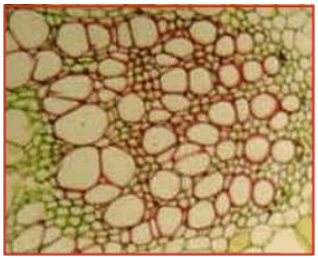
ESSENTIAL PLANT BIOLOGY

Plant Cells and Anatomy

This booklet will introduce you to plant cells and the names and functions of their structures and then go on to look at the internal anatomical structures of dicot and monocot plants and how they relate to the appearance and management of a plant.




LEARNING OUTCOMES

On completing this session learners will be able to:

- Describe the difference between prokaryotic and eukaryotic cells
- Describe the internal structures of a plant cell and their functions.
- Describe the structure and function of a range of specialised plant tissues.
- Describe the arrangement of specialised tissues in stems, roots and leaves of monocotyledon and dicotyledon plants and relate this to their appearance and management.

Cell Basics

There are two main types of cells:

Prokaryotic cells e.g. bacteria and blue green algae. These cells have **no nuclear membrane** and the DNA is stored in a region known as the nucleoid.

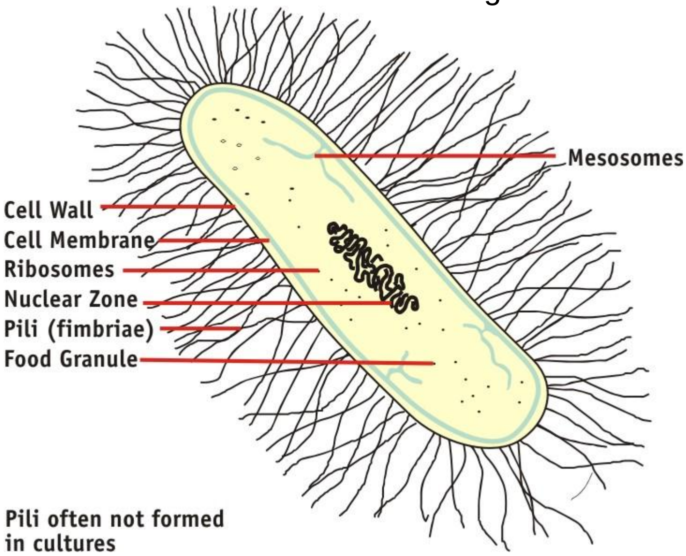


Figure 1: Prokaryotic cell (Bacteria)

Eukaryotic cells e.g. protists (single cell organisms), fungi, plants and animals. These cells have a **true nucleus** enclosed in a nuclear membrane and organelles suspended in cytosol.

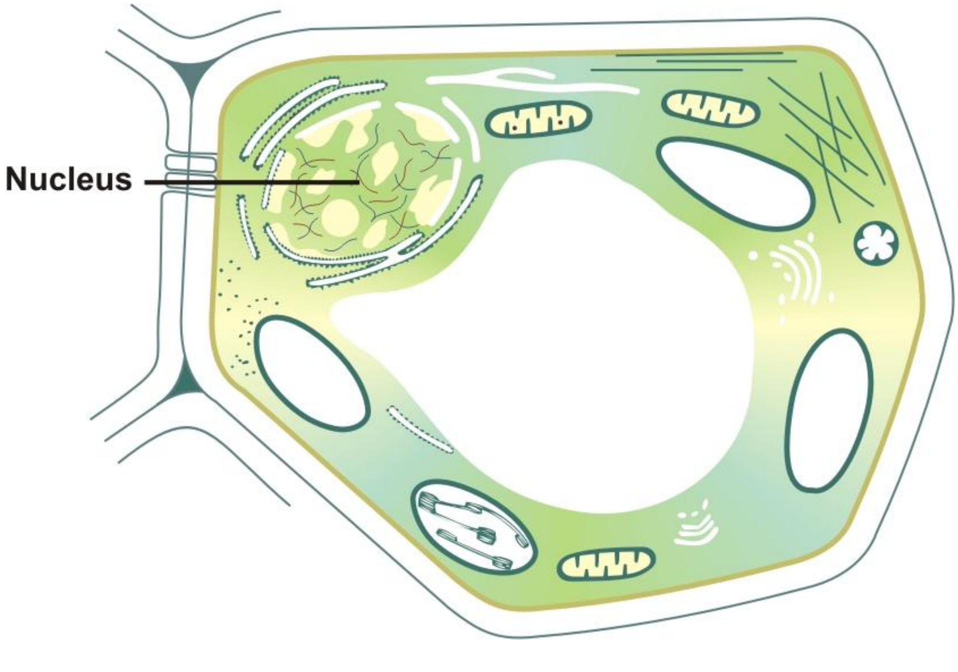


Figure 2: Eukaryotic cell (Plant cell)

Cell size

Cell size is measured in micrometres µm (one thousandth of a mm)

Examples of cell sizes:

- Smallest bacterial cell = 0.1µm
- Most bacteria = 10 µm
- Eukaryotes = 10 – 100 µm in diameter

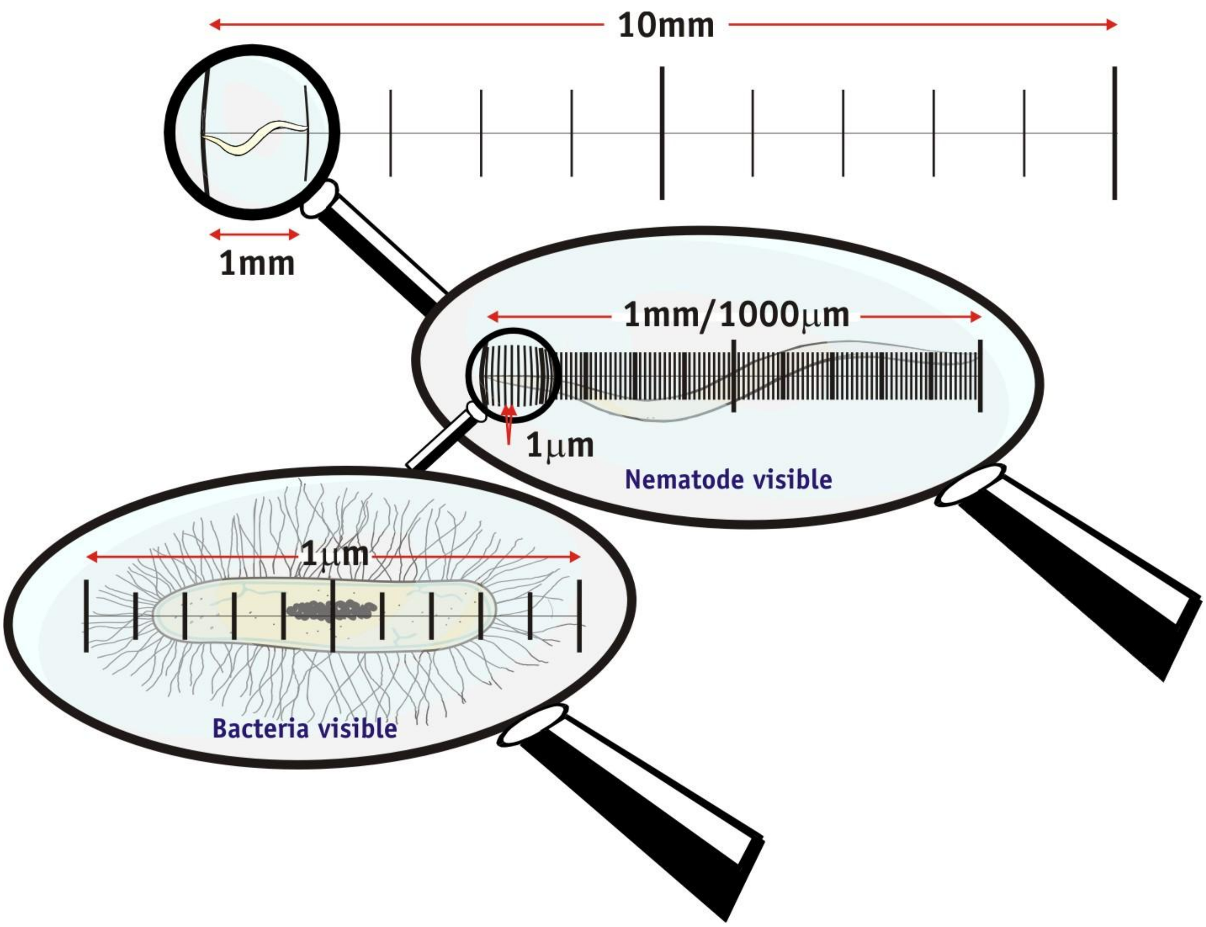


Figure 3: Cell size

Plant Cell Structures

The diagram below shows the main structures found in a plant cell. You may find it useful to refer back to this as you read about the various structures in the next few pages.

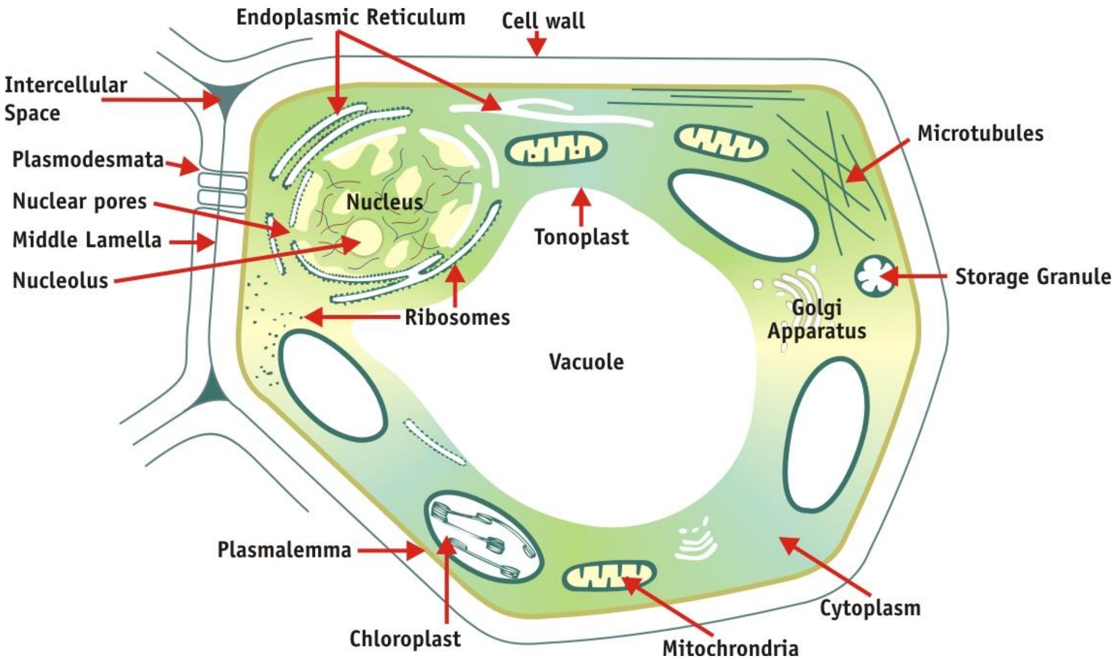


Figure 4: Plant Cell

The Cell wall

The cell wall is a dynamic structure that can change shape and thickness as cells grow and develop. It is largely made up of carbohydrates.

Young cells and actively growing cells have **primary cell walls** that are relatively thin and flexible. The wall is made of **cellulose** aggregated into bundles to form fibres or microfibrils. These are surrounded by hemicelluloses and pectins. **Secondary cell walls** contain cellulose microfibrils surrounded by polysaccharides and lignin.

Cell walls **protect** the plant cell, maintain its shape and prevent excessive uptake of water. As water is taken in by the cell the cell contents push out against the cell wall, the cell wall pushes back and stops the cell from expanding further or exploding as more water enters. Primary cell walls are usually **permeable** to water, and small molecules and the dynamic nature of the wall allows **cell expansion and growth**. Lignified secondary walls are **waterproof**, give greater **strength** and act as a barrier to pathogens.

Cells are connected by **plasmodesmata** where, cell membranes and strands of cytoplasm, bridge the cell wall allowing movement of substances between cells. The **middle lamella** is a layer of pectins which 'glue' cells together. To separate cells a pectinase enzyme can be used. This is sometimes a mechanism used by plant pathogens to help them attack a plant.

The Cell Membrane or Plasmalemma

The cell membrane is in close contact with the cell wall and the cytoplasm. It surrounds the cell and **regulates** the exchange of oxygen, nutrients and waste in and out of the cell. All membranes are similar in structure. The structure of plasma membrane is shown below.

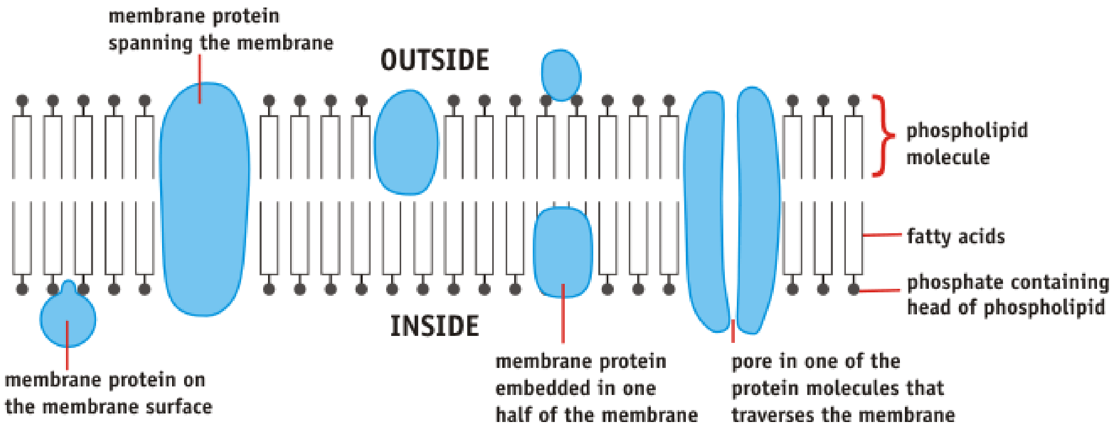


Figure 5: Structure of a plasma membrane

In 1935 Davson and Danielli proposed the structure of a membrane as a double layer of phospholipids. The hydrophilic (water loving) heads of the phospholipids in contact with the water in and around the cell (their charged nature makes them have an affinity for water); the hydrophobic (water repellent) fatty acid tails are in contact with each other and a way from the water. This was supported by the thickness of the membranes, and the triple layer staining, seen under a light microscope.

In 1972 Singer and Nicolson proposed the fluid mosaic model. This is a **phospholipid bilayer embedded with proteins**. The specific functions of the various membranes in the cell, the cell membrane, and those that make up the other organelles in the cell, depends on the kinds of phospholipids and proteins present.

The Nucleus

This contains most of the cell's **DNA**, the **genetic material**, in the form of chromosomes. These are surrounded by a double membrane, perforated by pores, that regulates the movement of large molecules between the nucleus and the cytoplasm. The **nucleolus** is a specialised region of the nucleus where components of **ribosomes** are made.

The Vacuole

The vacuole may occupy up to 90% of the cell volume and is surrounded by a membrane the **tonoplast**. As a cell expands much of the expansion is the vacuole. The vacuole can **store** molecules, such as sugars and amino acids, and ions, such as potassium (K+), and can also hold poisonous and waste materials that can then be lost at leaf fall. The pigments that colour flower petals are held in the vacuole.

The Cytoplasm

This is the region between the nucleus and the cell membrane. It contains organelles such as chloroplasts and mitochondria as well as storage bodies. The cytoplasm is where many of the chemical reactions that take place in a cell happen.

You may see reference to the term **protoplast** and perhaps confuse this with the cytoplasm. The cytoplasm is just part of the protoplast which is defined as the contents of the plant cell excluding the cell wall. That is, the cell membrane and everything inside it.

There are a number of important **structures within the cytoplasm** which are described below:

The Endoplasmic Reticulum

Much of the cytoplasm is taken up by the **Endoplasmic reticulum** (ER). This consists of a network of tubes and flattened sacs (the cisternae) enclosed by plasma membranes. The part of the cytoplasm outside the ER is known as the **cytosol**. The endoplasmic reticulum membranes are continuous with the outer nuclear membranes and form a transport network throughout the cell.

The Rough Endoplasmic Reticulum, Rough ER. has many **ribosomes** attached to the membrane's surface where they manufacture membrane proteins and proteins for export from the cell.

The Smooth ER has **no ribosomes** and is the site of fat, phospholipid and hormone synthesis

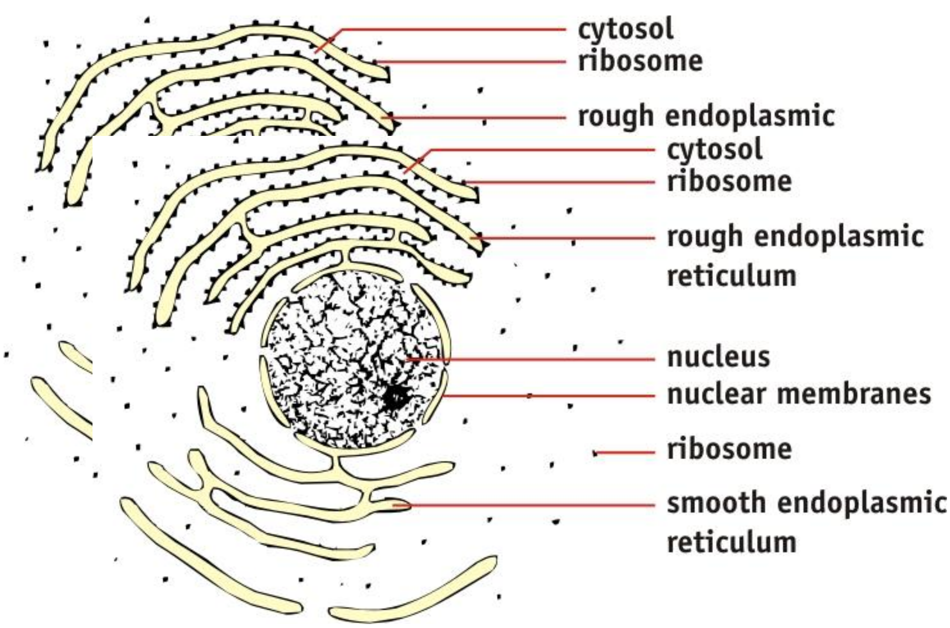


Figure 6: Endoplasmic reticulum

Ribosomes

These are the sites were the cell assembles proteins. They are found in two places in the cytoplasm:

- **Free ribosomes** are suspended in the cytosol of the cytoplasm. They make proteins to function within the cytosol.
- **Bound ribosomes** are attached to the endoplasmic reticulum and make proteins for inclusion into membranes or for export from the cell.

The bound and free ribosomes are structurally identical consisting of protein and RNA.

The Golgi Apparatus or Golgi Body

The **golgi apparatus** consists of a **stack of flattened membranous sacs**. A cell may have several of these stacks all interconnected. The membranes separate the internal space from the cystosol. Again, the membranes of the golgi body are connected to those of the endoplasmic reticulum.

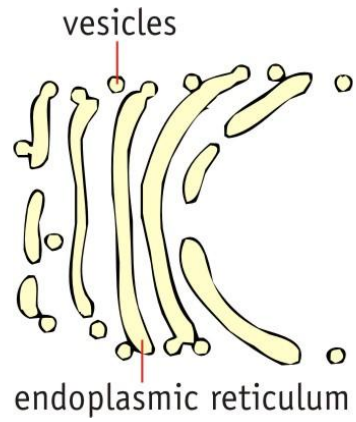


Figure 7: Golgi apparatus

The golgi apparatus takes in the products of the endoplasmic reticulum and helps direct them to specific parts of the cell. It also **modifies** some of them, for example by adding phosphates or by changing the carbohydrate groups on proteins. Proteins for export from the cell are packaged in **vesicles** that 'bud off' from the golgi body and move to the outside of the cell.

Mitochondria

These organelles within the cytoplasm are the site of **cellular respiration**. The number found in the cell depends on the tissue and can range from 100's to 1000's. These rod shaped bodies are surrounded by two membranes. The convoluted inner membrane has in foldings called cristae which create a large surface area and enclose the mitochondrial matrix. Some of the steps of cellular respiration take place in the matrix and some in the inner membrane. Cells which use a lot of energy have large numbers of mitochondria so that large amounts of energy can be produced from sugars by respiration. Mitochondria have their own DNA and can divide themselves.

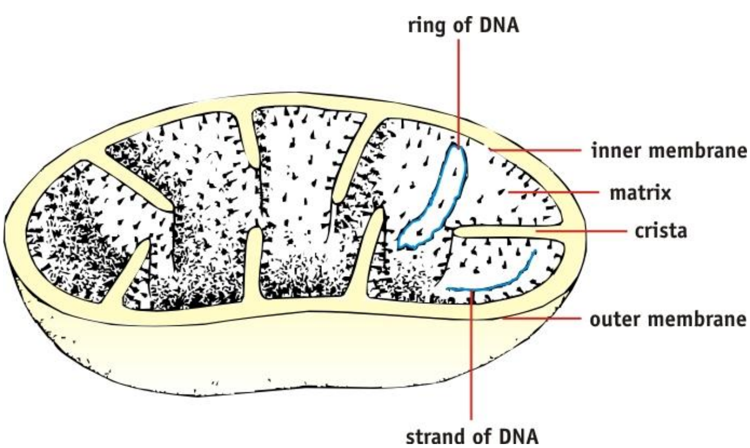


Figure 8: Mitochondria

Chloroplasts

These organelles are the site of **photosynthesis**. They contain the green pigment **chlorophyll** so vital in photosynthesis. They are surrounded by two membranes, the inner one enclosing a fluid called stroma. The stroma surrounds the thylakoid membranes which consist of flattened membranous sacs called thylakoids stacked to form grana. The grana are interconnected by membranous tubes.

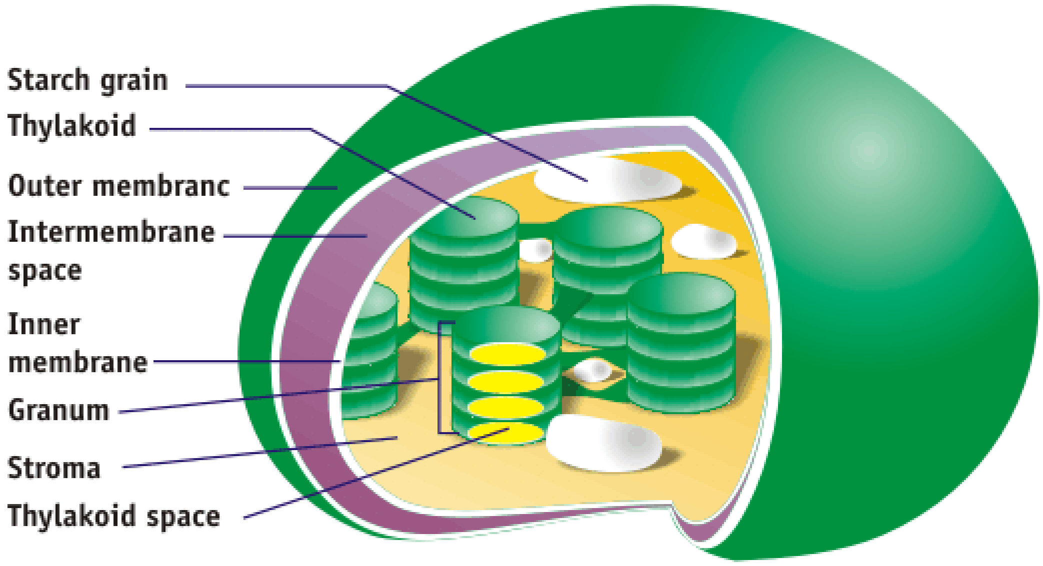


Figure 9: Chloroplast

Microtubules

These are small tubes made of protein and found in the cytoplasm. They pull the chromosomes apart during cell division and are involved in production of a new cell wall during cell division.

Storage Granules

These store starch (starch grains) or oils (oil droplets) in a plant cell and act as energy stores.

Learning Activities

You can now have a go at the **'Electron Microscope Photos of Plant Cell Structure - Labelling Activities'** looking at Electron Microscope pictures of cells, and the **'Plant Cell Structure Quiz'** in the Plant Cells and Anatomy 'Interactive Learning Activities' folder.

Filling in the **'Plant Cell Glossary'** (to be found at the end of this booklet) should also help you to learn the terminology.

Further Reading

For more information on cell wall structure, plasma membranes and on how the various structures within the cytoplasm work together you might like to refer to Campbell's book on Biology (Chapter 7&8) or a similar text. A-level text books may also have information on this subject.

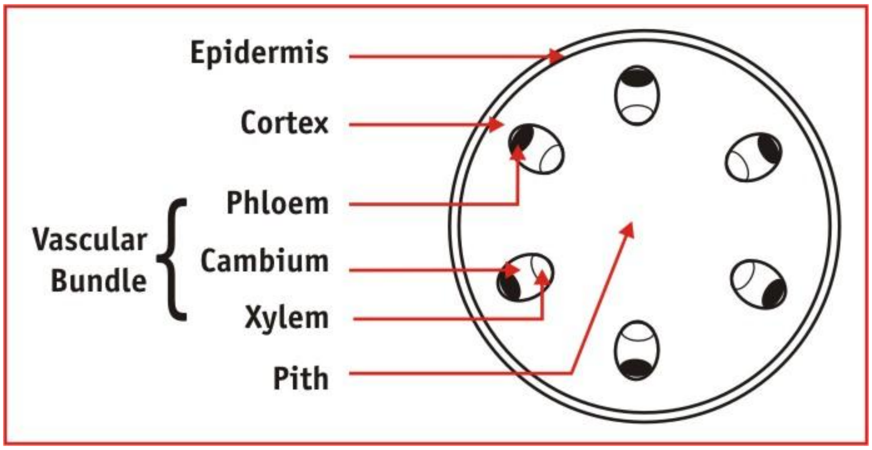
Dicotyledon Stem Structure

Basic Stem Structure

The sunflower (*Helianthus annuus*) is frequently used to illustrate the basic stem structure of Dicotyledonous plants. The Sunflower is a member of the *Compositae* family. (This is the largest of the families of Angiosperm plants, and comprises 900 genera and 13000 species). The stem can reach a length of up to 2.5 metres, and will support a very large flower head.

In a young stem the centre is occupied by a parenchymatous **pith**. This is surrounded by a ring of **vascular bundles** (including leaf trace bundles). Then there is a layer of parenchymatous cortex cells with the epidermis on the outside. In an older stem the centre of the stem is often hollow.

Figure 10a: Stem of Generalised *Dicotyledon* in Cross Section



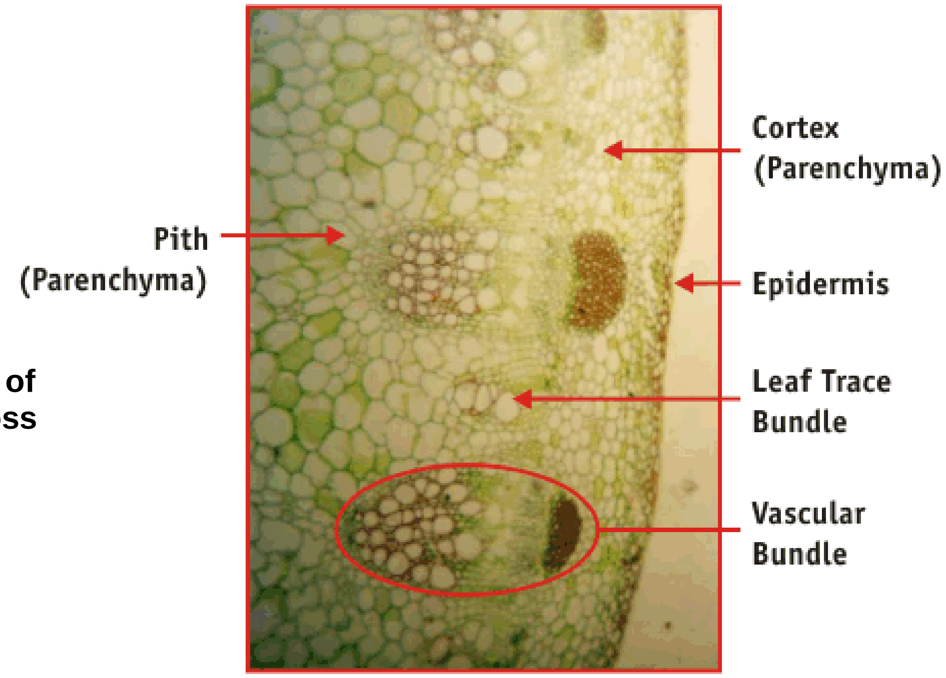


Figure 10b: Stem of *Helianthus* in Cross Section

Vascular bundles

In the dicotyledonous stem the vascular tissues, phloem and xylem are arranged together in compact masses called **vascular bundles**. Usually the **xylem** is situated in the inner part of each bundle near the stem centre, with the **phloem** towards the outer surface of the stem. Between the two is the **vascular cambium** producing more of each. The older phloem tissues often become lignified and turn into **sclerenchyma fibres** to help support the plant.

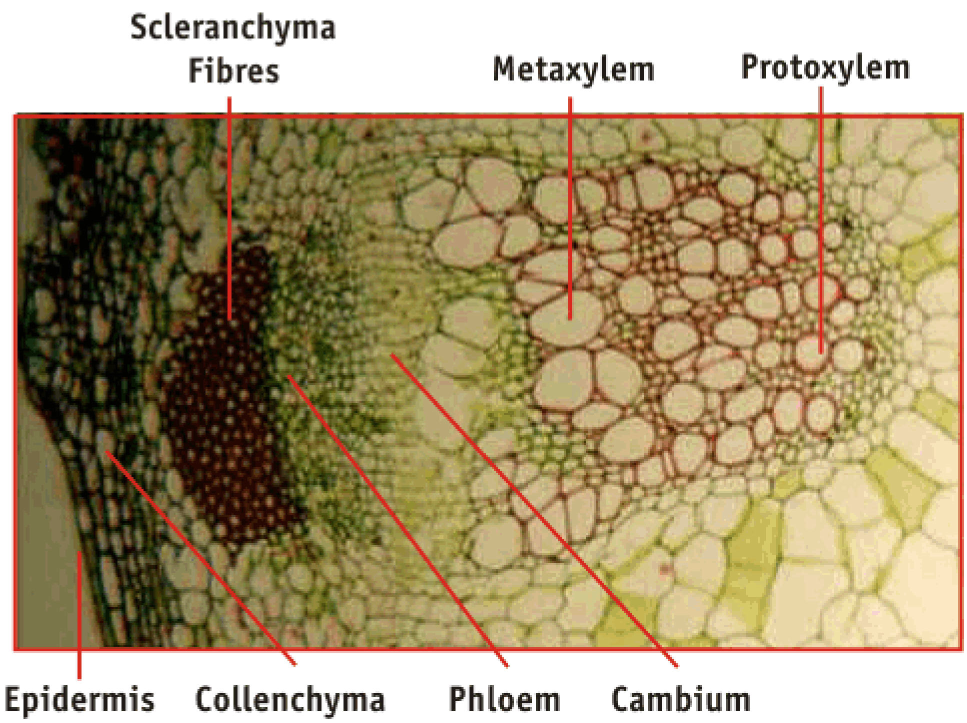


Figure 11: Vascular bundle in the stem

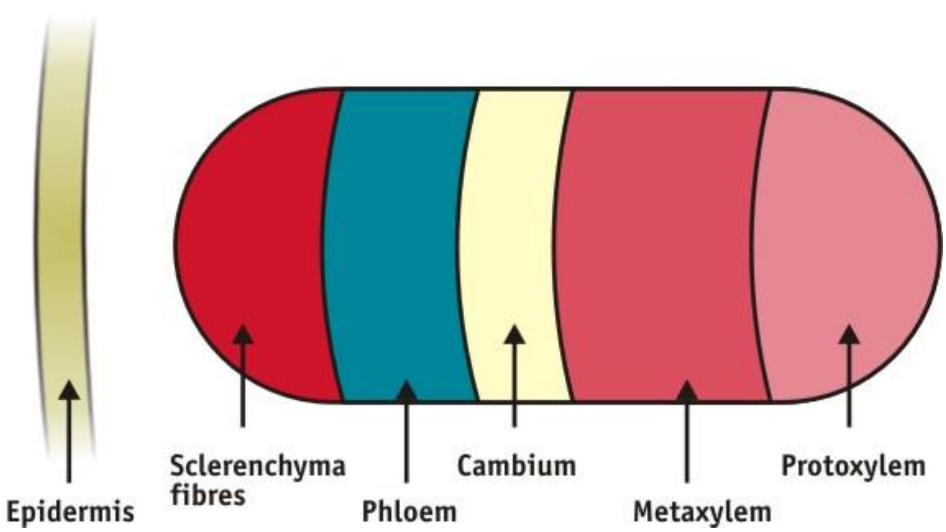


Figure 12: Generalised arrangement of tissues in a Dicotyledon vascular bundle

In the dicotyledonous stem, the vascular bundles and leaf traces form a girder system supporting the stem. As in most dicotyledonous plants, the leaf traces branch from the vascular bundles well below the nodes. The leaf traces are seen lying within the stem cross section between the main vascular bundles.

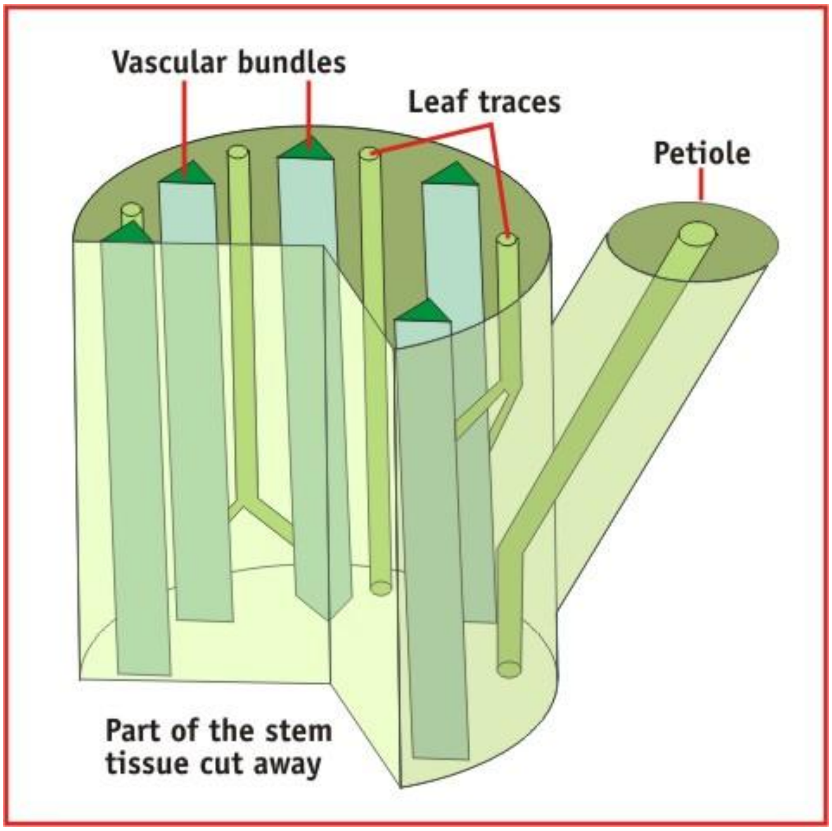


Figure 13: Diagram of stem structure

Learning Activity

Now go and try the **'Dicot Stem Anatomy Labelling Activity'** to check your knowledge of the layout of a dicot stem. You can find this in the Plant Cells and Anatomy 'Interactive Learning Activities' folder.

Cell Types and Plant Tissues

So now let's us look at the different cell types that make up a plant and are specially adapted to do the variety of different jobs that are required in the plant.

A) Xylem

This term describes cells whose function is to carry water and minerals from the roots to the aerial parts of the plant. There are two types, **vessels** and **tracheids**. Both types of cells are **dead at functional maturity**, (i.e. only the cell wall remains) which aids flow. They are both elongated in shape, also an advantage for flow of water. The primary cellulose cell wall is thickened before the cell dies. This secondary thickening **strengthens** the xylem tissue, preventing collapse and providing support for the plant. This thickening consists of a chemical called **lignin**. A dye used in the preparation of microscope slides means that the lignin strengthened walls of xylem appear red on such slides.

Tracheids

These cells taper at one end, have lignified cell walls and are connected to each other by numbers of pores or pits. The lignin makes them **waterproof**, useful in pipes that carry water!

In Gymnosperms, cone bearing trees such as pines and spruce, the water conducting tissues consist almost exclusively of this type of cell.

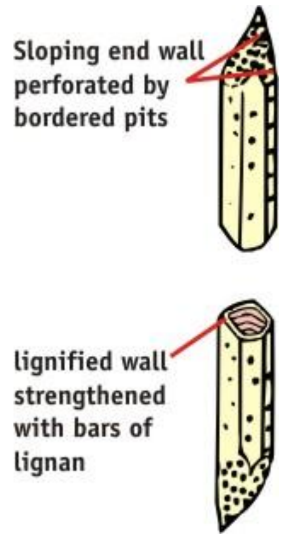


Figure 14: Tracheids

Vessels

a) Primary Xylem / Protoxylem

These types of xylem are only found in Angiosperms i.e. flowering plants. The initial secondary strengthening of these cells consists of spirals or annular rings of lignin, allowing these cells to be "stretchable". At maturity the cell contents die and the **end wall breaks down** producing empty tubes which allow free flow of water and minerals up the xylem.

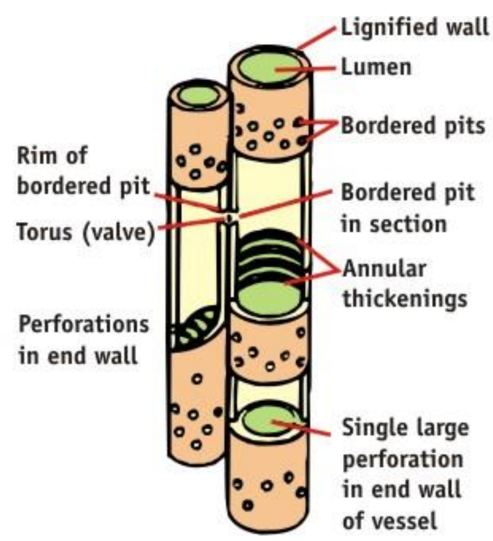


Figure 15: Vessels

b) Secondary Xylem / Metaxylem

These cells are heavily lignified with many layers of spiral and annular thickening, which often gives rise to a reticulate form of strengthening. The tissue so formed by these cells are non-stretchable and very strong. The lignin again makes these water carrying 'pipes' waterproof.

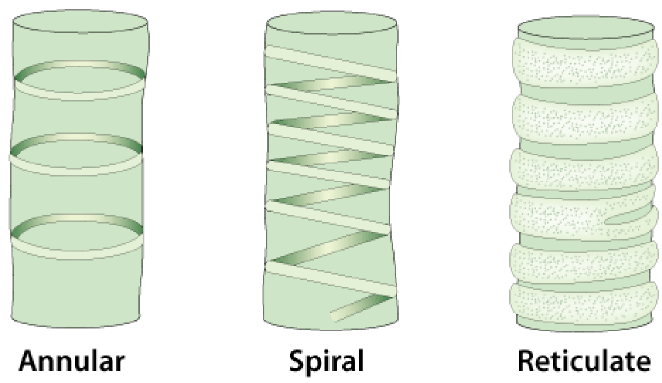
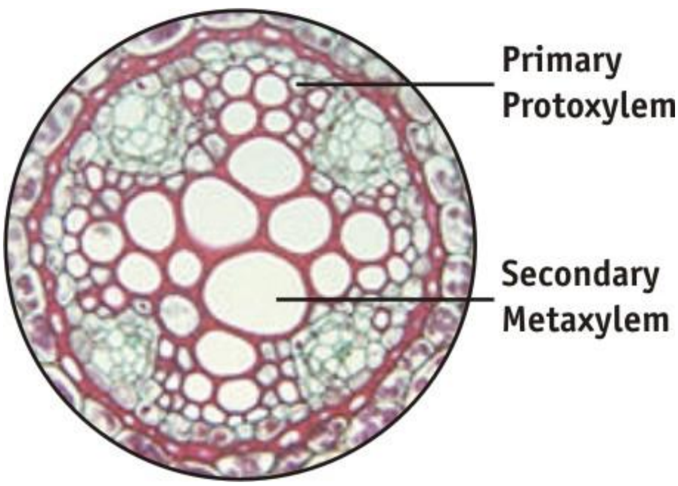


Figure 16: Secondary

In many trees and shrubs, the non-functioning, oldest xylem tissues at the centre of the stem become filled with resins and tannins which give additional strength to the stem. This is known as **heartwood**.

a) root



b) stem

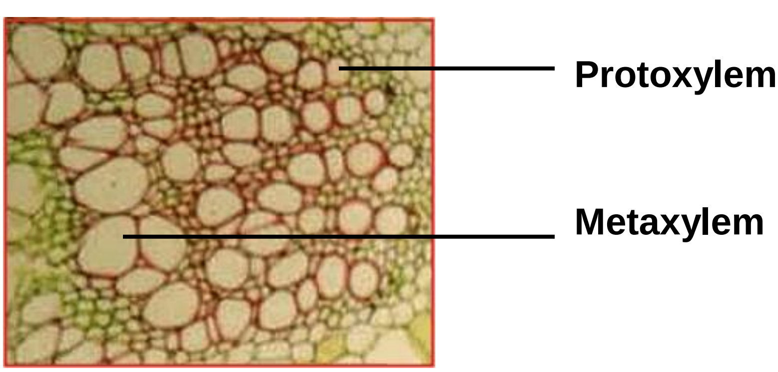


Figure 17a & b: Primary and Secondary Xylem in root and stem

B) Phloem

This term refers to cells modified to **carry food** manufactured in the photosynthetic part of the plant (the leaves and stems) to the rest of the plant, particularly to rapidly growing areas such as shoots, roots, young expanding leaves and developing flowers or fruit. Transport of sugars in the phloem is achieved through a process described as **translocation.** Viruses, translocatable herbicides and foliar feeds are also transported within the phloem tissue.

Phloem consists of two cell types **sieve tubes** and **companion cells**.

- **Sieve Tubes**
  These cells are interconnected by strands of cytoplasm which pass through the **sieve plates** that form the end walls of each tube element. They have **no nucleus** at maturity which presumably helps to allow movement through the tubes.

- **Companion Cells**
  These cells lie alongside the sieve tubes and are characterised by their **prominent nuclei** and dense cytoplasm including lots of **mitochondria**. Their precise function is not fully understood but it is thought that they play an active role in the translocation of sugars and other materials within the sieve tube cells.

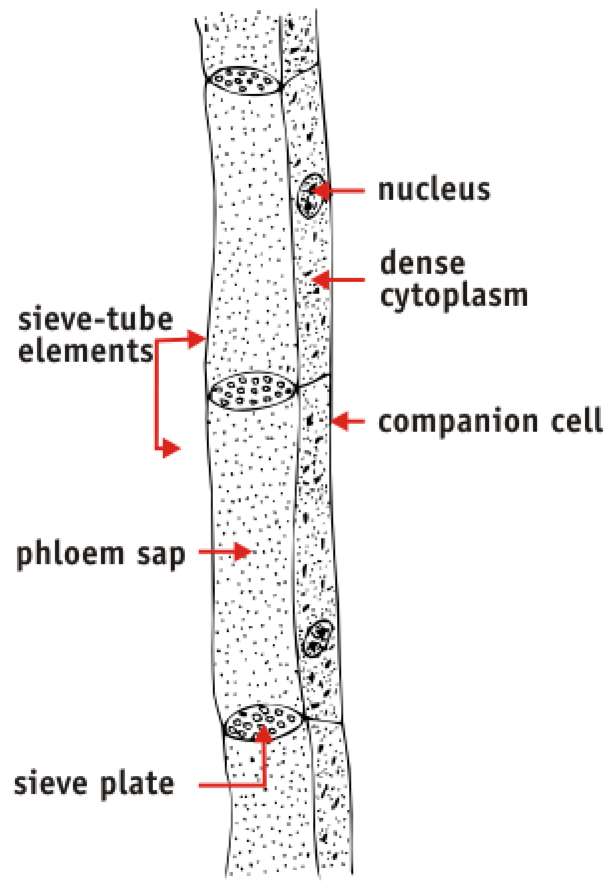


Figure 18: Phloem

The picture below shows a longitudinal section of phloem tissue in Maize (*Zea mays*). Metaphloem cells are seen in the region between the two red sclerenchyma cells (right), and an annular protoxylem element (left). The narrow **companion cells** can be seen to alternate with **sieve tubes**. Two **sieve plates** can be seen as "blue bars" which demonstrate the length of a single sieve tube element. The phloem shows blue on this section due to dyes used in preparation of the microscope slide.

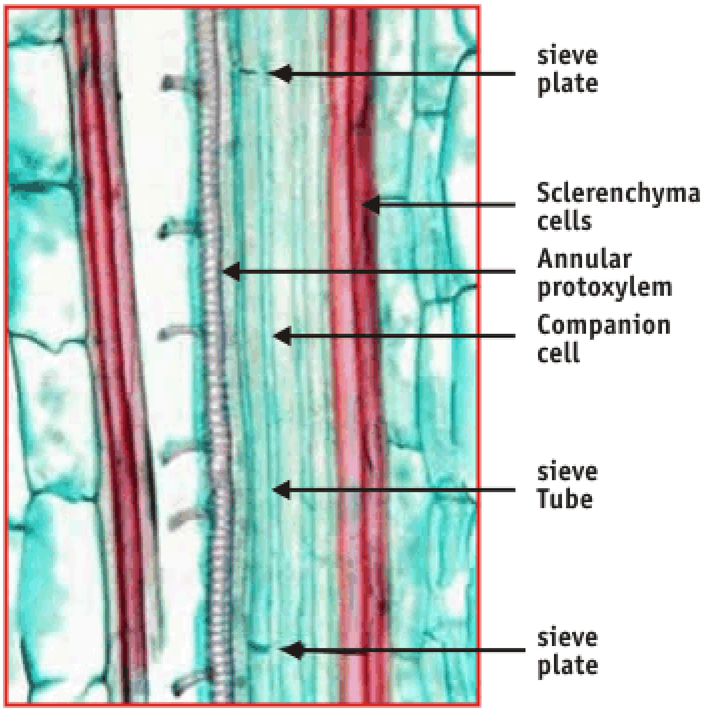


Figure 19: Appearance of primary phloem in longitudinal section

C) Cambium

The main function of a cambium is to allow an **increase in the girth** of a plant stem by plant cell division. Cambium tissues are known as **lateral meristems,** where a meristem is defined as an area where plant cells divide and the cambium allows a plant to get wider rather than taller. Cambium cells are small with little or no vacuole. These tissues are mainly seen in dicotyledonous plants and gymnosperms.

The **two basic types of cambium** are:

1) Vascular Cambium

This tissue generates **new phloem** and **xylem** in young stems and is initially found only within the vascular bundles. As growth progresses in dicotyledonous stems so the vascular cambium in the vascular bundles becomes connected by the **interfascicular cambium** (new cambial cells that differentiate from cortex cells between the vascular bundles) to form a complete cylinder.

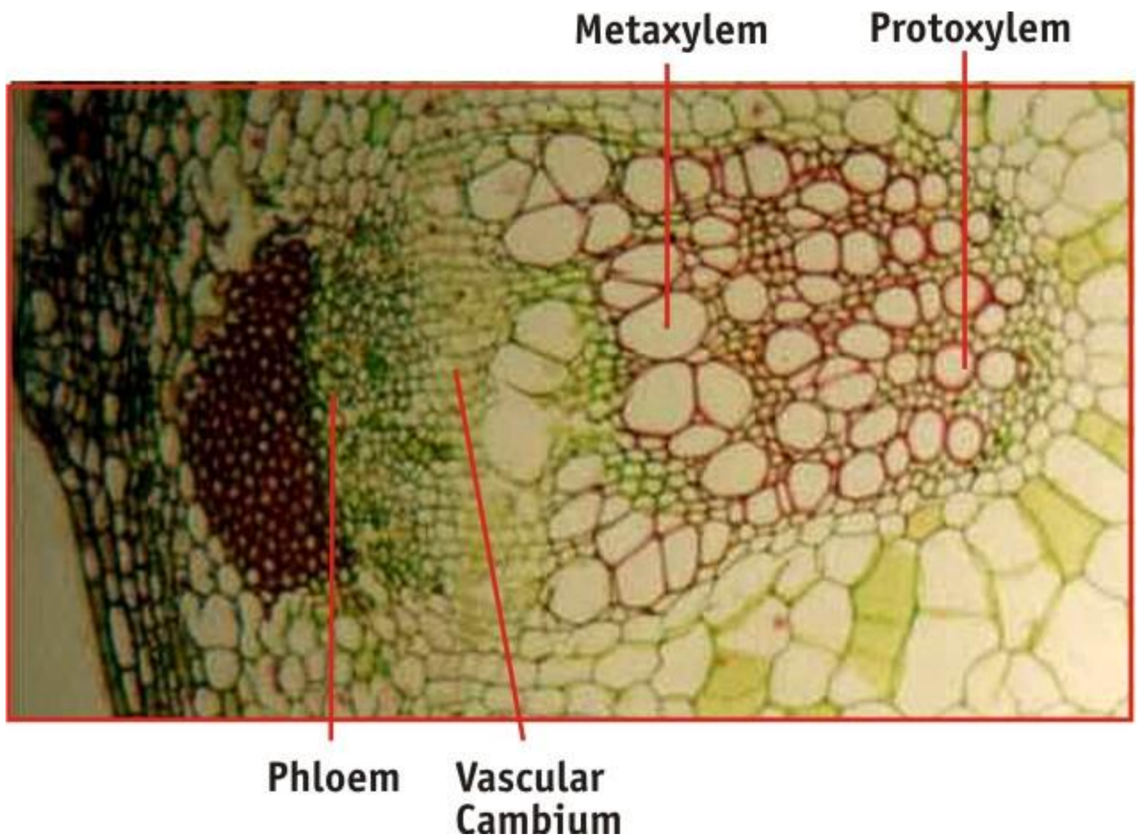


Figure 20: Vascular cambium

2) Cork Cambium (or Phellogen)

The cork cambium develops in a cylinder in the cortex of woody stems, between the vascular cambium and the epidermis of the plant stem. This produces new **secondary cortex** on the inside and **cork cells** on the outside. The cork cambium, new cortex and cork layer make up the bark. (More information on this type of cambium is included in the next section on Secondary Growth in a Dicotyledon Stem.)

D) Parenchyma

Parenchyma cells have fairly **thin and flexible primary cell walls**, usually with no secondary thickening. They are often more or less circular in cross section. They generally have a large central vacuole. Mature parenchyma cells do not generally undergo cell division but they retain the **ability to differentiate** into other types of plant cells under special conditions, for example after injury or to form a new cambium.

Parenchyma cells perform most of the metabolic functions of the plant. For example, **photosynthesis** occurs within the mesophyll cells in the leaf which are parenchyma cells. Other parenchyma cells in the stem and root cortex contain plastids that **store** starch.

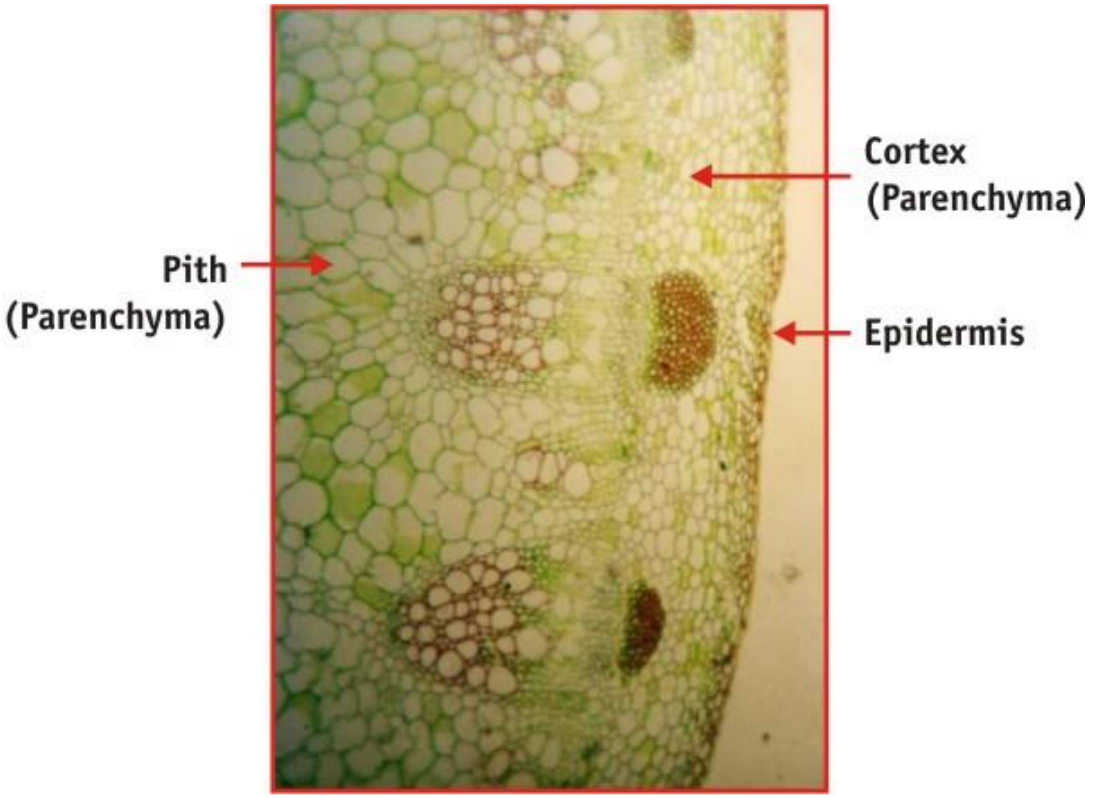


Figure 21: Transverse Section of Stem showing Parenchyma and Epidermis

E) Epidermis

Epidermal cells form a **single tightly packed layer** that covers and protects all parts of a young plant. Epidermal cells may have more specialised characteristics depending on the function of the part of the plant that they cover. Epidermal cells on the first few millimetres of a root produce **root hair** extensions to increase surface area and so aid absorption of water and minerals. Epidermal cells of leaves and stems secrete a waxy coating called the **cuticle** to help in waterproofing aerial parts of the plant. **Stomatal guard cells** are specially adapted to allow gases to move in and out of the leaf but otherwise gaps between epidermal cells are rare.

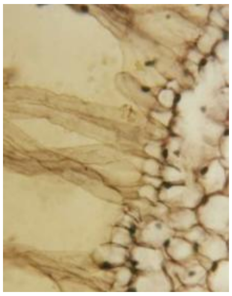


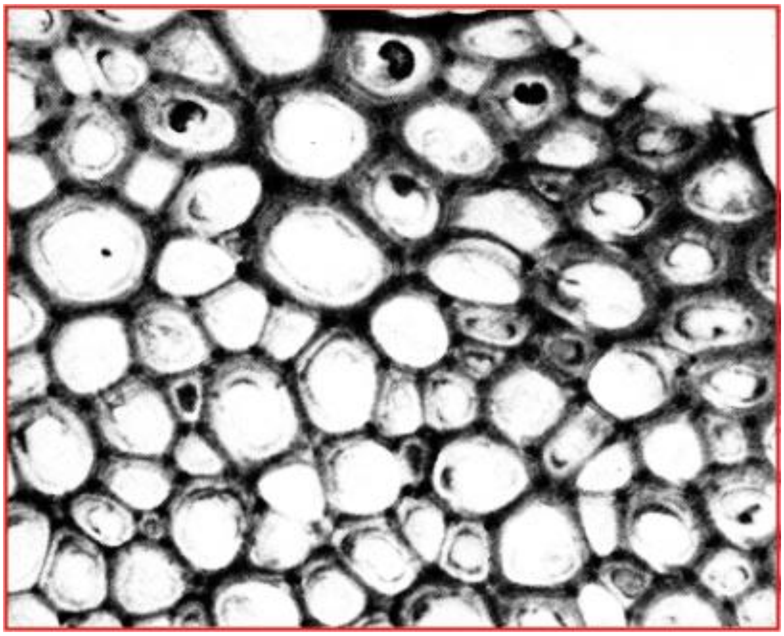
Figure 22: Root Hair Cells

F) Sclerenchyma

These are non-stretchable, waterproof, packing and strengthening cells. They are initially similar in form to parenchyma. There are two types, **fibres** and **sclerids**.

In the formation of **fibres** the cells elongate up to 500 times their original length. Lignin is laid down in layers behind the cell wall, and the cytoplasm and nucleus are forced into the centre and are eventually lost, thus creating an **empty lumen** in the centre of the cell. Fibres are generally strengthening cells in stems, roots and leaves.

Sclereids undergo a similar transformation but without elongation and form 'crush resistant' tissue as found in fruits such as pears and the 'stones' of fruit.



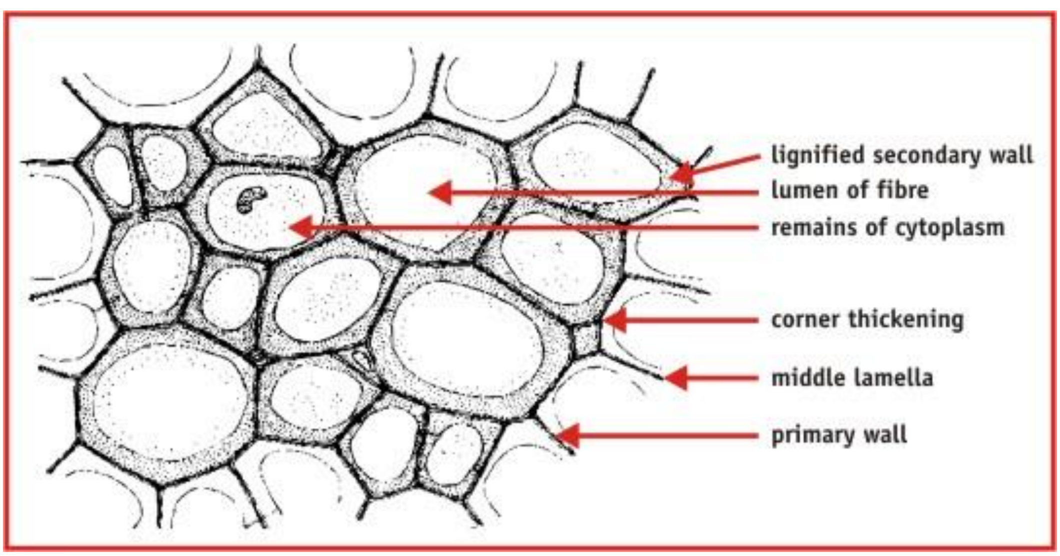
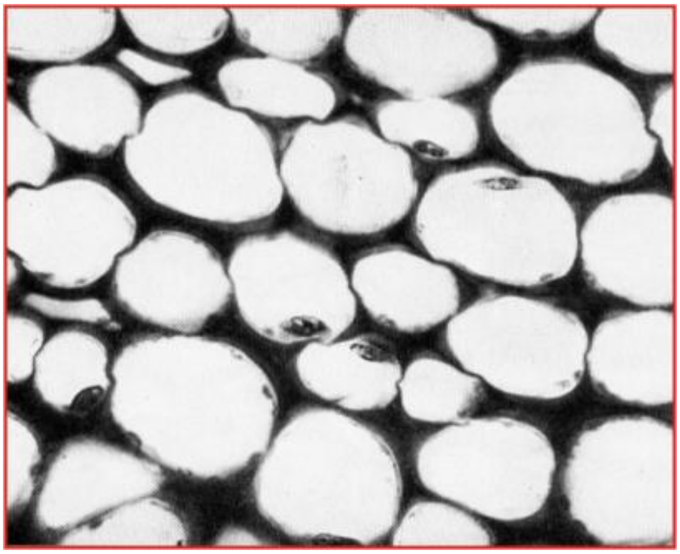


Figure 23: Sclerenchyma fibres in cross section

G) Collenchyma

These cells are usually to be found located just under the epidermis of plant stems. They are similar in shape to parenchyma cells with secondary deposits of cellulose, characteristically at the **corners** of the cells as seen in section. This tissue functions as a cushioning and shock-absorbing tissue and may also help in support.



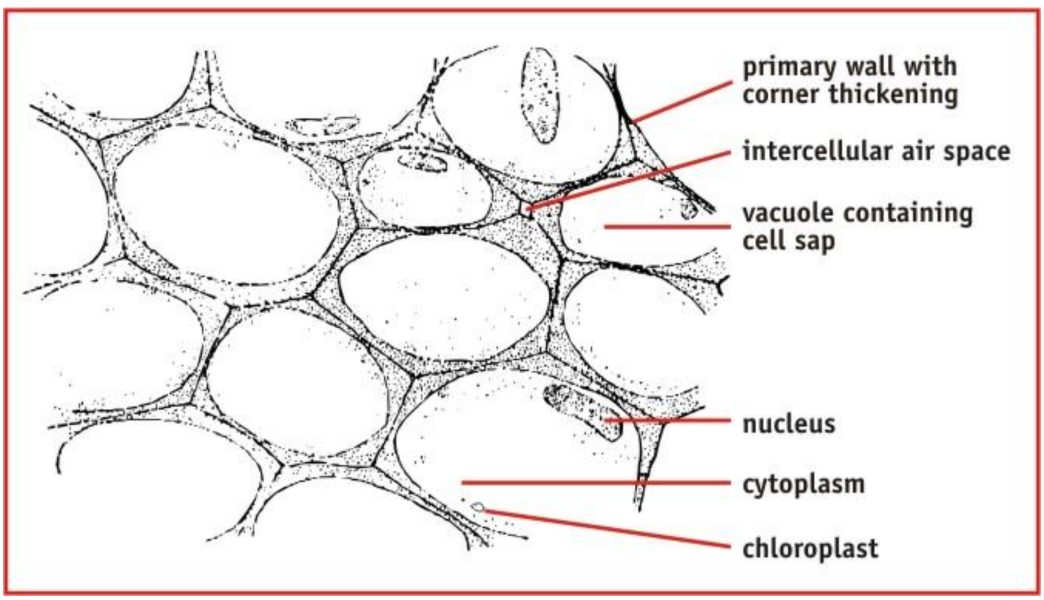


Figure 24: Collenchyma in cross Section

Learning Activity

Now go and do the **'Tissue Function v Features Quiz'** to be found in the Plant Cells and Anatomy 'Interactive Learning Activities' folder.

Secondary Growth in a Dicotyledon Stem

Secondary growth of dicotyledonous stems increases the girth of the stem. It involves lateral meristems, the vascular cambium and the cork cambium, and occurs in the following stages.

Stage 1: Formation of an Interfascicular Cambium

Cortex parenchyma cells differentiate to form a new cambium between the vascular bundles, called the **interfascicular cambium**. This and the cambium in the vascular bundles form a complete ring of vascular cambium around the stem.

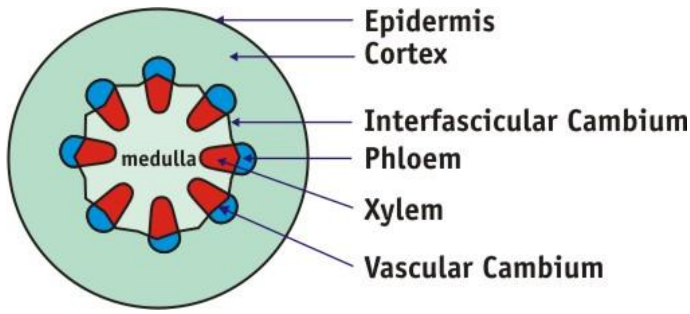


Figure 25: Interfascicular cambium

Stage 2: Production of Secondary vascular tissues

The Primary Cambium and Interfascicular Cambium both form secondary xylem and phloem. This may happen to strengthen stems in plants that one would not think of as woody plants such as the sunflower (*Helianthus annuus*).

In **woody perennial plants** the vascular cambium of the stem produces an annual ring of **secondary xylem** each summer. The cambium then becomes dormant in winter. Vessels produced early in the growing season are generally larger in diameter. These produced later in the year are smaller. This produces the **growth rings** we see in woody stems.

Phloem is also produced each year but there are no obvious layers in the phloem as older layers are crushed as growth continues. Phloem tubes are rarely used for much over a year.

Some of the cells produced in the vascular cambium are **parenchyma** cells that form **medullary rays** in the xylem and phloem. These allow for lateral transport of water and nutrients and storage of starch and other reserves.

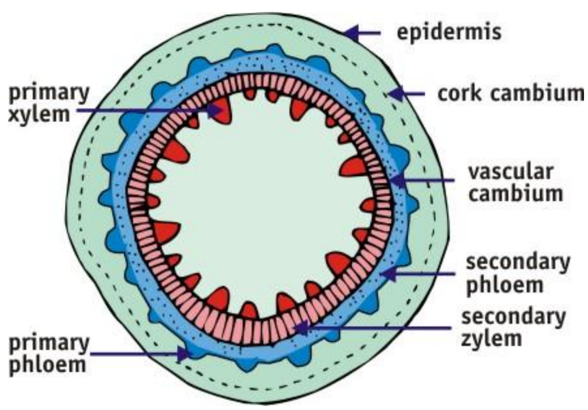


Figure 26: Secondary vascular tissues

Stage 3: Formation of a cork cambium

A **cork cambium** (or phellogen) forms, usually in the outer layers of the cortex. The cork cambium cells divide to form new **cortex** cells (phelloderm) on the inside and **cork** cells on the outside. The cork cells secrete a layer of waxy suberin into their secondary wall and die. The bark (**periderm**) consists of the cork layer, cork cambium and new cortex. These replace the epidermis and act to seal over any possible splits in the outer tissues as the stem increases in girth.

Patches of loosely arranged cork cells form **lenticels** in the bark which allow gas exchange for respiration between the living tissues in the trunk and the atmosphere. These are aligned with the medullary rays.

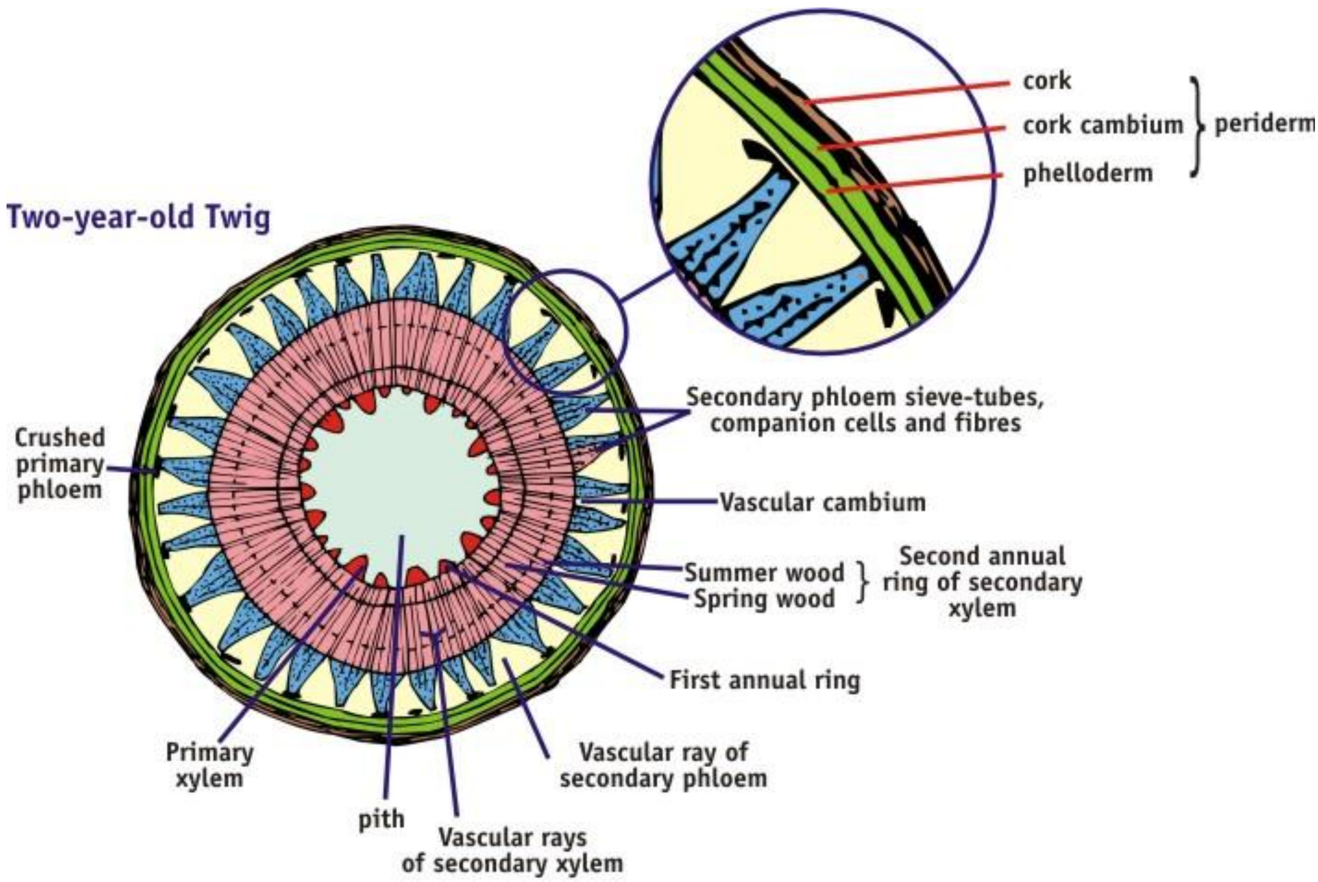


Figure 27: Growth of secondary tissues

Monocotyledon Stem Structure

Wheat and maize are good examples of monocotyledonous plants to study. They are part of the *Poaceae*, the family that contains all the cultivated grasses and cereals, but are larger than most of the family so structures are easier to see.

Monocots do not have the **vascular bundles** arranged in a ring as in dicots but **scattered** in a more complex or ‘random’ manner throughout the parenchyma ground tissue.

Maize

The vascular bundles of the maize plant show large metaxylem vessels that are a characteristic feature of many monocotyledonous plants. The protoxylem is often damaged as the stem elongates and no longer usable.

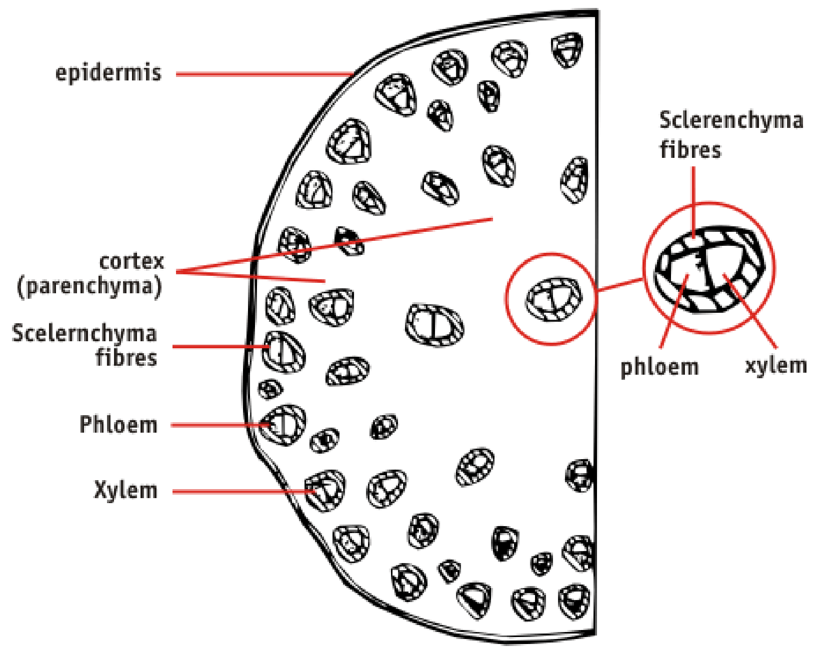


Figure 28: Tissue map diagram of maize stem

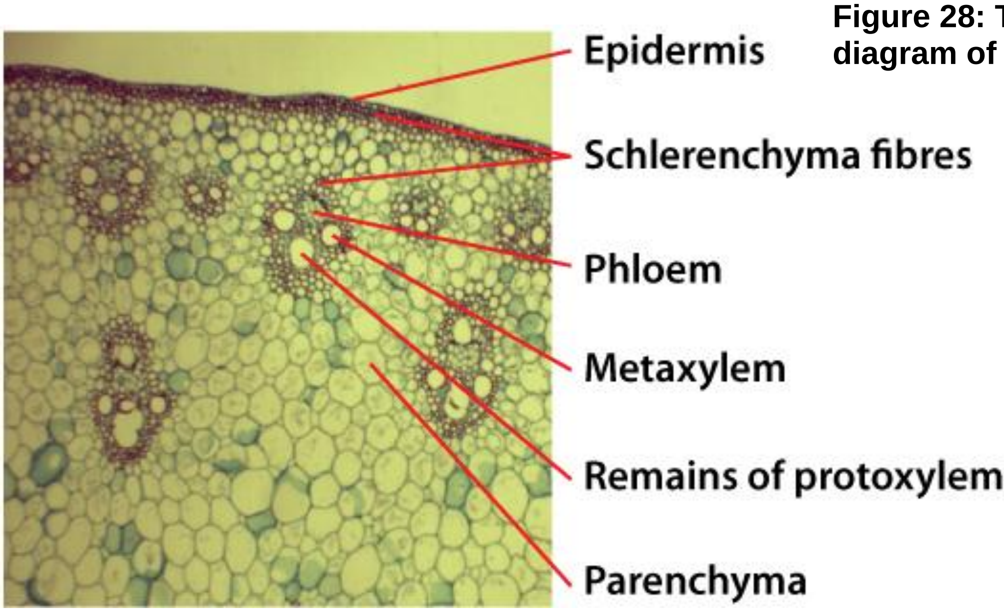


Figure 29: Transverse section of part of the stem of a maize plant

Wheat

Wheat like so many of our grasses supports a terminal inflorescence. After fertilisation a heavy head of fruit develops and the stem needs to be strong to stay erect. This is possible because within the circular hollow stem the main vascular bundles and leaf trace bundles form a compact system of strengthening rods and girders. The layer of fibres below the epidermis provides additional strength.

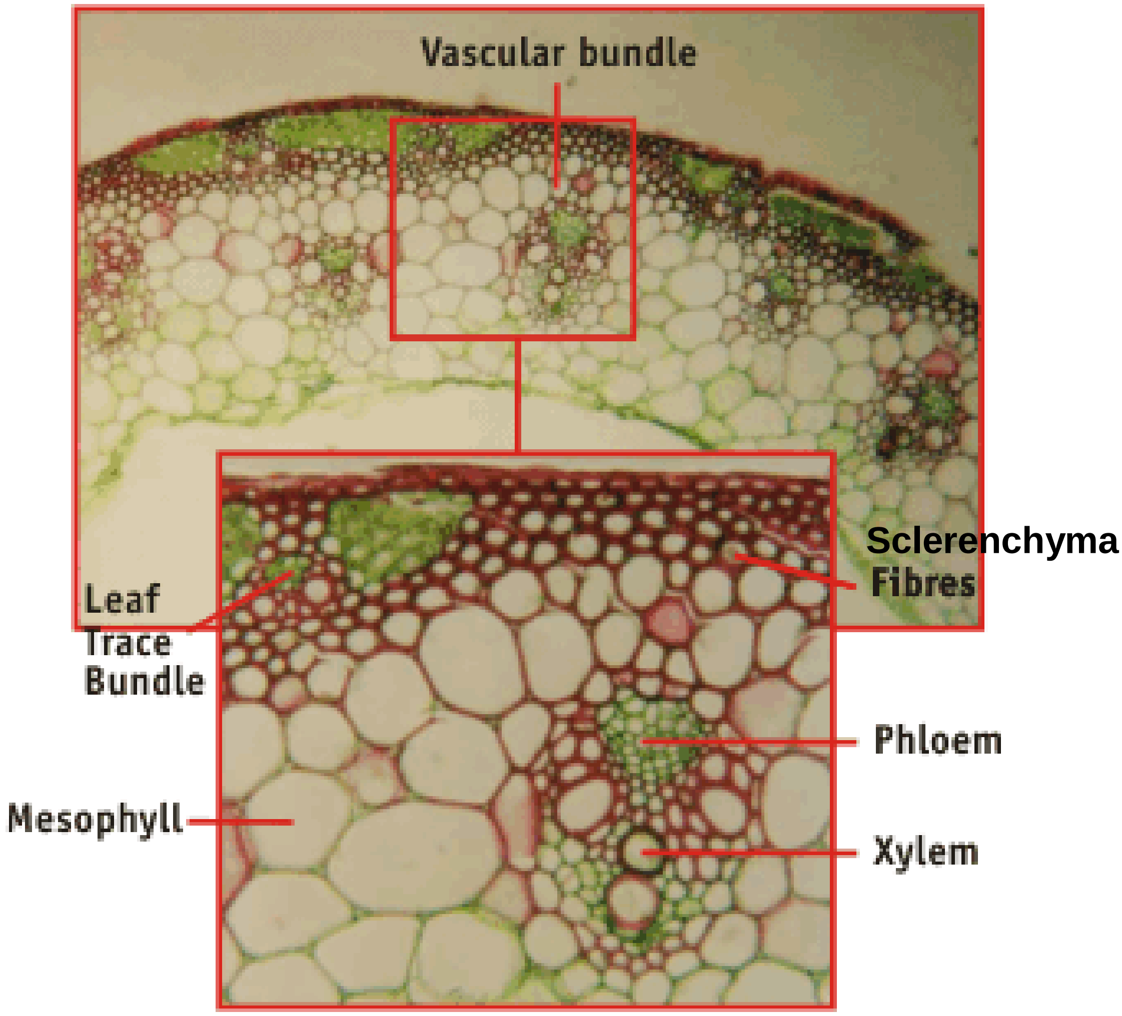


Figure 30: T.S. of stem of Wheat (*Triticum aestivum)*

Intercalary Meristems in Monocot Stems

In dicot plants root and shoot elongation is largely due to the production of new cells at **apical meristems** at the end of roots and shoots, what might be called growing points. In plants of the grass family, shoot growth is not entirely dependant on the apical meristem. Tissues at the base of each internode remain meristematic (that is able to divide), these are called **intercalary meristems**. This allows the internodes to continue to elongate and the plant to grow even if the apical meristem is removed. This is one reason why grass shoots regenerate rapidly after being cut back by grazing or mowing.

Apical meristems in grasses are also **held close to the soil level,** except when a shoot elongates for flowering, which also helps them to regenerate after grazing or mowing.

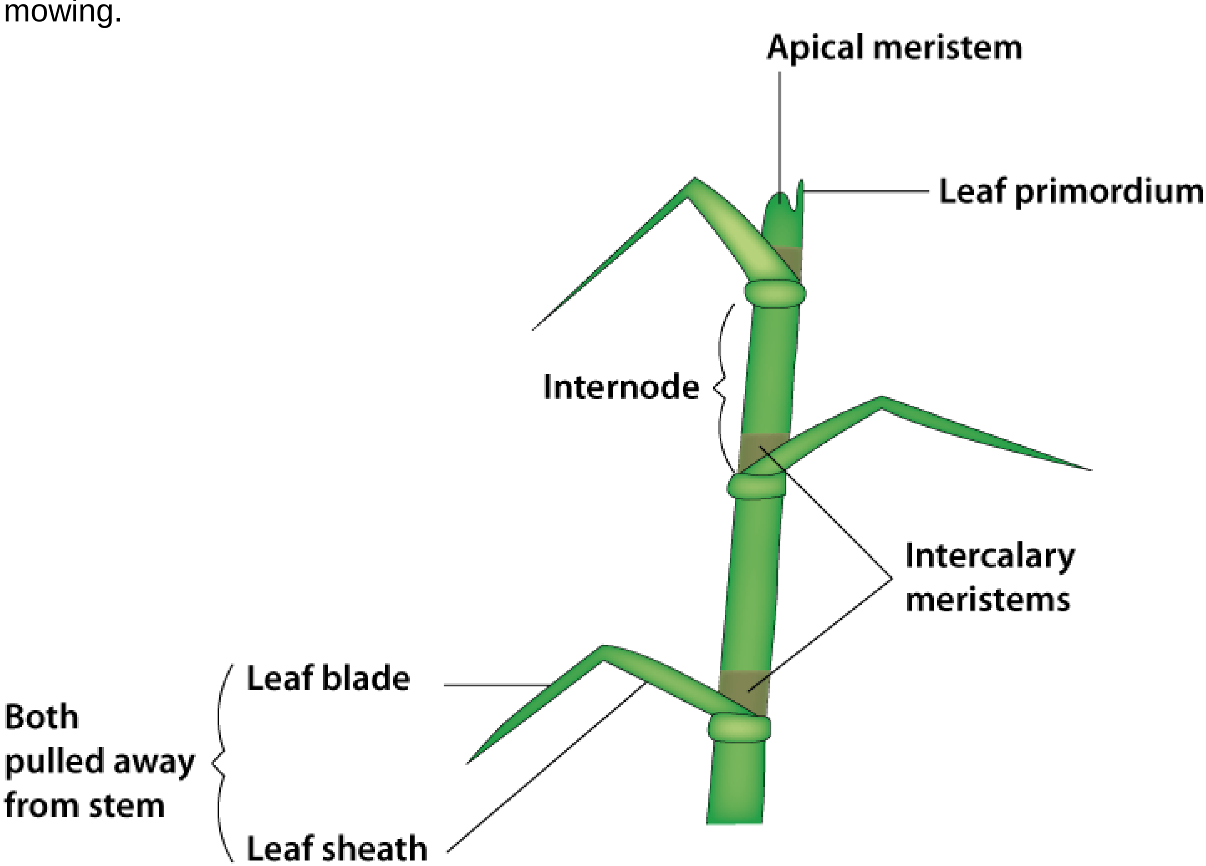


Figure 31: Diagram to show position of Intercalary Meristems

Dicotyledon Root Structure

The root of a dicotyledon contains many of the same tissues as the stem but their arrangement is slightly different.

Vascular Tissues of the Dicotyledon Root

When the position of the xylem and phloem in the root and the stem are compared this reveals two important differences:

A) Central v Ring

- **In the root** - Vascular tissue is found centrally in a compact **central stele**. The soil supports the root which needs to be flexible and act as a strong anchor for the plant.
- **In the stem** – there is a **circle of vascular bundles around the outside** acting as strengthening rods. Unlike soil, air is a non-supporting medium in which the stem has to support itself.

B) Endarch v Exarch

- **In the shoot** – the **xylem** and **phloem** are in vascular bundles and the metaxylem is formed towards the outside of the protoxylem (an arrangement described as **endarch**).
- **In the root** - **protoxylem** and **protophloem**, the first-formed of the xylem and phloem tissues, alternate around the stele The number of these groups is used to describe the stele. Hence a stele with five xylem groups is described as pentarch. Metaxylem forms on the inner side of the protoxylem (an arrangement called **exarch**).

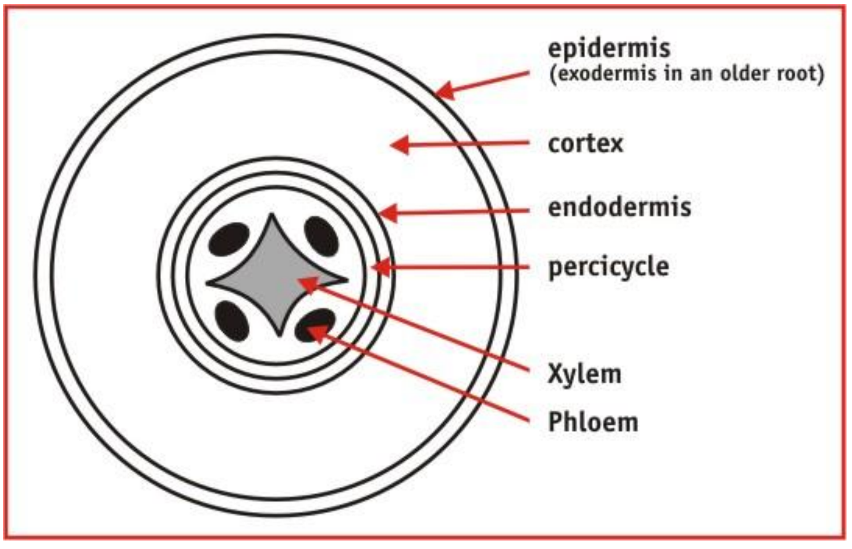


Figure 32: Vascular tissues in a Dicotyledon root

Specialised Root Structures

The root also has a number of very different structures to those found in a stem.

- In all but the very youngest roots the central stele containing the vascular bundles is surrounded by a waterproof layer called the **endodermis**. The cellulose cell walls are thickened with a chemical called suberin, a waxy waterproof substance. Water can only enter through occasional non-waterproofed passage cells. This allows the plant to control movement of both water and nutrients into and out of the vascular tissues of older roots.
- Inside the endodermis is a single layer of cells called the **pericycle**. This is where lateral roots start to grow.
- The epidermis also becomes waterproofed with suberin in older roots with no root hairs. This is known as the **exodermis**. This acts as a protective barrier for the root preventing entry and loss of water and providing some protection against pests and disease

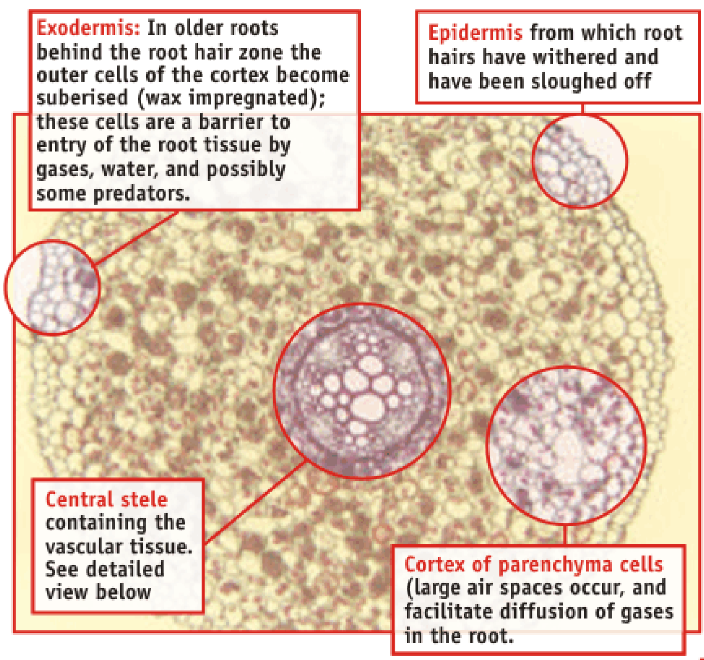


Figure 33: Section of a dicot root just behind the root hair zone

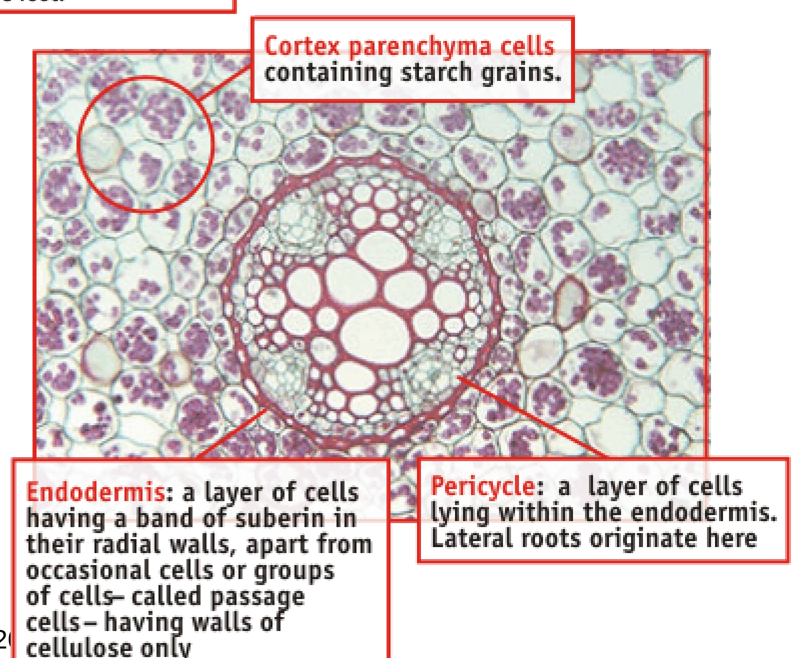
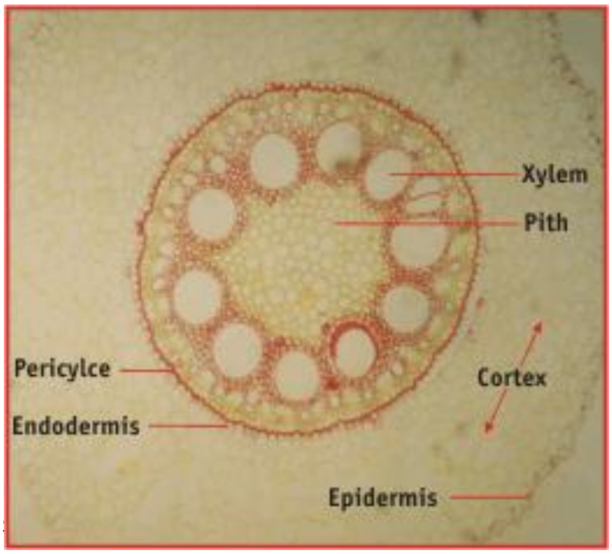


Figure 34: The central stele of the root

Monocotyledon Root Structure

In the roots of Monocotyledons the number of protoxylem groups is always large. The Iris root shown here has eleven such groups and is described as **polyarch.** The cells of the endodermis surrounding the stele of monocotyledons typically have very **thick suberised walls on three sides** (inner + two radial) which makes them waterproof. The occasional passage cell that allows water into the stele is conspicuous by its thin walls.



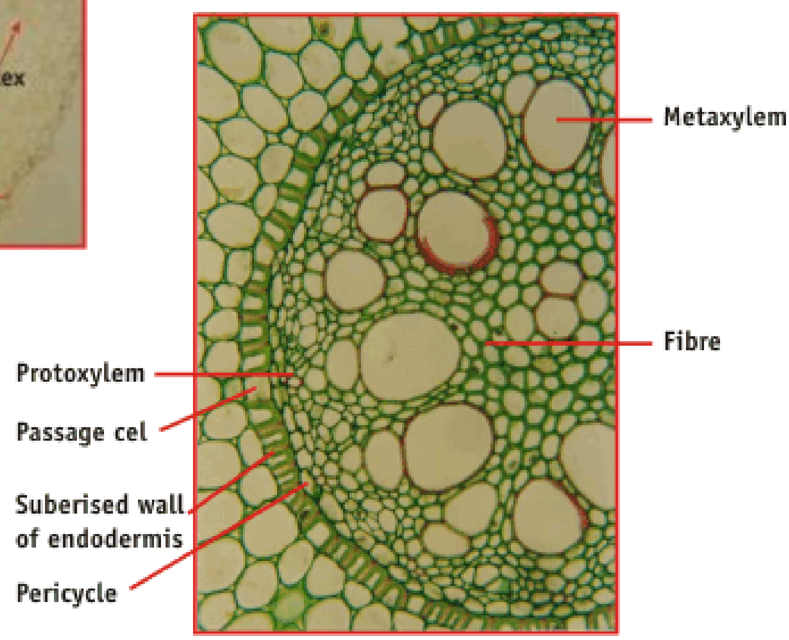


Figure 35: Internal structure of Maize roots

Learning Activities

Now go and try the **Dicot Root and Monocot Stem Anatomy Labelling Exercises** to check your knowledge of the layout and function of root and shoot tissues. You can find these in the Plant Cells and Anatomy 'Interactive Learning Activities' folder.

Research Activity

How do the roots of woody perennials expand to anchor large trees and shrubs? (Search for 'Secondary growth of dicot roots or trees'.)

Growth of the Shoot and Root

Cell Division and Growth

In plants, growth consists of three processes **cell division**, **cell elongation** and **cell differentiation**.

- **Cell Division:** The creation of new cells by cell division takes place in the **apical meristems** just behind the root and shoots tips. The cells that make up the apical meristem are small and have no vacuole. **Cell division** of these cells in the apical meristems (by mitosis) produces more small cells with no vacuole.
- **Cell Elongation:** Behind the apical meristem is a **zone of elongation** where the new cells start to expand and elongate mostly due to the expansion of the vacuole.
- **Cell Differentiation:** While cells are still continuing to expand, a third process, **cell differentiation** is initiated. It is this process that leads to the production of the various specialized cell types associated with the tissues of the primary root and shoot such a xylem and phloem.

Energy and raw materials for division, elongation and differentiation come from **respiration** of the sugars made in photosynthesis. A seed or seedling will be relying on stored food until the shoot emerges into the light, produces chlorophyll and can start to produce sugars by **photosynthesis**.

Growth at the Shoot Tip

In shoot tips the new cells produced by **cell division**, in the **shoot apical meristem**, remain behind the advancing growing point and **enlarge** and **differentiate** to produce the range of different tissue found further down the stem (xylem, phloem etc as described in the Anatomy notes). The various **zones** where these processes occur are shown in Figures 27 & 28 below.

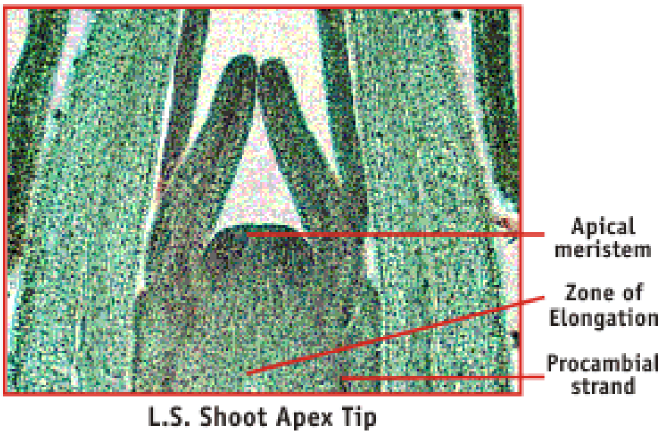


Figure 36: Section of a dicot shoot apex

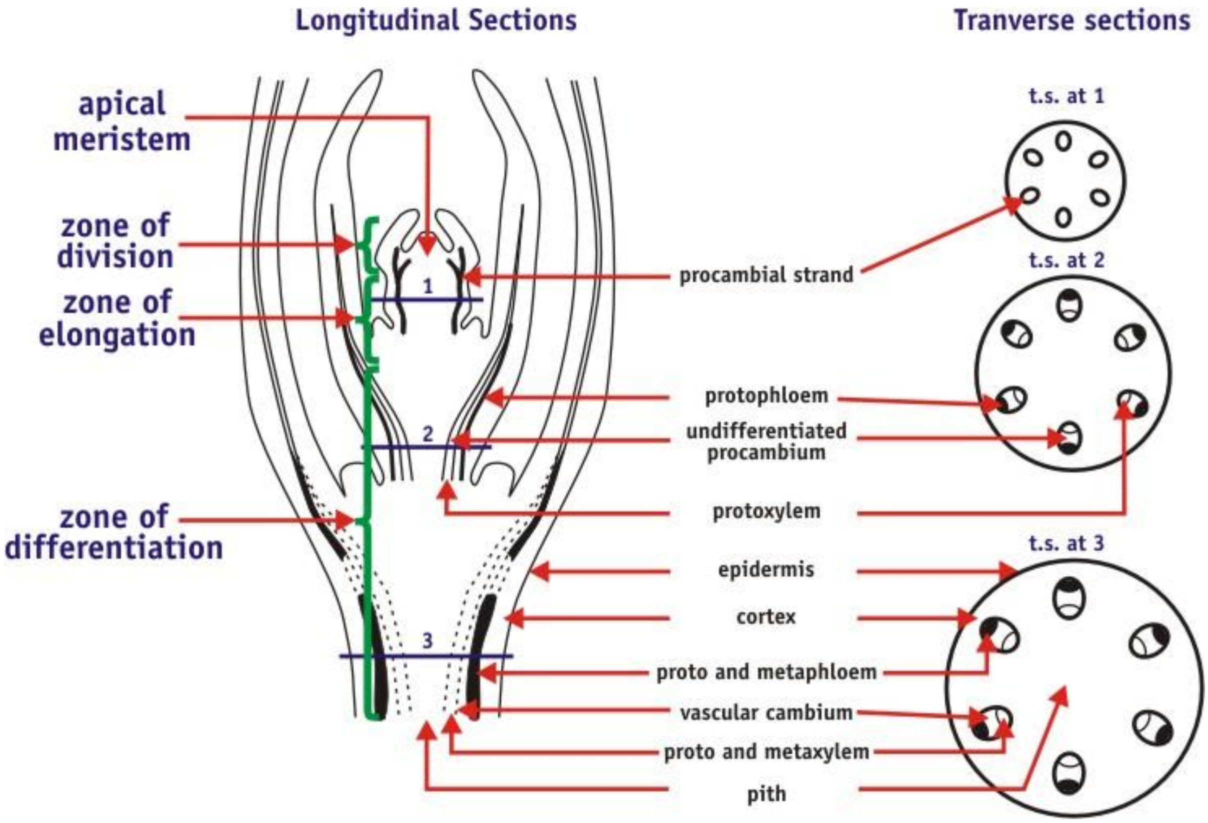


Figure 37: Zones of division, elongation and differentiation in the Shoot Apex of a Dicotyledon Plant

Growth at the Root Tip

The root apical meristem produces daughter cells to **replace the root cap cells** as well as cells which enlarge and differentiate to form the various root tissues (see Figures 29 & 30 below).

The role of the **root cap** is to protect the meristem as the root tip is pushed forward through the soil. The outermost cells die, disintegrate and are replaced by new cells from the meristem. Root cap cells show no special arrangement. They produce a polysaccharide slime to help the root move through the soil.

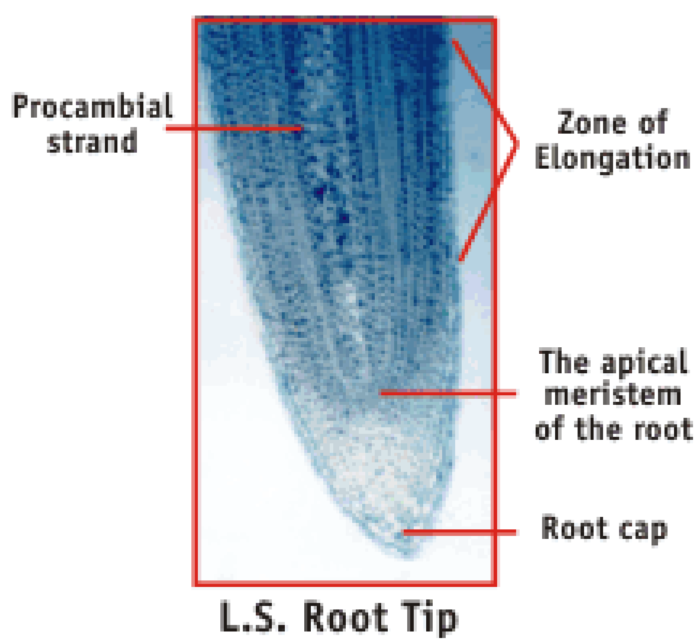


Figure 38: Section of a dicot shoot apex

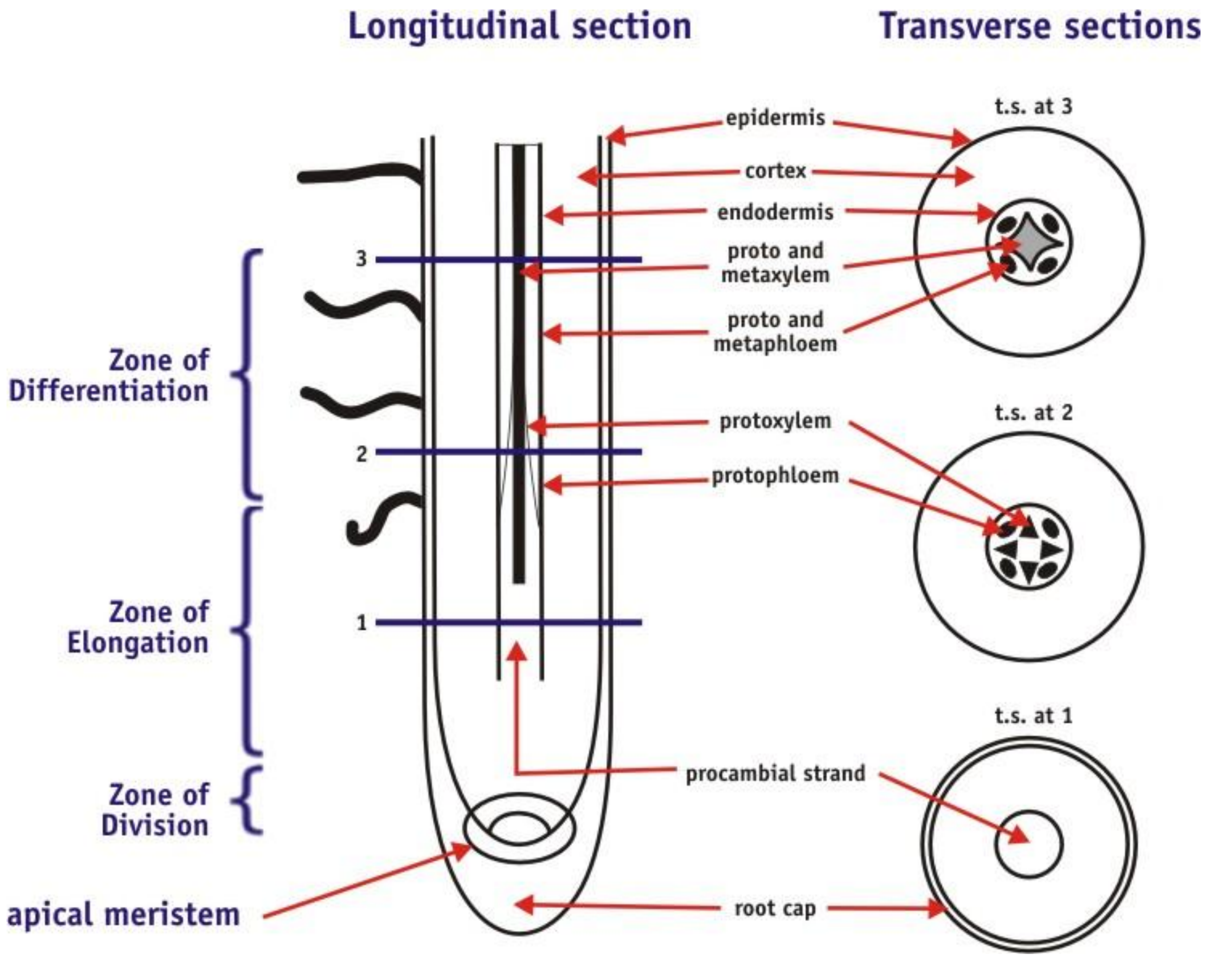


Figure 39: Zones of division, elongation and differentiation in the Root Apex of a Dicotyledon Plant

Specialised cells that develop behind the root tip include **epidermal root hair cells** to increase the surface area for absorption. The **endodermis** starts to develop in the zone of differentiation but does not usually form a complete cylinder until behind the section with root hairs.

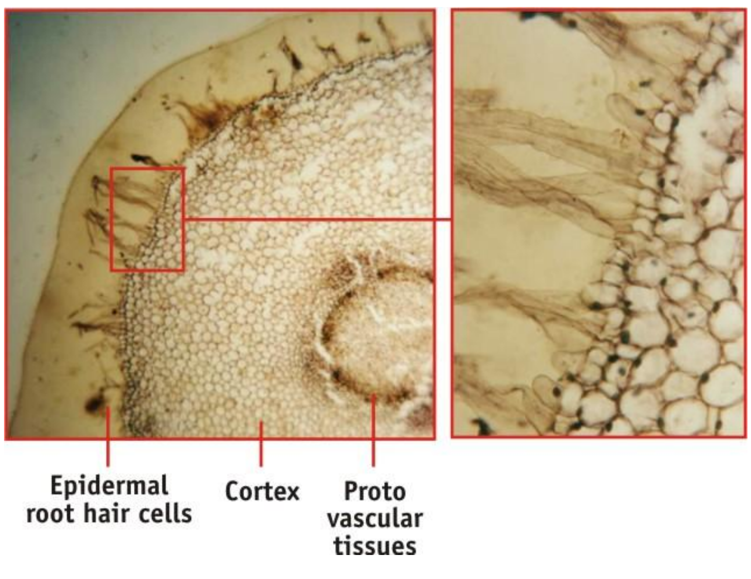


Figure 40: Root Hairs of Vicia faba just behind the root tip

Dicotyledon Leaf Structure

External structure of a leaf

This diagram will remind you of the basic morphology of a leaf.

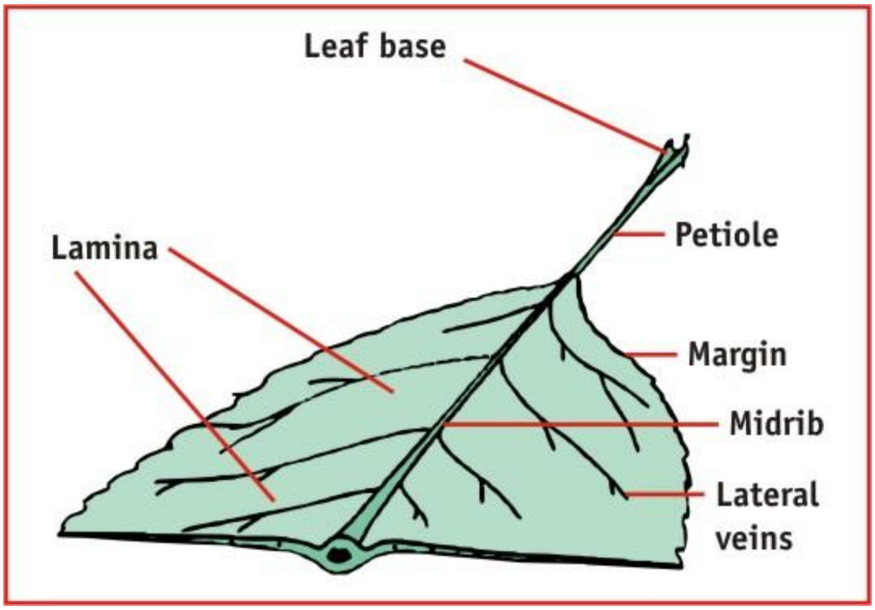


Figure 41: External Leaf structure

Internal structures of a leaf

Although in grasses and other monocotyledonous plants (such as Iris) leaves are held vertically, it is usual that most leaves grow at right angles to the light. For this reason the uppermost part of the leaf is different in its arrangement of tissues from the lower part. Many plants have this differentiation and can be described as being **mesomorphic** and having a **dorsiventral** arrangement of tissues.

The leaf of *Ligustrum ovalifolium* (Privet) (see Figure 31 on the next page) is an example of this type of organisation. It shows the following features:

- The leaf is **thin**, no more than about a dozen cells thick, but it has a very **large surface area**. Any thicker and the lower cells would get no light and so be unable to photosynthesise. The large surface area allows the leaf to intercept more sunlight. (Leaves of some plants can grow differently in shade conditions having a greater leaf area, being thinner and with more chloroplasts, so appearing a darker green.)
- The **upper epidermis** is nearly **transparent** to allow the light through and produces a **waterproof waxy cuticle** which is also relatively transparent.
- There is a **palisade mesophyll** layer of elongated, tightly packed, chlorophyll rich cells to catch the light.
- There is a **spongy mesophyll layer** with some chlorophyll for photosynthesis and many air spaces that allow gases to diffuse quickly to and from the main photosynthetic cells in the palisade layer.

- The **lower epidermis** has a thinner cuticle and **stomatal pores** which open during the day to allow gases to move in and out for use in photosynthesis and respiration.
- The **vascular bundles** (the veins) contain xylem to bring in water, phloem to transport sugars away to the rest of the plant and sclerenchyma fibres to help strengthen the leaf, helping to hold it flat to catch maximum amounts of light for photosynthesis.
- The **petiole** has a wide base to better resist the shearing forces from wind and rain.

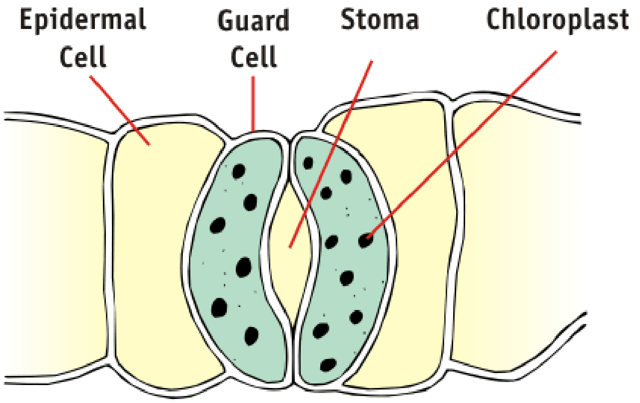


Figure 42: Stomatal Guard Cells (Stoma Open)

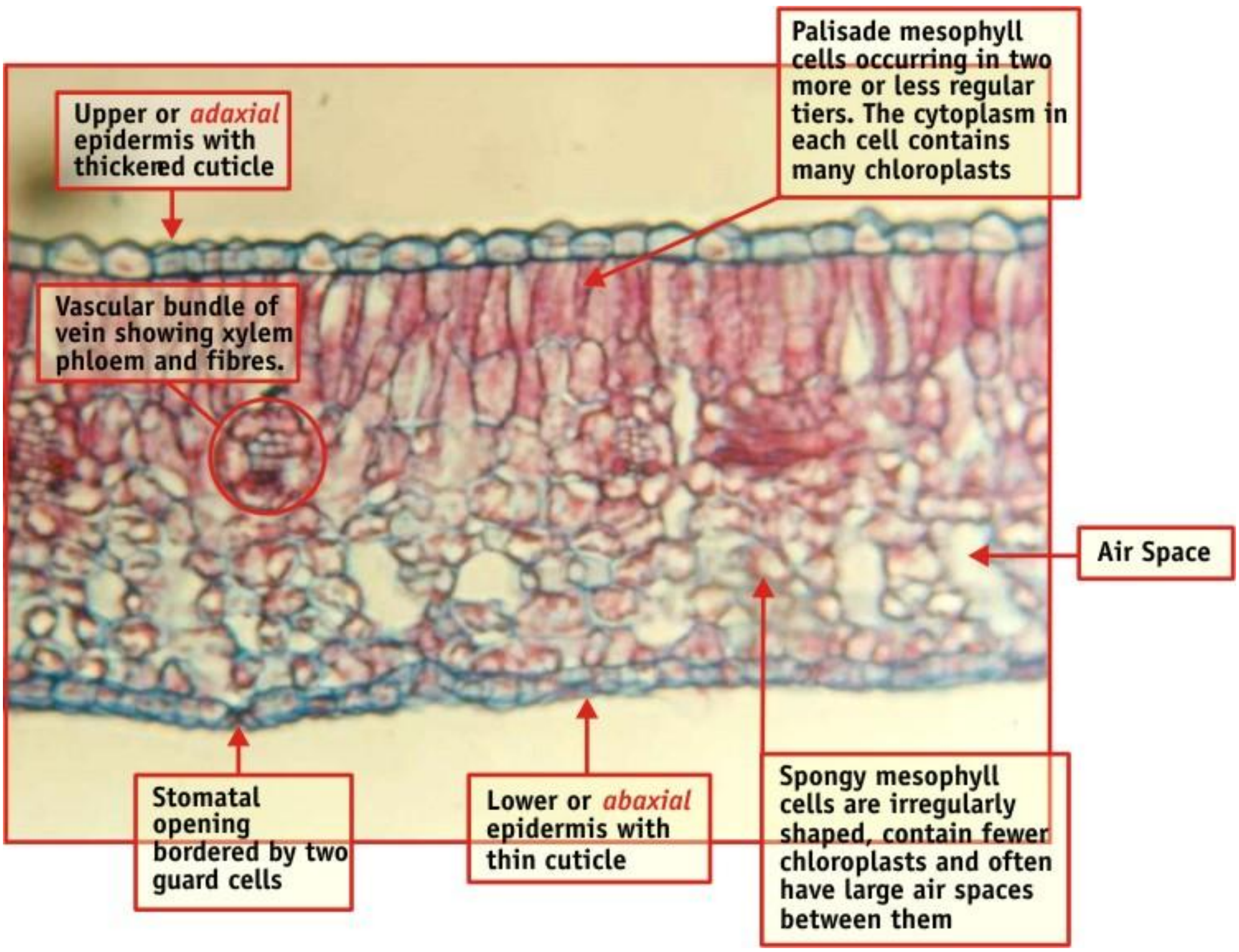


Figure 43: Internal structure of a mesomorphic privet leaf

Monocotyledon Leaf Structure

The leaves of monocotyledonous plants vary in form and structure. Some resemble the leaves of dicotyledonous plants and are differentiated into leaf blade and petiole.

The majority, however, have leaves differentiated into **blade** and **sheath**, as seen in grasses. The sheaths partially overlap younger leaves and conceal the growing point of the stem.

The leaf blade is usually narrow and the venation is typically parallel. Those leaf blades borne vertically are not differentiated into palisade and spongy mesophylls and are called **unifacial** or **iso-bilateral** leaves. *Iris* has a unifacial leaf.

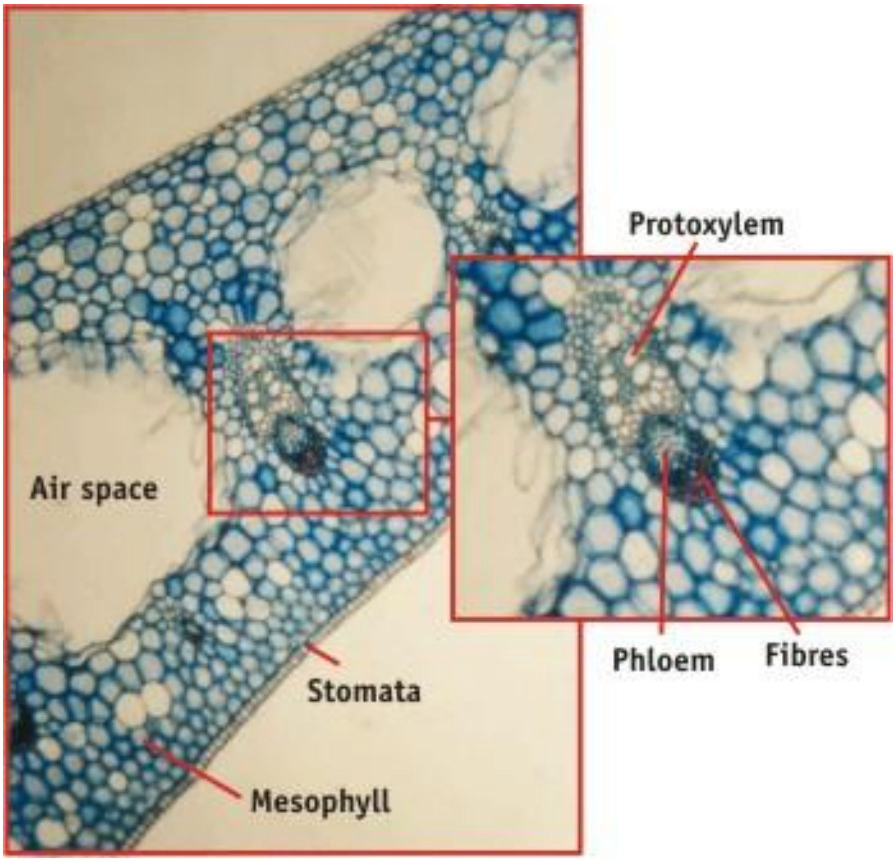


Figure 44: Internal structure of Leaf blade of *Iris sp*

Learning Activities

Now go and try the **'Dicot Leaf Anatomy Labelling Activity'** and the **'Plant Anatomy Quiz'** to check your knowledge of the layout and function of the tissues in the stem, root and leaf of Monocots and Dicots. You can also use the **'Myerscough Virtual Microscope'** to zoom in on real sections of plant tissue. You can find these in the Plant Cells and Anatomy 'Interactive Learning Activities' folder.

Making yourself a **'Plant Anatomy Glossary'** (outline table to use for this can be found at the end of this booklet) should help you to learn the terminology.

Plant Cell Glossary

This is a list of the **terms you need to know** in relation to cell structure. Filling in the definitions will help you to **learn them**.

Prokaryotic	
Eukaryotic	
Nucleus	
Cell Wall	
Plasmodesmata	
Plasmalemma	
Phospholipid bilayer	
Vacuole	
Tonoplast	
Cytoplasm	
Golgi apparatus	
Endoplasmic Reticulum	
Ribosome	
Mitochondria	
Chloroplast	

Plant Anatomy Glossary

Make yourself a list of **the terms that you need to know** in relation to plant internal structures. These are usually highlighted in **bold** in the text in this booklet. Filling in the definitions will help you to **learn them**.

Term	Definition