PLANT ANATOMY AND PHYSIOLOGY

Sean Bellairs
Charles Darwin University

LibreTexts™

Book: Plant Anatomy and Physiology (Bellairs)

The LibreTexts libraries are Powered by NICE CXOne and are supported by the Department of Education Open Textbook Pilot Project, the UC Davis Office of the Provost, the UC Davis Library, the California State University Affordable Learning Solutions Program, and Merlot. This material is based upon work supported by the National Science Foundation under Grant No. 1246120, 1525057, and 1413739.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation nor the US Department of Education.

This text was compiled on 01/01/2024

TABLE OF CONTENTS

Acknowledgements

The assistance of technical staff at the College of Engineering, IT and Environment, and of staff from the Innovative Media Production Studio at Charles Darwin University is acknowledged.

The many publishers of microscope images, diagrams, drawings and photos, who have made their work freely available to share for educational purposes online are also acknowledged.

Licensing

A detailed breakdown of this resource's licensing can be found in ***Back Matter/Detailed Licensing***.

Introduction

The structure and functioning of plants, even that of massive 100-metre tall trees, is dependent on the structure of, and processes occurring in, microscopic cells. In this book we look at the major organelles in cells, the range of cell types in plants and how they are combined into tissues to create functioning leaves and other organs.

Some cells are specialised for strength, others are specialised for protection, for storage, for gas exchange, for transport or for photosynthesis. These properties are assisted by differences in the construction of the cell walls, differences in the shapes of the cells and variation in organelle content.

We are introduced to the combining of cells to create plant tissues and tissue systems. The dermal tissue system provides protection for the exposed surfaces of the plant. It is specialised to allow gas exchange and control dehydration. The vascular tissue system allows long distance transport of water and nutrients from the roots to the shoots, and transport of sugars throughout the plant. The third tissue system, the ground tissue system, is important for photosynthesis and storage.

Tissue systems in turn create the stems, leaves, roots and reproductive organs of plants.

This book was created to support teaching of an introductory unit on plant environmental physiology at Charles Darwin University. It makes use of various images of cells and tissues to introduce and illustrate the range of plant organelles, cells, tissues and organs.

CHAPTER OVERVIEW

1: Inside a Plant Cell

1.1: Eukaryote cells

Plants have eukaryote cells. Compared to prokaryote cells, plant cells are larger and they have organelles. They have their DNA contained in a nucleus and photosynthesis occurs in chloroplasts. Like plant cells, animal cells are also eukaryote cells. Unlike animal cells, plant cells have a cell wall. The cell wall is made of cellulose but may be thickened and strengthened in some cells.

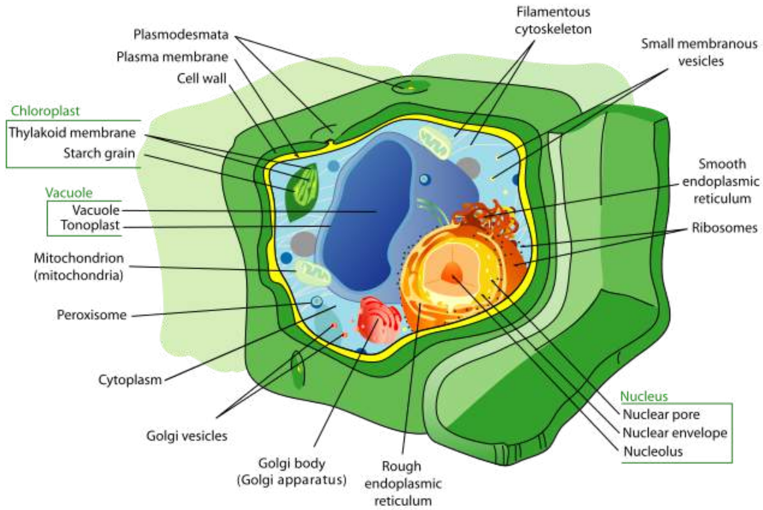


Figure 1.1. Features of a typical plant cell. (LadyofHats Mariana Ruiz. Public Domain)

A eukaryotic plant cell differs considerably from a prokaryotic cell of a bacteria or archaea. These are much simpler and smaller. Their DNA is found in a single chromosome and is not bound by a membrane. Similarly photosynthetic cyanobacteria do not have chloroplasts but rather photosynthesis occurs within the general cavity of the cell.

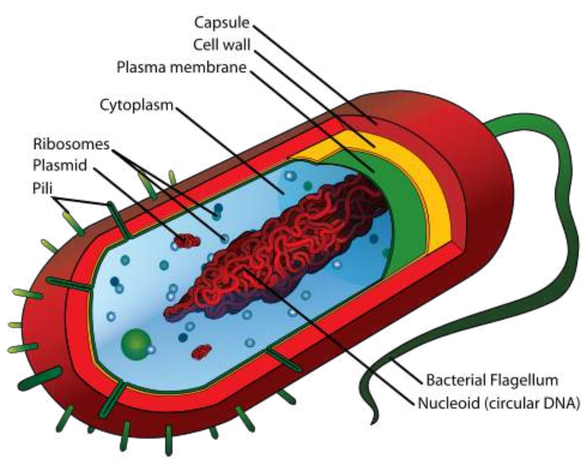


Figure 1.2. A diagram of a prokaryotic cell. It lacks organelles and is much smaller and simpler. (LadyofHats Mariana Ruiz. Public Domain).

1.2: Cell wall

The cell wall is initially deposited on the surface of the middle lamella. This primary cell wall occurs on the surface of all plant cells. It is substantially composed of cellulose molecules bundled together to form fibrils.

The primary cell wall is the only cell wall present in some cells. In other cells a secondary cell wall is deposited inside the primary cell wall. This secondary cell wall may contain lignin. Lignin makes the cell wall rigid and stronger. A cell membrane lies immediately adjacent to the cell wall, on the interior surface, and surrounds the contents of the cell.

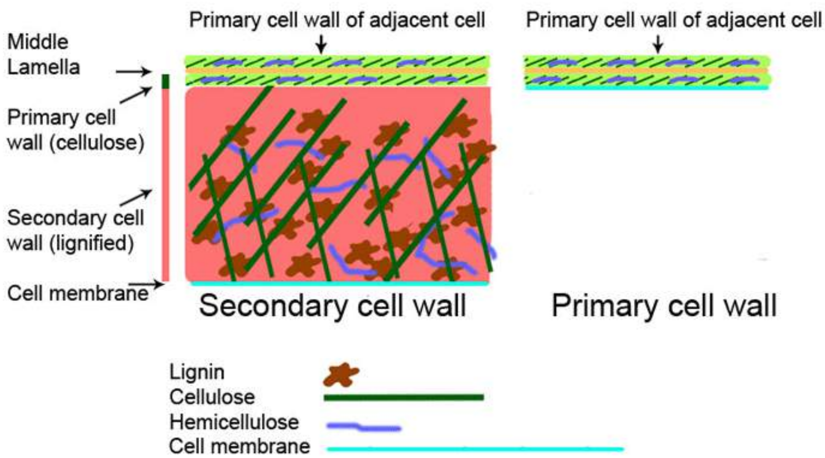


Figure 1.3. Diagrammatic structure of a primary cell wall (top) next to a secondary cell wall (lower left) and a primary cell wall (lower right). (Diagram Sean Bellairs CC: attribute, share alike).

To allow communication between cells there are membrane lined pores, or plasmodesmata, which run through the cell walls.

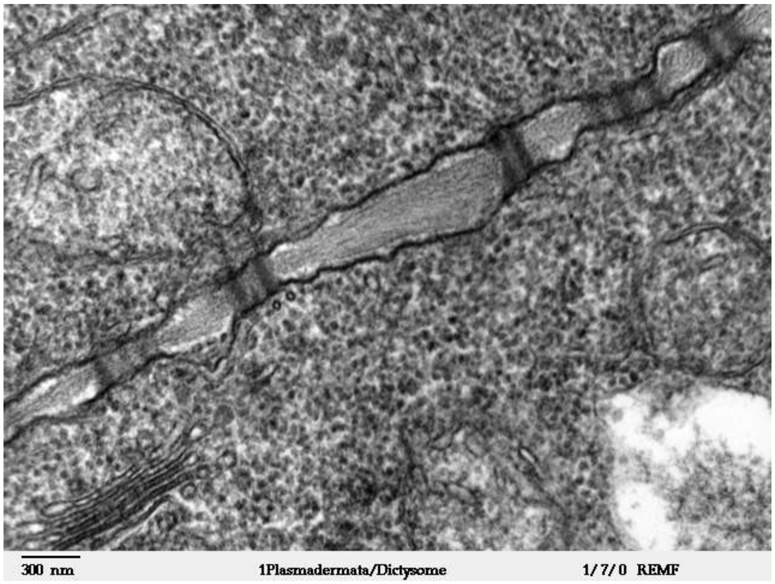


Figure 1.4. Plasmodesmata passing through the cell wall in a TEM of a *Coleus blumei* shoot apex. (Image: Louisa Howard, Charles Daghlian: public domain).

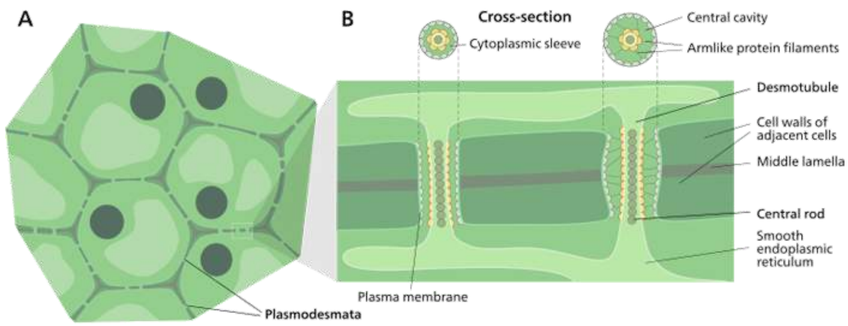


Figure 1.5. Diagram of a plasmodesmata connection between two cells. (Created by Zlir'a; English translation and recolouring by Kelvinsong (Kelvin Ma). Public Domain.)

1.3: Cell membrane

Immediately inside the cell wall there is a cell membrane surrounding the contents of the cell. It is made up of a phospholipid bilayer with proteins. The outer surface of the phospholipid layer is attracted by water (hydrophilic) whereas the tail of the phospholipid molecule is repelled by water (hydrophobic). The proteins may be embedded in the membrane or just attached to the surface. Some of the embedded protein molecules pass right through the membrane and are important for transport of substances through the membrane.

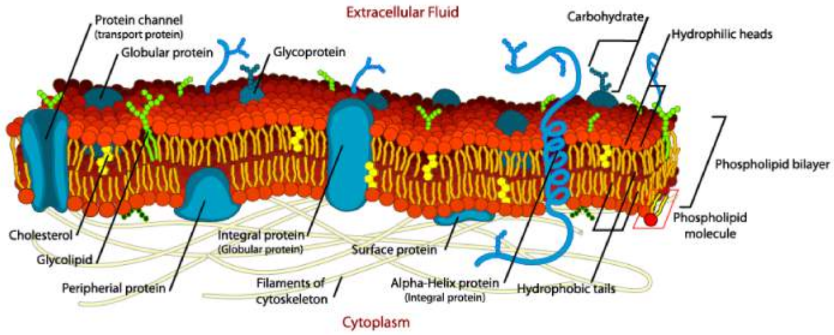


Figure 1.6. The cell membrane of a plant cell. (By LadyofHats Mariana Ruiz – Own work. Public Domain.)

Cell Membrane functioning

The cell membrane is important for compartmentalising different parts of the cell to allow metabolic functioning to occur and to control substances in the cell. It allows control of substances entering the cell and it allows the cell to compartmentalise waste into the vacuole. Oil droplets, vesicles from the golgi apparatus and vacuoles just have a single bilipid membrane around them. The nucleus, chloroplasts and mitochondria have a double bilipid membrane around them.

Diffusion

Diffusion is the process of random movement of molecules towards a state of equilibrium; the net movement is always from the direction of greater concentration to lesser concentration and in complex solutions, each substance moves independently of the other. Substances tend to diffuse until they are evenly distributed.

Small, non-polar molecules can pass through the lipid bilayer of a membrane by diffusing through it.

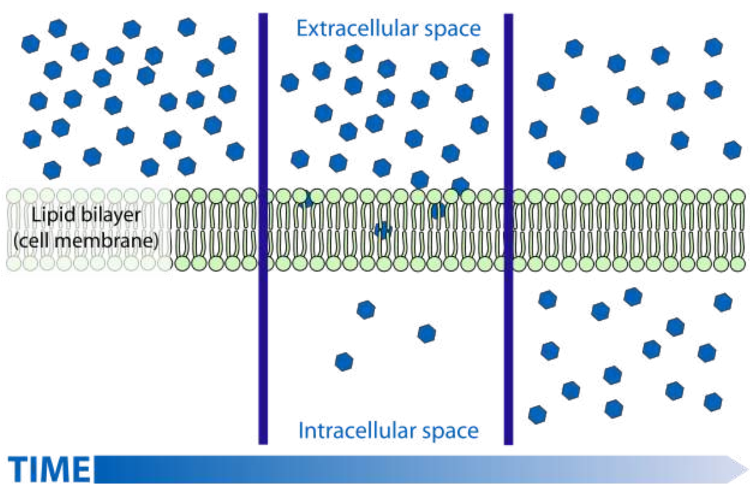


Figure 1.7. A diagram showing diffusion of a small non-polar molecule through a membrane. Diffusion results in the substance being at equal concentration on both sides of the membrane. (By LadyofHats Mariana Ruiz – Own work. Public Domain.)

Facilitated diffusion

Facilitated diffusion also involves molecule movement down a concentration gradient until the concentration of molecules are equal on both sides of the membrane. However in this case the solute molecules do not move through the membrane on their own.

They combine with a carrier molecule in the membrane which allows the solute molecule to pass through the membrane. No energy is used and they pass through the carrier protein until the concentration is the same on both sides of the membrane.

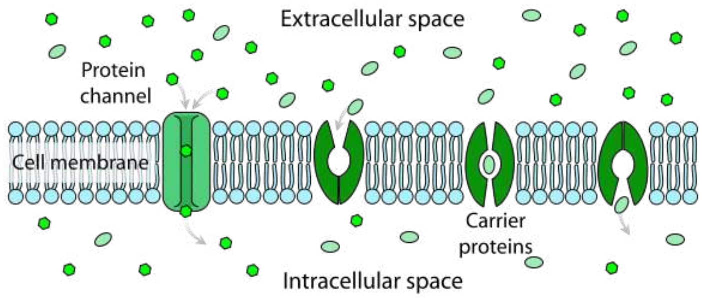


Figure 1.8. A diagram showing a molecule passing through a membrane passively using protein channels or carrier proteins. This occurs until the substance is at equal concentration on both sides of the membrane. (By LadyofHats Mariana Ruiz – Own work. Public Domain.)

Active transport

Active transport is different from the other transport processes above in that it involves transport of a solute against a concentration gradient (i.e. from an area of low concentration to one of higher concentration). This process relies on carrier molecules but also requires energy as it forces molecules to move against the concentration gradient. Energy comes from the energy storage molecule ATP and is generated through cellular respiration.

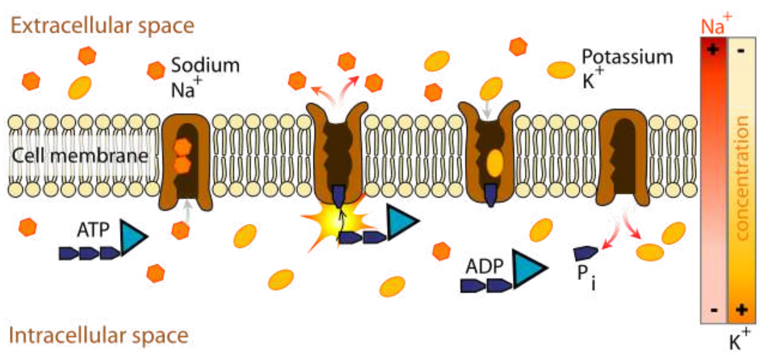


Figure 1.9. Sodium ions passing through a membrane by active transport through a protein using energy supplied by ATP. This is used to concentrate the substance one side of the membrane. (By LadyofHats Mariana Ruiz – Own work. Public Domain.)

Active transport may also be indirect. In the figure below the sodium ions have been concentrated above the membrane. The sodium ions seek to equilibrate the concentration each side of the membrane but for the sodium ions to travel though the membrane, the protein carrier requires an amino acid be attached and pumped in the opposite direction. Thus actively concentrating the sodium ions then results in transport of the amino acids indirectly as the sodium ions move down the concentration gradient.

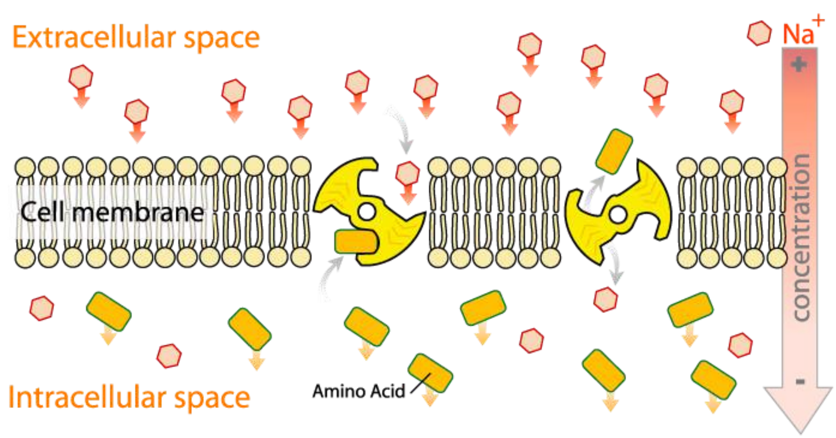


Figure 1.10. Indirect active transport due to a active transport achieving a high sodium concentration. (By LadyofHats Mariana Ruiz – Own work. Public Domain.)

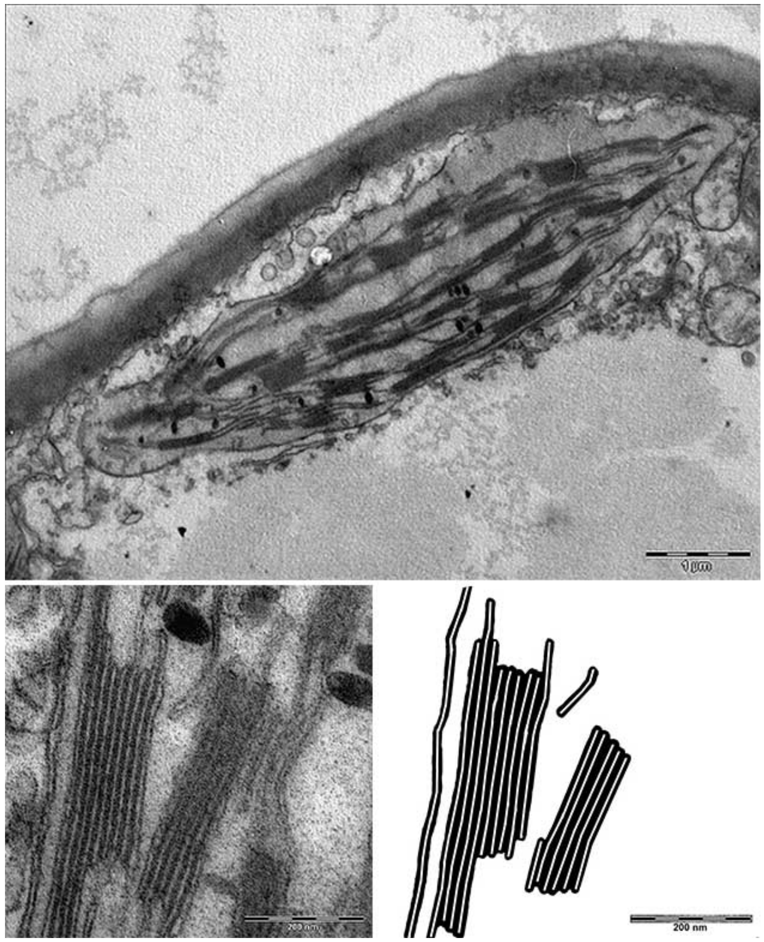


Figure 1.11. Membrane structures in plants can be very complex, such as in this Transmission Electron Microscope (TEM) image of a chloroplast (top). The expanded detail (bottom left) shows the stacks of pancake shaped membranes shown in cross section, as outlined (bottom right). (TEM images Bela Hausmann CC2.0; Diagram of membranes Sean Bellairs (CC: attribute, share alike).)

1.4: The nucleus

The nucleus is the control centre of the cell and is often the largest organelle in the cell. It contains about 20% ribonucleic acid (RNA) and 20% deoxyribonucleic acid (DNA). It has four parts: **nuclear envelope** (membrane), **nucleoplasm**, **nucleolus** and **chromosomes** or **chromatin**.

The nuclear envelope is a double membrane that surrounds the nucleus. It contains pores that allow rapid communication between the cytoplasm of the cell and the nucleoplasm.

Nucleoplasm is similar to the cytoplasm of the cell but contains more protein macromolecules and appears darker than the cytoplasm.

The nucleolus is a roughly spherical body consisting of a mass of fine threads and particles of RNA, proteins and DNA. Its major role is the synthesis of ribosomal RNA.

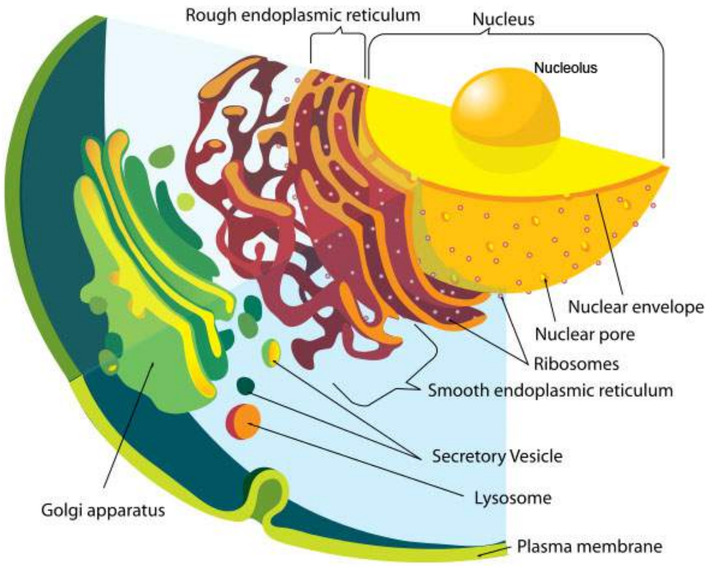


Figure 1.12. Nucleus of a cell showing the nucleolus in the centre of the nucleus, and the nuclear membrane. The nuclear membrane has numerous pores to allow communication with the rest of the cell. It is also connected to the rough endoplasmic reticulum membrane system. Beyond the rough endoplasmic reticulum is the smooth endoplasmic reticulum. (Diagram by LadyofHats Mariana Ruiz – Own work. Public Domain.)

1.5: Chromosomes and chromatin

The DNA is usually dispersed in the nucleus as chromatin, but during mitosis and meiosis it becomes condensed and forms into a number of approximately cylindrical structures, the chromosomes.

Chromosomes are the DNA-containing structures of eukaryotic nuclei that form during the process of cell division.

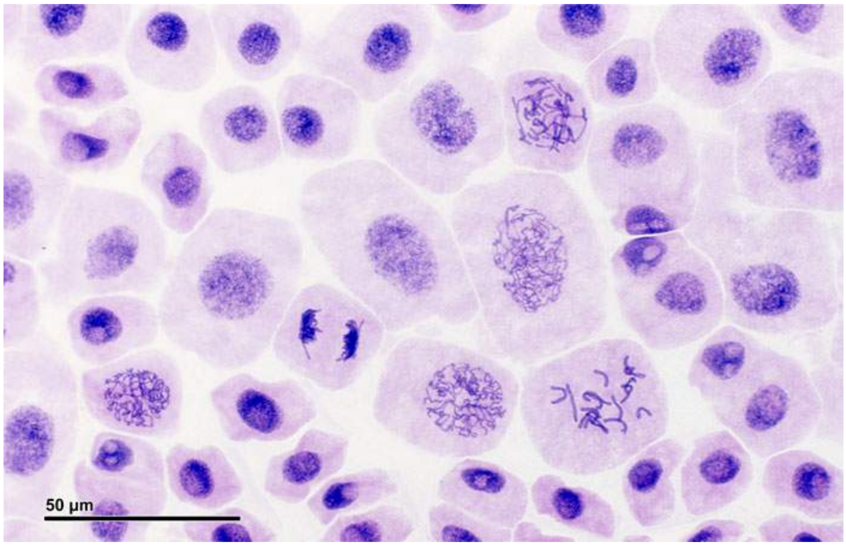


Figure 1.13. Chromosomes formed during mitosis. (Image: Josef Reischig CC 3.0 attribute, share alike)

1.6: Chloroplasts

Chloroplasts are large organelles and their function is the formation and storage of carbohydrates from photosynthesis. The chloroplast is bounded by a double membrane.

The matrix of the chloroplast is known as the **stroma**. Also inside the chloroplast are separate internal membranes that form lamellae or rounded tongue-like **thylakoids** within the enclosing double membrane. These tongue-like or disk-like thylakoid membranes may be stacked in layers and these are referred to as **grana**. Grana are joined to each other by other membranes.

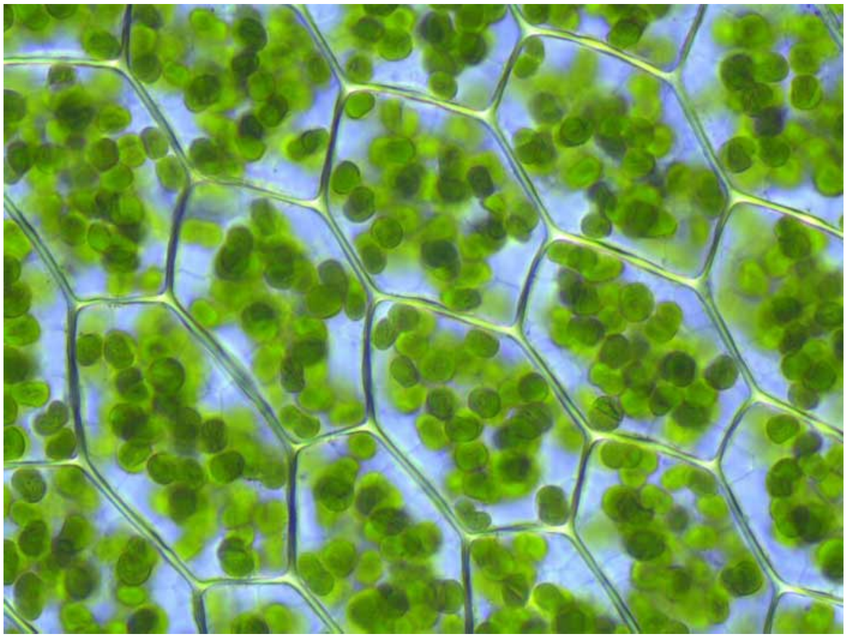


Figure 1.14. Chloroplasts in the leaf cell of a moss, *Plagiomnium affine*. (Image: Kristian Peters, CC 3.0 attribute, share alike)

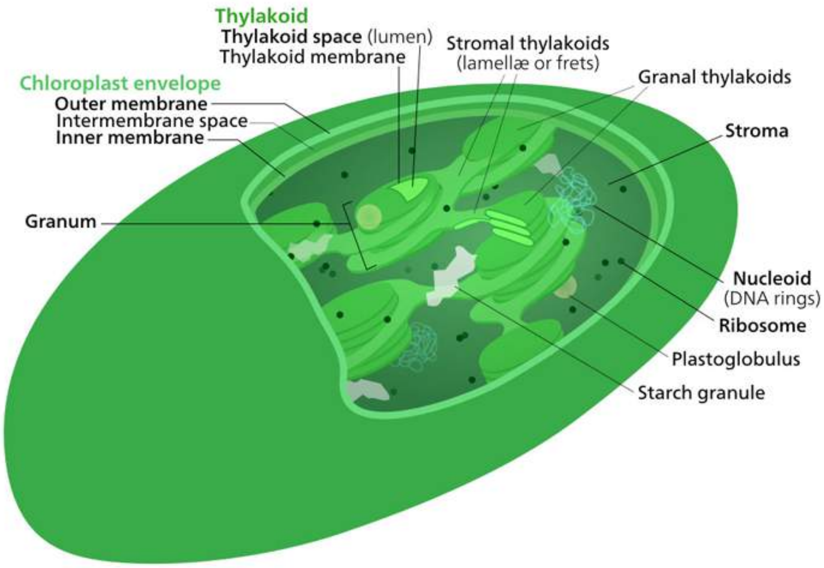


Figure 1.15. Internal membrane structure within a chloroplast. (Kelvinsong CC BY-SA 3.0).

There are a range of other organelles which are similar to chloroplasts that are used for storage and pigmentation.

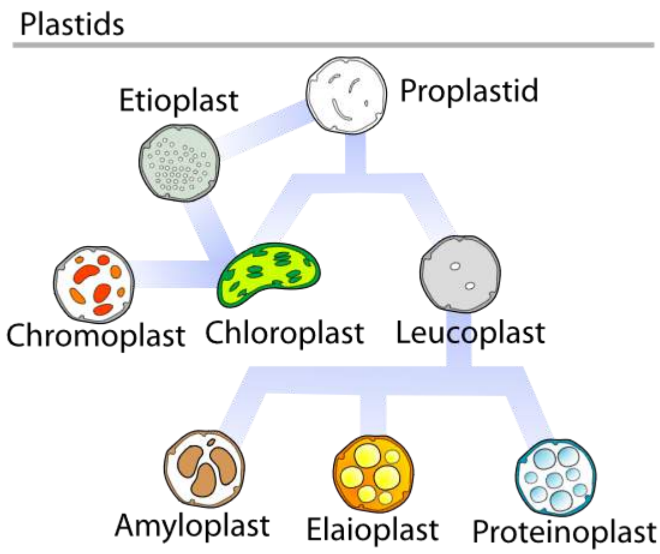


Figure 1.16. Other plastids in a plant cell. Chromoplasts contain colour pigments, whereas other plastids are used for storage. (By Mariana Ruiz Villarreal LadyofHats, Public Domain).

1.7: Mitochondria

Mitochondria are the major site of ATP and energy production in plants and animals. Numbers vary from 20 to 100,000 per cell and they vary in form and activity.

Mitochondria are double-membraned organelles (like the nucleus) so are said to be surrounded by an envelope. The outer membrane (**matrix**) is very elastic, the inner is folded many times (**christae**) and protrudes into the internal cavity.

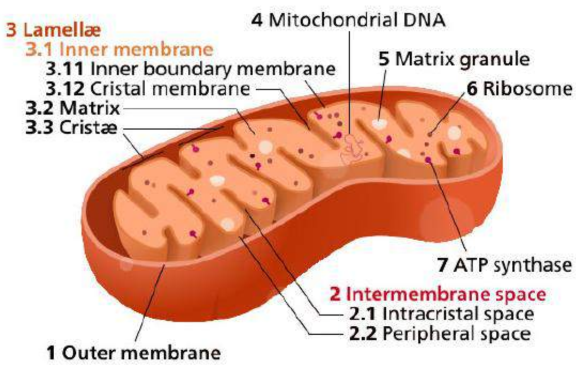


Figure 1.17. Diagram and transmission electron micrograph of mitochondria. (Diagram by Kelvinsong, public domain; TEM Louisa Howard, Dartmouth College public domain).

1.8: Endoplasmic reticulum

The endoplasmic reticulum (ER) is a complex system of membranes, tubules, cisternae and vesicles, appearing in two types: smooth and rough ER. Smooth ER is comprised of interconnected vesicles and cisternae that do not contain ribosomes. Smooth ER is involved in sterol biosynthesis, detoxification reactions and fatty acid desaturation. Rough ER membranes are associated with ribosomes attached to the outer surface of the membrane. Rough ER has a role in protein biosynthesis and are the sites where amino acids are assembled in a specific sequence to produce polypeptide chains.

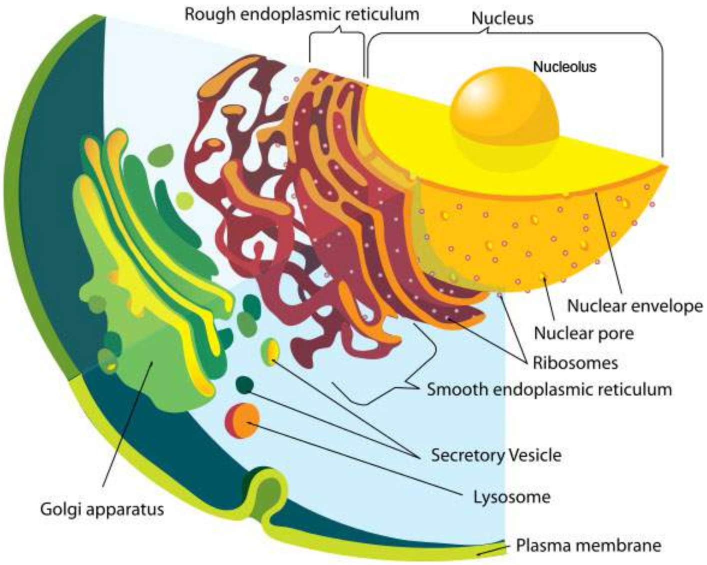


Figure 1.18. Diagram of the endoplasmic reticulum showing the rough endoplasmic reticulum membrane system containing ribosomes and beyond the rough endoplasmic reticulum is the smooth endoplasmic reticulum without ribosomes. (Diagram by LadyofHats Mariana Ruiz – Public Domain.)

1.9: Ribosomes

Ribosomes occur free in the cytoplasm and also attached to membranes of the ER. Ribosomes contain RNA. They temporarily bind to two other types of RNA molecules (messenger and transfer RNA) when amino acids are assembled to form proteins.

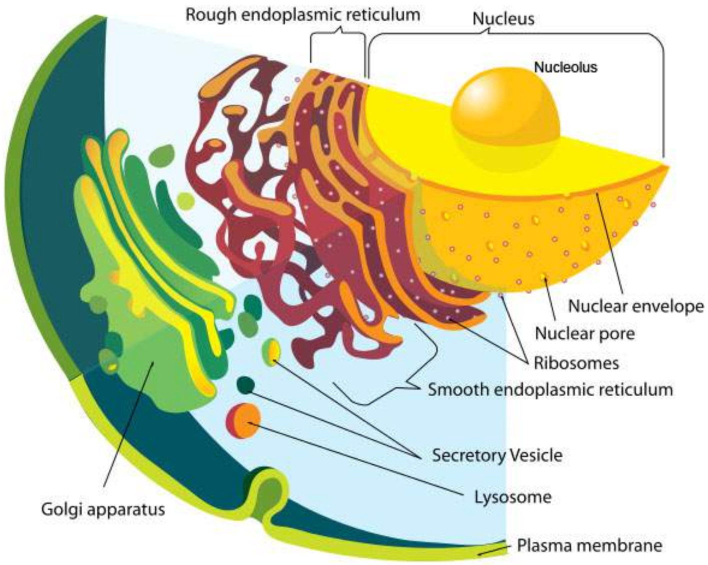
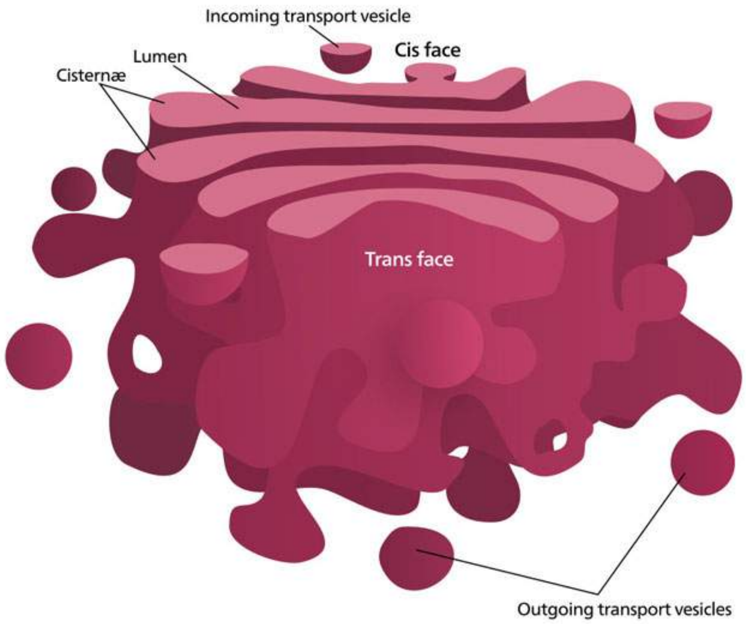


Figure 1.18 but note the ribosomes attached to the rough endoplasmic reticulum. (Diagram by LadyofHats Mariana Ruiz – Public Domain.). (Diagram by LadyofHats Mariana Ruiz – Public Domain.)

1.10: Golgi apparatus

The golgi apparatus is a stack of smooth **cisternae** (membrane-bound spaces) piled on each other. These flattened plate-like membrane-bound sacs contain tubules and have vesicles protruding from their margins. Vesicles bud off from the tubules and contain materials for cell wall construction. There is a maturing face and a forming face to the golgi body. New cisternae are added to the forming face and as they mature they move progressively across the stack. At the mature face, cisternae are swollen and secretory vesicles are shed. Once the vesicle detaches from the Golgi body (presumably after reaching a critical size) they move across the cytoplasm to the cell membrane and the material is discharged. The membrane of the vesicle ruptures and becomes continuous with the plasmalemma and the contents are released outside of the cell. Vesicles may also fuse with vacuoles.



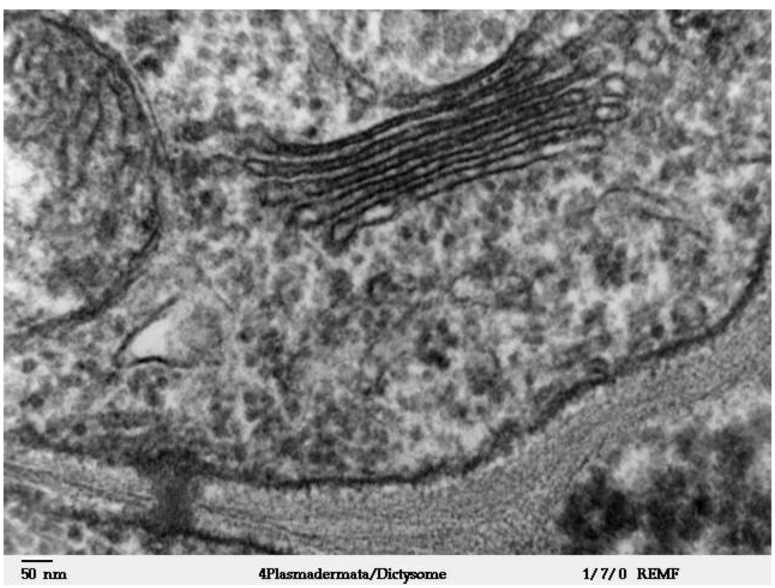


Figure 1.19. Golgi apparatus showing central membrane bound structure and the vesicles surrounded by a single membrane. (Diagram by Kelvinsong (CC BY-SA 3.0) and transmission electron micrograph courtesy of Louisa Howard, Dartmouth College (public domain).)

1.11: Vacuoles

Vacuoles are used for compartmentalising cellular contents and for controlling some waste products. They are also important for maintaining cell turgor and for cell expansion. The tonoplast is the membrane that surrounds the vacuole and controls movement of substances into and out of the vacuole.

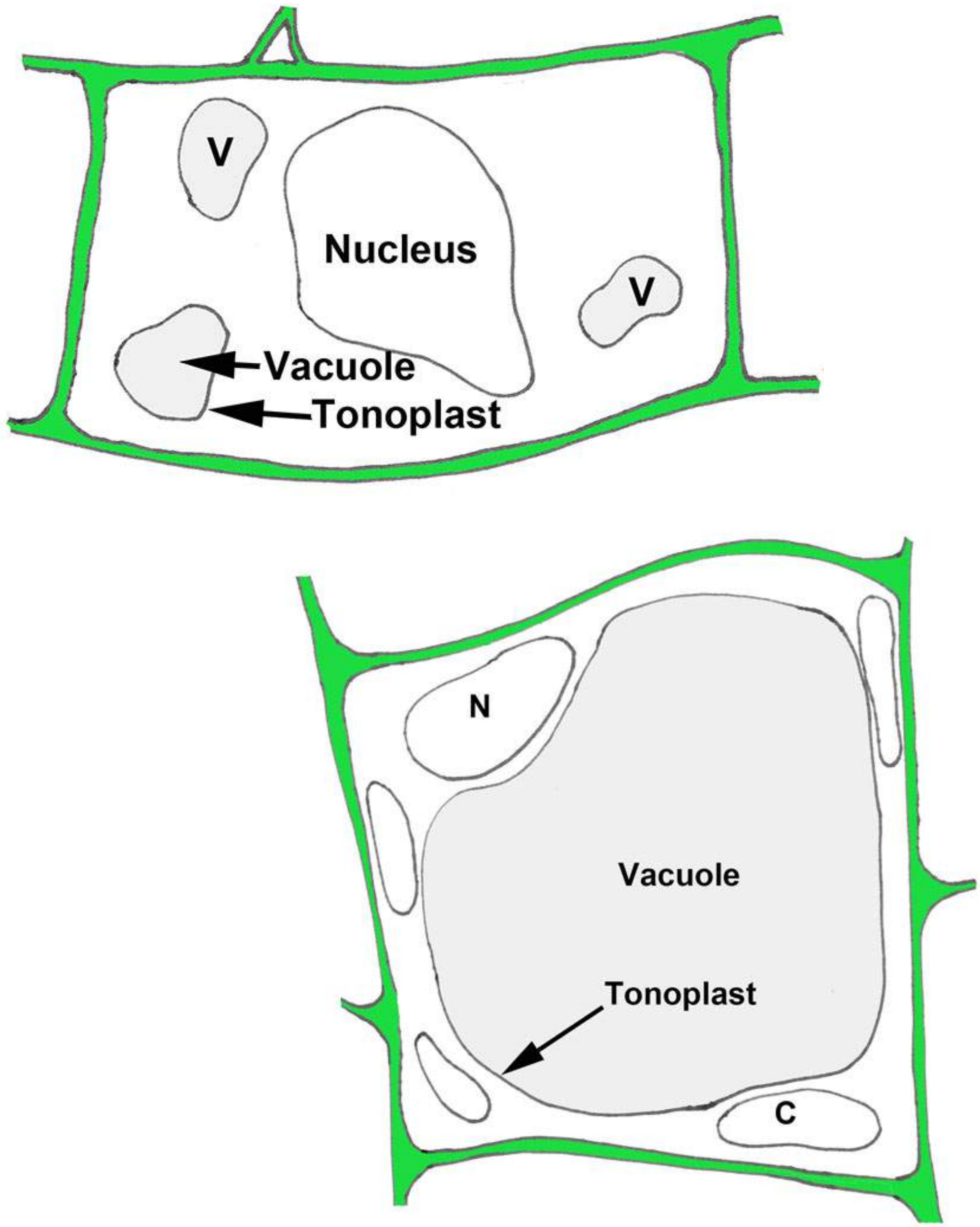


Figure 1.20. Diagram of a cell with multiple small vacuoles (above) and a large central vacuole (below). The vacuole is surrounded by the tonoplast membrane. (C = chloroplast, N = nucleus) (Images created by Sean Bellairs, attribute, share alike).

CHAPTER OVERVIEW

2: Plant Cells and Meristems

2.1: Development of a plant

The apical meristem produces new cells by cell division. These small squat cells divide and expand in size. They then differentiate into all the various cell types of the plant.

The great variety of cell types in a plant can be divided into three broad tissue systems: the dermal, vascular and ground tissue systems.

Tissue systems

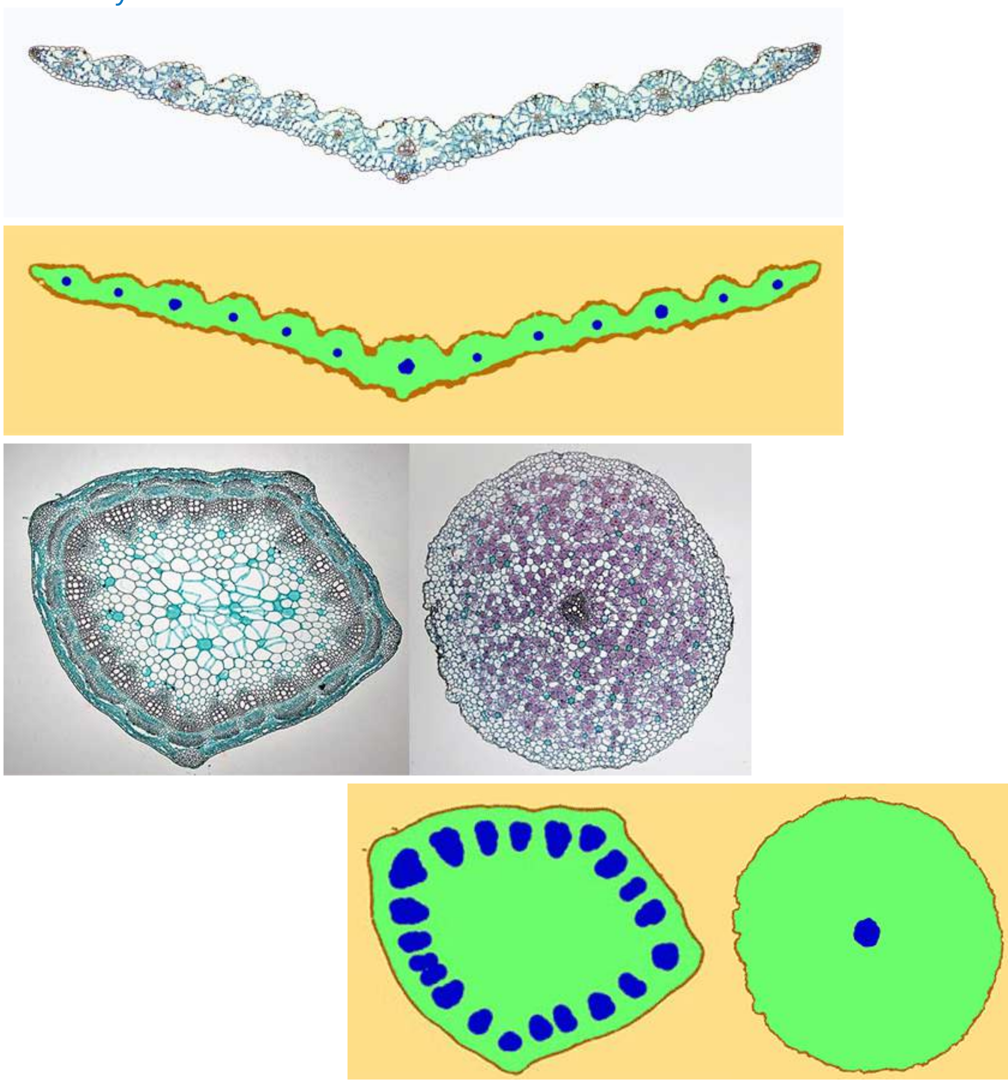


Figure 2.1 Diagrams showing the three tissue systems: dermal (dark brown), ground (green) and vascular (blue) in a leaf (top), stem (left) and root (right). Lignified cells have red cell walls and cells with primary growth have blue/green cell walls. (Micrographs of *Triticum leaf* (BlueRidgeKitties (attributed, share alike), *Trifolium* stem and *Ranunculus* root (Berkshire Community College Bioscience Image Library, public domain). Diagrams by Sean Bellairs CC: attribute, share alike).

Meristems and growth

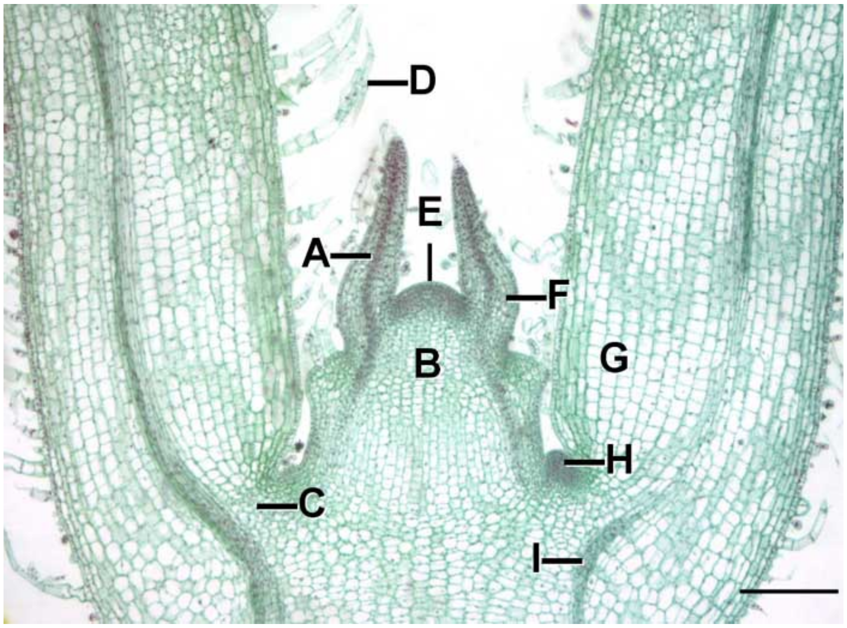
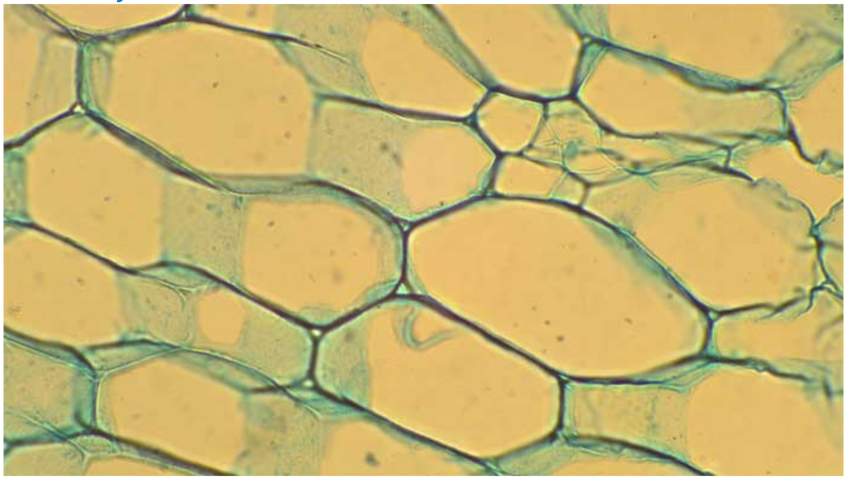


Figure 2.2 Apical meristem of Coleus. A and I =Procambium, B=Ground meristem, C=Leaf gap, D=Trichome, E=Apical meristem, F=Developing leaf primordia, G=Leaf Primordium, H=Axillary bud. Scale bar bottom right = 0.2mm. (Jon Houseman and Matthew Ford [CC BY-SA 4.0]).

2.2: Ground tissues

The main tissue types of the ground tissue system are parenchyma, collenchyma and sclerenchyma. Parenchyma have thin walls of cellulose, whereas collenchyma have cell walls with thickened areas of additional cellulose. Sclerenchyma cells have lignified cell walls. They can be further categorised into narrow long cells (fibers) and cells of various other shapes (sclereids).

Parenchyma



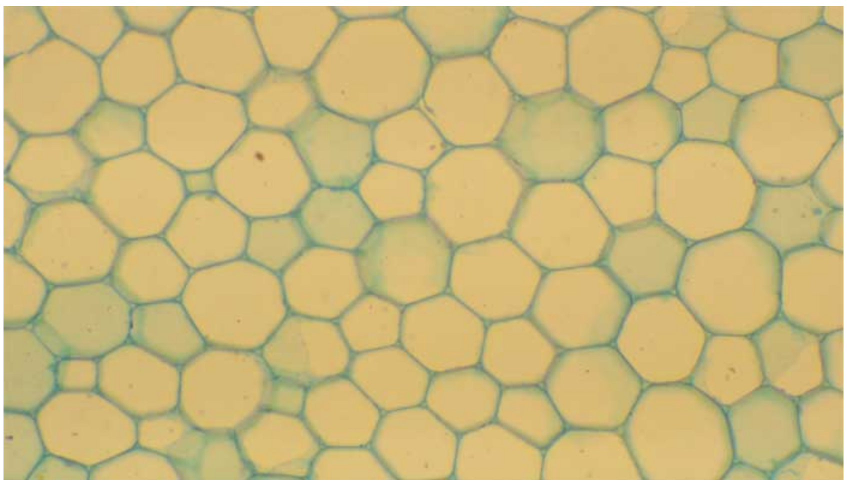


Figure 2.3. Parenchyma cells with blue green thin cellulose cell walls. (Sean Bellairs CC: attribute, share alike).

When parenchyma cells are modified to create tissues with air spaces for buoyancy or aeration of tissues, then the tissue is described as aerenchyma rather than parenchyma.

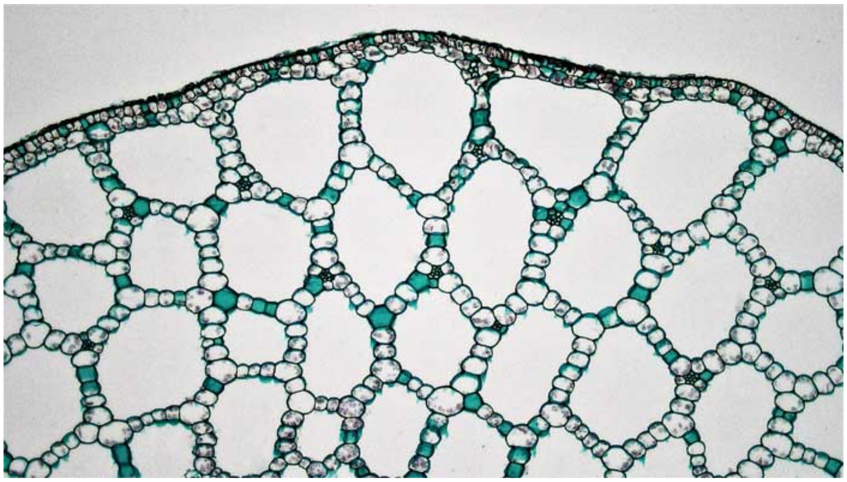


Figure 2.4. Aerenchyma in the stem of the aquatic monocot *Potamogeton*. Large air spaces can be seen between the cells of the cortex. There is a single layer of epidermal cells and behind that a single layer of cortical parenchyma cells, then aerenchyma tissue for buoyancy and movement of oxygen to the submerged tissues (Berkshire Community College Bioscience Image Library, public domain).

Collenchyma

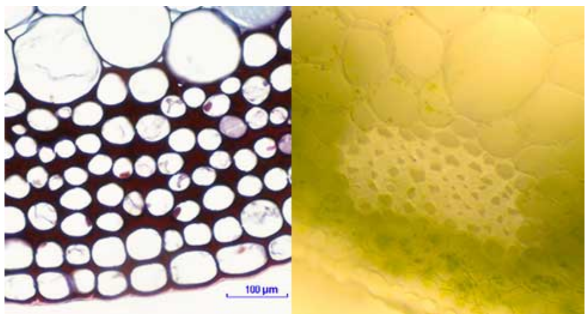


Figure 2.5. Collenchyma cells of *Fraxinus* (left). Upper cells are parenchyma, collenchyma with large dark cell walls and squat rectangular dermal cells at lower surface. (Jen Dixon (CC BY-NC-SA 2.0)). Collenchyma cells in celery (right) that are unstained and have large white cell walls (Sean Bellairs CC: attribute, share alike).

Sclerenchyma

Sclerenchyma cells have lignified cell walls. They can be of two broad types: sclereids and fiber cells.

2.2.3.1 Sclereids

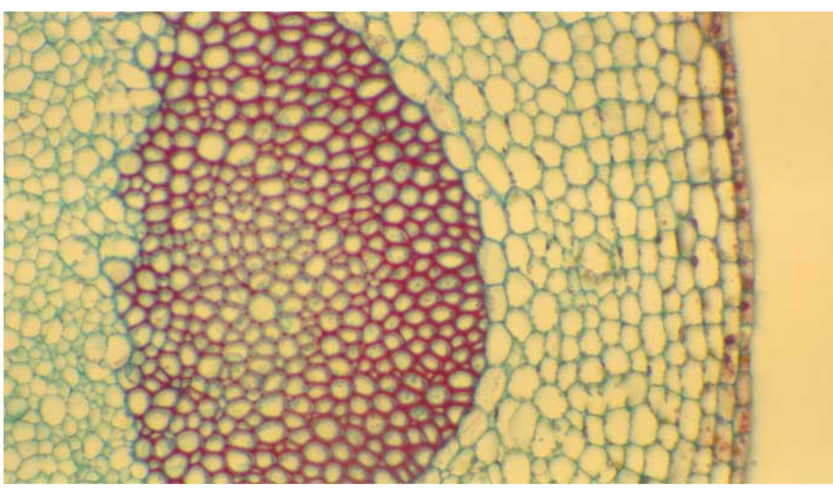


Figure 2.6. Sclerenchyma cells with thick cells walls that are stained red due to lignin in the cell walls. (Sean Bellairs CC: attribute, share alike)

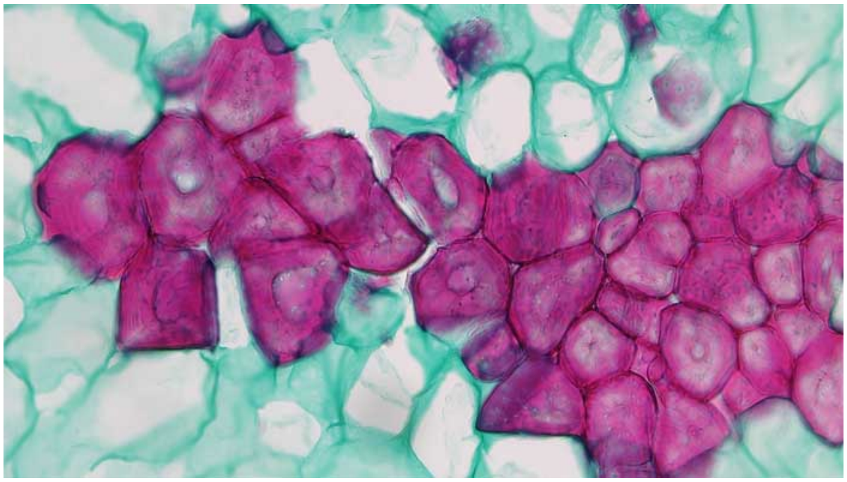


Figure 2.6. Sclereid cells or stone cells in the pear fruit. The sclereid cells have thick red stained cell walls are surrounded by blue green stained parenchyma cells. (Berkshire Community College Bioscience Image Library, public domain).

2.2.3.2 Fibers

Fiber cells are sclerenchyma cells that are long and thin.

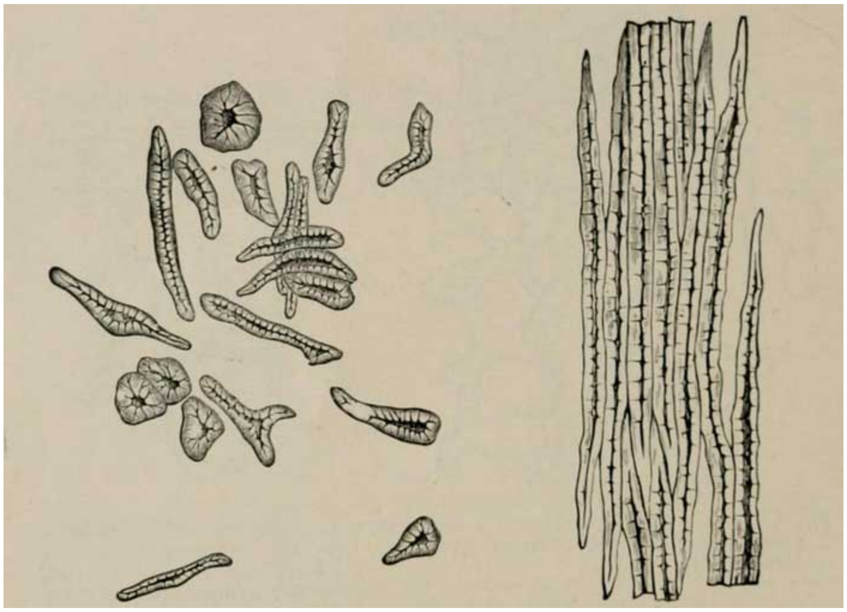


Figure 2.7. Drawings of stone cells from the coconut shell and fiber cells from the bark of *Sambucus nigra*. (Source: Winton, A.L., Moeller, J., Winton, K.G.B (1916) The microscopy of vegetable foods, with special reference to the detection of adulteration and the diagnosis of mixtures. New York, John Wiley & Sons: not copyright).

2.3: Vascular tissues and cell types

There are two vascular tissues in the vascular tissue system: xylem for water transport and phloem for transport of photosynthates.

Xylem

The xylem is a complex tissue containing a range of cell types including: vessel cells, tracheids, fibers, parenchyma

2.3.1.1 Vessel members

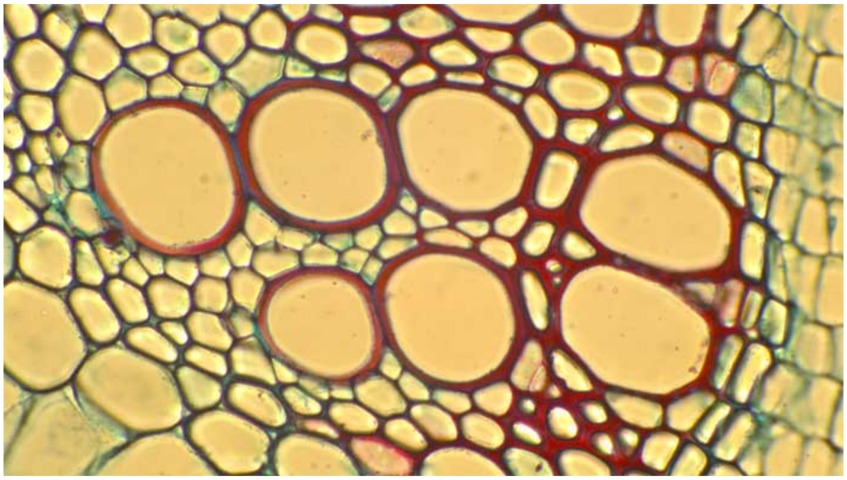


Figure 2.8. Large xylem vessel cells with thick red-stained lignified cell walls. Xylem parenchyma adjacent to the cells have blue green cell walls (Sean Bellairs CC: attribute, share alike).

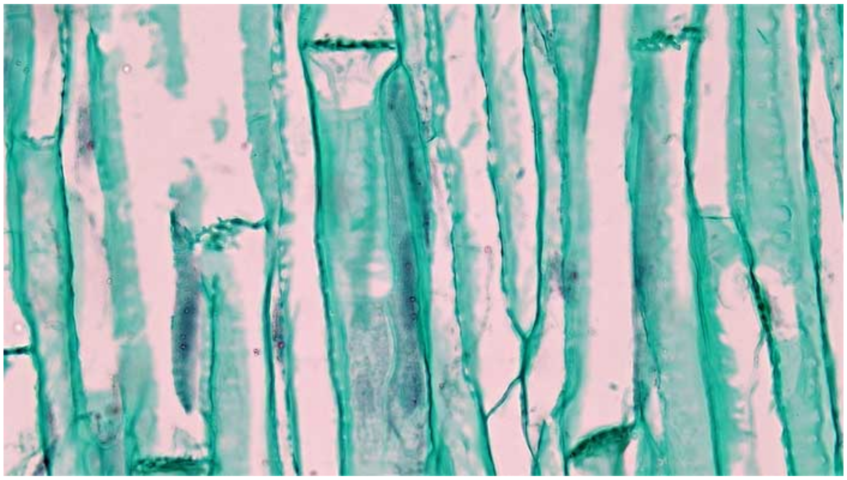
Figure 2.9. Xylem vessel cells with annular lignification in Coleus (left), annular and (centre) and reticulate lignification in corn (right). (Images by Berkshire Community College Bioscience Image Library (public domain); Sean Bellairs (CC: attribute, share alike); BlueRidgeKitties (CC attribute, share alike)).

2.3.1.2 Tracheids

Figure 2.10. Tracheids in tangential section in *Quercus* (oak). Long cells with oblique end walls and round pits in the walls are tracheids. Small round cells are lines of ray parenchyma with cellulose cell walls. Wide cell on lower right is a vessel cell. (Images: Berkshire Community College Bioscience Image Library, public domain).

Phloem

2.3.2.1 Sieve cells and companion cells



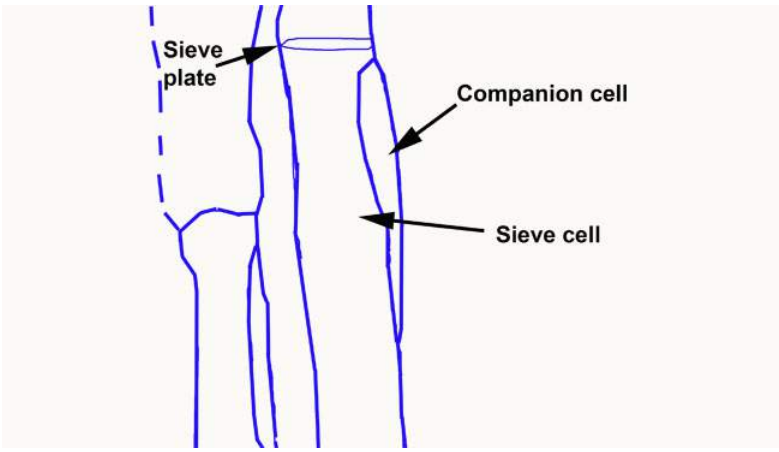


Figure 2.12. Phloem tissue in LS including sieve cells and companion cells (Berkshire Community College Bioscience Image Library, public domain). Diagram shows location of a narrow companion cell alongside a sieve cell and the sieve plate connecting two of the sieve cells (Sean Bellairs CC: attribute, share alike).

Procambium cell development

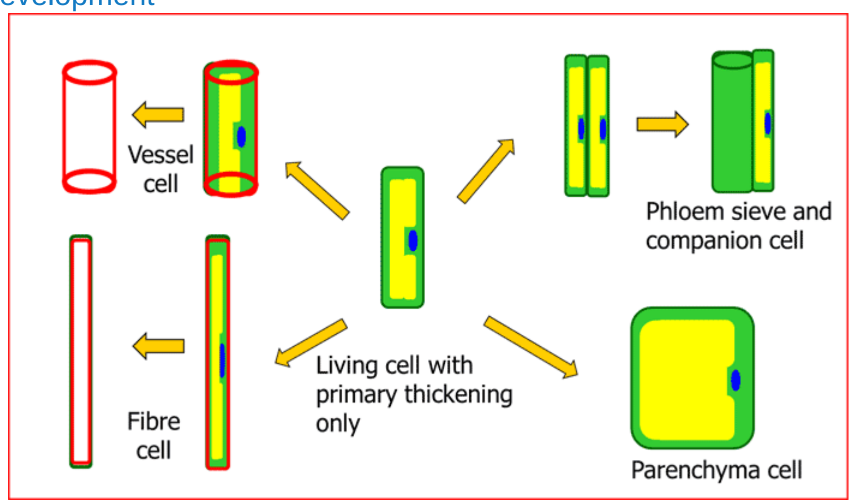


Figure 2.12. Development of a procambium cell into various vascular tissue cell types. (Sean Bellairs CC: attribute, share alike).

2.4: Dermal tissues and features

The dermal tissue is largely composed of squat more or less cubic dermal cells, but it also contains specialist guard cells around the stomata, and various trichomes and root hairs.

Cuticle

The cuticle is a layer of cutin and waxes external to and embedded in the cell wall on the exterior surface of the plant on stems and leaves.

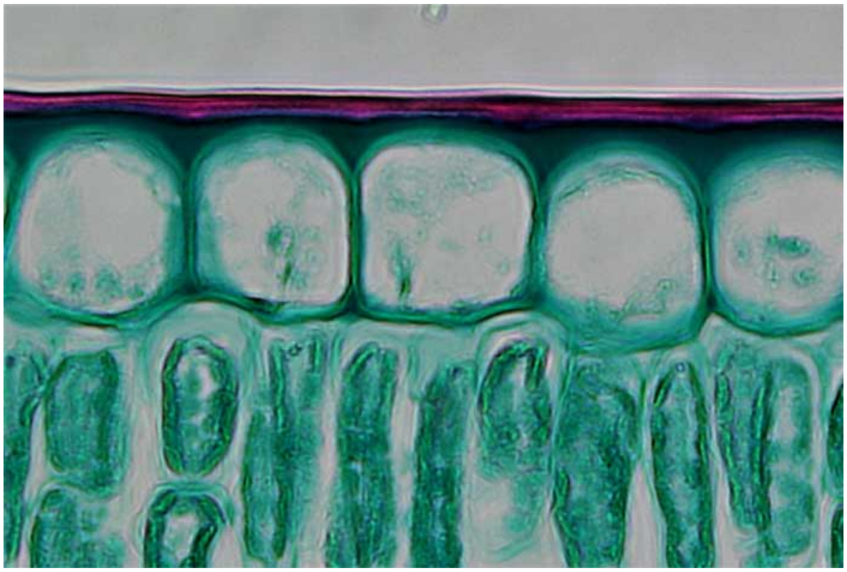


Figure 2.14. Cuticle (red stained) and the underlying square dermal cells on the upper surface of a mesophyte leaf. (Berkshire Community College Bioscience Image Library, public domain).

Stomata, guard cells and trichomes

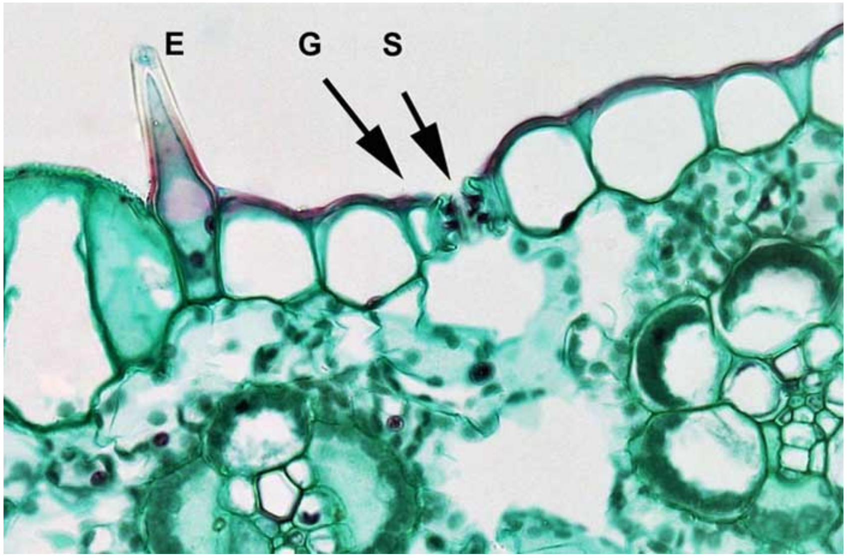


Figure 2.15. Stoma (S), (plural stomata) on the upper surface of a mesophyte leaf, in the middle of two guard cells (G). An epidermal hair or trichome can also be seen (E). (Berkshire Community College Bioscience Image Library, public domain).

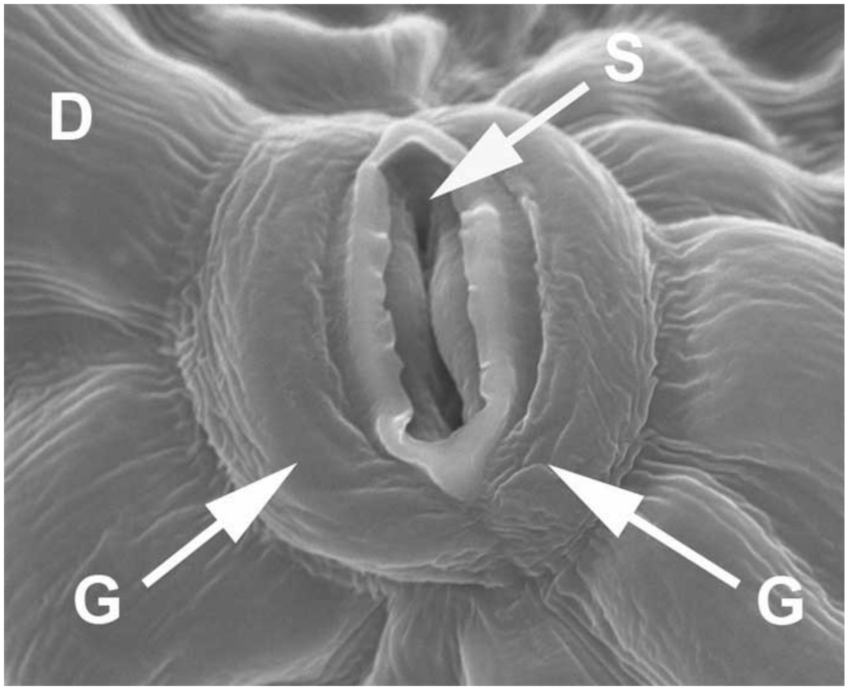


Figure 2.16. Stomate on the surface of a sunflower leaf (Louisa Howard, Dartmouth College; Public Domain; modified with labels by Sean Bellairs).

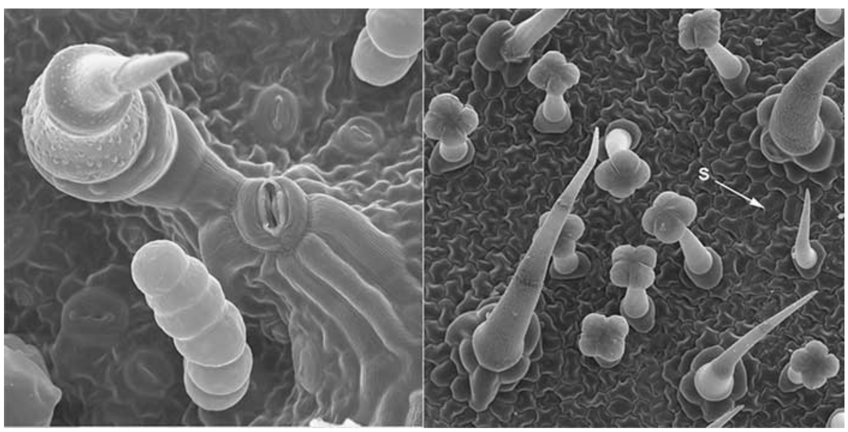


Figure 2.17. Trichomes and stomata on the surface of a sunflower leaf (left) and tomato leaf (right) (Louisa Howard, Dartmouth College; Public Domain).

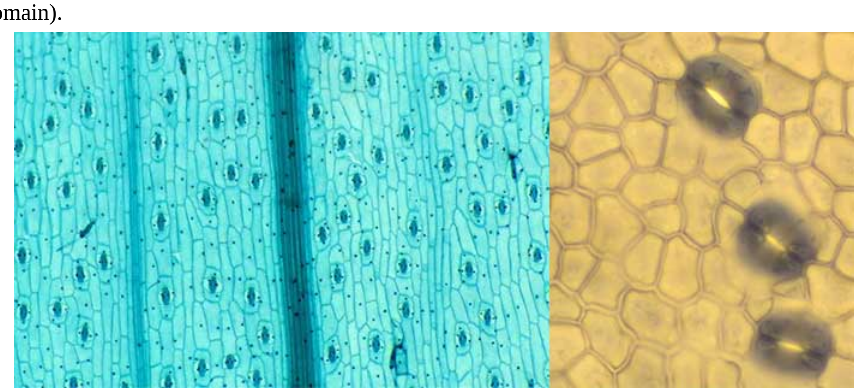


Figure 2.17. Stomata across the surface of the epidermis of a leaf of two plant species (Left – *Tradescantia pallida* by BlueRidgeKitties (CC: attribute, share alike); Right – Sean Bellairs (CC: attribute, share alike)).

2.5: Secondary tissues

Secondary tissues are produced in woody plants. Secondary xylem and secondary phloem are produced from a cylinder of meristematic tissue within the woody stems and roots. This cylinder of meristematic tissue is the vascular cambium. The secondary xylem provides additional structural support and additional water conduction tissue in shrubs and trees. The secondary phloem replaces the primary phloem.

Similarly, as the trunk of a woody plant gets larger, the dermal tissue need to be expanded and replaced. New dermal tissue is produced by the cork cambium, which lies beneath the bark.

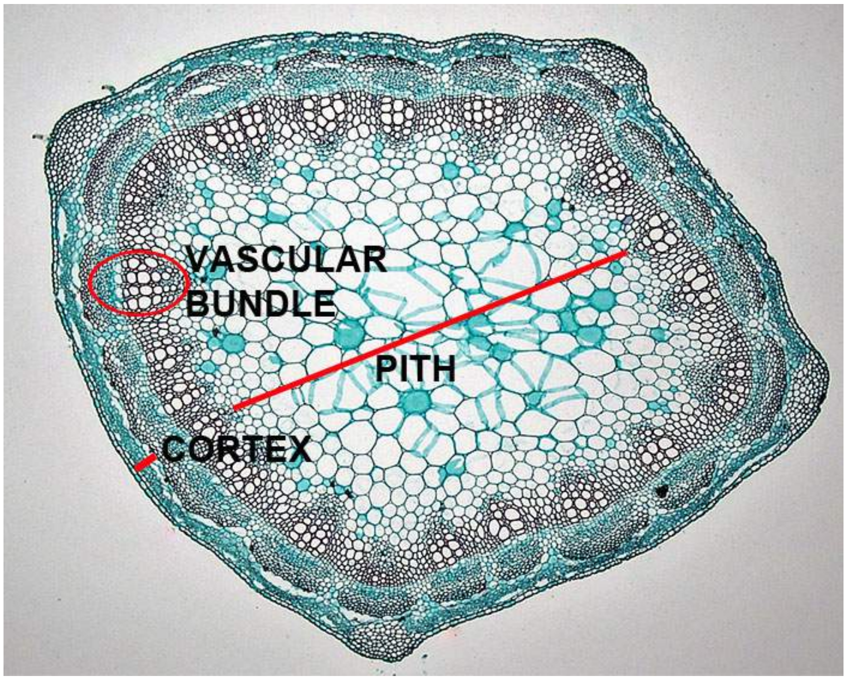


Figure 2.18. Stem of a dicotyledon plant with only primary tissues. The ground tissue system includes the pith and cortex and the vascular tissue system is in discrete bundles. (Background image, Berkshire Community College Bioscience Image Library, public domain. Labels Sean Bellairs).

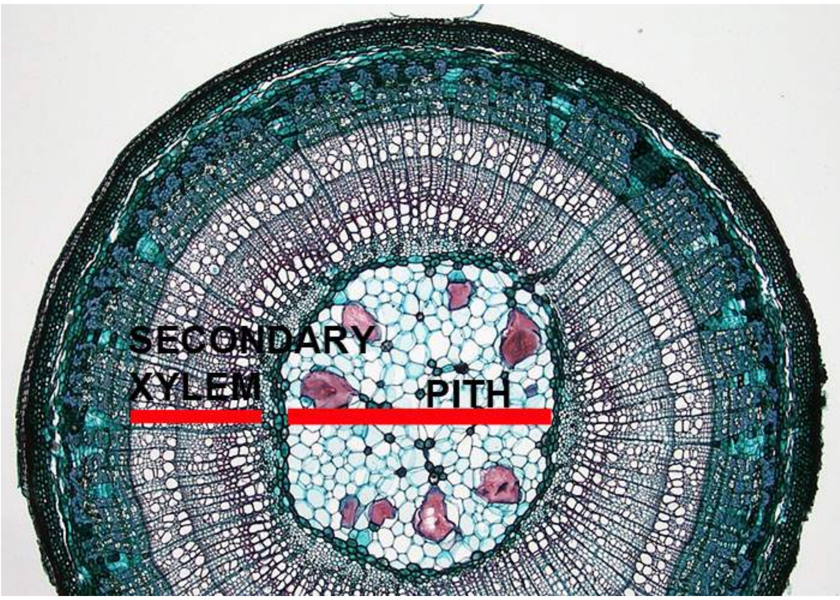


Figure 2.19. Stem of a dicotyledon plant with secondary tissues. The pith has been compressed into the centre of the stem by the expanding secondary xylem. The secondary xylem now forms a complete ring, later the pith will be completely compressed and no longer be present. (Background image, Berkshire Community College Bioscience Image Library, public domain. Labels Sean Bellairs).

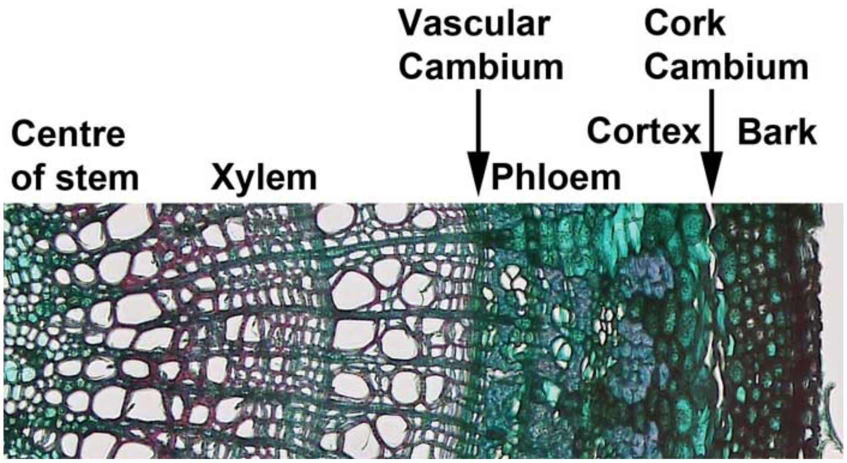


Figure 2.20. The locations of the secondary xylem, vascular cambium, secondary phloem, cortex, cork cambium and bark. The interior of the stem is the left and the exterior is to the right. (Background image, Berkshire Community College Bioscience Image Library, public domain. Labels Sean Bellairs).

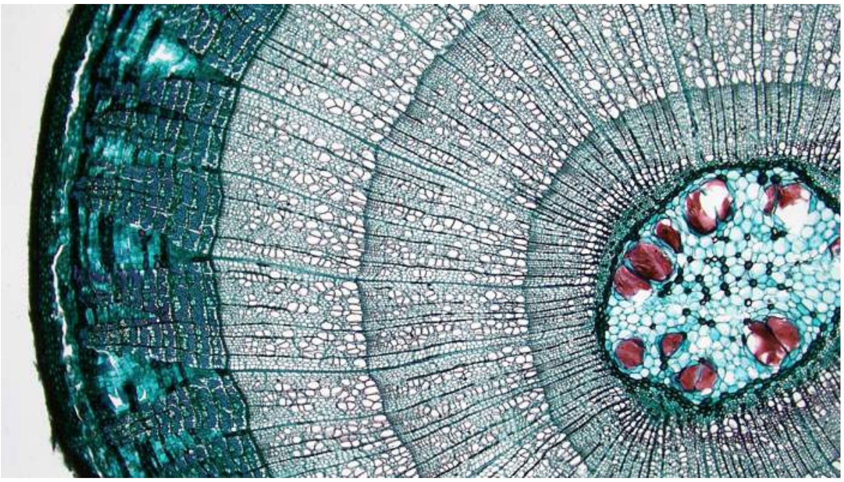


Figure 2.21. Three year old woody stem of *Tilia* showing annual formation of xylem growth rings in the stem. Pith is still present in the middle of the stem. (Berkshire Community College Bioscience Image Library, public domain).

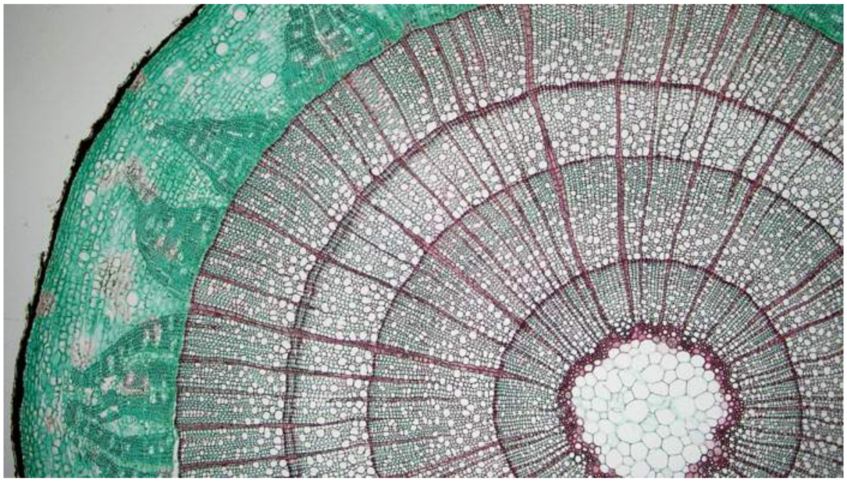


Figure 2.22. Four year old woody stem of Liriodendron showing the pith in the centre and purple stained xylem tissue. Darker purple lines of cells are ray parenchyma. (Berkshire Community College Bioscience Image Library, public domain).

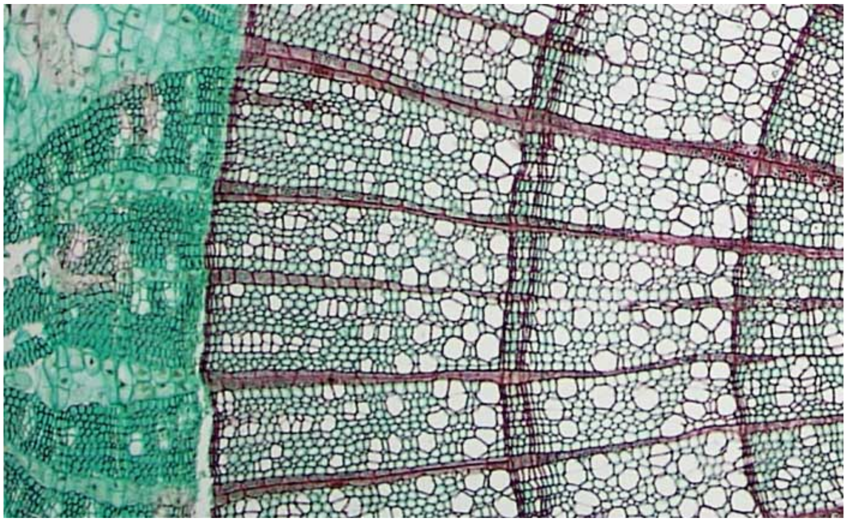


Figure 2.23. Magnified view of the ray parenchyma. The lines of parenchyma cells continue out into the green stained phloem tissue. Xylem vessel cells are large at the beginning of the growth season and become smaller at the end of the growth season. (Berkshire Community College Bioscience Image Library, public domain).

CHAPTER OVERVIEW

3: Stem, Leaf, and Root Anatomy

3.1: Stems

Stems are produced by the primary apical meristem in but may be increased in girth in woody plants due to secondary growth. Secondary growth is produced by lateral meristems in the woody stems and roots of woody plants.

Secondary xylem and secondary phloem are produced from a cylinder of meristematic tissue within the woody stems and roots. This cylinder of meristematic tissue is the vascular cambium. The secondary xylem provides additional structural support and additional water conduction tissue in shrubs and trees. The secondary phloem replaces the primary phloem.

Similarly, as the trunk of a woody plant gets larger, the dermal tissue need to be expanded and replaced. New dermal tissue is produced by the cork cambium, which lies beneath the bark.

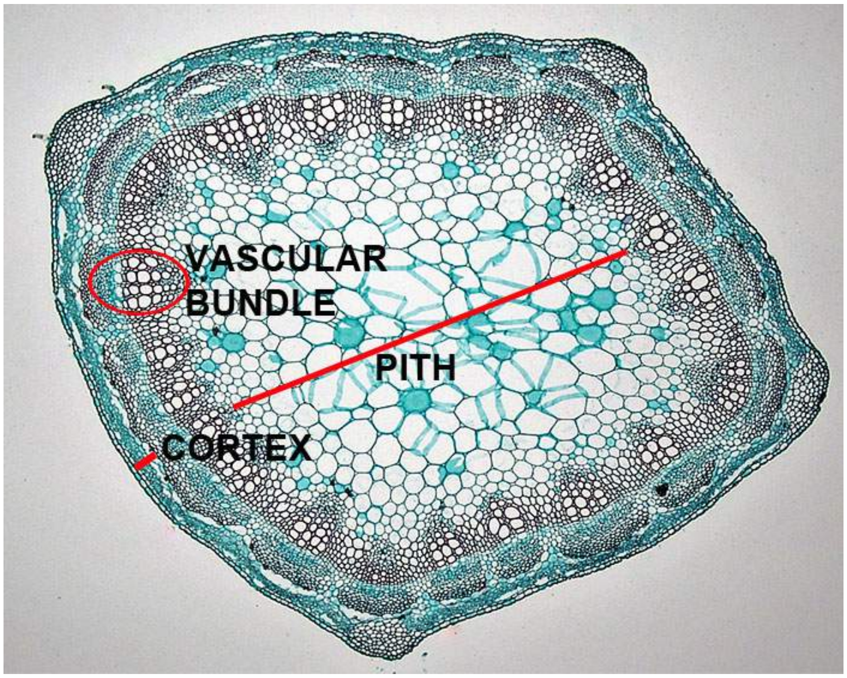


Figure 3.1 Stem of a dicotyledon plant with only primary tissues. The ground tissue system includes the pith and cortex and the vascular tissue system is in discrete bundles.

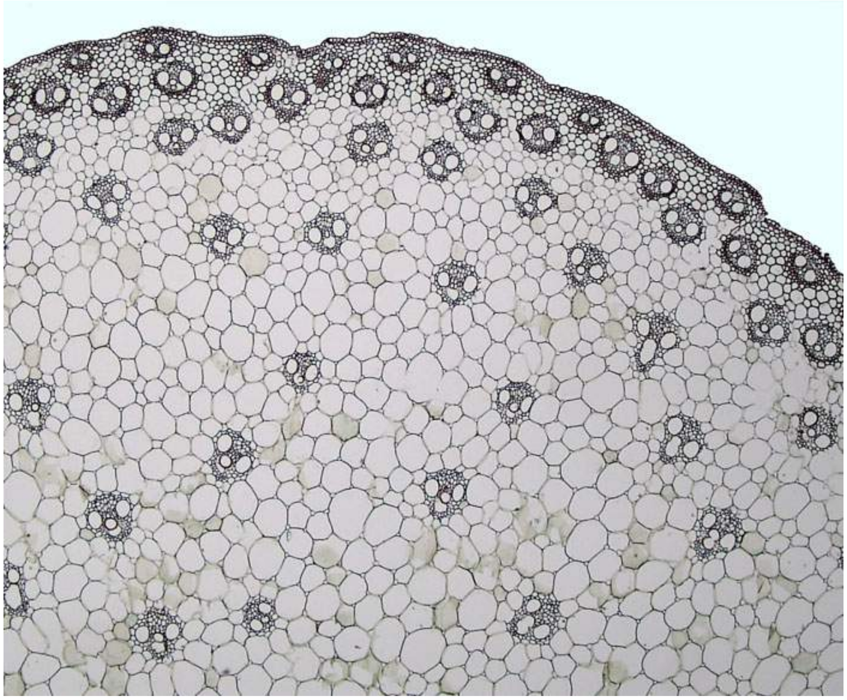


Figure 3.2. Stem of a monocotyledon plant with primary tissues. The vascular bundles are scattered throughout the stem with the xylem to the middle and the phloem towards the outside. Some monocotyledons stems are hollow.

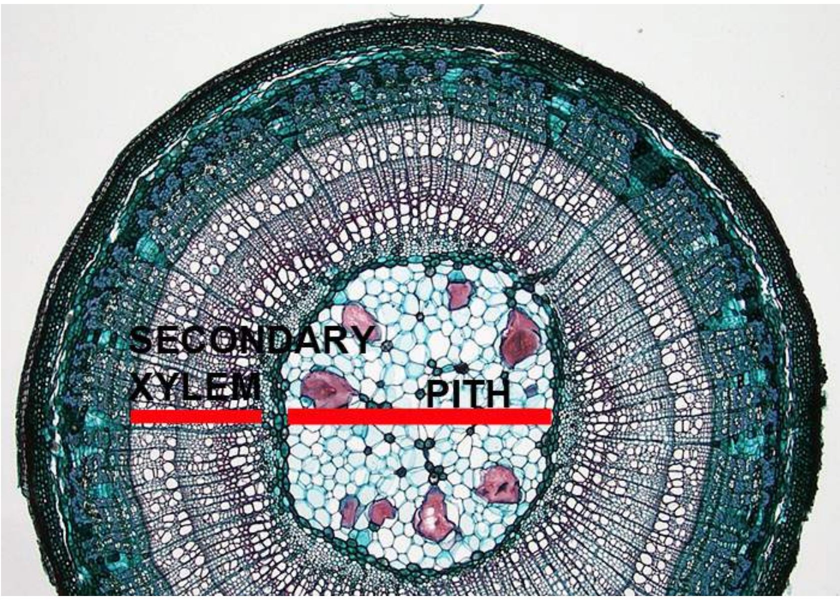


Figure 3.3. Stem of a dicotyledon plant with secondary tissues. The pith has been compressed into the centre of the stem by the expanding secondary xylem. The secondary xylem now forms a complete ring, later the pith will be completely compressed and no longer be present.

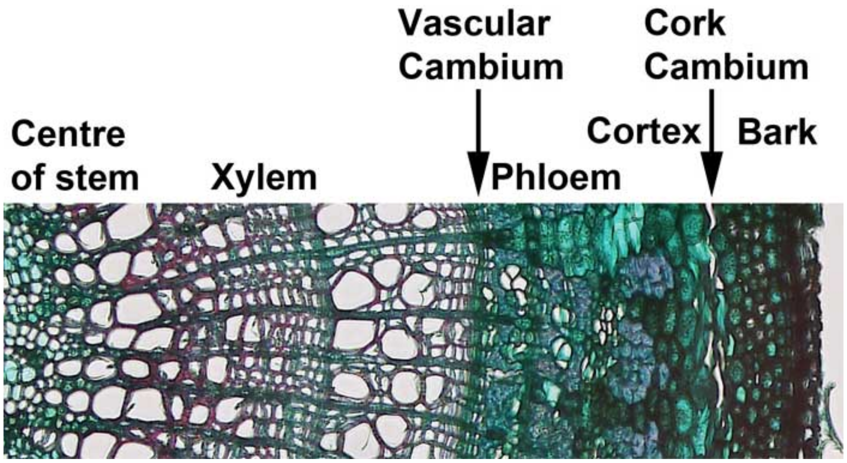


Figure 3.4. The locations of the secondary xylem, vascular cambium, secondary phloem, cortex, cork cambium and bark. The interior of the stem is the left and the exterior is to the right.

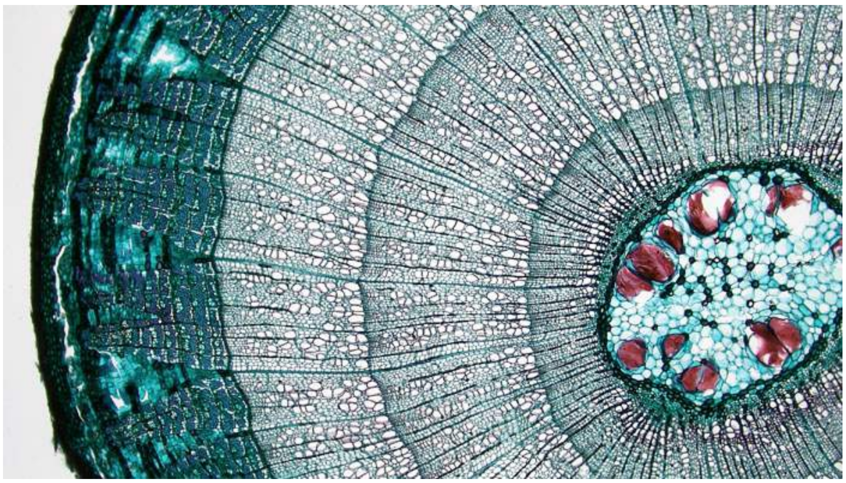


Figure 3.5. Three year old woody stem of *Tilia* showing annual formation of xylem growth rings in the stem. Pith is still present in the middle of the stem.

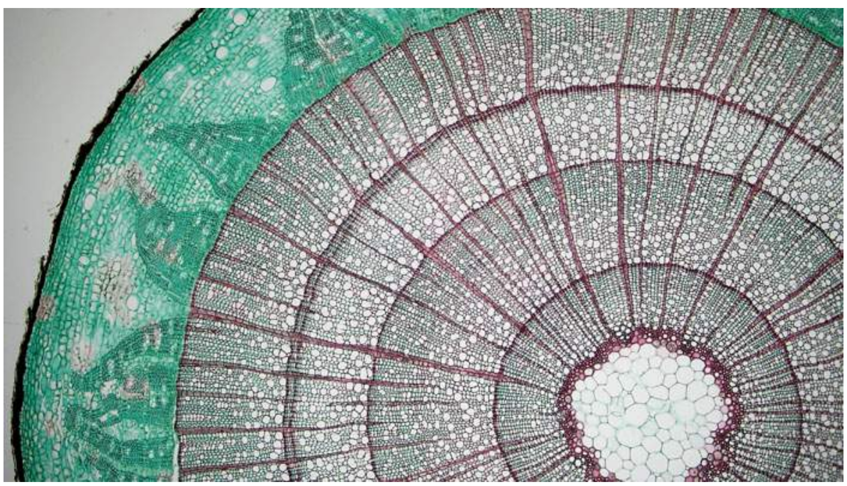


Figure 3.6. Four year old woody stem of *Liriodendron* showing the pith in the centre and purple stained xylem tissue. Darker purple lines of cells are ray parenchyma.

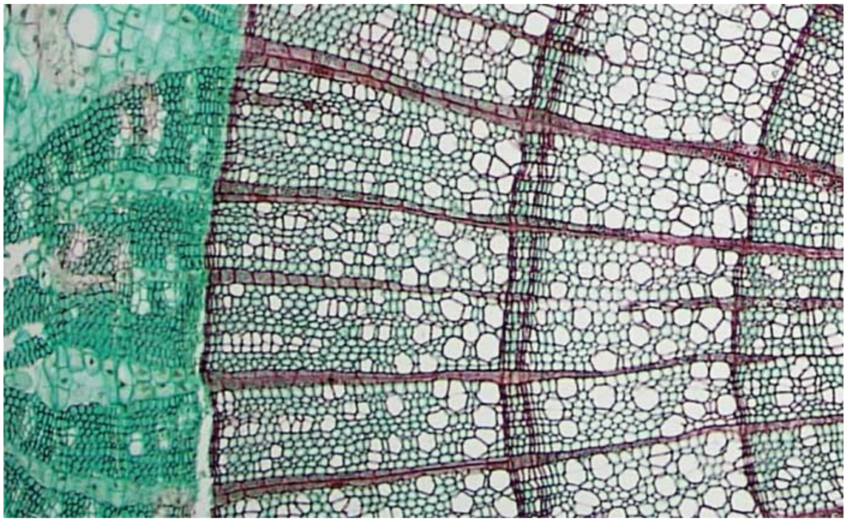


Figure 3.7. Magnified view of the ray parenchyma. The lines of parenchyma cells continue out into the green stained phloem tissue. Xylem vessel cells are large at the beginning of the growth season and become smaller at the end of the growth season.

Media Attributions

- Figure 3.1 Trifolium primary stem © Berkshire Community College Bioscience Image Library adapted by Sean Bellairs is licensed under a CC BY-SA (Attribution ShareAlike) license
- Figure 3.2. Zea mays stem © Berkshire Community College Bioscience Image Library adapted by Sean Bellairs is licensed under a CC BY-SA (Attribution ShareAlike) license
- Figure 3.3. Two year Tilia © Berkshire Community College Bioscience Image Library adapted by Sean Bellairs is licensed under a CC BY-SA (Attribution ShareAlike) license
- Figure 3.4. Vascular cambium © Berkshire Community College Bioscience Image Library adapted by Sean Bellairs is licensed under a CC BY-SA (Attribution ShareAlike) license
- Figure 3.5. Tilia 3 growth rings © Berkshire Community College Bioscience Image Library adapted by Sean Bellairs is licensed under a CC BY-SA (Attribution ShareAlike) license
- Figure 3.6. Liriodendron stem © Berkshire Community College Bioscience Image Library is licensed under a Public Domain license
- Figure 3.7. Liriodendron stem © Berkshire Community College Bioscience Image Library adapted by Sean Bellairs is licensed under a CC BY-SA (Attribution ShareAlike) license

3.2: Leaves

We see a massive amount of variation in the sizes and shapes of leaves. Similarly, the anatomical structure of leaves can vary considerably. Plant leaves may be specialised to maximise light utilisation, to minimise water loss, to facilitate C4 photosynthesis or CAM photosynthesis, to resist damage due to water stress, or to float on water.

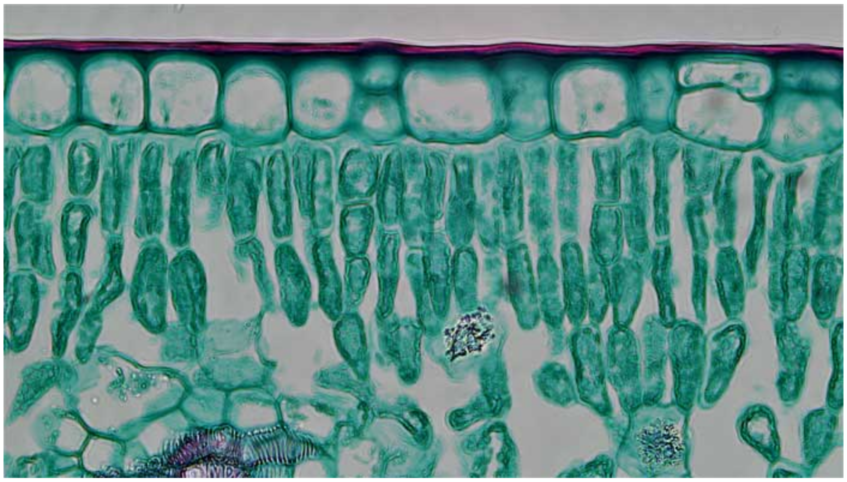


Figure 3.1. A typical leaf of a mesophyte plant with the cuticle above the dermal cells and then a later of closely packed palisade parenchyma cells. In the bottom third of the image, spongy parenchyma has large airspaces between the cells to maximise contact with carbon dioxide flowing in through the stomata. (Berkshire Community College Bioscience Image Library, public domain).

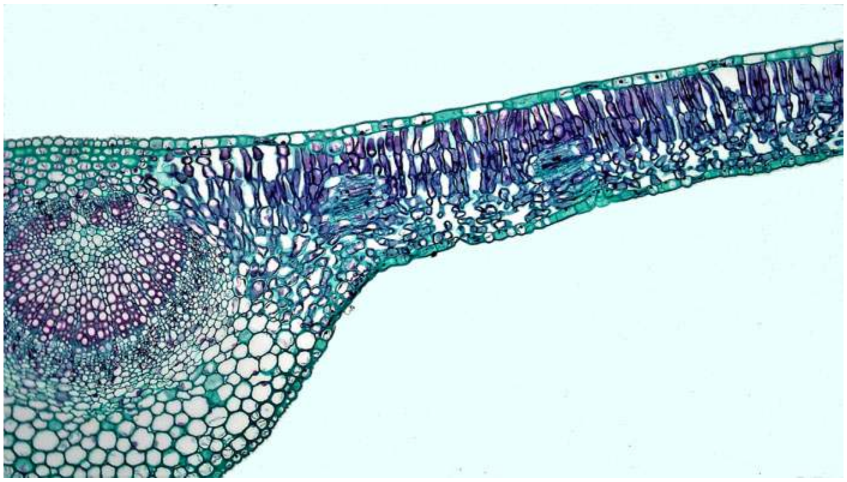


Figure 3.2. Another example of a typical leaf of a mesophyte plant with the closely packed palisade parenchyma cells on the upper side of the leaf and the spongy parenchyma below. (Berkshire Community College Bioscience Image Library, public domain).

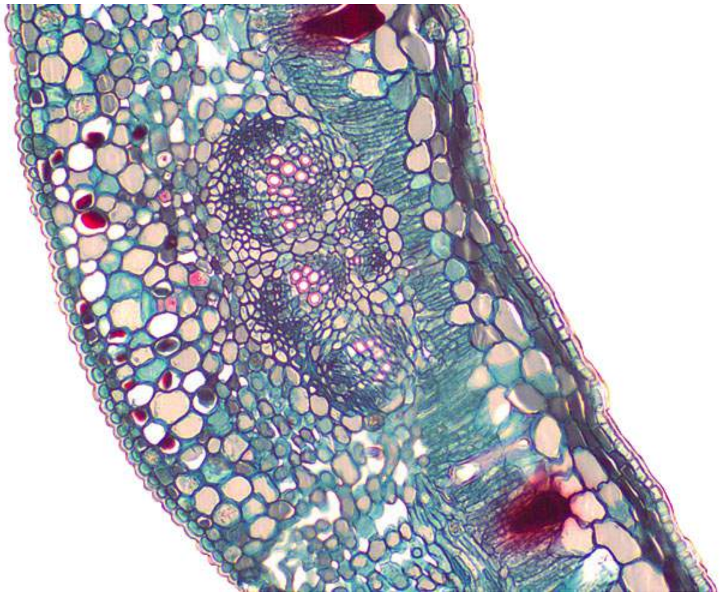


Figure 3.3. An example of a leaf with some xerophyte features. Although it still has closely packed palisade parenchyma cells on the upper right surface and spongy parenchyma to the left, the cells are more closely packed and the cuticle is thicker. This is the leaf of a mangrove, *Rhizophora*. (Sean Bellairs, CC: attribute, share alike).

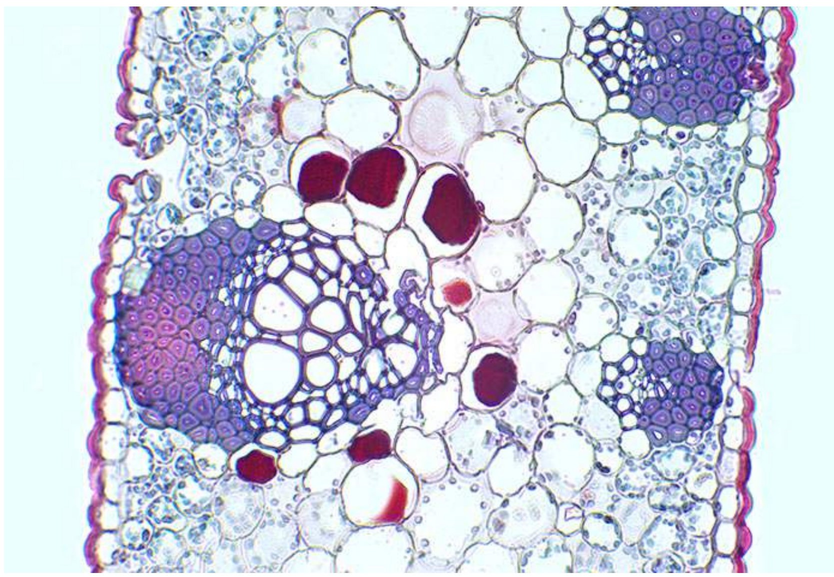


Figure 3.4. An example of a leaf with clearer xerophyte features. Parenchyma tissues are not differentiated into palisade and spongy parenchyma. The cells are closely packed and as well as a thick cuticle there is substantial sclerenchyma (purple cells with very thick cell walls). The lignified cells have reddish-purple cell walls. This is the leaf of a drought adapted Myrtaceae, *Callistemon*. (Sean Bellairs, CC attribute, share alike).

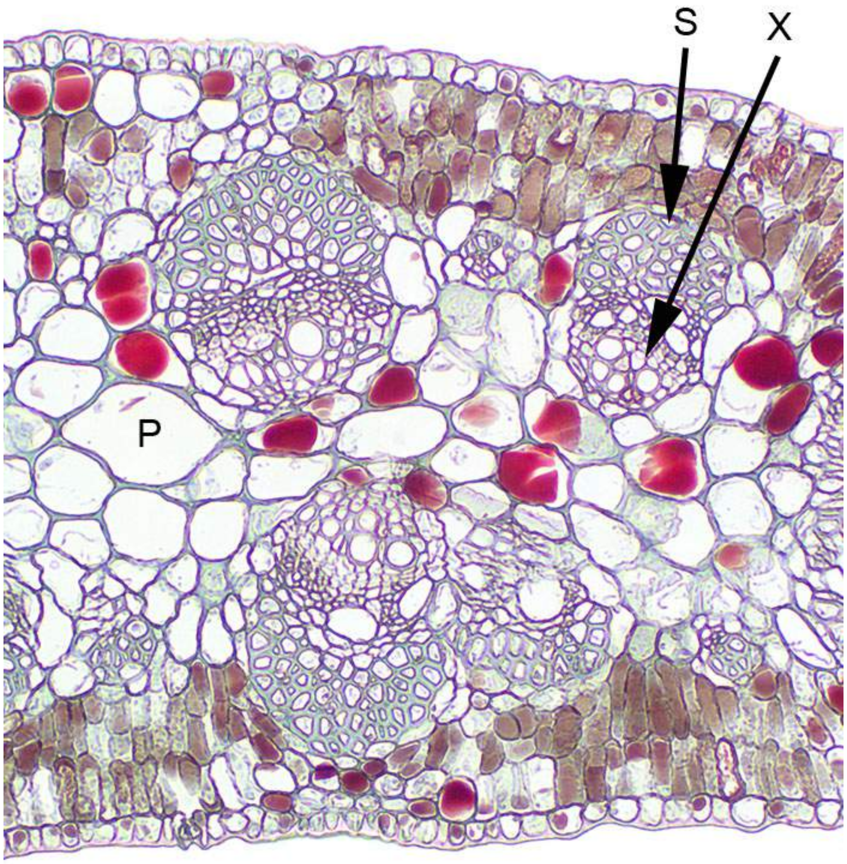


Figure 3.5. A drought adapted *Acacia* leaf with clear xerophyte features. Although parenchyma tissues are differentiated into palisade and storage parenchyma in the centre of the leaf (P), the cells are closely packed with few air spaces. The cuticle is thick. Lignified cells include sclerenchyma (S) for strength as well as xylem vessel cells (X). (Sean Bellairs, CC attribute, share alike).

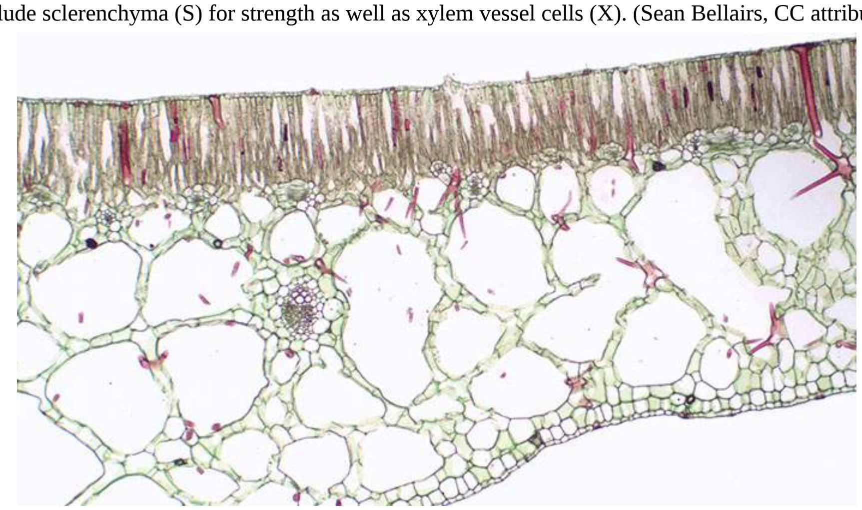


Figure 3.6. An example of a leaf with hydrophyte features. Parenchyma tissue below the palisade parenchyma has large air spaces between the cells. This tissue is termed aerenchyma and it allows the leaves to float. The cuticle is much thinner than on the other leaves. This is the leaf of a water lily, *Nymphaea*. (Sean Bellairs, CC attribute, share alike).

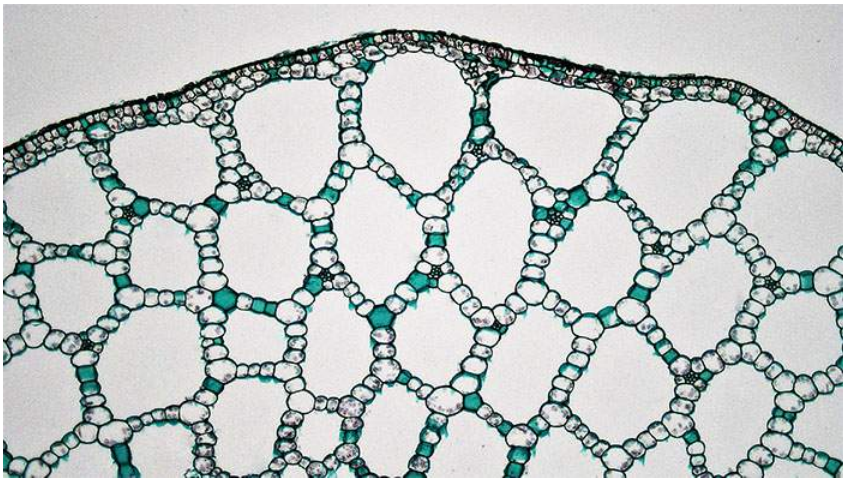
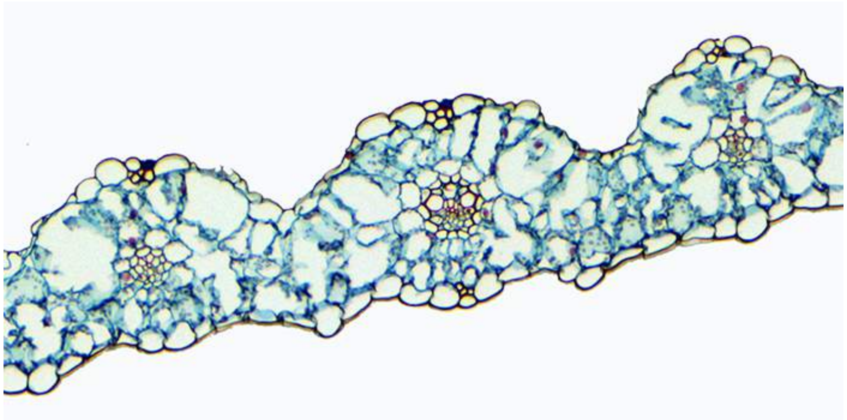


Figure 3.7. Aerenchyma tissue in stem of the hydrophyte pondweed, *Potamogeton*. (Berkshire Community College Bioscience Image Library, public domain).



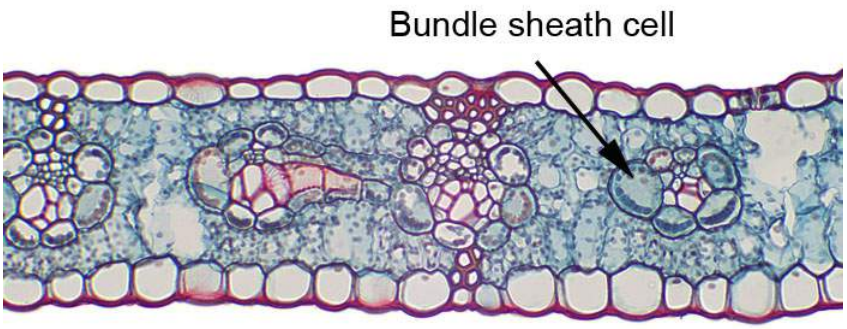


Figure 3.8. A leaf of a species with C3 leaf architecture (*Triticum*) (above) and of a leaf with C4 leaf architecture (*Zea mays*) (below). The C4 grass has a ring of parenchyma cells surrounding the veins, which are the bundle sheath cells. (Images by BlueRidgeKitties (CC attribute, share alike) above, and Sean Bellairs (CC attribute, share alike) below.)

3.3: Roots

Though unseen, the roots of a plant also have specialist anatomical features that enable plants to efficiently obtain nutrients and control the substances entering a plant.

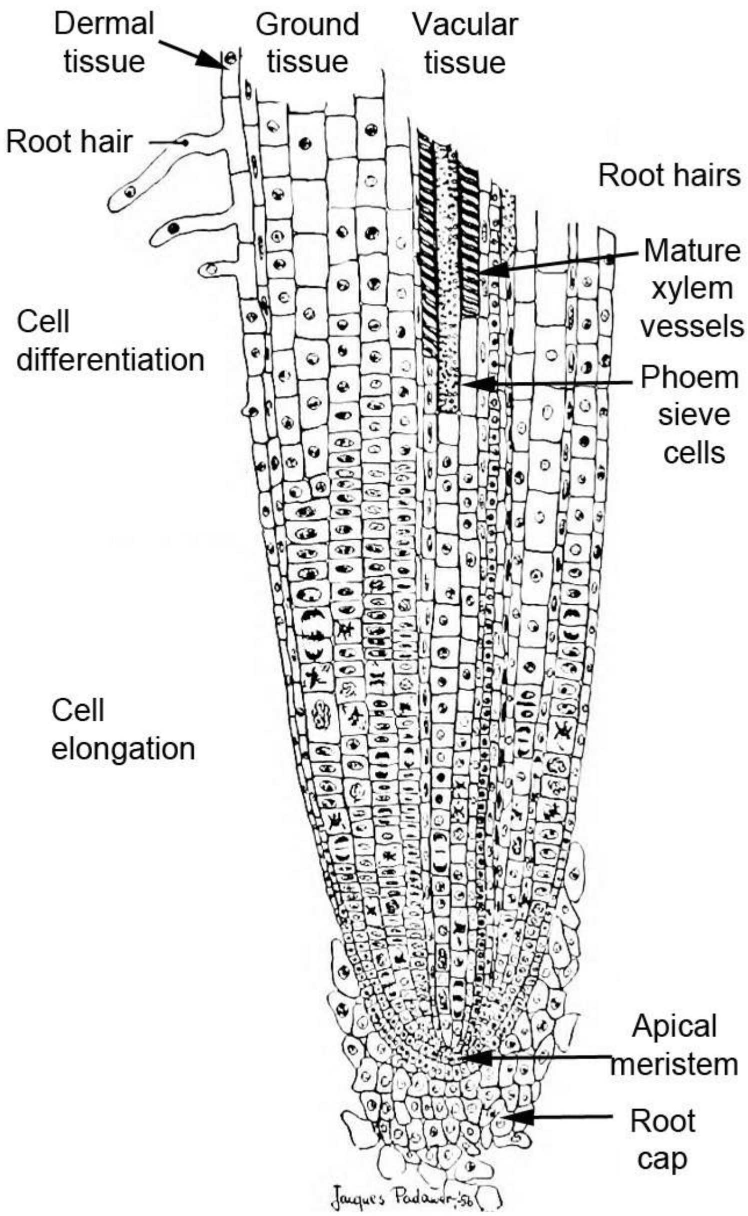


Figure 3.9. Diagram of the structures of and areas of a developing root. (Image from: Marsland, Douglas. (1964) Principles of modern biology. Holt, Rinehart and Winston, New York. Digitized Cornell University Library, No known copyright restrictions. Text Sean Bellairs.)

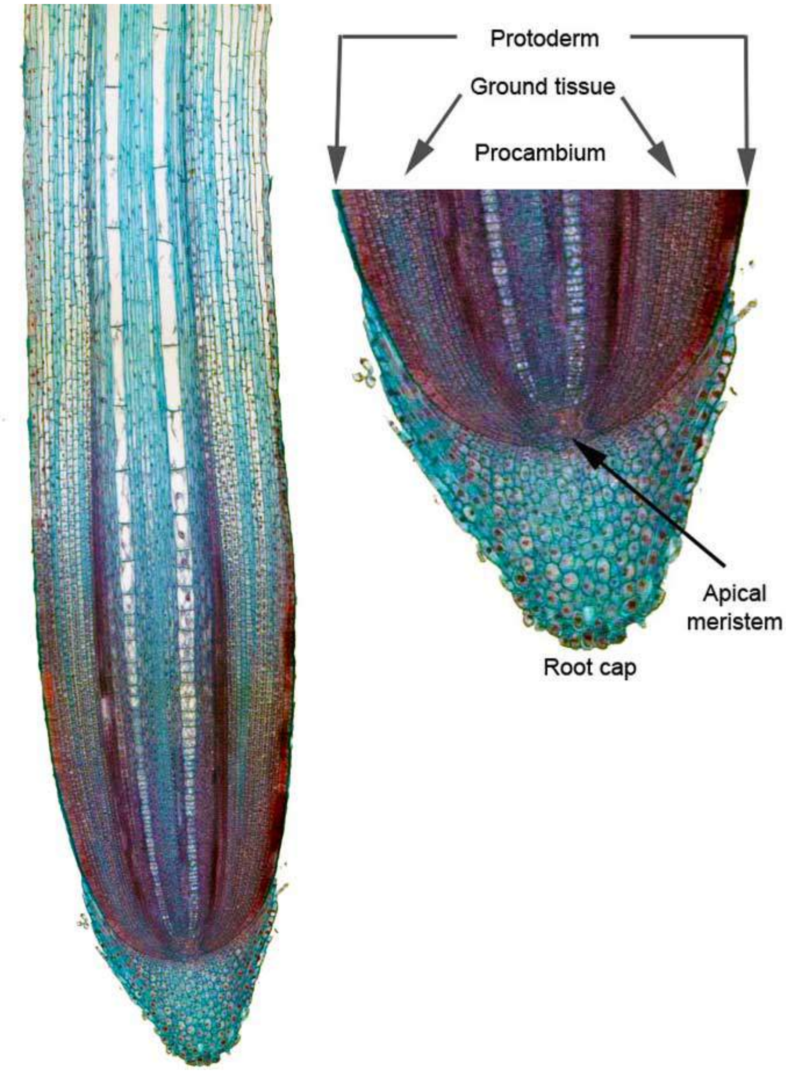


Figure 3.10. The apical meristem and meristematic tissues developing from the apical meristem of the root. (Image Jen Dixon (CC attribute, share alike). Text and arrows Sean Bellairs.)

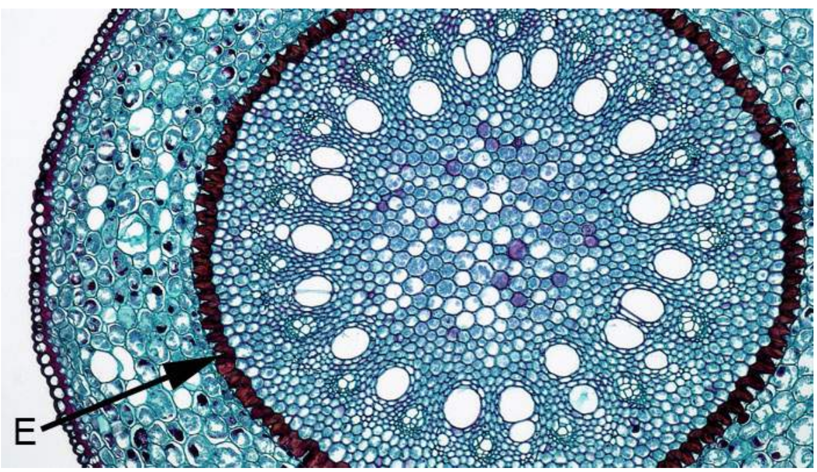


Figure 3.11. The endodermis (E) in the monocot *Smilax*. Cells making up the endodermis have walls that are heavily impregnated with suberin, forming the Casparian strip. Suberin is a fatty acid and highly hydrophobic, thus creating a barrier to water and solutes. (Berkshire Community College Bioscience Image Library, public domain; text and arrow Sean Bellairs).

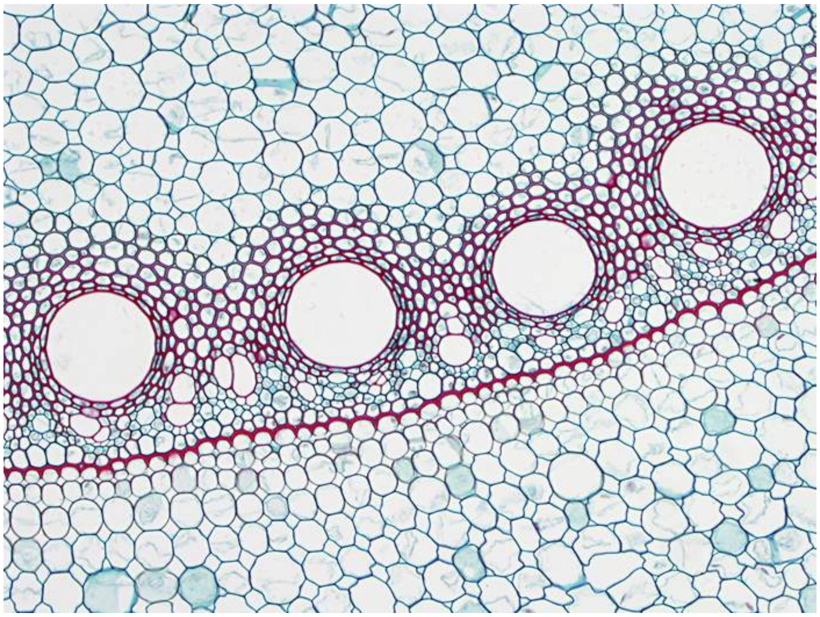


Figure 3.12. The endodermis denoted by the band of the red stained casparian band in *Zea mays*. The interior of the root is at the top and the casparian band is between the vascular tissue and the cortex. (Image by BlueRidgeKitties (CC attribute, share alike)).

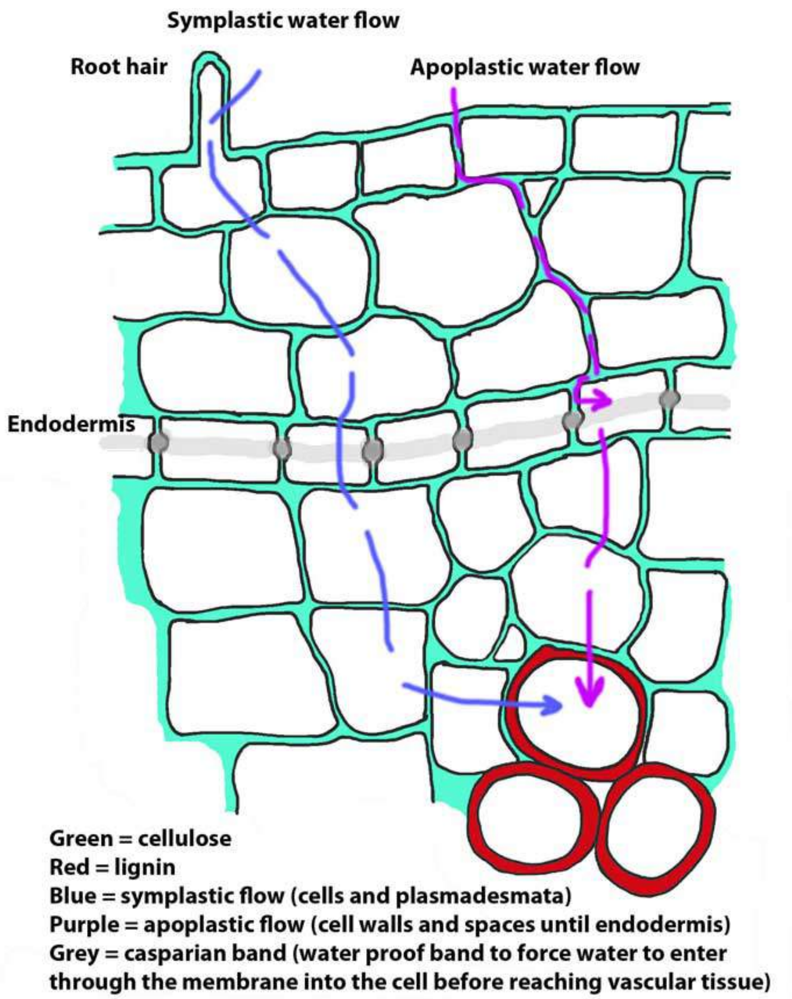


Figure 3.13. Effect of the casparian band on water flow between the cortex and the xylem. In the cortex water and solutes can move symplastically (through the living cells) or apoplastically (through the non-living cellulose cell walls and intercellular spaces. The casparian band forces all water movement into the vascular tissues to move though the cell membranes (Diagram by Sean Bellairs, CC attribute, share alike).

Index

C

Glossary

Sample Word 1 | Sample Definition 1

Detailed Licensing

Overview

Title: Plant Anatomy and Physiology (Bellairs)

Webpages: 35

All licenses found:

- CC BY-SA 4.0: 62.9% (22 pages)
- Undeclared: 37.1% (13 pages)

By Page

- Plant Anatomy and Physiology (Bellairs) - *CC BY-SA 4.0*
  - Front Matter - *Undeclared*
    - TitlePage - *Undeclared*
    - InfoPage - *Undeclared*
    - Table of Contents - *Undeclared*
    - Acknowledgements - *Undeclared*
    - Licensing - *Undeclared*
    - Introduction - *Undeclared*
  - 1: Inside a Plant Cell - *CC BY-SA 4.0*
    - 1.1: Eukaryote cells - *CC BY-SA 4.0*
    - 1.2: Cell wall - *CC BY-SA 4.0*
    - 1.3: Cell membrane - *CC BY-SA 4.0*
    - 1.4: The nucleus - *CC BY-SA 4.0*
    - 1.5: Chromosomes and chromatin - *CC BY-SA 4.0*
    - 1.6: Chloroplasts - *CC BY-SA 4.0*
    - 1.7: Mitochondria - *CC BY-SA 4.0*
    - 1.8: Endoplasmic reticulum - *CC BY-SA 4.0*
    - 1.9: Ribosomes - *CC BY-SA 4.0*
    - 1.10: Golgi apparatus - *CC BY-SA 4.0*
    - 1.11: Vacuoles - *CC BY-SA 4.0*
  - 2: Plant Cells and Meristems - *CC BY-SA 4.0*
    - 2.1: Development of a plant - *CC BY-SA 4.0*
    - 2.2: Ground tissues - *CC BY-SA 4.0*
    - 2.3: Vascular tissues and cell types - *CC BY-SA 4.0*
    - 2.4: Dermal tissues and features - *CC BY-SA 4.0*
    - 2.5: Secondary tissues - *CC BY-SA 4.0*
  - 3: Stem, Leaf, and Root Anatomy - *CC BY-SA 4.0*
    - 3.1: Stems - *Undeclared*
    - 3.2: Leaves - *CC BY-SA 4.0*
    - 3.3: Roots - *CC BY-SA 4.0*
  - Back Matter - *Undeclared*
    - Index - *Undeclared*
    - Glossary - *Undeclared*
    - Glossary - *Undeclared*
    - Detailed Licensing - *Undeclared*