Dicotyledonous (Dorsiventral) Leaf :

- Upper and lower surfaces of leaf are bound by the epidermis.
- A **thick cuticle** is usually present on the outer walls of epidermis.
- Stomata are absent and if present, these are fewer in number as compared to those **on the lower epidermis.**
- The entire tissue between the upper and lower epidermis is called the **mesophyll.** The mesophyll consists of two regions the **palisade parenchyma and the spongy parenchyma.**
- The palisade parenchyma are vertically elongated cells which may be organised in one or more layers. The palisade cells are compactly arranged and show little intercellular spaces. They possess abundant chloroplasts and carry out photosynthesis.
- The spongy parenchyma is extended from below the palisade layer to the lower epidermis. Its cells are oval or rounded, enclosing numerous large air spaces and air cavities. Spongy parenchyma cells contain chloroplasts to perform photosynthesis.
- Vascular bundles can be seen in the veins and the midrib.
- The vascular bundles are surrounded by a layer of **thick walled bundle sheath cells**.
- The vascular bundles are **conjoint, collateral and endarch.**
- **The xylem is situated towards the upper epidermis (adaxial surface) and phloem lies towards the lower epidermis (abaxial surface).**
- Surrounding each vascular bundle, there is a compact layer of thin walled parenchymatous cells; this layer is known as the bundle sheath.

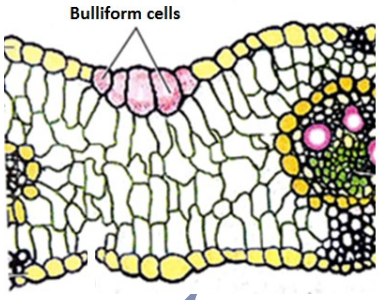
Monocotyledonous (Isobilateral) Leaf :

- Epidermis is single layer of thin-walled, barrel shaped, non-green cells on both the lower and upper surfaces.
- Epidermis is cuticularised and possesses more or less **equally distributed stomata on both the surfaces.**
- In grasses, certain **adaxial epidermal cells along the veins modify themselves into large, empty, colourless cells**. These are called **bulliform cells.** When the bulliform cells in the leaves have absorbed water and are turgid, the leaf surface is exposed. When they are flaccid due to water stress, they make the leaves curl inwards to minimise water loss.
- **Mesophyll is not differentiated** into palisade and spongy parenchyma. All the cells are thin walled and parenchymatous with few intercellular spaces.
- Vascular bundles are of similar sizes (except in main veins); **vascular bundles arranged in a parallel manner.**
- Each vascular bundle is **conjoint, collateral, endarch and closed**, and is surrounded by a distinct parenchymatous bundle sheath in some grasses.
- Two distinct **patches of sclerenchyma** are present above and below each of the large vascular bundles and extend up to the upper and lower epidermal layers, respectively.
- The xylem is located towards the upper epidermis and the phloem towards the lower epidermis (endarch).

Bulliform cells :

The epidermis of some grasses is made up of a variety of cell types. Most of the epidermal cells are narrow, elongated cells. Some especially large ones, termed **bulliform cells,** or motor cells, occur in longitudinal rows and are believed by some botanists to participate in the mechanism of folding and unfolding, or rolling and unrolling, of the leaves, responses resulting from changes in water potential .

During excessive loss of water, the bulliform cells in some leaves become flaccid and the leaf folds or rolls. The epidermis also contains narrow, thickwalled guard cells, which are associated with subsidiary cells



Leaf of annual bluegrass *(Poa annua).*

Major Anatomical Differences between Dorsiventral and Isobilateral Leaf

S. No.	Characters	Dicot leaf	Monoct leaf
1.	Type of leaf	Doraiventral	Isobilateral
2.	Stomata	Usually more on lower epidermis (hypoatomatic)	Equal on both lower and upper epidermia (amphiatomatic)
3.	Mesophyll	Made up of two types of tissues (a) Palisade tissue (b) Spongy parenchyma with large intercellular space	Equal on both lower and upper epidermis (amphiatomatic)
4.	Bundle sheath	Made up of parenchyma. Just above and below the vascular bundle some parenchymatous cella or collenchymatous cells are present up to epidermis.	Made of parenchyma but just above and below the vascular bundles are found aclerenchymatous cells (up to epidermis)
5.	Bulliform cells	Absent	Present

Dicotyledonous Stem :

- Epidermis consists of a single layer of cells which bears **multicellular, uniseriate trichomes** and stomata.
- A thin layer of **cuticle** is present on the epidermis as well as the trichomes.
- **Cortex** is divided into three sub-zones – hypodermis, general cortex and endodermis.
- Hypodermis consists of 3 to 4 layers of **collenchymatous cells**.
- General cortex is parenchymatous and multilayered.
- Secretory (oil) ducts, surrounded by a glandular parenchymatous layer, also occur
- **Endodermis** is the innermost layer of the cortex, and consists of a single layer of barrel-shaped cells. Since it is rich in starch, it is also referred to as the **starch sheath.**
- Pericycle is present on the inner side of the endodermis and above the phloem in the **form of semi-lunar patches of sclerenchyma**. Each patch associated with phloem of the vascular bundle is called the **hard bast.**
- Medullary rays are a few layers of radially placed parenchymatous cells between the vascular bundles. Usually these are polygonal in outline and **exhibit no intercellular spaces in between.**
- The vascular bundles are arranged in **a ring.** Each vascular bundle is **conjoint, collateral, endarch** protoxylem and open. It is composed of xylem, phloem and cambium.
- Phloem is situated on the outerside of the vascular bundle.
- Xylem lies below the phloem.
- **Cambium** present between xylem and the phloem consists of **2-3 layers of thin-walled, rectangular cells.**
- Pith consists of rounded, parenchymatous cells with plenty of intercellular spaces.

Monocotyledonous Stem :

- Cells of hypodermis are sclerenchymatous.
- The entire tissue lying inside the epidermis, except for the vascular bundles, is known as the **ground tissue**. It consists of rounded parenchymatous cells **with distinct intercellular spaces.**
- The **ground tissue is not differentiated into cortex, endodermis, pericycle and pith.**
- Vascular bundles are many in number and are of variable size. They are collateral and closed and lie **scattered** in the ground tissue.
- Each vascular bundle is oval and usually surrounded by a sheath of sclerenchymatous cells, the **bundle sheath.**
- Peripheral vascular bundles are **generally smaller than the centrally located ones.**
- The vascular bundles which lie toward periphery are more in number than the centre but are smaller in size.
- Each bundle is surrounded by a **bundle sheath.**
- The vascular bundle consists of xylem and phloem. The xylem is Y- shaped and consists of bigger metaxylem and smaller protoxylem. In protoxylem, there is lacuna called **Lysigenous cavity**.
- **Phloem parenchyma is absent in most of monocot stems.**

Differences between dicot stem and monocot stem

Characters	Dicot stem	Monocot Stem
1. Epidermis	Single layered with hair (trichome)	Single, layered without hair.
2. Hypodermis	Collenchymatous	Sclerenchymatous
3. Cortex	Made up of several layers of parenchymatous tissue	Absent but parenchymatous ground tissue present from hypodermis to centre of stem.
4. Endodermis	Single layered which is usually not well differentiated	Absent
5. Peicycle	Made up of one or morelayers of parenchymatousor sclerenchymatous cells.	Absent
6. Medullary rays	Found between the vascularbundless	Absent
7. Vascular bundles	Vascular bundles arranged in ring. Conjoint, collateral or bicollateral, endarch and open Almost all of them uniform in size Wedge shape Bundle sheath absent Vessels arranged in rows (radial) Phloem parenchyma present. Schizolysigenous cavity absent.	Scattered, throughout the ground tissue Conjoint, collateral, exarch and closed. Larger towards centre and smaller towards outer side. Oval in shape Bundle sheath present. Vessels arranged in V or Y shaped manner. It is absent Schizolysigenous water canal or cavity present (formed by disintegration of protoxylem)

Secondary Growth :

The growth of the roots and stems in length is called the primary growth.
Most dicotyledonous and gymnosperm plants exhibit an **increase in girth.** This increase is called the **secondary growth**.
Secondary growth is increase in girth or diameter of axis (root and stem) of the plant by formation of secondary tissue by activity of lateral meristem (vascular cambium and cork cambium)."

The tissues involved in secondary growth are the two **lateral meristems:**

- **Vascular cambium –** responsible for growth in steler region
- **Cork cambium -** responsible for growth in extrasteler region

The secondary tissue is of two types :

- **Secondary tissue formed by true cambium** or **vascular cambium** or **intrastelar cambium**. e.g., Secondary xylem and secondary phloem and secondary medullary rays.
- **Secondary tissue formed by cork cambium** or **phellogen** or **extrastelar cambium**. e.g., Phellem or cork cells and phelloderm (sec. cortex).

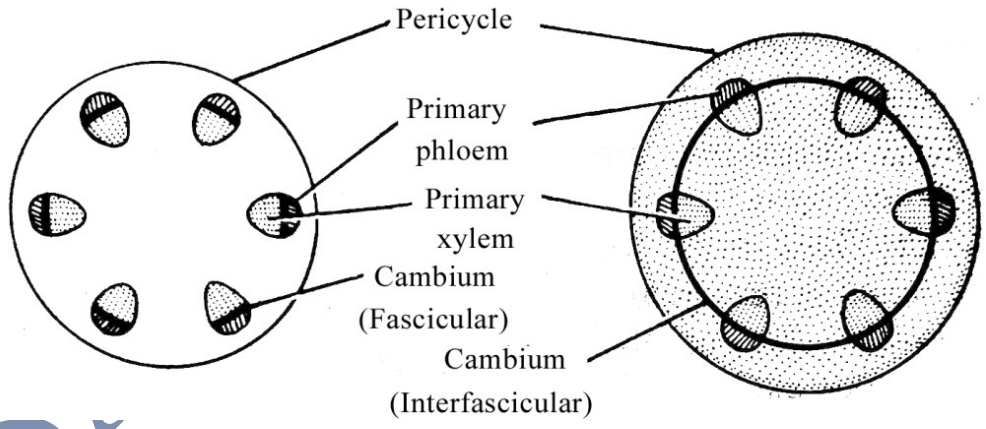
Secondary growth in dicot stems

Growth in Steler Region : Formation of the Cambial Ring

In dicot stems an **intrafascicular cambium** is present between xylem and phloem, which is primary in nature.

The parenchymatous cells of each medullary ray, lying between the intrafascicular cambium of the adjacent bundles divide and become meristematic and form a strip of cambium called the interfascicular cambium.

Both types of cambia (**intrafascicular** and **interfascicular**) joinBoth types of cambia (intrafascicular and interfascicular) join laterally together to form a **complete ring of vascular cambium,** which is, thus partly primary and partly secondary in origin.



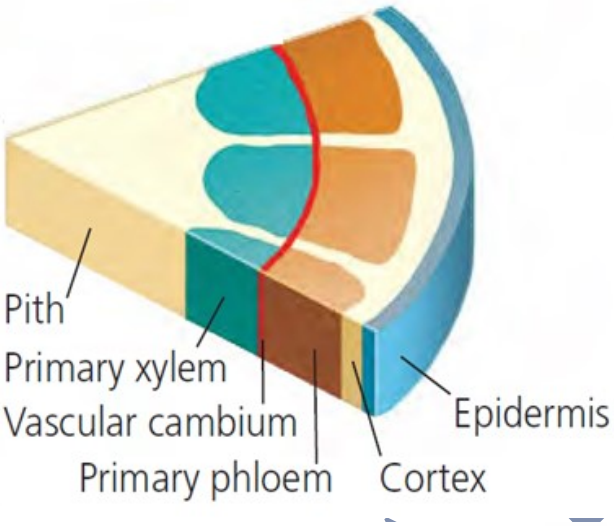
Activity of the Cambial Ring :

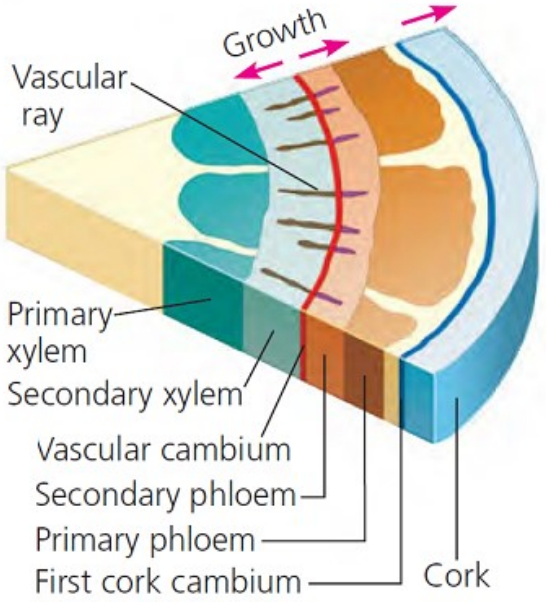
The cambial ring becomes active and begins to cut off new cells, both towards the inner and outer side, by vertical or oblique divisions of the elongated fusiform initials.
The derivatives which are cut off towards the outer side get differentiated into the **secondary phloem** whereas those produced on the inner side are differentiated into **secondary xylem**

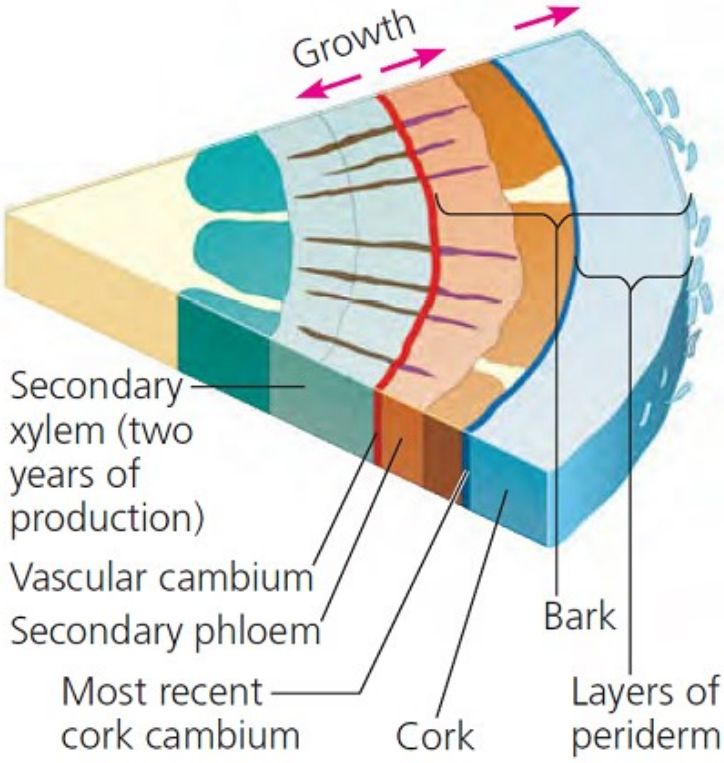
The cambium is generally more active on the inner side than on the outer side. As a result, the xylem increases more rapidly in bulk than the phloem, and soon forms a compact mass.

This forms the main bulk of the plant body. Due to the continued formation of secondary xylem both the primary and secondary phloem of the earlier years get gradually crushed. The primary xylem however remains more or less intact, in or around the centre.

At places, cambium forms some narrow bands of parenchyma from ray initials which pass through secondary phloem and the secondary xylem in the radial directions. These are the **secondary medullary rays** which conduct water and dissolved materials laterally in the stem.







Annual Rings :

The activity of the cambium is under the control of a series of physiological and environmental factors.

During the spring and summer, temperature is high which alongwith the higher relative humidity, longer duration of sunshine, and the hormones supplied by the newly formed young leaves, favour cambial activity. Therefore, the cells of the cambium divide rapidly.

A larger volume of xylem tissue is produced, having comparatively larger, thin walled and light-staining components.

On the other hand, during winter/autumn, the temperature is low due to which the activity of the cambium also slows down. Therefore, the amount of xylem elements produced and their diameter is much less, have narrow vessels, are small, have thicker walls and take darker stain.

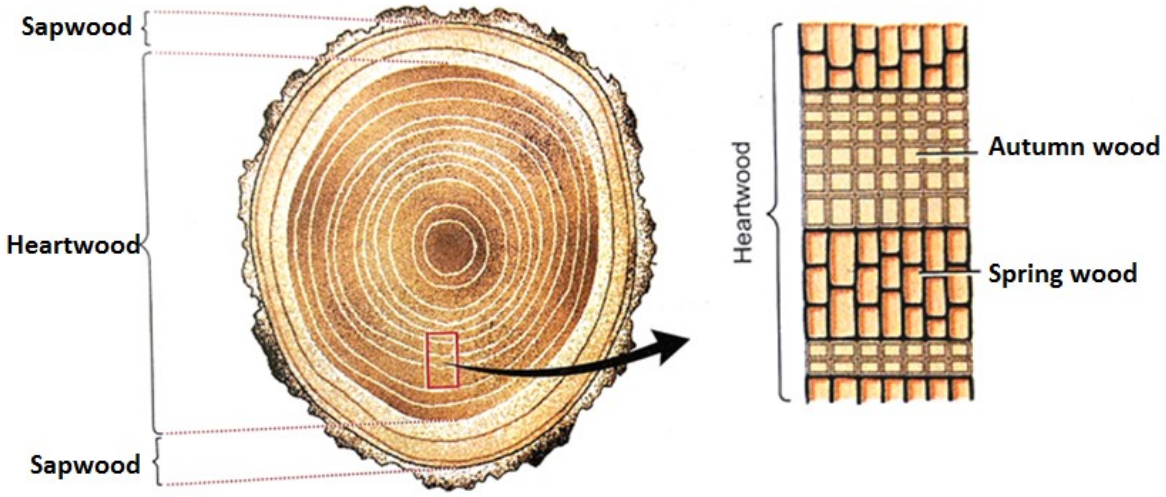
The wood formed during the spring and summer is known as the **early** or **spring wood** and that produced during winter is known as **late** or **autumn wood**.

The spring wood is lighter in colour and exhibits low density whereas the autumn (or winter) wood is darker and has higher density.

Spring wood / early wood	Autumn wood / late wood
Develops in spring	Develops in winter /autumn
Composed of large and wide vessels	Composed of short and narrowvessels
Lighter colour	Darker colour
Fewer fibres present	Fibres common
First part of annual ring	Later part of annual ring
Major part of annual ring	Narrow part of annual ring
More developed due to increased activity of cambium	Less developed due to increased activity of cambium
Has lower density	Higher density

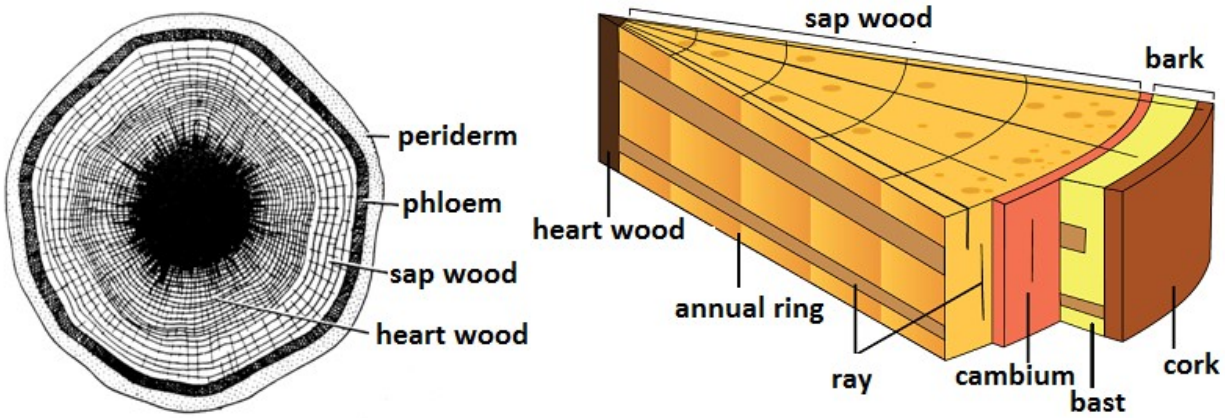
The two kinds of woods that appear as alternate concentric rings and one light and one dark coloured zone comprises one year's growth and this is known as the **annual** ring or **growth** ring.

Since each annual ring corresponds to the growth of wood of one year. One can estimate the age of a tree to some degree of accuracy by counting them.



The science of **dendrochronology** is the study of growth rings to date past events and climates.

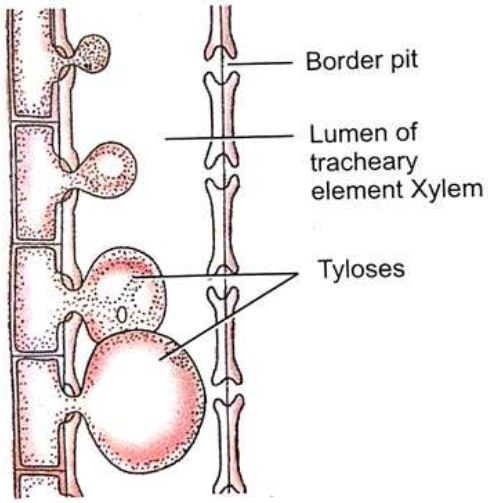
Heartwood and sapwood :



Sap wood / Alburnum	Heart wood / Duramen
Outer peripheral part of secondary xylem	Inner central part of secondary xylem
Contain both living and non living cells	Contain only non living cells
Functional and active	Non functional and inactive
No extractives present	Extractives such as tannins, resins, gums, dyes pigments phenols , essential oils , aromatics are present
Conductive in function	Supportive in function
No tyloses	Tyloses present (tracheal plugs)
Light weight and light brown colour	Dark brown and heavier
Not mite resistant wood	Mite resistant wood
Not suitable for furniture making	Suitable for furniture making

Tyloses :

- These are balloon-like structures which are produced due to ingrowth of adjacent xylem parenchyma cells into the lumen of xylem vessels through pits.
- Tyloses always passes through pit.
- Tyloses are always found in heart wood.



Growth in Extrasteler Region :

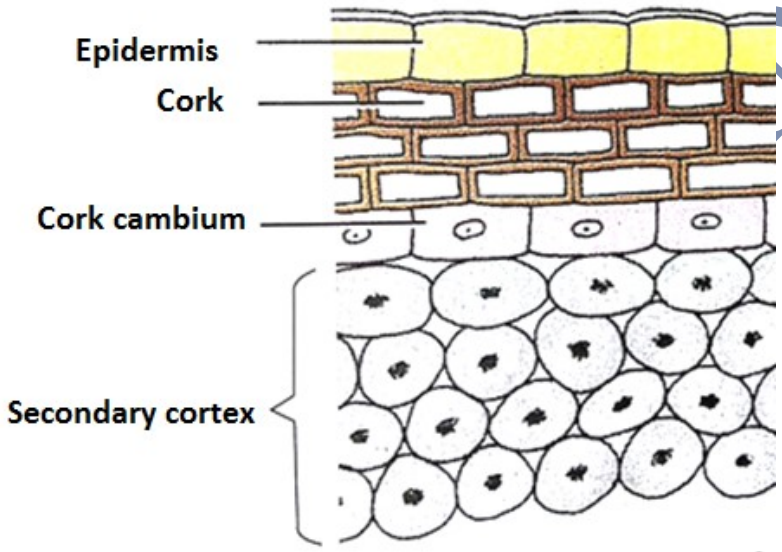
Activity of **Cork Cambium** or **Phellogen**

Due to the addition of secondary phloem and secondary xylem elements, the outermost layer of the cortex and epidermis layers becomes highly stretched and get broken and may crack open.

A few layers of meristematic tissue arise in the cortex or in the epidermal layer or in the pericycle. This is called the **cork cambium** or **phellogen**. The nature of this cambium is secondary.

Phellogen is a couple of layers thick. It is made of narrow, thin-walled and nearly rectangular cells and these cut off cells on both the sides. Those formed on the outer side become suberised and constitute the **cork** or **phellem** which is impervious to water and air. Cork with heavily suberized, tightly packed, dead-at-maturity cells, lies to the outside of the cork cambium and serves to waterproof, insulate, and protect the underlying stem tissues.The inner cells become parenchymatous and may contain chloroplasts. These constitute the **secondary cortex** or **phelloderm.**

The cork (phellem), cork cambium (phellogen) and the secondary cortex (phelloderm) are collectively known as the periderm.



Formation of Periderm

Cork :

- Lignified and suberised walls & Water proof
- Rectangular radially flattened cells having no intercellular cells
- Before death cork cells get filled with tannins etc and become insect repellent and decay proof
- Dead cells are filled with air and become heat proof and light weight
- Protects trees from freezing temp , high temperature and entry of fungi ,bacteria
- **Resistant to fire,airtight, impervious, inert,non reactive**
- Lighter and compressible due to lenticels
- The commercial cork is obtained from the plant ***Quercus suber*,** which is commonly found in Portugal and parts of Spain.

Bark :

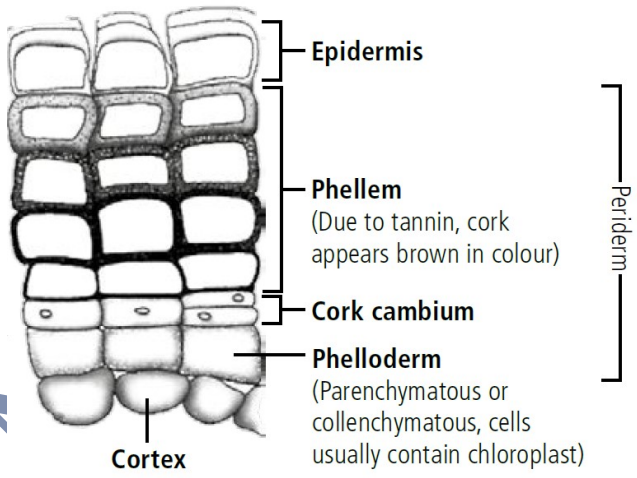
Bark develops in the vicinity of the periderm which includes all the tissues outside the vascular cambium, i.e. secondary phloem, the elements of the primary phloem and primary as well as the secondary cortex, in the crushed state.

Bark = Periderm + Cortex + Pericycle + Primary and secondary phloem

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. Its cells are living and some of them take part in the conduction of the metabolites.

Bhojpatra is derived from the **bark of *Betula utilis*.** It was earlier used to write ancient manuscripts.

Bark of ***Cinnamonum*** is used as **dalchini**.Bark of walnut is used as cleaning teeth.Bark of *Acacia* is used as source of tannins



Concept booster :

The bark constitute of both type of tissues - **living** and **non-living** .

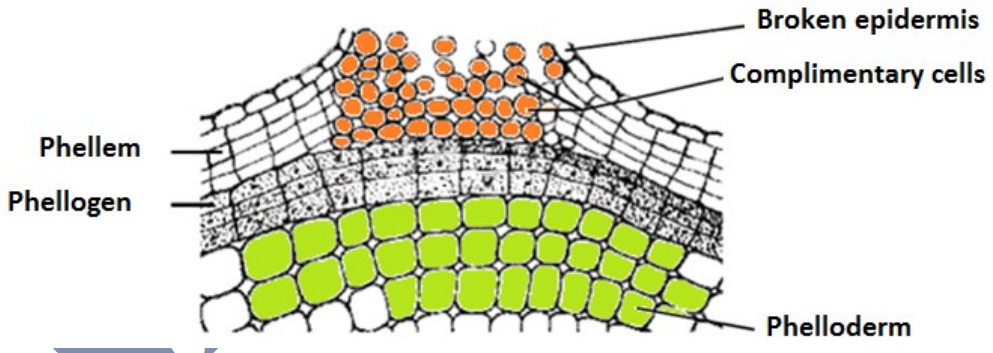
A plant will die if we remove the complete bark of the plant because maximum loss of water occurs from this. If a ring of bark removed from the base of the plant, within a few days plant will die because phloem is separated due to this activity and plant comes in the state of deficiency of food.

Functions of Bark :

- In general, outermost bark layer is considered to be a replacement for the epidermis of the stem and root
- Bark, and cork in particular, are excellent for thermal insulation in cold biomes
- Cork is indigestible, creating a surface that is not very attractive to many animals
- Cork, with its fat and wax, is fairly water repellent, and thus creates a resistance to water loss from the plant in a drier atmosphere.
- Occurrence of dead cells, without nutritional value, on the outer surface is a strategy to discourage growth of fungi and bacteria.

Lenticels :

- At certain regions, the phellogen cuts off closely arranged parenchymatous cells on the outer side instead of cork cells. These parenchymatous cells soon rupture the epidermis, forming a **lens shaped openings called lenticels**.
- These are **openings or breaks in the cork tissue** which look like raised spots on the surface of the stem and permit the exchange of gases between the outer atmosphere and the internal tissue of the cells of the stem.
- These occur in most of the woody trees **except the climbers.**
- From the lenticel, phellogen cells are also produced to the outside and inside, but the outer cells tend to round up and thereby have intercellular air spaces called **filling tissue** or **complementary tissue**.
- Lenticels also can be **found on fruits,** e.g., the specks on apples and pears and warts on avocado.



Cross-sectional view from the stem showing lenticel

Secondary growth in Dicotyledonous Root :

The secondary growth in a dicot root is similar to that in the dicot stem, but there is a marked difference in the manner of the formation of cambium and tissue differentiation.The vascular cambium in a dicot root is completely secondary in origin. In the beginning, a portion of the conjunctive tissue just below the phloem bundles becomes meristematic and gives rise to cambium.

The vascular cambium in root is dual in origin because it is produced from two sources.

- **Partly from the conjuctive parenchyma cells** and
- **Partly from the cells of pericycle.**

This strip of cambium extends laterally between the xylem and phloem bundles.
At the same time, a portion of the pericycle above the protoxylem also becomes meristematic and forms a strip of cambium.

Both the cambial strips join together forming a complete and **continuous wavy ring** which passes below the phloem bundles and above the xylem bundles.
The cambial ring below the phloem bundles cuts off more derivatives towards the inner side.

Due to this over production of secondary tissue at this site, the cambium as well as the primary phloem are pushed outwards. As a result, the wavy band of cambium becomes **circular**.

Now, this entire circular ring of cambium becomes active and cuts off secondary tissues on either side.
The secondary tissues corresponding to each protoxylem bundle modify into parenchyma to form the primary medullary rays. These are more prominent in roots than in stems.
The primary **phloem bundles are gradually crushed** and are not seen in older roots.Lenticels may also be present in the roots scattered here and there.

Important Points :

- The heartwood in certain cases is the source of pigments of commercial importance e.g. **haematoxylin** (from *Haematoxylon campechianum*), **brasilin** (from *Caesalpinia sappan*)
- Source of **commercial rubber** is latex of *Hevea brasiliensis, Ficus elastica, Manihot*
- Cotton fibres are not true because they are neither lignified nor cells.
- Lateral roots always develop from the pericycle, so they are said to be **endogenous**.
- Stem branches develop from a few outer layers of cortex so they are said to be **exogenous**.
- Annual rings are not formed in the tropical where there are no seasonal fluctuations.
- Determination of age of a tree by counting the annual rings is called **dendrochronology**.
- Annual rings are rarely formed in the root.
- **Ground tissue system**: Cortex + Pericycle + Pith and Medullary rays
- **Cortex has three sub-zones :** Hypodermis + General cortex + Endodermis
- One vascular bundles is present in ***Trapa*** and more than 6 vascular bundles in ***Ficus*** roots .
- In orchids **Velamen** is multiple epidermis
- Vascular bundles are 25 - 30 in maize roots

- Stem hairs are multicellular and cutinised
- **Leaf Rolling** is present in ***Poa, Psamma ,Agropyron , Ammophilla*** .
- Secondary growth also occurs in stems and roots of gymnosperms.