rays & phloem rays) or **secondary medullary rays** which passes through the secondary xylem and secondary phloem in the radial direction. They **conduct water** and **food** in **radial direction**. The order of development of vascular rays are both centripetal and centrifugal.

(iii) Formation of Annual Rings :-

Annual rings are formed due to unequal activity of vascular cambium.

- The activity of cambium does not remain same, it is changeable in the whole year.



T.S. of woody dicot stem showing annual rings

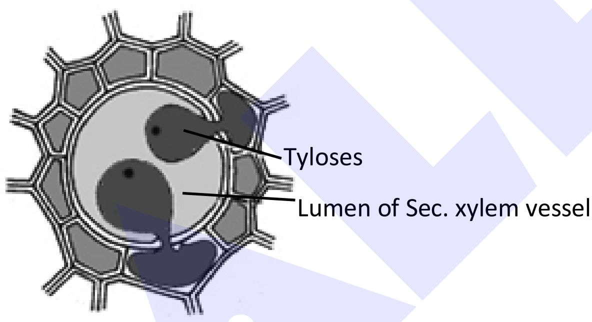
- Activity of vascular cambium is under the control of many physiological and environmental factors.
- In temperate regions, the climatic conditions are not uniform through the year.
- In the spring season, vascular cambium is very active and produces a large number of secondary xylem elements having vessels with wider cavities / lumens. The wood formed during this season is called **spring wood** or **early wood.**

- In winter and autumn season, the vascular cambium is less active and forms fewer secondary xylem elements that have vessels with narrow lumen and this wood is called winter wood or **autumn wood** or **late wood.**
- The spring wood is lighter in colour and has a lower density whereas the autumn (or winter) wood is darker and has a higher density.
- The **autumn** and **spring wood** are formed in the form of concentric rings. The two kinds of woods that appear as alternate concentric rings, constitute an annual ring.
- A **ring of autumn wood** and a **ring of spring wood** are collectively known as **Annual ring**. The number of annual rings, formed in a tree give the idea of the age of the tree.

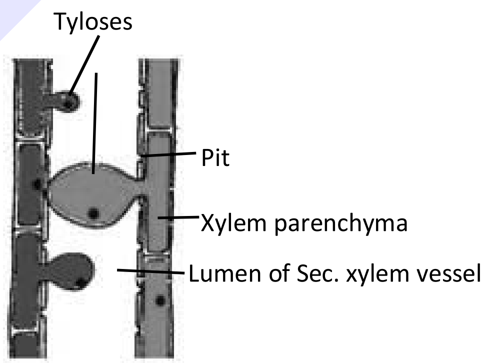
- The study of determination of age of a tree/plant by counting annual rings is called **Dendrochronology**.
- The annual rings are counted from the **base of the stem** because basal part has maximum annual rings and upper part has less. Therefore, counting from the basal region can give the correct idea.
- A piece of wood is taken from the stem up to central region from the base of stem with the help of **increment borer** instrument. The annual rings are counted from that piece and again inserted (fitted) into the same stem at the same place.
- More distinct/clear annual rings are formed in that regions where climatic variations are sharp.
- **More distinct annual rings** are formed in **temperate plants**. Because in temperate regions, the climatic conditions are not uniform throughout the year.
- Distinct annual rings are not formed in tropical plants. Distinct/clear annual rings are not formed in India except Himalayan regions (Shimla, Nainital etc.).
- Least distinct annual rings are formed in seashore regions/coastal regions because the climate remains the same throughout the year.
- More clear annual rings are formed in deciduous plants as compared to evergreen plants.(In temperate region)
- In deserts annual rings are less distinct.

(iv) HEART WOOD & SAP WOOD :

- In old trees, the greater part of secondary xylem is dark brown.
- The organic compounds like tannins, resins, gums, oils and aromatic substances etc. are filled in lumen of tracheids and vessels of secondary xylem. Due to this, **central region** of secondary xylem becomes **dark brown**. It is called **heart wood**. These substances make it hard, durable and resistant to the attack of micro-organisms and insects. Heart wood comprises dead elements with highly lignified walls. Heart wood provides mechanical strength to stem.
- The **peripheral region** of secondary xylem which is **light** in colour, is called **sap wood**.
- The function of sap wood is conduction of water and minerals.
- **Heart wood does not conduct water** and mineral **because :-**
- Cavities of tracheids and vessels are progressively filled with waste materials.
- The bladder/balloon like ingrowth of parenchyma cells enter in the lumen of vessels (mainly) & tracheids through the pits. Such bladder like ingrowths are called **tyloses** or tracheal plugs. Tyloses block the **lumen** of tracheary elements (vessels & tracheids).



T.S. of Sec. xylem vessel showing tyloses



L.S. of Sec. xylem vessel showing tyloses

- Study the structure of wood is known as **Xylology**. The wood is actually a **secondary xylem**.
- Position of youngest secondary phloem is just outside the vascular cambium.
- Position of oldest secondary phloem is just inside the primary phloem.
- Position of youngest layer of secondary xylem is just inside the vascular cambium.
- Position of oldest layer of secondary xylem is just outside the primary xylem.
- As the time passes amount of heart wood increases more as compared to sap wood.

(v) Classification of wood :

Classification based on vessels :-

On the basis of presence or absence of vessels, wood is classified into two categories -

- **Non-porous wood / Homoxylous wood** :- **Vessels are absent** in this type of wood.

  Example :- **In most of the gymnosperms**

- **Porous wood / Heteroxylous wood** :- **Vessels are present** in this type of wood. e.g **In most of the dicots**.

Most durable wood ⟶ ***Tectona grandis*** **(Teak = Sagwan)**

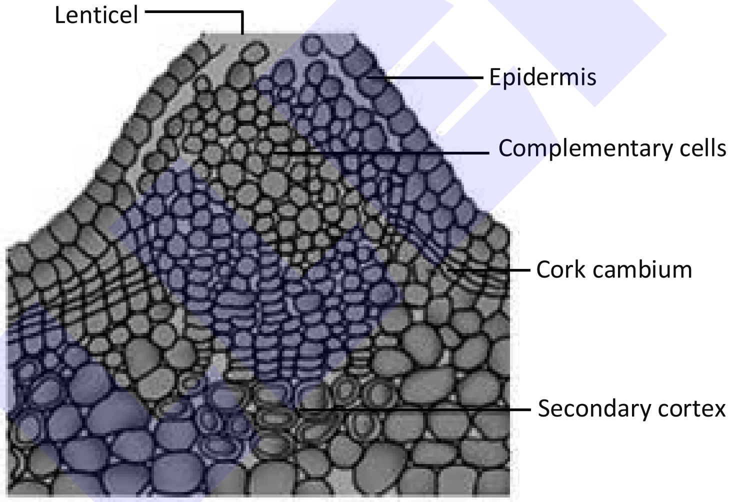
(B) Secondary Growth in Extra Stelar Region by Cork Cambium :

- Secondary growth takes place in extra stelar region **due to the activity of cork cambium**. Cork cambium is also known as **phellogen** or **extrastelar cambium**. The cells of the cork cambium are narrow, thin walled and nearly rectangular. Cork cambium develops usually in cortical region by hypodermis.
- As the stem continues to increase in girth due to activity of vascular cambium the outer cortical & epidermal layers get broken & need to be replaced to provide new protective cell layers Hence sooner or later another meristematic tissue called cork cambium or phellogen develops.
- Cork cambium is derived from the **hypodermis (outer part of cortex)** by dedifferentiation. Cork cambium is **single** or **a couple of layers thick (mainly)**. It forms secondary tissues in extra stelar region.
- Cork cambium divides usually by periclinal division to form some cells towards the outside (towards epidermis) and some cells towards the inside (towards general cortex). Those cells which are formed towards outside, become suberized. Due to this, these cells become dead. These dead cells are known as **cork or phellem**. Those cells which are formed towards the inside, are differentiated into parenchyma and may contain chloroplasts. These are called **secondary cortex or phelloderm**.
- Phellem, phellogen and phelloderm are collectively known as periderm.
- The **cork is impervious to water** due to **suberin deposition** in the cell wall.
- **Commercial cork** is obtained from ***Quercus suber*** (**oak**). Common bottle cork is made from this cork. Cork is an excellent material for making bottle stopper because it is air tight.
- Cork is formed in high quantity and secondary cortex is in less quantity because activity of cork cambium is more towards outside.

- Due to activity of the cork cambium, pressure builds up on the remaining layers peripheral to phellogen and ultimately these layers die and slough off.
- Cork cambium remains living and active only for one year.**Each year, a new cork cambium is formed** below the previous cambium. This new cambium is derived from the secondary cortex or phelloderm.

(i) Lenticels :

- At certain regions, the phellogen (cork cambium) cuts off/forms closely arranged parenchymatous cells on the outer side instead of cork cells. These thin walled, rounded, colourless, parenchymatous cells are called complementary cells. These cells are **not suberized.** As the complementary cells increase in number, pressure is exerted on the epidermis due to which it ruptures, forming a lens-shaped openings called **lenticels**.
- Complementary cells are formed by the activity of **phellogen** (cork cambium).



Transverse section of woody dicot stem passing through a lenticel

NCERT XI Page No. 97, Figure No. 9.10(a)

- Lenticels occur in most woody trees.
- Lenticels are mainly **found on woody stems** and they are **never found** on **leaves**. They are also present on some **fruits**.
- Lenticels are not found in herbaceous dicots and monocot plants.

Functions :

- **Exchange of gases :** Lenticels permit the exchange of gases between the outer atmosphere and the internal tissue of the stem (main function).
- **Help in transpiration** i.e., Lenticular transpiration.

(ii) Bark :

There are two views about the bark.

(a) Old view :- All the tissues situated outside the cork cambium are called bark. According to old view bark includes mainly dead tissues.

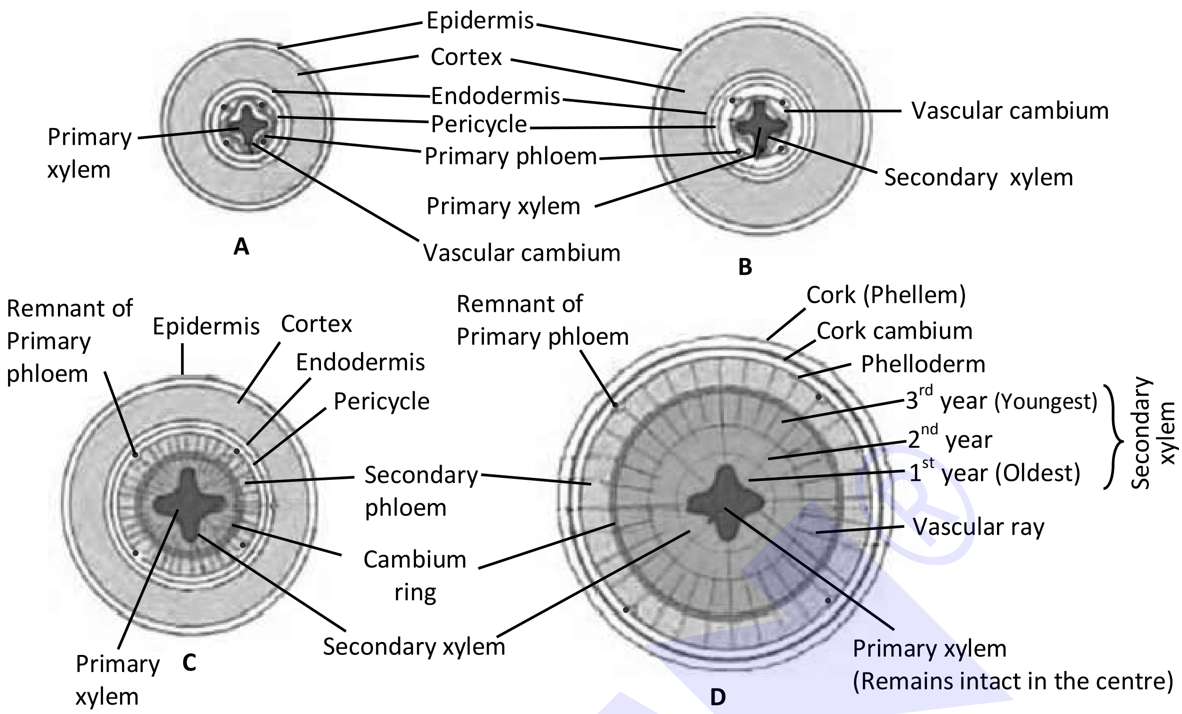
(b) Modern view :- Bark is a non-technical term that refers to **all tissues exterior to the vascular cambium**, therefore including secondary phloem. According to modern view bark includes both living and dead tissues.

- If bark is removed in the form of a ring (Girdling) from the base of main stem then root dies first due to lack of food.
- Girdling is not possible is monocot stem because vascular bundles are scattered.
- If complete bark is removed then plant dies due to excessive water loss.
- Bark that is formed early in the season is called early or soft bark. Towards the end of the season late or hard bark is formed.
- Secondary phloem and periderm are included in bark.

2. SECONDARY GROWTH IN DICOTYLEDONOUS ROOT

- In the dicot root, the vascular cambium is completely secondary in origin.
- First of all, the tissue located just below the phloem bundles means **conjunctive tissue** becomes meristematic during the secondary growth in a dicotyledonous root and forms separate curved strips of vasular cambium below the phloem bundles. Then after, the **cells of pericycle lying above the protoxylem** also become meristematic to form additional strips of cambium. In this way a complete wavy ring of vascular cambium is formed.
- The shape of **vascular cambium** is **wavy in the beginning**, but later on it becomes circular due to the pressure of secondary xylem.

The portion of vascular cambium formed by conjunctive tissue becomes meristematic first and forms the secondary xylem towards the centre. Ultimately the cambium becomes circular by the pressure of secondary xylem.



Different stages of the secondary growth in a typical dicot root

NCERT XI Page No. 98, Figure No. 6.1

- The activity of vascular cambium of root is the same as the activity of vascular cambium of stem. **Secondary xylem** is formed towards the inner side and **secondary phloem** is formed towards the outer side by vascular cambium.
- In dicot root both primary and secondary medullary rays are formed during secondary growth hence, they are secondary in origin.
- **Cork cambium** is originated **from the pericycle** by the process of **dedifferentiation** in roots. **Cork** is formed towards the outside and **secondary cortex** is formed towards the inner side by the cork cambium.
- Lenticels are also found in roots but less in number as compared to stem.
- Primary cortex completely degenerates in roots after the secondary growth of one or two years. This falls down due to the pressure of cork, whereas in stem, it degenerates after the long duration

- Secondary growth is essential in roots to provide strength to the growing aerial parts of the plants and fulfill the requirement of water and minerals.
- Generally clear annual rings are not seen in roots because roots are not effected by the changes of environment.
- Secondary growth is not found in monocot roots.
- In dicot roots, all cambia and pith rays (medullary rays) are secondary in origin.
- Xylem / lignin is stained by safranin and phloem is stained by fast green.
- Transition of exarch bundles of root to endarch bundles of stem occurs in hypocotyl.
- In some plants like datepalm increase in length as well as girth of stem due to primary thickening meristem.

Golden Key Points

- In roots, the parenchymatous cells which lie between the xylem and the phloem are called conjunctive tissue.
- The tissues involved in secondary growth are the two lateral meristems i.e. vascular cambium and cork cambium.
- During secondary growth the primary xylem however remains more or less intact, in or around the centre.
- Bark is a non-technical term that refers to all tissues exterior to the vascular cambium.
- In monocot stem, water containing cavities are present within the vascular bundles.
- The growth of the roots and stems in length with the help of apical meristem is called the primary growth. Apart from primary growth most dicotyledonous plants exhibit an increase in girth. This increase is called the secondary growth. The tissues involved in secondary growth are the two lateral meristems: vascular cambium and cork cambium.
- The meristematic layer that is responsible for cutting off vascular tissues – xylem and pholem – is called vascular cambium. In the young stem it is present in patches as a single layer between the xylem and phloem. Later it forms a complete ring.
- In dicot stems, the cells of cambium present between primary xylem and primary phloem is the intrafascicular cambium. The cells of medullary rays, adjoining these intrafascicular cambium become meristematic and form the interfascicular cambium. Thus, a continuous ring of cambium is formed.
- In the dicot root, the vascular cambium is completely secondary in origin. It originates from the tissue located just below the phloem bundles, a portion of pericycle tissue, above the protoxylem forming a complete and continuous wavy ring, which later becomes circular.

BEGINNER'S BOX — PRIMARY INTERNAL STRUCTURE TO SECONDARY GROWTH

1. Monocot roots are usually :-
(1) Diarch (2) Triarch
(3) Tetrarch (4) Polyarch

2. In which of the following sclerenchymatous pericycle is found in the form of semi-lunar patches:
(1) Sunflower stem (2) Sunflower root
(3) *Zea mays stem* (4) *Cucurbita stem*

3. Position of protoxylem in the vascular bundle of dorsiventral leaf is :-
(1) Adaxial (2) Abaxial
(3) Both (1) & (2) (4) Towards dorsal surface

4. The innermost layer of bark is :-
(1) Primary phloem (2) Secondary phloem
(3) Periderm (4) Phelloderm

5. Lenticels are found in :-
(1) All plants (2) Woody trees
(3) Monocots (4) All vascular plants

BEGINNER'S BOX — ANSWERS KEY

MERISTEM TO VASCULAR BUNDLES

Que.	1	2	3	4	5
Ans.	2	4	1	4	1

PRIMARY INTERNAL STRUCTURE TO SECONDARY GROWTH

Que.	1	2	3	4	5
Ans.	4	1	1	2	2

ESSENCE

Tissue

Meristematic tissue
Having Cell division capacity

Apical meristem
- Present at root and shoot apex
- Primary meristem

Intercalary meristem
- Present in between mature tissues
- Primary meristem

Lateral meristem
- Parallel to longitudinal axis of plants
- Primary and **secondary** **(Mainly)**

Permanent tissue
No cell division capacity

Simple permanent
- Made up of only one type of cells (Homogenous tissue)

Parenchyma
- Thin walled
- Form major bulk of plant organ
- Storage, Secretion, photosynthesis

Collenchyma
- Localized thickening
- Present in Young dicot stem
- Living mechanical tissue

Sclerenchyma
- Highly thickened wall
- Lignified wall
- Dead mechanical tissue

Complex permanent
- Made up of more than one type of cells (Heterogenous tissue)

Xylem
(Sap conduction & Mechanical support)
Tracheids, Vessels, X. Fibres – Dead, Thick walled, Lignified
X. Parenchyma- Living

- Tracheids and vessels are sap conducting elements

Phloem
(Food conduction)
Sieve tube, Companion cells, P. Parenchyma – Living
P. Fibres - Dead
- Sieve tube and companion cells are found in angiosperms

- Sieve cells & Albuminous cells are found in gymnosperms & pteridophytes.

Tissue system

Epidermal tissue system
- Protection
- Epidermis, root and stem hair
- Parenchymatous

Ground tissue system
- Major part of plant organ
- Consists of Simple permanent tissues (Mainly parenchymatous)

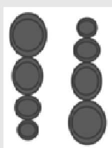
Vascular tissue system
- Conducting tissue
- Xylem and phloem
- Water, mineral and food conduction

Types of development of primary xylem :-

Centrifugal | Centripetal

Towards periphery

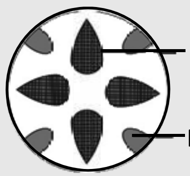
Towards centre



Endarch Xylem | Exarch Xylem

Types of vascular bundles

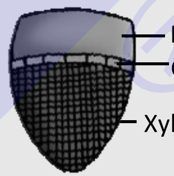
Radial



eg.Roots

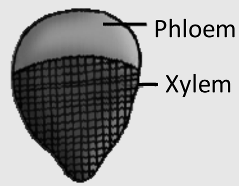
Conjoint collateral

Open



eg.Dicot stem

Closed



eg.Monocot stems, Dicot and monocot leaves

Dicotyledonous stem	**Monocotyledonous stem**
Presence of Trichomes	Absence of Trichomes
Collenchymatous hypodermis	Sclerenchymatous hypodermis
Pith is large & well developed	pith is Undifferentiated
Vascular bundles are open and arranged in a ring	Vascular bundles are closed and scattered

- Ground tissue is undifferentiated in Monocotyledonous stem.

Dicotyledonous root	**Monocotyledonous root**
Usually 2 to 4 xylem bundles	Usually More than 6 xylem bundles
Hexagonal vessels	Oval shaped vessels
Pith is small or inconspicuous	Pith is large and conspicuous

- In a dorsiventral leaf, mesophyll is differentiated into spongy and palisade mesophyll.
- In a isobilateral leaf, mesophyll is not differentiated into spongy and palisade mesophyll.
- In both types of leaves, xylem is towards adaxial surface while phloem is towards abaxial surface
- Heart wood : Physiologically inactive, Dark brown, Central part of secondary xylem
- Sap wood : Physiologically active, lighter in colour, peripheral part of secondary xylem

Spring wood	**Autumn wood**
Large number of secondary xylem elements	Fewer secondary xylem elements
Vessels with wide lumens	Vessels with narrow lumens
Lighter in colour	Darker in colour
Lower density	Higher density

- Phellem, Phellogen & Phelloderm are collectively termed as **Periderm**.
- Secondary phloem and periderm are included in bark.
- In dicotyledonous stem, vascular cambium is partly primary and partly secondary in origin.
- In dicot root vascular cambium is completely secondary in origin
- In dicot stem cork cambium usually develops in cortical region (usually from hypodermis) while in dicot root it is usually originated from pericycle.
- Estimate Age of a tree can be determined by counting the annual rings.

Sec. growth in dicot stem

- **Stelar secondary growth** → **By Vascular cambium**
  (Intra fascicular cambium (Primary) + interfascicular cambium (secondary))
  - More active in spring and towards inner side
  - Usually formed only once in life
  - → **Secondary phloem (Bast)** (Outer side)
  - → **Secondary Medullary rays**
  - → **Secondary Xylem (wood)** (Inner side)
- **Extra stelar secondary growth** → **By Cork cambium (Phellogen)**
  - Always Secondary in origin
  - More active towards outer side
  - Formed new every year
  - → **Cork (Phellem)** • (Outer side)
  - → **Secondary cortex (Phelloderm)** • (Inner side)