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GENERAL SCIENCE

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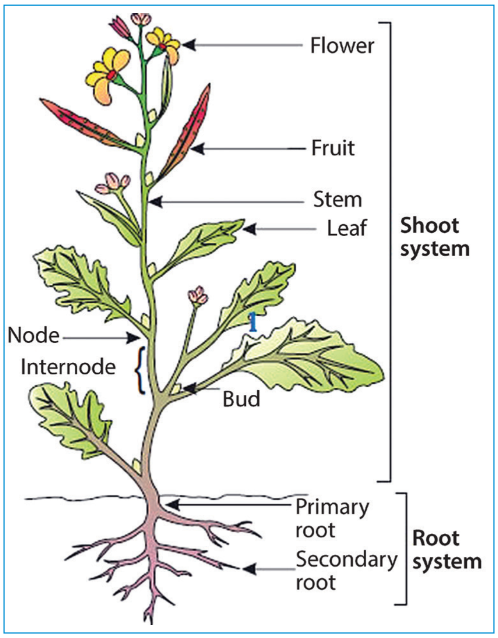
Unit I

Biology

9 CHAPTER PLANT MORPHOLOGY

9.1 Morphology of Flowering Plants

- Morphology refers to the study of the size, shape, and structure of animals, plants, and microorganisms and of the relationships of their constituent parts
- Even though the angiosperms show such a large diversity in external structure or morphology, they are all characterised by presence of roots, stems, leaves, flowers and fruits.
- The underground part of the flowering plant is the root system while the portion above the ground forms the shoot system.



The Root System

- The main functions of the root system are
  - Absorption of water and minerals from the soil,
  - Providing a proper anchorage to the plant parts,
  - Storing reserve food material and
  - Synthesis of plant growth regulators.
- The growth and metabolism of the plant root system is supported by the process of photosynthesis occurring in the leaves.
- Photosynthate from the leaves is transported via the phloem to the root system. Root structure aids in this process.
- Types of root systems
  - **Tap Root System:**
    - Characterized by having one thick main root (the taproot) from which smaller branch roots emerge.
    - When a seed germinates, the first root to emerge is the radicle, or primary root.
    - This radicle develops into the taproot.
    - It can plumb very deep-water sources and store a lot of food to help the plant survive drought and other environmental extremes.
    - The taproot also anchors the plant very securely in the ground.
  - **Modification of Tap Roots**
    - **Conical:** One of the most distinguishing characteristics of the main root is that it is conical in shape, with a broad base that tapers gradually toward the tip. Take, for example, carrots.
    - **Napiform:** This tap root has a spherical shape and tapers sharply at the tip, indicating that it is a type of tap root. Turnip and beetroot are examples of root vegetables.
    - **Fusiform:** The main root is swollen in the middle and tapers at both ends, forming a fusiform shape. A good example is the radish.
    - **Tuberous:** This root does not have a distinct form. It swells up and becomes fleshy. An example is a plant that blooms at 4 o'clock.
  - **Fibrous Root System:**
    - It has many small branching roots, called fibrous roots, but no large primary root.
    - The huge number of threadlike roots increases the surface area for absorption of water and minerals, but fibrous roots anchor the plant less securely.
    - Plants with fibrous roots systems are excellent for erosion control, because the mass of roots cling to soil particles.
  - **Adventitious Roots:**
    - These arise from an organ other than the root—usually a stem, sometimes a leaf.
    - They are especially numerous on underground stems, such as rhizomes, corms, and tubers, and make it possible to vegetatively propagate many plants from stem or leaf cuttings
    - **Tobulose:** These roots are swollen but do not have a distinct shape. They are formed by the nodes of the prostate stem elongating the stem.

      Example: sweet potato.
    - **Fasciculated:** The swollen roots develop in clusters at the base of the stem and take on distinct shapes as they develop. Dahlias and asparagus are just a couple of examples.
    - **Nodulose:** Only the tips of the roots swell as a result of the accumulation of food in this type of root. Mango-ginger and arrowroot are two such examples.

- **Moniliform (Beaded Roots):** The roots are swollen at regular intervals, giving the appearance of being beaded on the surface. Grasses and bitter gourds are examples of such plants.
- **Annulated:** The roots appear to be made up of a number of discs that have been stacked one on top of the other. Ipecac is a good example.

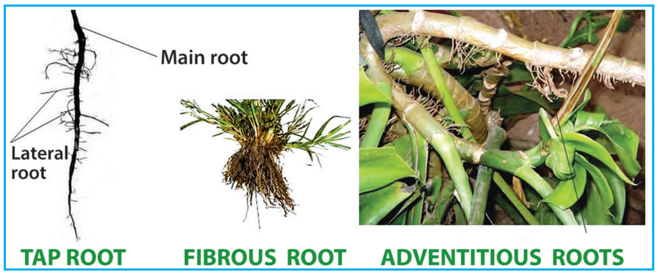


Figure: Types of root systems

- **Regions of the Root:**
  - **Root Cap**
    - The root is covered at the apex by a thimble-like structure called the root cap.
    - It protects the tender apex of the root as it makes its way through the soil.
  - **Region of meristematic activity**
    - A few millimetres above the root cap is the region of meristematic activity.
    - The cells of this region are very small, thin-walled and with dense protoplasm.
    - They divide repeatedly.
  - **Region of elongation**
    - It's adjacent to region of meristematic activity
    - The cells in this region undergo rapid elongation and enlargement and are responsible for the growth of the root in length.
  - **Region of maturation**
    - The cells of the elongation zone gradually differentiate and mature.
    - Hence, this zone, proximal to region of elongation, is called the region of maturation.

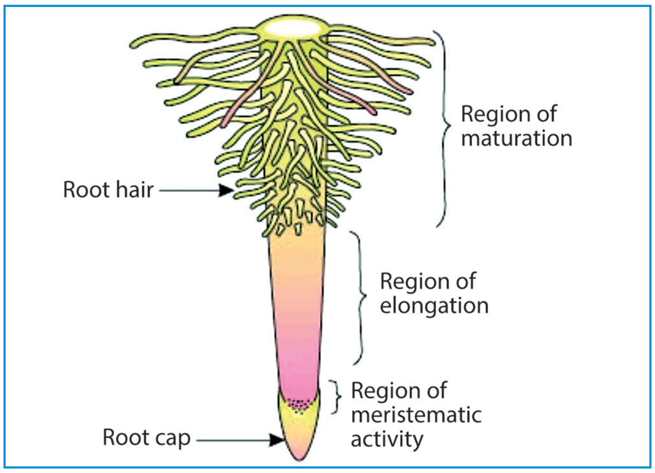


Figure: Tap Roots Parts

    - From this region some of the epidermal cells form very fine and delicate, thread-like structures called root hairs.
    - These root hairs absorb water and minerals from the soil.

The Stem System

- The stem is the ascending part of the axis bearing branches, leaves, flowers and fruits.
- It develops from the plumule of the embryo of a germinating seed.
- The stem bears nodes and internodes.
  - The region of the stem where leaves are born are called **nodes**
  - **Internodes** are the portions between two nodes.
- The stem bears buds, which may be terminal or axillary.
  - An **axillary bud** is usually found in the axil (the area between the base of a leaf and the stem) where it can give rise to a branch or a flower.
- Stem is generally green when young and later often become woody and dark brown.

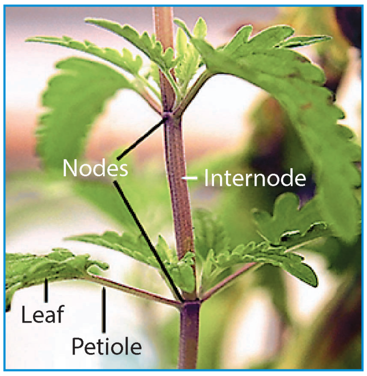


Figure: The Stem System

- **Functions**
  - The main function of the stem is spreading out branches bearing leaves, flowers and fruits.
  - It conducts water, minerals and photosynthates.
  - Some stems perform the function of storage of food, support, protection and of vegetative propagation.

The Leaf System

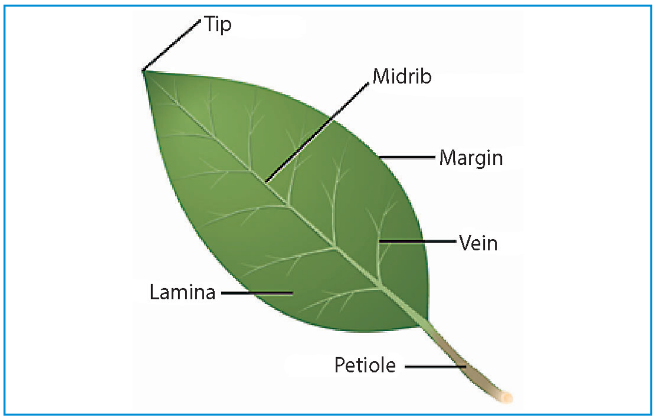


Figure: The Leaf System

- A typical leaf consists of three main parts: leaf base, petiole and lamina
- The leaf is attached to the stem by the leaf base and may bear two lateral small leaf like structures called stipules
  - Stipules are small green appendages usually found at the base of the petiole.
- **Petiole**
  - The stalk that extends from the stem to the base of the leaf is the petiole.
  - The petiole help hold the blade(lamina) to light.
  - Long thin flexible petioles allow leaf blades to flutter in wind, thereby cooling the leaf and bringing fresh air to leaf surface.
  - Leaves that do not have a petiole and are directly attached to the plant stem are called sessile leaves
- **The lamina or the leaf blade**
  - It is the green expanded part of the leaf with veins and veinlets.
  - It is also the widest part of the leaf.
  - There is, usually, a middle prominent vein, which is known as the midrib.
  - Veins provide rigidity to the leaf blade and act as channels of transport for water, minerals and food materials.
  - The edge of the leaf is called the margin.
- **Venation**
  - The arrangement of veins and the veinlets in the lamina of leaf is termed as venation.
  - When the veinlets form a network, the venation is termed as reticulate.
  - When the veins run parallel to each other within a lamina, the venation is termed as parallel.

The Flower System

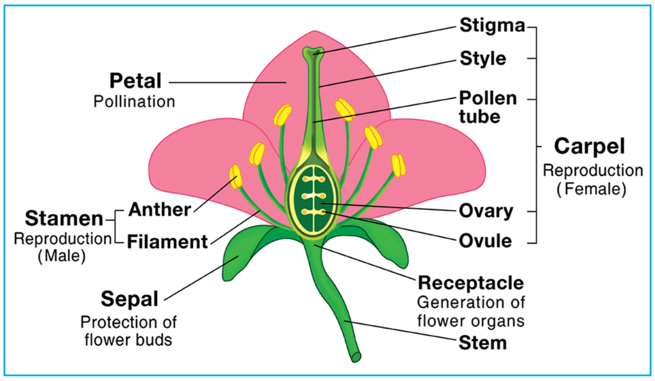


Figure: Parts of a Flower

- Flowers are responsible for seed development and reproduction.
- There are four main flower parts in angiosperms: sepals, petals, stamens, and carpels.
- **Sepal:**
  - This typically green, leaf-like structure protects the budding flower.
  - Collectively, sepals are known as the **calyx**.
- **Petal:**
  - This plant structure is a modified leaf that surrounds the reproductive parts of a flower.
  - Petals are typically colorful and often scented to attract insect pollinators.
- **Stamen:** The stamen is the male reproductive part of a flower. It produces pollen and consists of a filament and an anther.
  - **Anther:** This sac-like structure is located at the tip of the filament and is the site of pollen production.
  - **Filament:** A filament is a long stalk that connects to and holds up the anther.
- **Carpel & Pistil:** The female reproductive part of a flower is the **carpel**. It consists of the stigma, style, and ovary. **Pistil** can either be the same as individual carpel or it can be a collection of one or more carpels fused together.
  - **Stigma:** The tip of the carpel is the stigma. It is sticky so it can collect pollen.
  - **Style:** This slender, neck-like portion of the carpel provides a pathway for sperm to the ovary.
  - **Ovary:** The ovary is located at the base of the carpel and houses the ovules.
- While flowers are necessary for sexual reproduction, flowering plants can sometimes reproduce asexually through vegetative propagation.

9.2 Anatomy of Flowering Plants

- Study of internal structure of plants is called anatomy.
- Plants have cells as the basic unit, cells are organised into tissues and in turn the tissues are organised into organs.
- Different organs in a plant show differences in their internal structure.
- Within angiosperms, the monocots and dicots are also seen to be anatomically different.
- Internal structures also show adaptations to diverse environments.

Plant Tissues

- Tissues are classified into two main groups, namely, meristematic and permanent tissues based on whether the cells being formed are capable of dividing or not.
  - **Meristematic tissue is analagous to stem cells in animals:** meristematic cells are undifferentiated cells that continue to divide and contribute to the growth of the plant. There are three types of

meristematic tissues: apical (at the tips), intercalary (in the middle), and lateral (at the sides).

- **Apical meristems:** The meristems which occur at the tips of roots and shoots and produce primary tissues are called apical meristems
- **Intercalary meristems:** It is a type of meristematic tissue that is found at the **base of nodes and leaf blades** of monocots. They are associated with the growth in length in the middle position of the stem.

  For e.g. – Grasses have Intercalary meristems located along the stems near the nodes. Cell divisions in this tissue push the stem upward.
- **Lateral meristem:** The meristem that occurs in the mature regions of roots and shoots of many plants, particularly those that produce woody axis and appear later than primary meristem is called the secondary or lateral meristem.

Primary Growth and Secondary Growth

- The increase in length of the shoot and the root is referred to as **primary growth**.
  - It is the result of cell division in the shoot apical meristem.
- **Secondary growth** is characterized by an increase in thickness or girth of the plant.
  - It is caused by cell division in the lateral meristem.

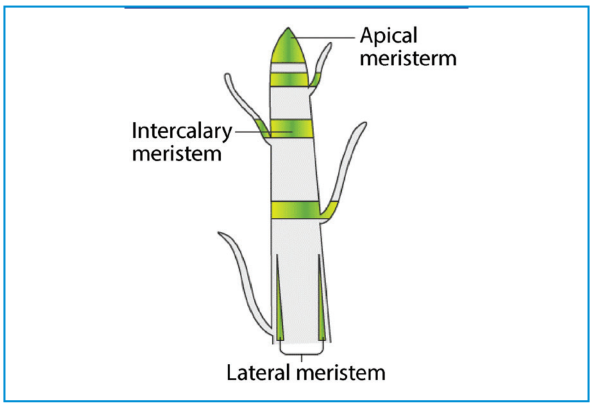


Figure: Meristematic Tissue

- In contrast, **permanent tissue** consists of plant cells that are no longer actively dividing.
  - Permanent tissues having all cells similar in structure and function are called simple tissues.
  - Permanent tissues having many different types of cells are called **complex tissues**
- On the basis of their structure and location, there are three types of tissue systems. These are the
  - Epidermal tissue system,
  - Ground or fundamental tissue system and
  - Vascular or conducting tissue system.

Epidermal Tissue System

- The epidermal tissue system forms the outer-most covering of the whole plant body and comprises epidermal cells, stomata and the epidermal appendages – the trichomes and hairs.
- The epidermis is the outermost layer of the primary plant body. It mediates most of the interactions between a plant and its environment.
- Dermal tissue covers and protects the plant, and controls gas exchange and water absorption (in roots).
- The outside of the epidermis is often covered with a waxy thick layer called the **cuticle** which prevents the loss of water. Cuticle is absent in roots
- **Stomata** are structures present in the epidermis of leaves. Stomata regulate the process of transpiration and gaseous exchange.

The Ground Tissue System

- All tissues except epidermis and vascular bundles constitute the ground tissue.
- Ground tissue carries out different functions based on the cell type and location in the plant
- It consists of simple tissues such as
  - **Parenchyma** (photosynthesis in the leaves, and storage in the roots),

    They are living permanent tissues that have the ability to divide at maturity and help in the regeneration and healing of wounds

    Parenchyma cells are the foundation of a plant as reproductive cells (spores, gametes) are parenchymatous in nature

    Single parenchyma cell of a zygote has an ability to develop into an entire plant. These cells are called "totipotent" cells

    Parenchyma cells occur in the form of continuous masses as homogeneous parenchyma tissues e.g. in pith and cortex of stems and roots, mesophyll of leaves, the flesh of succulent fruits and in the endosperm of seeds

    Parenchyma cells may be associated with other types of cells to form heterogeneous complex tissues such as parenchyma of xylem and phloem

    Parenchyma cells are essential for activities like photosynthesis, storage, secretion, assimilation, respiration, excretion and radial transport of water and solute
  - **Collenchyma** (shoot support in areas of active growth), and

    The cells are extendable and flexible, allowing them to support the organs in which they are found.

    Collenchyma-containing chloroplasts can do photosynthesis.

    In other circumstances, such as phellogen, the cork cambium, which divides to form the periderm, the peripheral thick walled collenchyma spreads and regains meristematic activity.

    The mechanical cell of mature plants is the sclerified collenchyma.

Collenchyma can operate as a storage location for antibacterial chemicals that are used to fight bacteria. Solanum tuberosum agglutinins are hydroxyproline-rich bacterial agglutinins.

- **Schlerenchyma** (shoot support in areas where growth has ceased)

- They provide a supporting matrix for the vascular tissue, provides structural support for the stem, and helps to store water and sugars.

The Vascular Tissue System

- Vascular tissue transports water, minerals, and sugars to different parts of the plant.
- Vascular tissue is made of two specialized conducting tissues: xylem and phloem.
  - **Xylem** tissue transports water and nutrients from the roots to different parts of the plant, and also plays a role in structural support in the stem.
  - **Phloem** tissue transports organic compounds from the site of photosynthesis to other parts of the plant.
- In dicotyledonous stems, **cambium** is present between phloem and xylem.
  - The **vascular cambium** is a meristematic tissue that is responsible for lateral growth and the continued production of new xylem and phloem; in woody plants, the shoot vascular cambium makes wood.

Monocotyledons (Monocots) and Dicotyledons (Dicots)

- Plants can be separated into two distinct categories: monocots and dicots.
  - **Monocots** differ from dicots in four distinct structural features: leaves, stems, roots and flowers.
  - But the differences start from the very beginning of the plant's life cycle: the seed.
  - Whereas monocots have one cotyledon, dicots have two.
    - Cotyledon is the first seed leaf within the embryo of a seed.
    - Cotyledons help supply the nutrition a plant embryo needs to germinate and become established as a photosynthetic organism
  - This small difference at the very start of the plant's life cycle leads each plant to develop vast differences.

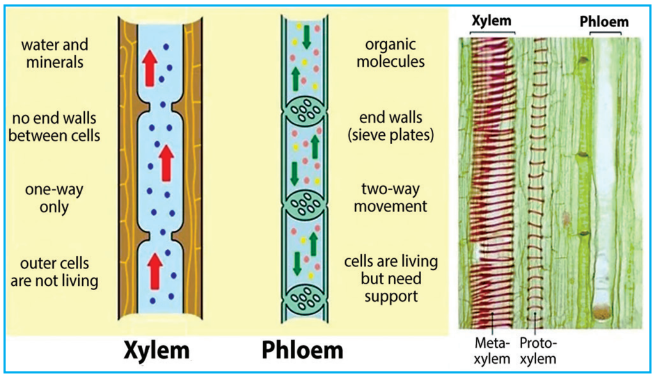
Basis for Comparison	Monocotyledons (Monocots)	Dicotyledons (Dicots)
Definition	These are flowering plants or angiosperms bearing seeds with a single cotyledon or embryonic leaf.	These are flowering plants or angiosperms bearing seeds with two cotyledons or embryonic leaves.
Root	Monocots have an adventitious or fibrous root system.	Most dicots have a tap root system.
Stem	The Monocot stem is unbranched and fleshy.	Dicot stem is branched and hard
	Within the stem of monocots, the vascular bundles are scattered in no particular pattern.	Within the stem of dicots, the vascular bundles are arranged in concentric circles.
	The roots and stems of Monocotyledons do not possess a cambium and cannot increase in diameter i.e lacks secondary growth	The roots and stems of Dicotyledons possess a cambium and have the ability to increase in diameter i.e secondary growth occurs.
Leaf	Monocots usually have long, narrow, and slender leaves.	They usually have broad leaves.
Venation	The leaves have a parallel venation system.	The leaves have a reticulate or net venation system.
Flowers	Monocot flowers usually form in threes	Dicot flowers occur in groups of four or five
Examples	Bamboos, bananas, asparagus, ginger, tulips, lilies, palms, grass	Roses, oak trees, daisies, peas, beans, cactus

■■■■

10 CHAPTER PLANT PHYSIOLOGY

10.1 Transport in Plants

- In a flowering plant the substances that would need to be transported are water, mineral nutrients, organic nutrients and plant growth regulators.
- Over small distances substances move by diffusion and by cytoplasmic streaming supplemented by active transport.
  - **Cytoplasmic streaming**, also called protoplasmic streaming, is the movement of the fluid substance (cytoplasm) within a plant or animal cell.
    - It transports nutrients, proteins, and organelles within cells
  - **Imbibition** is a special type of diffusion when water is absorbed by solids – colloids – causing them to increase in volume. E.g. - Absorption of water by seeds and dry wood.
- Transport over longer distances proceeds through the vascular system (the xylem and the phloem) and is called translocation.
  - Water and minerals, and food generally move by a mass or bulk flow system due to pressure differences between the two points.
    - Mass flow substances, whether in solution or in suspension, are swept along at the same pace during the flow irrespective of their concentration gradients.
  - **Xylem** is associated with translocation of mainly water, mineral salts, some organic nitrogen and hormones, from roots to the aerial parts of the plants.
    - It is also responsible for supporting the plant
    - **Tracheid:** Elongated cells in the xylem of vascular plants that serve in the transport of water and mineral salts
  - The **phloem** translocates a variety of organic and inorganic solutes, mainly from the leaves to other parts of the plants.



Differences between Xylem and Phloem

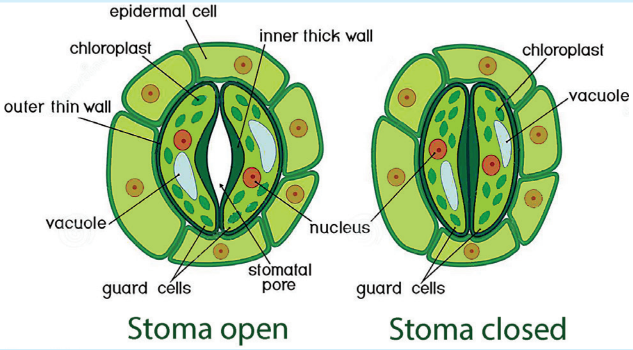
Basis for Comparison	Xylem	Phloem
Definition	Xylem is a vascular tissue that transports water and dissolved minerals absorbed from the roots to the rest of the plant.	Phloem is a vascular tissue that transports soluble organic compounds prepared during photosynthesis from leaves to the rest of the plant.
Location	Xylem is mainly located in the center of the vascular bundles.	Phloem is mainly localized towards the periphery of the vascular bundles.
	Xylem forms most of the bulk of the wood.	Phloem forms most of the bulk of the bark.
Found in	Xylem tissues are found in leaves, roots, and stems.	Phloem tissues are found in stems and leaves which later grow in the roots, fruits, and seeds.
Composed of	Xylem tissue is composed of xylem vessels, fibers, and tracheids.	Phloem tissue is composed of sieve tubes, companion cells, phloem fibers, and phloem parenchyma.
Fibers	Xylem fibers are robust and longer.	Phloem fibers are flexible in shorter.
Cells	The cells of the xylem tissue are dead cells except for the parenchyma cells.	The cells of the phloem tissue are living cells except for the blast fibers.
	The cell wall of the cells in the xylem is thick-walled.	The cell wall of the cells of the phloem is thin-walled.
Quantity	The quantity of xylem tissue in the vascular bundles is more than the phloem tissue.	The quantity of phloem tissue is comparatively less in the vascular tissue.

Basis for Comparison	Xylem	Phloem
Differentiation	In mature plants, xylem is differentiated into heartwood and sapwood	No such differentiation is observed in the phloem
Direction	The transport by xylem is unidirectional; the water and mineral are only moved up from the roots.	The transport by phloem is bidirectional; the food can travel both up and down the plant.
Mechanical support	Xylem also aids in providing physical support to the plant.	Phloem is not involved in mechanical support.

- Terrestrial plants take up huge amount water daily but most of it is lost to the air through evaporation from the leaves, i.e., **transpiration**.
  - Transpiration occurs mainly through stomata.
  - Besides the loss of water vapour in transpiration, exchange of oxygen and carbon dioxide in the leaf also occurs through these stomata.
  - **Transpiration is affected by several external factors:** temperature, light, humidity, wind speed.
  - Plant factors that affect transpiration include number and distribution of stomata, per cent of open stomata, water status of the plant, canopy structure etc.

Stomata

- They are the microscopic openings or pores in the epidermis of leaves and young stems.
- They are generally more numerous on the underside of leaves.
- They provide for the exchange of gases between the outside air and the branched system of interconnecting air canals within the leaf.
- A stomate opens and closes in response to the internal pressure of two sausage-shaped guard cells that surround it.
- Guard cells work to control excessive water loss, closing on hot, dry, or windy days and opening when conditions are more favourable for gas exchange.
- Normally stomata are open in the day time and close during the night.



10.2 Mineral Nutrition

Essential Mineral Elements

- **Macronutrients**
  - These are generally present in plant tissues in large amounts (in excess of 10 mole Kg –1 of dry matter).
  - The macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorous, sulphur, potassium, calcium and magnesium.
  - Of these, carbon, hydrogen and oxygen are mainly obtained from CO_2 and H_2O, while the others are absorbed from the soil as mineral nutrition
- **Micronutrients** or trace elements
  - These are needed in very small amounts (less than 10 mole Kg –1 of dry matter).
  - These include iron, manganese, copper, molybdenum, zinc, boron, chlorine and nickel
- Some other beneficial elements are also needed such as sodium, silicon, cobalt and selenium.

Various forms and functions of essential nutrient elements

- **Nitrogen:** It is one of the major constituents of proteins, nucleic acids, vitamins and hormones. It is required by plants in the greatest amount.
- **Phosphorus:** It is a constituent of cell membranes, certain proteins, all nucleic acids and nucleotides, and is required for all phosphorylation reactions.
- **Potassium:** It helps to maintain an anion-cation balance in cells and is involved in protein synthesis, opening and closing of stomata, activation of enzymes and in the maintenance of the turgidity of cells.
- **Calcium:**
  - It is required by meristematic and differentiating tissues.
  - It is used in the synthesis of cell wall during cell division.
  - It is also needed during the formation of mitotic spindle.
  - It is involved in the normal functioning of the cell membranes.
  - It activates certain enzymes and plays an important role in regulating metabolic activities
- **Magnesium:**
  - It activates the enzymes of respiration, photosynthesis and are involved in the synthesis of DNA and RNA.
  - Magnesium is a constituent of the ring structure of chlorophyll and helps to maintain the ribosome structure.

- **Iron:** It is an important constituent of proteins involved in the transfer of electrons. It activates catalase enzyme, and is essential for the formation of chlorophyll.
- **Manganese:**
  - It activates many enzymes involved in photosynthesis, respiration and nitrogen metabolism.
  - The best-defined function of manganese is in the splitting of water to liberate oxygen during photosynthesis.
- **Boron:** It is required for uptake and utilisation of Ca^{2+}, membrane functioning, pollen germination, cell elongation, cell differentiation and carbohydrate translocation.
- **Molybdenum:** It is a component of several enzymes, including nitrogenase and nitrate reductase both of which participate in nitrogen metabolism.
- **Chlorine:**
  - Along with Na^+ and K^+, it helps in determining the solute concentration and the anion cation balance in cells.
  - It is essential for the water-splitting reaction in photosynthesis, a reaction that leads to oxygen evolution.

10.3 Photosynthesis In Higher Plants

- Photosynthesis is the process by which green plants and certain other organisms transform light energy into chemical energy.
- During photosynthesis in green plants, light energy is captured and used to convert water, carbon dioxide, and minerals into oxygen and energy-rich organic compounds.
- The process of photosynthesis is commonly written as:

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Location of Photosynthesis

- Photosynthesis takes place in 'the green leaf' or 'in the chloroplasts and also other green parts like assimilitory roots, green stems etc.
- **Mesophyll cells** in the leaves, have a large number of chloroplasts.
  - Mesophyll cells are highly differentiated cells that make up the mesophyll layer found in plant leaves.
  - Usually, the chloroplasts align themselves along the walls of the mesophyll cells
- Within the chloroplast there is membranous system consisting of grana, the stroma lamellae, and the matrix stroma.
- There is a clear division of labour within the chloroplast.
  - The membrane system is responsible for trapping the light energy and also for the synthesis of Adenosine Triphosphate (ATP) and Nicotinamide adenine dinucleotide phosphate (NADPH).
    - Since they are directly light driven, these are called **light reactions** (photochemical reactions).
    - ATP and NADPH are energy carrier molecules. The energy that these molecules carry is stored in a bond that holds a single atom to the molecule. For ATP, it is a phosphate atom, and for NADPH, it is a hydrogen atom.
  - In stroma, enzymatic reactions synthesise sugar, which in turn forms starch.

    They are called **dark reactions** (carbon reactions) as they are not directly light driven but are dependent on the products of light reactions (ATP and NADPH)

    However, this should not be construed to mean that they occur in darkness or that they are not light-dependent.

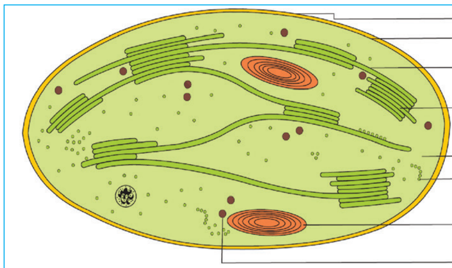


Figure: Diagrammatic representation of an electron micrograph of a section of chloroplast

Types of Pigments Involved in Photosynthesis

- The colour that we see in leaves is not due to a single pigment but due to four pigments:
  - Chlorophyll a (bright or blue green)
  - Chlorophyll b (yellow green)
  - Xanthophylls (yellow)
  - Carotenoids (yellow to yellow-orange)
- Chlorophyll a is the chief pigment responsible for trapping light and thus for the process of photosynthesis
- The other thylakoid pigments like chlorophyll b, xanthophylls and carotenoids, are called **accessory pigments** are also important.
  - Thylakoids are usually arranged in stacks (grana) and contain the photosynthetic pigment (chlorophyll).
  - They absorb light and transfer the energy to chlorophyll a.
  - Thus, they not only enable a wider range of wavelength of incoming light to be utilized for photosynthesis but also protect chlorophyll a from photo-oxidation.

Light and Dark Reactions

- **Light reactions** or the 'Photochemical' phase include light absorption, water splitting, oxygen release, and the formation of high-energy chemical intermediates, ATP and NADPH.

- **Dark reactions/Carbon Reactions/ Reactions of Calvin Cycle**
  - These do not directly depend on the presence of light but are dependent on the products of the light reaction, i.e., ATP and NADPH, besides CO_2 and H_2O.
  - They use ATP and NADPH and drive the processes leading to the synthesis of food, more accurately, sugars. This is the biosynthetic phase of photosynthesis.
  - Unlike the light reactions, which take place in the thylakoid membrane,

    The reactions of the Calvin cycle take place in the stroma (the inner space of chloroplasts).

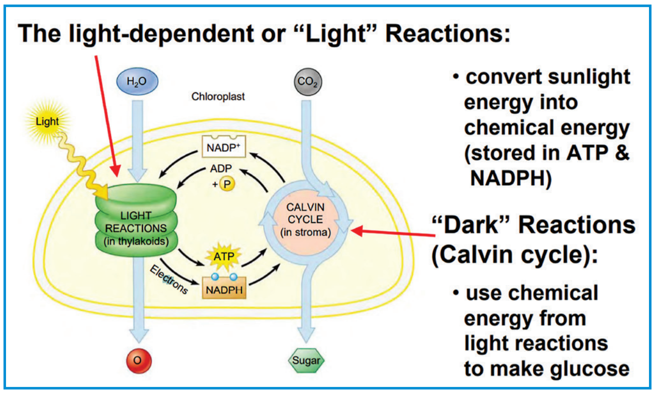


Figure: Light and Dark Reactions

Calvin Cycle

- In the Calvin cycle, carbon atoms from CO_2 are fixed (incorporated into organic molecules) and used to build three-carbon sugars.
  - This process is fueled by, and dependent on, ATP and NADPH from the light reactions.
- Calvin Cycle explains how these reactions proceed and it thus helps us find out about the first product formed when CO_2 is taken into a reaction or fixed.
- The Calvin cycle can be described under three stages:
  - **Carboxylation**

    It is the fixation of CO_2 into a stable organic intermediate (3-phospho-glyceric acid).

    It is the most crucial step of the Calvin cycle where CO_2 is utilised for the carboxylation of ribulose-1,5-bisphosphate (RuBP).
  - **Reduction:** In this second stage, ATP and NADPH are used to convert organic intermediate into three-carbon sugar, glyceraldehyde-3-phosphate (G3P). The glucose is formed from G3P.
  - **Regeneration:** In stage 3, RuBP, the molecule that starts the cycle, is regenerated so that the cycle can continue. It is generated from left G3P molecules using ATP.
- **Important points:**
  - The fixation of six molecules of CO_2 and 6 turns of the cycle are required for the formation of one molecule of glucose.
  - For every CO_2 molecule entering the Calvin cycle, 3 molecules of ATP and 2 of NADPH are required.

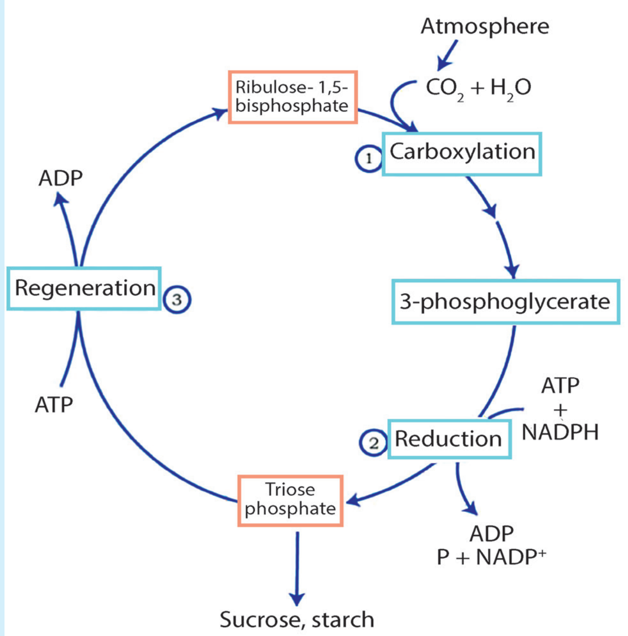


Figure: Calvin Cycle

C3 Pathway and C4 Pathway

- In the Calvin Cycle, the first product identified was 3-phosphoglyceric acid or in short PGA in majority of the plants. They had 3 carbon atoms in it.
- However, in another group of plants, the first stable product of CO_2 fixation was again an organic acid, but one which had 4 carbon atoms in it.
  - This acid was identified to be oxaloacetic acid or OAA
- Since then, CO_2 assimilation during photo-synthesis was said to be of two main types:
  - Those plants in which the first product of CO2 fixation is a C3 acid (PGA), i.e., the C3 pathway, and
  - Those in which the first product was a C4 acid (OAA), i.e., the C4 pathway.
- Calvin pathway occurs in all photosynthetic plants; it does not matter whether they have C3 or C4 (or any other) pathways.
  - The C4 pathways first follow Hatch and Slack Pathway (C4 Cycle) which is again a cyclic process.
    - In Hatch and Slack Pathway, the C4 acid OAA is formed in the mesophyll cells.
    - It then forms other 4-carbon compounds like malic acid which are then transported to the bundle sheath cells.
    - Bundle sheath cells - A layer of cells in plant leaves and stems that forms a sheath surrounding the vascular bundles.
    - In the bundle sheath cells these C_4 acids are broken down to release CO_2 and a 3-carbon molecule

- The CO_2 released in the bundle sheath cells enters the C_3 or the Calvin pathway, thus C_4 also following Calvin Pathway.
- Hence, in the C_4 plants Calvin cycle does not take place in the mesophyll cells but does so only in the bundle sheath cells.

Some Important differences between C_3 and C_4 Plants	
C_3 Plants	**C_4 Plants**
The first stable intermediate stable product is phosphoglyceric acid having 3 carbon atoms.	The first stable intermediate product is oxaloacetate acid having 4 carbon atoms.
Calvin cycle is found in all photosynthetic plants.	C_4 cycle is found only in certain tropical plants.
The efficiency of CO_2 absorption at low concentration is far less. So, they are less efficient.	The efficiency of CO_2 absorption from low concentration is quite high. So, they are more efficient plants and have higher rate to photosynthesis.
The CO_2 concentration inside leaf remains high	The CO_2 concentration inside the leaf remains low
Only C_3 cycle is found.	Both C_3 and C_4, cycles are found
They are adapted to cool and wet environments.	They are adapted to tropical and dry environments. They can thus tolerate higher temperatures.
Photosynthetic functions occur only in mesophyll cells – on the surface of the leaves	Photosynthetic functions occur in mesophyll and bundle sheath cells.
They do not have Kranz anatomy.	They have a special type of leaf anatomy called Kranz leaves. Kranz' means 'wreath' or 'ring' and is a reflection of the arrangement of cells.
Majority of the plants on earth are C3 plants (95% of green plants)	They are very low in numbers. (Around 5%)
Examples include rice, wheat, oats, barley, cotton, sunflower, soyabean etc.	Examples include Maize, Sugarcane, sorghum etc.
Photorespiration Rate is High	Photorespiration does not occur. This is because they have a mechanism that increases the concentration of CO_2 at the enzyme site.

Photorespiration

- Photorespiration is a wasteful pathway that occurs when the Calvin cycle enzyme **Ribulose Bisphosphate Carboxylase Oxygenase** (**RUBISCO)** acts on oxygen rather than carbon dioxide.
- The majority of plants are C3 plants, which have no special features to combat photorespiration.
- C4 plants minimize photorespiration by separating initial CO_2 fixation and the Calvin cycle in space, performing these steps in different cell types (as discussed in earlier section).
- **Crassulacean acid metabolism (CAM)** plants minimize photorespiration and save water by separating initial CO_2 fixation and the Calvin cycle in time, between night and day.

Crassulacean acid metabolism (CAM) plants

- Certain plants belonging to the Crassulaceae, Cactaceae, Orchidaceae, Liliaceae, Vitaceae and Euphorbiaceae show diurnal pattern of organic acid formation.
  - They are adapted to dry environments and use the crassulacean acid metabolism (CAM) pathway to minimize photorespiration.
  - Instead of separating the light-dependent reactions and the use of CO_2 in the Calvin cycle in space, CAM plants separate these processes in time.
  - At night, CAM plants open their stomata, allowing CO_2 to diffuse into the leaves.
  - This CO_2 s fixed into oxaloacetate in the same steps used by C4 plants, then converted to malate or another type of organic acid.

Factors Affecting Photosynthesis

- **Light**
  - At low intensities, there is a linear relationship between incident light and CO_2 fixation rates.
  - At higher light intensities, gradually the rate does not show further increase as other factors become limiting.
  - Light saturation occurs at 10 per cent of the full sunlight. Hence, except for plants in shade or in dense forests, light is rarely a limiting factor in nature.
  - Increase in incident light beyond a point causes the breakdown of chlorophyll and a decrease in photosynthesis.

- **Carbon dioxide Concentration**
  - It is the major limiting factor for photosynthesis.
  - The concentration of CO_2 is very low in the atmosphere (between 0.03 and 0.04 per cent).
  - Increase in concentration upto 0.05 per cent can cause an increase in CO_2 fixation rates; beyond this the levels can become damaging over longer periods.
  - The C3 and C4 plants respond differently to CO_2 concentrations
    - At low light conditions neither group responds to high CO_2 conditions.
    - At high light intensities, both C3 and C4 plants show increase in the rates of photosynthesis.
    - What is important to note is that the C4 plants show saturation at about 360 µlL-1 while C3 responds to increased CO_2 concentration and saturation is seen only beyond 450 µlL-1.
    - Thus, C3 plants show higher increase in response to increased CO_2 concentration than C4 plants.
- **Temperature**
  - The dark reactions being enzymatic are temperature controlled and show increase in CO_2 fixation on increase in temperature.
  - Though the light reactions are also temperature sensitive they are affected to a much lesser extent.
  - The C4 plants respond to higher temperatures and show higher rate of photosynthesis while C3 plants have a much lower temperature optimum.
  - The temperature optimum for photosynthesis of different plants also depends on the habitat that they are adapted to.
    - Tropical plants have a higher temperature optimum than the plants adapted to temperate climates.
- Water
  - Even though water is one of the reactants in the light reaction, the effect of water as a factor is more through its effect on the plant, rather than directly on photosynthesis.
  - Water stress causes the stomata to close hence reducing the CO_2 availability.
  - Besides, water stress also makes leaves wilt, thus, reducing the surface area of the leaves and their metabolic activity as well.

10.4 Plant Growth Regulators/Plant Hormones

- Plant growth regulators may be defined as any organic compounds, which are active at low concentrations in promoting, inhibiting or modifying growth and development.
  - The naturally occurring (endogenous) growth substances are commonly known as plant hormones, while the synthetic ones are called growth regulator.
- Plant hormone is an organic compound synthesised in one part of the plant and translocated to another part, where in very low concentrations it causes a physiological response.
- Initial research into plant hormones identified five major classes: abscisic acid, auxin, cytokinins, ethylene and gibberellins.
- Based on their action, they are broadly classified as follows:
  - **Plant Growth Promoters:** They promote cell division, cell enlargement, flowering, fruiting and seed formation. Examples are auxins, gibberellins and cytokinins.
  - **Plant Growth Inhibitors:** These chemicals inhibit growth and promote dormancy and abscission in plants. An example is an abscisic acid.

Plant Hormones

Auxins

- Auxins was first isolated from human urine by **Darwin** in 1880.
- They are generally produced by the growing apices of the stems and roots, from where they migrate to the regions of their action
- Auxin causes several responses in plants:
  - Bending toward a light source (phototropism).
  - Downward root growth in response to gravity (geotropism).
  - Contribute to the elongation of shoots but at higher concentrations can promote apical dominance

    Apical Dominance: The tendency of an apical bud to produce hormones that suppress the growth of the buds below it on the stem.
  - **Flower formation.**
  - **Fruit set and growth:** They help to prevent fruit and leaf drop at early stages but promote the abscission of older mature leaves and fruits.
  - Formation of adventitious roots.
  - It controls xylem differentiation and helps in cell division
- They are widely used as herbicides
- Auxin is the active ingredient in most rooting compounds in which cuttings are dipped during vegetative propagation.

Gibberellins

- Gibberellins were first discovered by Japanese scientist **Kurasava** in 1926.

- Gibberellins cause fruits like apple to elongate and improve its shape.
- They also delay senescence. Thus, the fruits can be left on the tree longer so as to extend the market period.
- They hasten the maturity period, thus leading to early seed production.
- They also promote bolting (internode elongation just prior to flowering) in beet, cabbages and many plants with rosette habit.
- Thus, in a nutshell, Gibberellins stimulate cell division and elongation, break seed dormancy, and speed germination.

Cytokinins

- Cytokinins are discovered by **Miller** in 1955.
- Natural cytokinins are synthesized in regions where rapid cell division occurs, for example, root apices, developing shoot buds, young fruits etc
- It helps to promote cell division and thus produce new leaves, chloroplasts in leaves, lateral shoot growth and adventitious shoot formation.
- Cytokinins help overcome the apical dominance.
- They are thus involved in branching and stimulating bud initiation.
- They promote nutrient mobilisation which helps in the delay of leaf senescence
- They are used as fruit thinners.
  - Fruit thinning is defined as the removal of certain flowers or clusters of flowers or individual fruitlets after fruit set and natural dropping have occurred.
  - It improves fruit yield and quality and return bloom for the following year.

Ethylene

- Ethylene is unique in that it is found only in the gaseous form
- Ethylene is discovered by **Burg** in 1962.
- It is synthesised in large amounts by tissues undergoing senescence and ripening fruits.
- It promotes abscission of leaves and fruits, inhibits shoot elongation and inhibits lateral bud development.
- It is highly effective in fruit ripening.
- It enhances the respiration rate during ripening of the fruits.
  - This rise in rate of respiration is called respiratory climactic.
- Ethylene also promotes root growth and root hair formation, thus helping the plants to increase their absorption surface.
- Plants often increase ethylene production in response to stress, and ethylene often is found in high concentrations within cells at the end of a plant's life.

Abscisic acid

- Abscisic acid is discovered by **Carnes** and **Adicote**.
- It acts as a general plant growth inhibitor and an inhibitor of plant metabolism.
- It causes abscission of leaves, fruits, and flowers.
- It inhibits seed germination
- It stimulates the closure of stomata and increases the tolerance of plants to various kinds of stresses.
  - Therefore, it is also called the stress hormone.

Some key terms related to Plant Growth

- **Phototropism:** In phototropism a plant bends or grows directionally in response to light. Shoots usually move towards the light; roots usually move away from it.
- **Photoperiodism:** In photoperiodism flowering and other developmental processes are regulated in response to the photoperiod, or day length.
  - Plants require a periodic exposure to light to induce flowering and such plants are able to measure the duration of exposure to light.
  - Short-day plants flower when day length is below a certain threshold, while long-day plants flower when day length is above a certain threshold.
  - Day-neutral plants - there is no such correlation between exposure to light duration and induction of flowering response
- **Vernalization:**
  - There are plants for which flowering is either quantitatively or qualitatively dependent on exposure to low temperature. This phenomenon is termed vernalization.
  - It is thus the artificial exposure of plants (or seeds) to low temperatures in order to stimulate flowering or to enhance seed production.

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