GOVERNMENT OF TAMIL NADU

BIO-BOTANY

HIGHER SECONDARY FIRST YEAR

VOLUME - 2

Untouchability is Inhuman and a Crime

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HOW TO USE THE BOOK

Learning Objectives: Learning objectives are brief statements that describe what students will be expected to learn by the end of school year, course, unit, lesson or class period.

Chapter Outline — Illustrate the complete overview of chapter

Amazing facts, Rhetorical questions to lead students to biological inquiry

Activity — Directions are provided to students to conduct activities in order to explore, enrich the concept.

Infographics — Visual representation of the lesson to enrich learning .

Evaluation — Assess students to pause, think and check their understanding

To motivate the students to further explore the content digitally and take them in to virtual world

ICT — To enhance digital Science skills among students

Concept Map — Conceptual diagram that depicts relationships between concepts to enable students to learn the content schematically

References — List of related books for further details of the topic

Web links — Digital resources

Glossary — Explanation of scientific terms

List of Botanical terms — Tamil terminology for Botanical terms given for easy understanding

Competitive Exam questions — Model questions to face various competitive exams

Scope of Botany
Higher Studies and Career Opportunities

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- Medical Lab Technology
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M.Sc in Life sciences- 5 year Integrated course

- Indian institute of Science, Bengaluru
  Website: http://www.iisc.ac.in/
- National Institute of Science Education and Research (NISER) , Bhubaneswar, Kolkata , Pune , Mohali, Bhopal ,Thiruvananthapuram , Tirupati and Berhampur
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- Regional Institute of Education
  Ajmer, Bhopal, Bhubaneswar, Mysuru and Shilillong

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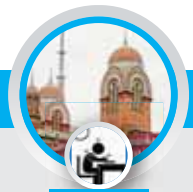

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- M.Sc. Plant Biology & Plant Biotechnology
- M.Sc. Plant molecular Biology
- M.Sc. Mycology & Plant pathology
- M.Sc. Plant science

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International Centre for Genetic Engineering and Biotechnology (ICGEB), New Delhi	Mammalian Biology; Plant Biology; Synthetic Biology and Biofuels.	www.icgen.org
National Institute of Virology, Pune	Epidemology, Basic virology; Diagnostics.	www.niv.co.in
Center for DNA Fingerprinting and Diagnostics, Hyderabad	Computational Biology, Bioinformatics; Protein structure, Dynamic and Interactions Epigenetic	www.cdfd.org.in
Institute of Life Sciences, Bhubaneswar	Infectious disease;Immune biology; Cancer biology; Nanotechnology	www.ils.res.in
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Central food Technological Research Institute, Mysore.	Food science and Technology	www.cftri.com
Central Institute of medicinal and Aromatic Plants, Lucknow.	Agronomy & soil sciences; Biotechnology, Crop protection; Genetics and plant breeding;	www.cimap.res.in
National Botanical Research Institute, Lucknow.	Genetics and molecular biology; Plant microbe interaction & Pharmacogonosy.	www.nbri.res.in
Institute of Genomics and Integrative Biology	Genomics and Molecular medicine, Chemical and systems biology.	www.igib.res.in
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Birbal Sahni Institute od Palaeobotany (BSIP) Lucknow.	Palynology in fossil fuel exploration; Dendrochronology; Ethnobotany; Micropaleontology; Carbon 14Dating	www.bsip.res.in
School of Medical Science and Technology, Indian Institute of Technology, Kharagpur, West Bengal.	Tissue Engineering; Biomaterials; Herbal medicine & Bio-Engineering.	www.smstweb.iitkgp.ernet.in
Institute of Wood Science and Technology, Bengaluru.	Tree improvement and Genetics; Chemistry of Forest Products.	iwst.icfre.gov.in
Centre for Ecological Sciences, Indian Institute of Science. Bengaluru.	Behaviour Ecology; Evolution; climate change & conservation.	www.ces.iisc.ernet.in
Botanical Survey of India(BSI), Kolkatta	To Survey, research and conservation of plant resources, flora and endangered species.	www.bsi.gov.in

Research Institutions in various areas of Botany		
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Indian Agricultural Research Institute (IARI) New Delhi	Genetics & Plant Breeding; Plant Pathology; Microbiology; Post Harvest Technology	www.iari.res.in
Indian Institute of Horticultural Research, Bengaluru	Horticultural Research; Biotechnology; Entomology; Pathology	www.iihr.res.in
Agharkar Research Institute, Pune	Biodiversity & Palaeobiology, Bioenergy, BioprospectingNanobioscicence	www.aripune.org
National Bureau of Plant Genetic Resources (NBPGR) New Delhi	Plant genetic resources management and use.	www.nbpgr.ernet.in
Institute of Forest Genetics and Tree Breeding, Coimbatore.	Tree improvement; Bio-prospecting of Forest Natural Resources	www .ifgtb.icfre.gov.in
Central Soil Salinity Research Institute, Karnal, Haryana	Reclamation and Management of Salt affected soils. Bio-remediation of waste waters. Carbon Sequestration	www .cssri.nic.in
Central Institute of Post Harvest Engineering & Technology, Ludiana	Rapid Evaluation of Food Quality and Safety; Packaging and storage of agricultural produce and products.	www.ciphet.in
Central Plantation crops Research Institute, Kerala	Crop improvement; Production; Protection; Plant physiology and Biochemistry.	www.cpcri.gov.in
Indian Institute of Crop Processing Technology, Thanjavur.	Agricultural Process Engineering Renewable energy for food processing .	www.iicpt.edu.in
Central Tuber Crops Research Institute, Thiruvananthapuram.	Development of Agro techniques for tuber crops	www.ctcri.org
National Centre for Integrated Pest Management (ICAR) New Delhi	Pest Management	www.ncipm.org.in
Indian Institute of Spices Research, Kozhikode.	Collection, conservation, evaluation and cataloging of germplasm.	www.spices.res.in
Central Institute for Cotton Research, Nagpur, (Regional station: Coimbatore & Sirsa)	Crop improvement, Crop Production and Crop Protection.	www.cicr.org.in
Central Institute for Research on Cotton Technology, (CIRCOT) Mumbai	Improvement in Ginning of cotton; Improvement and quality evaluation of fibers and production of value added products.	www.circot.res.in
Directorate of Cashewnut & Cocoa, Agri, Kerala	Cocoa production and processing	www.dccd.gov.in

Research Institutions in various areas of Botany		
Name of the Institution	**Research Areas**	**Website**
National Research Center on Plant Biotechnology, New Delhi	Genetic engineering for biotic resistance.	www.nrcpb.org
Indian Institute of Soil Sciences (IISS), Bhopal	Study of organic and inorganic nutrient sources affect soil biological activity.	www.iiss.nic.in
National Institute of Plant Genome Research (NIPGR), New Delhi	Structural and Functional Genomics in Plants; Computational biology; Genome analysis and molecular mapping.	www.nipgr.res.in
Sugarcane Breeding Institute, ICAR, Coimbatore.	Breeding of superior sugarcane varieties/ genotypes;	www.sugarcane.res.in
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National Institute of Abiotic Stress Management., Pune	Basic and strategic research on management of abiotic stresses of crop plants.	www.niam.res.in
Central Research Institute for Dryland Agriculture, Hyderabad	Dryland, Agrometerology and Crop sciences	crida.in
Central Research Institute for Jute & Allied Fibres, Kolkata, West Bengal	Crop improvement, Crop production, Crop protection, Agricultural research.	www.crijaf.org.in
Indian Institute of Pulses Research (IIPR), Kanpur	Genetics & Plant Breeding and Seed Science	www.iipr.res.in
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- Once the scanner button in the application is clicked, camera opens and then bring it closer to the QR code in the text book.
- Once the camera detects the QR code, a url appears in the screen.Click the url and goto the content page.

Unit IV: Plant Anatomy (Structural Organisation)

Chapter 9

Tissue and Tissue System

Learning Objectives

The learner will be able to,

- *Study major types of plant cells and their function.*
- *Differentiate the various types of cells.*
- *Study the relationship between the distribution of tissues in the various parts of plants.*
- *Describes the ground tissue system [cortex and pith] and vascular systems*
- *Interpret cross sections and longitudinal sections of dicot and monocot root, stem and leaf.*
- *Compare the internal organization of dicot root and monocot root.*

Nehemiah Grew
Father of Plant Anatomy

1641–1712

Katherine Esau (1898–1997)

A legendary Role model for women in science. She was a scintillating Botany teacher and pioneering researcher for six decades. Her classic book **Anatomy of Seed Plants** is the best literature in Plant Anatomy. In recognition of her distinguished service to science, she was awarded **National Medal of Science (1989) by USA.**

CL3PMM

Chapter Outline

This chapter introduces the internal structure of higher Plants. The study of internal structure and organisation of plant is called plant Anatomy (*Gk: Ana = as under; temnein = to cut*). Plants have cells as the basic unit. The cells are organised into tissues. The tissues in turn are organised into organs. The different organs in a plant have different internal structures. It is studied by means of dissection and microscopic examination.

Milestones in Anatomy

- 1837 Hartig: Coined the term **Sieve tubes**
- 1839 Schleiden: Coined the term **Collenchyma**
- 1857 Hofmeister: Proposed **Apical cell theory**
- 1858 Nageli. C: Coined the term **Xylem and Phloem, Meristem and** supporter of **Apical cell theory**
- 1865 Mettenius: Coined the term **Sclerenchyma**
- 1868 Hanstein: Proposed **Histogen theory**
- 1885 Tschirch: Coined the term **Sclereids** Named Four types of **Sclereids** (Brachy, Macro, Osteo & Astro) in 1889
- 1914 Haberlandt: Coined the term xylem as **Hadrome** and Phloem as **Leptome and Classification of meristem.**
- 1924 Schmidt A: Proposed **Tunica – Corpus theory**
- 1926 Schűepp: **Mass, rib, & plate meristem**
- 1946 Bloch: Discovered the **Trichosclereids**
- 1952 Popham: Explained the organization of **Shoot apex of Angiosperms**
- 1955 Duchaigne: Discovered the **Annular collenchyma**
- 1961 Clowes: Proposed **Quiescent centre concept**
- 1963 Sanio: Coined the term **Tracheids**

The Tissues

A Tissue is a group of cells that are alike in origin, structure and function. The study of tissue is called Histology. A plant is made up of different types of tissues.

There are two principal groups:

1. Meristematic tissues
2. Permanent tissues

9.1 Meristematic Tissue

9.1.1 Characteristics and classification

The characters of meristematic tissues: (Gr. *Meristos*-**Divisible**)

The term meristem is coined by **C. Nageli** 1858.

- The meristematic cells are isodiametric and they may be, oval, spherical or polygonal in shape.
- They have generally dense cytoplasm with prominent nucleus.
- Generally the vacuoles in them are either small or absent.
- Their cell wall is thin, elastic and essentially made up of cellulose.
- These are most actively dividing cells.
- Meristematic cells are self-perpetuating.

Classification of Meristem

Meristem has been classified into several types on the basis of position, origin, function and division.

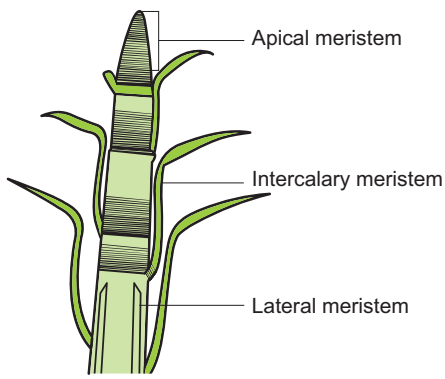


Figure 9.1: Different types of meristems on the basis of position in plant body

Classification of Meristem

Position	Origin	Function	Plane of division
Apical meristem Present in apices of root and shoot. It is responsible for increase in the length of the plant, it is called as primary growth.	**Primary Meristem** It is derived from embryonic stages and differentiated into primary permanent tissues.	**Protoderm** It gives rise to epidermal tissue system and develops into epidermis,stomata and hairs.	**Mass meristem** It divides in all planes. Example: endosperm,young embryo and sporangium
Intercalary meristem Occurs between the mature tissues. It is responsible for elongation of internodes.		**Procambium** It gives rise to primary vascular tissues. Example: xylem and phloem .	**Rib meristem or File meristem** It divides anticlinally in one plane. Example: development of cortex and pith
Lateral meristem Occurs along the longitudinal axis of stem and root. It is responsible for secondary tissues and thickening of stem and root. Example: vascular cambium and cork cambium.	**Secondary meristem** It is derived during later stage of development of the plant body. It produces cork cambium and interfascicular cambium.	**Ground Meristem** It gives rise to all tissues except epidermis and vascular strands.	**Plate meristem** It divides anticlinally in two planes. Example: development of epidermis

Theories of Meristem Organization and Function

Many anatomists illustrated the root and shoot apical meristems on the basis of number and arrangement and accordingly proposed the following theories – An extract of which are discussed below.

Shoot Apical Meristem

Apical Cell Theory

Apical cell theory is proposed by **Hofmeister** (1852) and supported by **Nageli** (1859). A single apical cell is the structural and functional unit.

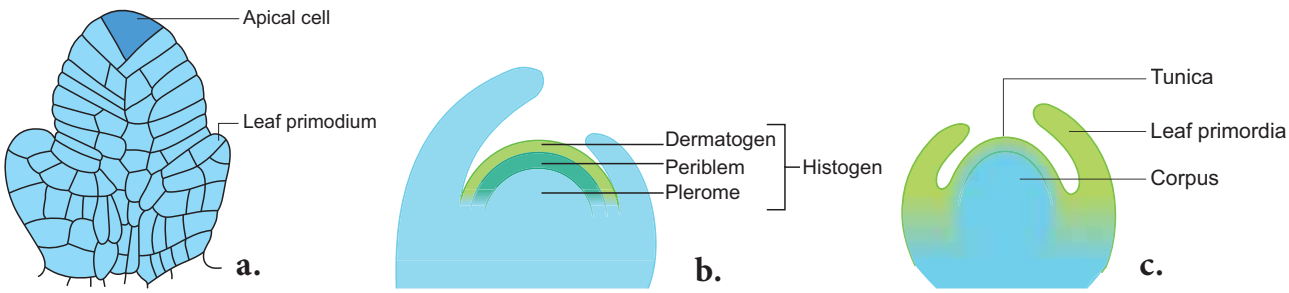


Figure 9.2: Shoot apical meristem a) Apical cell theory, b) Histogen theory, c) Shoot Tunica corpus theory

This apical cell governs the growth and development of whole plant body. It is applicable in Algae, Bryophytes and in some Pteridophytes.

Histogen Theory

Histogen theory is proposed by **Hanstein** (1868) and supported by **Strassburgur.** The shoot apex comprises three distinct zones.

1. **Dermatogen:** It is a outermost layer. It gives rise to epidermis.
2. **Periblem:** It is a middle layer. It gives rise to cortex.
3. **Plerome:** It is innermost layer. It gives rise to stele

Tunica Corpus Theory

Tunica corpus theory is proposed by **A. Schmidt** (1924).

Two zones of tissues are found in apical meristem.

1. **The tunica**: It is the peripheral zone of shoot apex, that forms epidermis.
2. **The corpus**: It is the inner zone of shoot apex,that forms cortex and stele of shoot.

Root Apical Meristem

Root apex is present opposite to the shoot apex. The roots contain root cap at their apices and the apical meristem is present below the root cap. The different theories proposed to explain root apical meristem organization is given below.

Apical Cell Theory

Apical cell theory is proposed by **Nageli.** The single apical cell or apical initial composes the root meristem. The apical initial is tetrahedral in shape and produces root cap from one side. The remaining three sides produce epidermis, cortex and vascular tissues. It is found in vascular cryptogams.

Histogen Theory

Histogen theory is proposed by **Hanstein (1868)** and supported by **Strassburgur**. The histogen theory as appilied to the root apical meristem speaks of four histogen in the meristem. They are respectively

i. **Dermatogen:** It is a outermost layer. It gives rise to root epidermis.

ii. **Periblem:** It is a middle layer. It gives rise to cortex**.**

iii. **Plerome:** It is innermost layer. It gives rise to stele

iv. **Calyptrogen:** It gives rise to root cap.

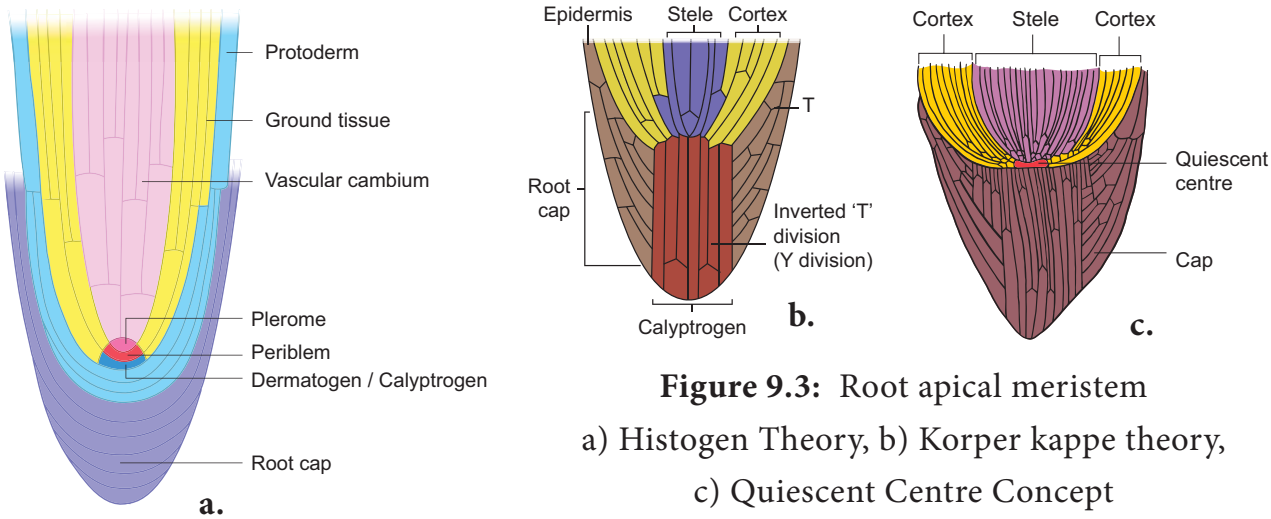


Figure 9.3: Root apical meristem

a) Histogen Theory, b) Korper kappe theory, c) Quiescent Centre Concept

Korper Kappe Theory

Korper kappe theory is proposed by **Schuepp**. There are two zones in root apex – Korper and Kappe

1. **Korper zone** forms the body.
2. **Kappe zone** forms the cap. This theory is equivalent to tunica corpus theory of shoot apex.The two divisions are distinguished by the type of T (also called Y divisions). Korper is characterised by inverted T divisions and kappe by straight T divisions.

Quiescent Centre Concept

Quiescent centre concept was proposed by **Clowes** (1961) to explain root apical meristem activity. These centre is located between root cap and differentiating cells of the roots. The apparently inactive region of cells in root promeristem is called quiescent centre. It is the site of hormone synthesis and also the ultimate source of all meristematic cells of the meristem.

9.2 Permanent Tissues

The Permanent tissues develop from apical meristem. They lose the power of cell division either permanently or temporarily. They are classified into two types:

1. Simple permanent tissues.
2. Complex permanent tissues.

Simple Permanent Tissues

Simple tissues are composed of one type of cells only. The cells are structurally and functionally similar. It is of three types.

1. Parenchyma
2. Collenchyma
3. Sclerenchyma

Parenchyma (Gk: *Para*-beside; *enehein*- to pour)

Parenchyma is generally present in all organs of the plant. It forms the ground tissue in a plant. Parenchyma is a living tissue and made up of thin walled cells. The cell wall is made up of cellulose. Parenchyma cells may be oval, polyhedral, cylindrical, irregular, elongated or armed. Parenchyma tissue normally has prominent intercellular spaces. Parenchyma may store various types of materials like, water, air, ergastic substances. It is usually colourless. The turgid parenchyma cells help in giving rigidity to the plant body. Partial conduction of water is also maintained through parenchymatous cells.

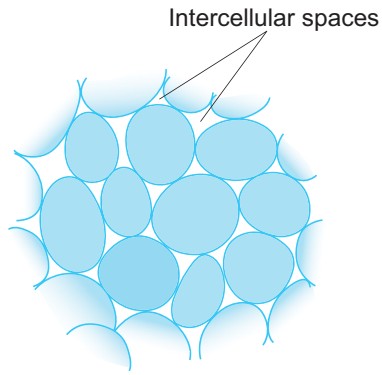


Figure 9.4: Parenchyma

Occsionally Parenchyma cells which store resin, tannins, crystals of calcium carbonate, calcium oxalate are called idioblasts. Parenchyma is of different types and some of them are discussed as follows.

Types of Parenchyma

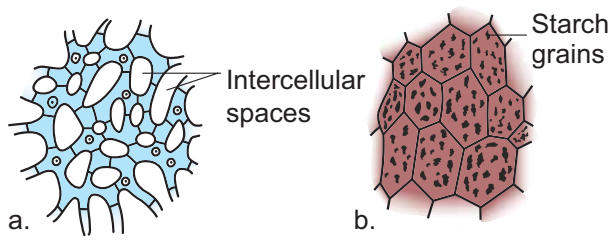


Figure 9.5: Types of Parenchyma
a) Aerenchyma, b) Storage parenchyma

1. Aerenchyma:
Parenchyma which contains air in its intercellular spaces. It helps in aeration and buoyancy. Example: *Nymphae and Hydrilla*.

5. Prosenchyma:
Parenchyma cells became elongated, pointed and slightly thick walled. It provides mechanical support.

Parenchyma

2. Storage Parenchyma:
Parenchyma stores food materials. Example: Root and stem tubers.

4. Chlorenchyma
Parenchyma cells with chlorophyll. Function is photosynthesis. Example: Mesophyll of leaves.

3. How?.... Stellate Parenchyma
Star shaped parenchyma. Example: Petioles of *Banana and Canna*.

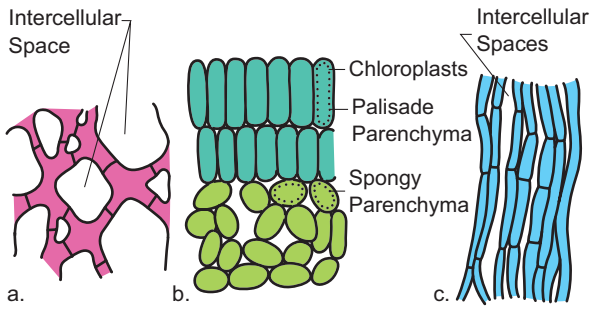


Figure 9.5: a) Stellate parenchyma, b) Chlorenchyma, c) Prosenchyma

Collenchyma (Gk. Colla-glue; enchyma – an infusion)

Collenchyma is a simple, living mechanical tissue. Collenchyma generally occurs in hypodermis of dicot stem. It is absent in the roots and also occurs in petioles and pedicels. The cells are elongated and appear polygonal in cross section. The cell wall is unevenly thickened. It contains more of hemicellulose and pectin besides cellulose. It provides mechanical support and elasticity to the growing parts of the plant. Collenchyma consists of narrow cells. It has only a few small chloroplast or none. Tannin maybe present in collenchyma.Based on pattern of pectinisation of the cell wall, there are three types of collenchyma

Types of Collenchyma

1. Angular collenchyma
It is the most common type of collenchyma with irregular arrangement and thickening at the angles where cells meets. Example:Hypodermis of *Datura* and *Nicotiana*

2. Lacunar collenchyma
The collenchyma cells are irregularly arranged. Cell wall is thickening on the walls bordering intercellular spaces. Example:Hypodermis of *Ipomoea*

3. Lamellar collenchyma
The collenchyma cells are arranged compactly in layers(rows). The Cell wall is thickening is at tangential walls.These thickening appear as successsive tangential layers. Example:Hypodermis of *Helianthus*

Diagramatic structures

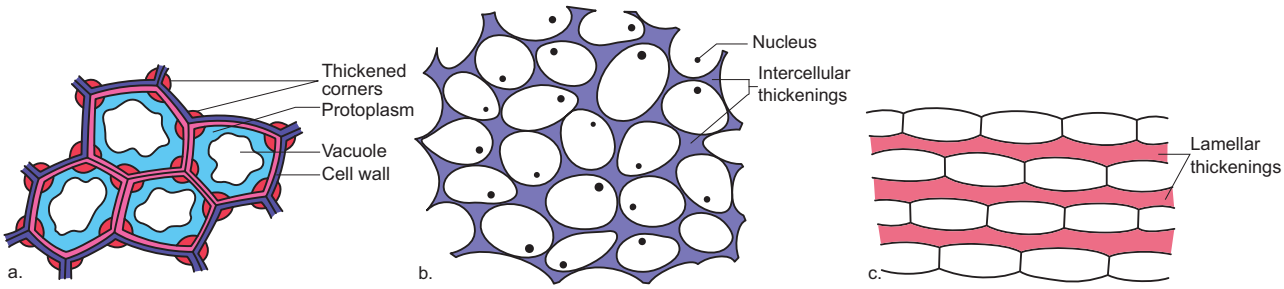


Figure 9.6: Types of Collenchyma a) Angular collenchyma, b) Lacunar collenchyma, c) Lamellar collenchyma

Annular Collenchyma: Duchaigne (1955) reported another type called Annular collenchyma in petiole of Nerium. The lumen is more or less circular in shape.

Sclerenchyma (Gk. Sclerous- hard: enchyma-an infusion)

The sclerenchyma is a dead cell and lacks protoplasm. The cells are long or short, narrow thick walled and lignified secondary walls. The cell walls of these cells are uniformly and strongly thickened. The sclerenchymatous cells are of two types:

1. Sclereids
2. Fibres

Sclereids (Stone Cells)

Sclereids are dead cells, usually these are isodiametric but some are elongated too. The cell wall is very thick due to lignification. Lumen is very much reduced. The pits may simple or branched. Sclereids are mechanical in function. They give hard texture to the seed coats, endosperms etc., Sclereids are classified into the following types.

Types of Sclereids

1. Branchysclereids or Stone cells:
Isodiametric sclereids, with hard cell wall. It is found in bark, pith cortex, hard endosperm and fleshy portion of some fruits. Example: - Pulp of *Pyrus*.

2. Macrosclereids:
Elongated and rod shaped cells, found in the outer seed coat of leguminous plants. Example: *Crotalaria and Pisum sativum*.

3. Osteosclereids (Bone cells):
Rod shaped with dilated ends. They occur in leaves and seed coats. Example: seed coat of *Pisum and Hakea*

4. Astrosclereids:
Star cells with lobes or arms diverging form a central body. They occur in petioles and leaves. Example: *Tea, Nymphae and Trochodendron*.

5. Trichosclereids:
Hair like thin walled sclereids. Numerous small angular crystals are embedded in the wall of these sclereids, present in stems and leaves of hydrophytes. Example: *Nymphaea leaf* and Aerial roots of *Monstera*.

Diagramatic Structures

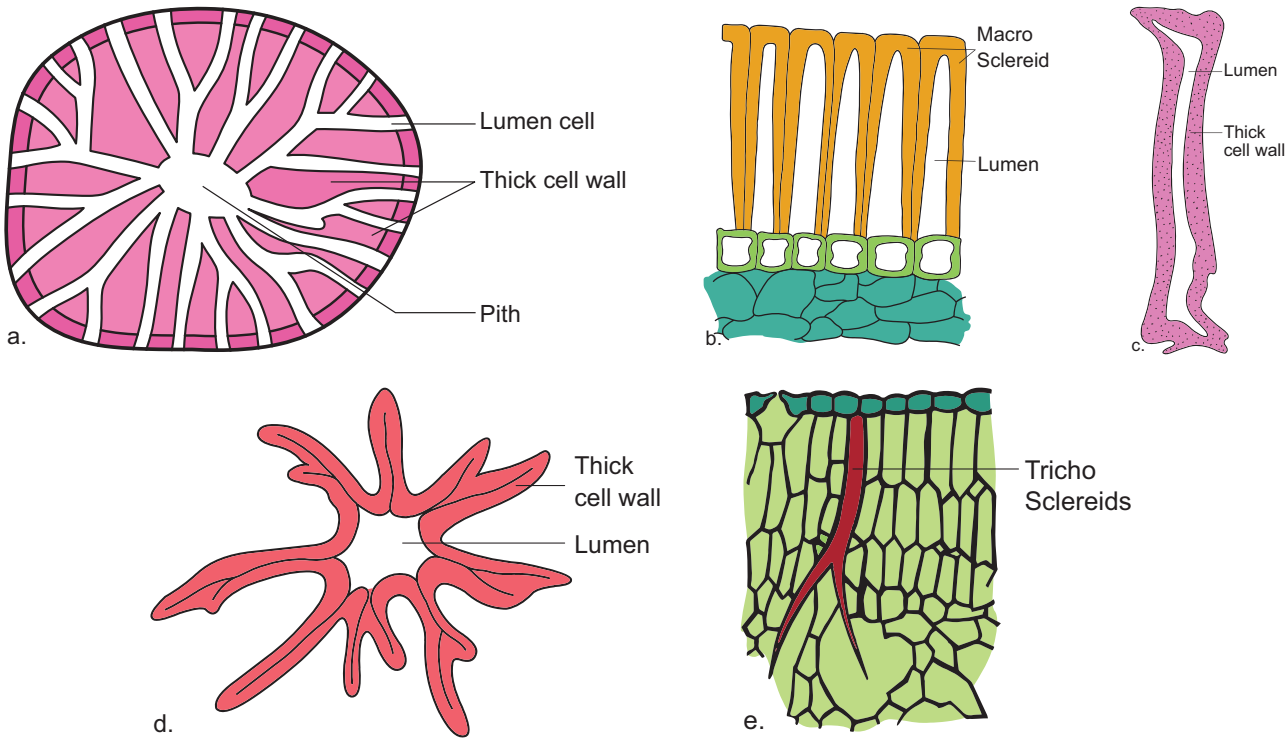


Figure 9.7: Types of Sclereids a) Brachysclereids, b) MacroSclereids, c) Osteosclereids, d) Astrosclereids, e) Trichosclereids

Filiform Sclereids: The sclereids are present in the leaf lamina of Olea europaea. They are very much elongated fibre like and about 1m.m length.

Sclerenchyma Found in Some Fruits

Figure 9.8: a) Pear fruit, b) Strawberry, c) Guava

Fibres

Fibres are very much elongated sclerenchyma cells with pointed tips. Fibres are dead cells and have lignified walls with narrow lumen. They have simple pits. They provide mechanical strength and protect them from the strong wind. It is also called supporting tissues. Fibres have a great commercial value in cottage and textile industries.

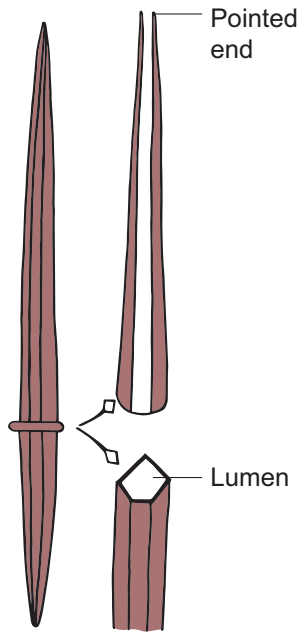


Figure 9.9 T.S of fibre

Fibres are of five types

Wood Fibres or Xylary Fibres

These fibres are associated with the secondary xylem tissue. They are also called xylary fibres. These fibres are derived from the vascular cambium. These are of four types. a. Libriform fibres

b. Fibre tracheids c. Septate fibres d. Gelatinous fibres.

Fibres are the longest plant cells. Longest Fibres occur in *Boehmeria* (Ramie fibre) 55 cm long

a. **Libriform fibres:** These fibres have slightly lignified secondary walls with simple pits. These fibres are long and narrow.
b. **Fibre tracheids:** These are shorter than the libriform fibres with moderate secondary thickenings in the cell walls. Pits are simple or bordered.
c. **Septate fibres:** Fibres that have thin septa separating the lumen into distinct chambers. Eg. Teak
d. **Gelatinous fibres:** Fibres in which lignin is less in amount and cellulose is more in this cell walls.

These fibres are characteristic of tension wood which is formed in the underside of leaning stems and branches.

Bastfibres or Extra Xylary Fibres

These fibres are present in the phloem. Natural Bast fibres are strong and cellulosic. Fibres obtaining from the phloem or outer bark of jute, kenaf, flax and hemp plants. The so called pericyclic fibres are actually phloem fibres.

Surface Fibres

These fibres are produced from the surface of the plant organs. Cotton and silk cotton are the examples.They occur in the testa of seeds.

Mesocarp Fibres

Fibres obtained from the mesocarp of drupes like Coconut.

Leaf Fibres

Fibres obtained from the leaf of *Musa, Agave and Sensciveria.*

Fibres in Our Daily Life

Economically fibres may be grouped as follows

1. **Textile Fibres:** Fibres utilized for the manufacture of fabrics, netting and cordage etc.
   a. **Surface Fibres**: Example: Cotton.
   b. **Soft Fibres**: Example: Flax, Jute and Ramie
   c. **Hard fibres:** Example: Sisal, Coconut, Pineapple, Abaca *etc.*
2. **Brush fibre:** Fibres utilized for the manufacture of brushes and brooms.
3. **Rough weaving fibres:** Fibres utilized in making baskets, chairs, mats etc.
4. **Paper making fibres:** Wood fibres utilized for paper making.
5. **Filling fibres:** Fibres used for stuffing cushions, mattresses, pillows, furniture etc. Example: *Bombax* and Silk cotton.

Complex Tissues

A complex tissue is a tissue with several types of cells but all of them function together as a single unit. It is of two types – xylem and phloem.

Xylem

The xylem is the principal water conducting tissue in a vascular plant. The term xylem was introduced by **Nageli**(1858) and is

derived from the Gk. *Xylos* – wood. The xylem which is derived from Procambium is called **primary xylem** and the xylem which is derived from vascular cambium is called **secondary xylem**. Early formed primary xylem elements are called protoxylem, whereas the later formed primary xylem elements are called metaxylem.

Protoxylem lies towards the periphery and metaxylem that lies towards the centre is called **Exarch.** It is common in *roots*.

Protoxylem lies towards the centre and meta xylem towards the periphery this condition is called **Endarch**. It is seen in *stems*.

Protoxylem is located in the centre surrounded by the metaxylem is called **Centrarch**. In this type only one vascular strand is developed. Example: *Selaginella sp.*

Protoxylem is located in the centre surrounded by the metaxylem is called **Mesarch**.In this type several vascular strands are developed. Example: *Ophioglossum sp.*

Student Activity

Cell lab: students prepare the slide and identify the different types tissues.

Xylem Consists of Four Types of Cells

1. Tracheids
2. Vessels or Trachea
3. Xylem Parenchyma
4. Xylem Fibres

Xylem is called **hadrome phloem** is called **leptome.** These terms are coined by **haberlandt (1914)**

Tracheids

Tracheids are dead, lignified and elongated cells with tapering ends. Its lumen is broader than that of fibres. In cross section, the tracheids are polygonal.

There are different types of cell wall thickenings due to the deposition of secondary wall substances. They are annular (ring like), spiral (spring like), scalariform (ladder like) reticulate (net like) and pitted (uniformly thick except at pits). Tracheids are imperforated cells with bordered pits on their side walls. Only through this conduction takes place in Gymnosperms. They are arranged one above the other. Tracheids are chief water conducting elements in Gymnosperms and Pteridophytes. They also offer mechanical support to the plants.

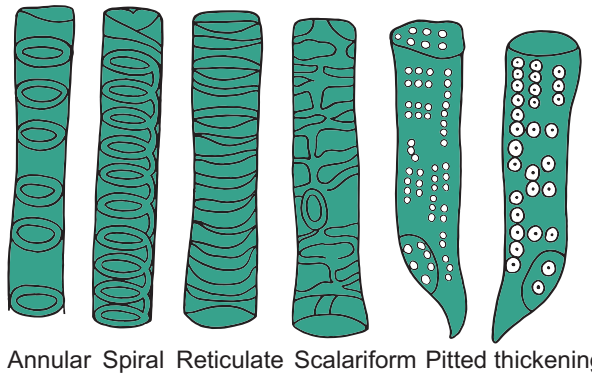


Figure 9.10: Types of secondary wall thickenings in tracheids and vessels

Vessels or Trachea

Vessels are elongated tube like structure. They are dead cells formed from a row of vessel elements placed end to end. They are perforated at the end walls. Their lumen is wider than Tracheids. Due to the dissolution of entire cell wall, a single pore is formed at the perforation plate. It is called **simple perforation plate**, Example: *Mangifera*. If the perforation

plate has many pores, it is called **multiple perforation plate**. Example *Liriodendron*.

The secondary wall thickening of vessels are annular, spiral, scalariform, reticulate, or pitted as in tracheids, Vessels are chief water conducting elements in Angiosperms and absent in Pteridophytes and Gymnosperms. In *Gnetum* of Gymnosperm, vessels occur. The main function is conduction of water, minerals and also offers mechanical strength.

Xylem Fibre

The fibres of sclerenchyma associated with the xylem are known as xylem fibres. Xylem fibres are dead cells and have lignified walls with narrow lumen. They cannot conduct water but being stronger provide mechanical strength. They are present in both primary and secondary xylem. Xylem fibres are also called libriform fibres.

The fibres are abundantly found in many plants. They occur in patches, in continuous bands and sometimes singly among other cells. Between fibres and normal tracheids, there are many transitional forms which are neither typical fibres nor typical tracheids. The transitional types are designated as **fibre-tracheids**. The pits of fibre-tracheids are smaller than those of vessels and typical tracheids.

Vessels are found in Gymnosperms like *Ephedra, Gnetum* and *Welwitschia*

Vesselless angiospermic families *Winteraceae, Tetracentraceae* and *Trochodendracae*.

Xylem Parernchyma

The parenchyma cells associated with the xylem are known as xylem parenchyma. These are the only living cells in xylem tissue. The cell wall is thin and made up of cellulose. Parenchyma arranged longitudinally along the long axis is called **axial parenchyma**. Ray parenchyma is arranged in radial rows. Secondary xylem consists of both axial and ray parenchyma, Parenchyma stores food materials and also helps in conduction of water.

Phloem

Phloem is the food conducting complex tissues of vascular plants. The term phloem was coined by **C. Nageli** (1858) The Phloem which is derived from procambium is called primary phloem and the phloem which is derived from vascular cambium is called secondary phloem. Early formed primary phloem elements are called **protophloem** whereas the later formed primary phloem elements are called **metaphloem**. Protophloem is short lived. It gets crushed by the developing metaphloem.

Phloem Consists of Four Types of Cells

1. Sieve elements
2. Companion cells
3. Phloem parenchyma
4. Phloem fibres

Sieve Elements

Sieve elements are the conducting elements of the phloem. They are of two types, namely sieve cells and sieve tubes.

Sieve Cells

These are primitive type of conducting

elements found in Pteridophytes and Gymnosperms. Sieve cells have sieve areas on their lateral walls only. They are not associated with companion cells.

Sieve Tubes

Sieve tubes are long tube like conducting elements in the phloem. These are formed from a series of cells called sieve tube elements. The sieve tube elements are arranged one above the other and form vertical sieve tube. The end wall contains a number of pores and it looks like a sieve. So it is called as sieve plate. The sieve elements show nacreous thickenings on their lateral walls. They may possess simple or compound sieve plates The function of sieve tubes are believed to be controlled by campanion cells.

In mature sieve tube, Nucleus is absent. It contains a lining layer of cytoplasm. A special protein (P. Protein = Phloem Protein) called slime body is seen in it. In mature sieve tubes, the pores in the sieve plate are blocked by a substance called **callose** (callose plug).The conduction of food material takes place through cytoplasmic strands. Sieve tubes occur only in Angiosperms.

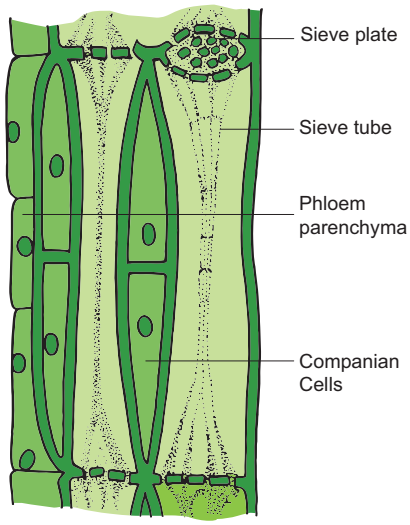


Figure 9.11: Different types of phloem elements

Companion Cells

The thin walled, elongated, specialized parenchyma cells, which are associated with the sieve elements, are called companion cells. These cells are living and they have cytoplasm and a prominent nucleus. They are connected to the sieve tubes through pits found in the lateral walls. Through these pits cytoplasmic connections are maintained between these elements. These cells are helpful in maintaining the pressure gradient in the sieve tubes. Usually the nuclei of the companion cells serve for the nuclei of sieve tubes as they lack them. The companion cells are present only in Angiosperms and absent in Gymnosperms and Pteridophytes. They assist the sieve tubes in the conduction of food materials.

Phloem Parenchyma

The parenchyma cells associated with the phloem are called phloem parenchyma. These are living cells. They store starch and fats. They also contain resins and tannins in some plants. Primary phloem consists of axial parenchyma and secondary phloem consists of both axial and ray parenchyma. They are present in Pteridophytes,Gymnosperms and Dicots.

Phloem Fibres (or) Bast Fibres

The fibres of sclerenchyma associated with phloem are called phloem fibres or bast fibres. They are narrow, vertically elongated cells with very thick walls and a small lumen. Among the four phloem elements, phloem fibres are the only dead tissue. These are the strengthening as well as supporting cells.

Concept Map

Plant tissues

Meristematic tissue:
Capable of active cell division.
Thin walled and living.
Compactly arranged.
Found in root and shoot apex.

Based on position:
1. Apical
2. Intercalary
3. Lateral

Based on origin:
1. Primary
2. Secondary

Based on function:
1. Periderm (Epidermis)
2. Procambium (Primary vascular tissues)
3. Ground meristem (Cortex and Pith)

Based on division:
1. Mass meristem: Divides in all planes
2. Rib meristem: Anticlinal division in one plane
3. Plate meristem: Anticlinal division in two planes.

Syncyte: Cell which is formed by fusion of cell is called Syncyte.

Example: Vessels (Dead syncyte), sieve tube (living syncyte)

Permanent tissues:
Lose the power of cell division.
Have definite shape, size and form.

Simple tissues:
One type of cells.

Parenchyma:
Thin walled,isodiametric, found in all the parts.
Types:
1. Aerenchyma.
2. Storage parenchyma.
3. Stellate parenchyma.
4. Chlorenchyma.
5. Prosenchyma.

Collenchyma:
Hypodermal position. Provide mechanical strength.
Types:
1. Angular collenchyma.
2. Lacunar collenchyma.
3. Lamellar collenchyma.

Sclerenchyma: Dead cells and lignified walls.
Types:
1. Sclereids
2. Fibres

Sclereids:
1. Brachysclereids: Stone cells
2. Macro sclereids: Rod shaped
3. Osteosclereids: Bone shaped
4. Astrosclereids: Star shaped
5. Trichosclereids: Hair cells

Fibres:
1. Wood fibres xylary fibres
2. Bastfibres: Extra xylary fibres
3. Surface fibres: *Cottan*
4. Mesocarp fibres: *Ccoconut*
5. Leaf fibres: *Musa, Agave*

Complex tissues:
More than one type of cells.

Xylem: Water conducting tissue.
1. Tracheids: Dead, elongated with tapering end
2. Vessels: Made of row of dead cells
3. Xylem fibres: Lignified and sclerenchymatous.
4. Xylem parenchyma: Living and cellulosic

Phloem: Food conducting tissue
1. Sieve elements: Sieve cells & sieve tubes
2. Companion cells: Only in Angiosperms.
3. Phloem parenchyma: Living & absent in Monocots.
4. Phloem fibres: Thick walled & sclerenchymatous, giving mechanical strength.

Table 9.1: Different types of tissues					
	Distribution	**Main functions**	**Nature**	**Cell shape**	**Wall materials**
Parenchyma	Cortex, Pith medullary rays and Packing tissues in vascular system	Packing tissue, support, gaseous exchange, food storage	Living	Usually Isodiametric	Mainly Cellulose and Pectinase
Collenchyma	Outer region of cortex as in angles of stems, mid-rib of leaves	Mechanical	Living	Elongated, Polygonal	Mainly Cellulose, Pectin and Hemi-cellulose
Sclerenchyma (a) Fibre	Outer region of cortex, pericycle of stems, vascular bundles	Mechanical	Dead	Elongated and Polygonal with tapering ends	Mainly Lignin
(b) Sclereids	Cortex, Pith, Phloem shells and stones of fruits and seed coats	Mechanical Protection	Dead	Roughly Isodiametric with much variation	Mainly lignin
Tracheids and Vessels	Vascular System	Translocation of water and mineral salts	Dead	Elongated and Tubular	Mainly lignin
Phloem Sieve tubes	Vascular System	Translocation of organic solutes	Living	Elongated and Tubular	Cellulose, Pectin and Hemicellulose
Companion Cells	Vascular System	Work in association with sieve tubes	Living	Elongated and narrow	Cellulose, Pectin and Hemicellulose

Difference Between Meristematic Tissue and Permanent Tissue

Meristematic tissue	Permanent tissue
• Cells divide repeatedly	• Do not divide
• Cells are undifferentiated	• Cells are fully differentiated
• Cells are small and Isodiametric	• Cells are variable in shape and size
• Intercellular spaces are absent	• Intercellular spaces are present
• Vacuoles are absent	• Vacuoles are present
• Cell walls are thin	• Cell walls maybe thick or thin
• Inorganic inclusions are absent	• Inorganic inclusions are present

Difference Between Collenchyma and Sclerenchyma

Collenchyma	Sclerenchyma
• Living Cells	• Dead cells
• Contains Protoplasm	• Cells are empty
• Cell walls are cellulosic	• Cell walls are lignified
• Thickening of cell wall is not uniform	• Thickening of cell wall is uniform
• Keeps the plant body soft	• Keeps plant body stiff and hard
• Sometimes it has chloroplast	• Do not have chloroplast

Difference between Fibre and Sclereids

Fibre	Sclereids
• Long cells	• Short cells
• Narrow, Elongated pointed ends	• Usually short and broad
• Occurs in bundles	• Occurs individually or in small groups
• Commonly unbranched	• Maybe branched
• Derived directly from meristematic tissue	• Develops from secondary sclerosis parenchyma cells

Difference between Tracheids and Fibres

Tracheids	Fibres
• Not much elongated	• Very long cells
• Possess oblique end walls	• Possess tapering end walls
• Cell walls are not as thick as Fibres	• Cell wall are thick and lignified
• Possess various types of thickenings	• Possess only pitted thickenings
• Responsible for the conduction and also mechanical support	• Provide only mechanical support

Difference Between Sieve Cells and Sieve Tubes

Sieve cells	Sieve tubes
• Have no companion cells	• Have companion cells
• The sieve areas do not form sieve plates	• The sieve areas are confined to sieve plates
• The sieve areas are not well differentiated	• The sieve areas are well differentiated
• They are elongated cells and are quite long with tapering end walls	• They consist of vertical cells placed one above the other forming long tubes connected at the walls by sieve pores
• The sieve are smaller and numerous	• The sieve pores are longer and fewer
• Found in Pteridophytes and Gymnosperms	• Found in Angiosperms

9.3 The Tissue System

Introduction to Tissue System, Types and Characteristics of tissue System

As you have learnt, the plant cells are organised into tissues, in turn the tissues are organised into organs. Different organs in a plant show differences in their internal structure. This part of chapter deals with the different type of internal structure of various plant organs and its adaptations to diverse environments.

A group of tissues performing a similar function, irrespective of its position in the plant body, is called a ***tissue system***. In 1875, German Scientist ***Julius von Sachs*** recognized three tissue systems in the plants. They are:

Figure 9.12: Julius von Sachs

1. Epidermal tissue system (derived from protoderm)
2. Ground tissue system (derived from ground meristem)
3. Vascular tissue system (derived from procambium)

Histology

(Greek. histos – web, logos – science) It is the study of tissues, their composition, and structure as observed with the help of microscope.

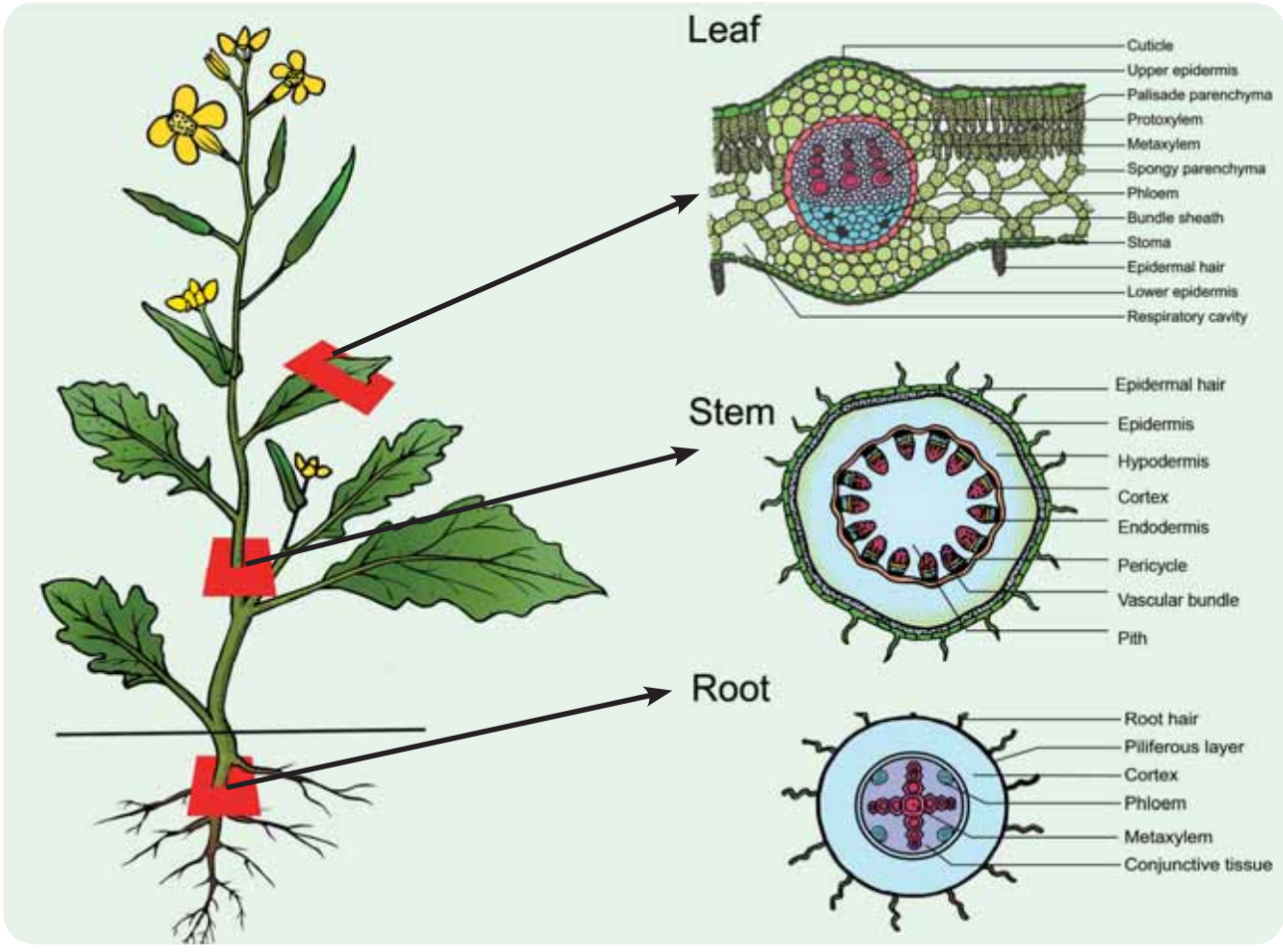


Figure 9.13: Tissue system

Table 9.2: Types and characteristics of tissue systems				
S.No.	**Types/ Characters**	**Epidermal tissue system**	**Ground or fundamental tissue system**	**Vascular or conduction tissue system**
1.	Formation	Forms the outermost covering protoderm	Forms the ground meristem	Forms the procambial bundles
2.	Components	epidermal cells, stomata and epidermal outgrowths	Simple permanent tissues – Parenchyma and Collenchyma	Xylem and Phloem
3.	Functions	Protection of plant body; absorption of water in roots; gas exchange for photosynthesis and respiration; transpiration in shoots	Gives mechanical support to the organs; prepares and stores food in leaf and stem	Conducts water and food; gives mechanical strength

9.4 Epidermal Tissue System

Introduction

Epidermal tissue system is the outer most covering of plants. It is in direct contact with external environment. It consists of epidermis derived from protoderm. Epidermis is derived from two Greek words, namely 'Epi' and 'Derma'. 'Epi' means *upon* and 'Derma' means *skin*. Although epidermis is a continuous outer layer, it is interrupted by stomata in many plants.

Root Epidermis

The outer layer of the root is known as ***piliferous layer* or *epiblema*.** It is made up of single layer of parenchyma cells which are arranged compactly without intercellular spaces. It is devoid of epidermal pores and cuticle. Root hair is always single celled, it absorbs water and mineral salts from the soil. The another important function of *piliferous layer* is *protection.*

Stem Epidermis

It is protective in function and forms the outermost layer of the stem. It is a single layer of parenchymatous rectangular cells. The cells are compactly arranged without intercellular cells. The outer walls of epidermal cells have a layer called *cuticle*. The cuticle checks *transpiration*. The cuticle is made up of *cutin*. In many plants it is also mixed wax to form epicuticular wax. Epidermal pores may be present here and there. Epidermal cells are living. Chloroplasts are usually absent except in guard cells of stomata. In many plants a large number of epidermal hairs occur on the epidermis.

Leaf Epidermis

The leaf is generally *dorsiventral*. It has upper and lower epidermis. The epidermis is usually made up of a single layer of cells that are closely packed. Generally the

cuticle on the upper epidermis is thicker than that of lower epidermis. The minute openings found on the epidermis are called ***stomata (singular: stoma).*** Usually, stomata are more in number on the lower epidermis than on the upper epidermis. A stoma is surrounded by a pair of specialised epidermal cells called guard cells. In most dicots and monocots the guard cells are bean-shaped. While in grasses and sedges, the guard cells are dumbbell- shaped. The guard cells contain chloroplasts, whereas the other epidermal cells normally do not have them.

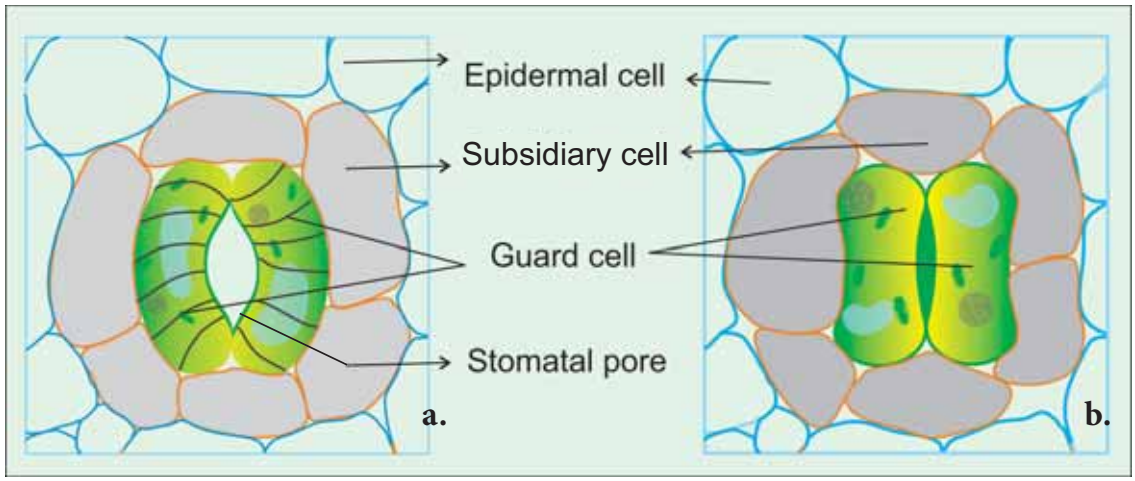


Figure 9.14: (a) Stoma with bean-shaped guard cells. (b) Stoma with dumb-bell shaped guard cells

Some cells of upper epidermis (Example: Grasses) are larger and thin walled. They are called **bulliform cells** or **motor cells**. These cells are helpful for the rolling and unrolling of the leaf according to the weather change. Some of the epidermal cells of the grasses are filled with silica. They are called **silica cells.**

Check Your Grasp!

In which group of plants the guard cells are dumb-bell shaped?

Grasses and sedges

Subsidiary Cells

Stomata are minute pores surrounded by two guard cells. The stomata occur mainly in the epidermis of leaves. In some plants addition to guard cells, specialised epidermal cells are present which are distinct from other epidermal cells. They are called **Subsidiary cells**. Based on the number and arrangement of subsidiary cells around the guard cells, the various types of stomata are recognised. The guard cells and subsidiary cells help in opening and closing of stomata during gaseous exchange and transpiration.

Sunken Stomata

In some Xerophytic plants (Examples: Cycas, Nerium), stomata is sunken beneath the abaxial leaf surface within stomatal crypts. The sunken stomata reduce water loss by transpiration.

Multilayered or Multiseriate Epidermis

Generally, epidermis is single layered, but in certain leaves, multilayered upper epidermis is present, Example: ***Ficus, Nerium, and Peperomea***.

In *Ficus* upper epidermal layer contains cystoliths made up of calcium carbonate crystals.

In *Nerium*, in the multilayered epidermis the outer layer alone is **cutinized.**

Epidermal Outgrowths

There are many types of epidermal outgrowths in stems. The unicellular or multicellular appendages that originate

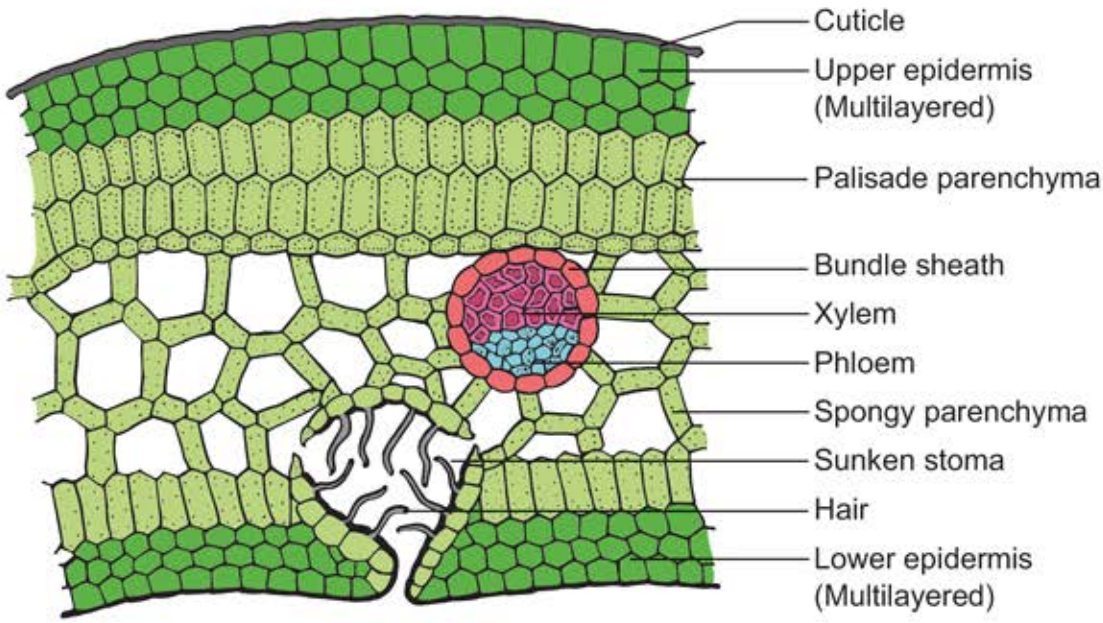


Figure 9.15: T.S. of *Nerium* Leaf

from the epidermal cells are called **trichomes**. Trichomes may be branched or unbranched and are one or more one celled thick. They assume many shapes and sizes. They may also be glandular (Example: *Rose, Ocimum*) or non-glandular.

The trichomes on the leaves of insectivorous plants secrete muco-polysaccharides that trap insects.

Piliferous layer of the root has two types of epidermal cells, long cells and short cells. The short cells are called **trichoblasts**. Trichoblasts are elongate into root hairs. Epidermal hairs can also be in the form of stellate hairs (star shaped) present in plants. Example: styrax, many members of Malvaceae and Solanaceae.

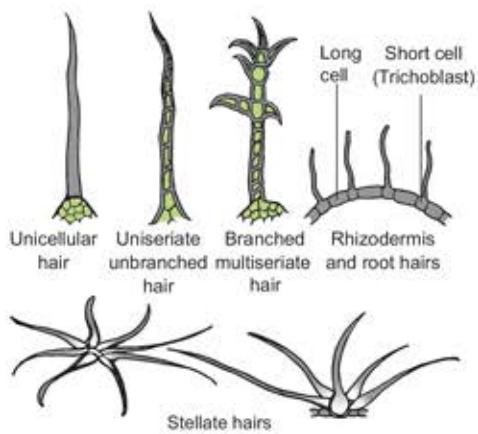


Figure 9.16: Types of Trichomes

Prickles

Prickles, are one type of epidermal emergences with no vascular supply. They are stiff and sharp in appearance. (Example: Rose).

Figure 9.17: Prickles

Functions of Epidermal Tissue System

1. This system in the shoot checks excessive loss of water due to the presence of cuticle.
2. Epidermis protects the underlying tissues.
3. Stomata is involved in transpiration and gaseous exchange.
4. Trichomes are also helpful in the dispersal of seeds and fruits, and provide protection against animals.
5. Prickles also provide protection against animals and they also check excessive transpiration
6. In some rose plants they also help in climbing.
7. Glandular hairs repel herbivorous animals.

9.5 Fundamental Tissue System

The ground or fundamental tissue system constitutes the main body of the plants. It includes all the tissues except epidermis and vascular tissues. In monocot stem, ground tissue system is a continuous mass of parenchymatous tissue in which vascular bundles are found scattered. Hence ground tissue is not differentiated into cortex, endodermis, pericycle and pith. Generally in dicot stem, ground tissue system is differentiated into three main zones – cortex, pericycle and pith. It is classified into extrastelar ground tissue (Examples: cortex and endodermis) and intrastelar ground tissue (Examples: pericycle, medullary ray and pith)

Extrastelar Ground Tissue

The ground tissues present outside the stele is called extrastelar ground tissue. (Cortex)

Intrastelar Ground Tissue

The ground tissues present within the stele are called intrastelar ground tissues. (pericycle, medullary rays and pith).

Different Components of Ground Tissue Systems are as follows

Hypodermis

One or two layers of continuous or discontinuous tissue present below the epidermis, is called hypodermis. It is protective in function.

In dicot stem, hypodermis is generally collenchymatous, whereas in monocot stem, it is generally sclerenchymatous. In many plants collenchyma form the hypodermis.

General Cortex

The Cortex occurs between the epidermis and pericycle. Cortex is a few to many layers in thickness, In most cases, it is made up of parenchymatous tissues. Intercellular spaces may or may not be present.

The cortical cells may contain non living inclusions of starch grains, oil, tannins and crystals.

Sometimes in young stem, chloroplasts develop in peripheral cortical cells, which is called **chlorenchyma.**

In the leaves, the ground tissue consists of chlorenchyma tissues. This region is called mesophyll. In hydrophytes, cortex is **Aerenchymatous** (with air cavities).

Its general function is storage of food as well as providing mechanical support to organs.

Endodermis

The cells of this layer are barrel shaped and arranged compactly without intercellular spaces.

Endodermis is the innermost cortical layer that separates cortex from the stele. This layer may be a true endodermis as in root or it is an endodermis like layer in stems. This layer is morphologically homologous to the endodermis found in the root.

The cells of endodermis like layer had living cells containing starch grains. Hence it is known as starch sheath. In true root endodermis, radial and inner tangential walls of endodermal cells possess thickenings of **lignin, suberin and some other carbohydrates** in the form of strips they are called **casparian strips**.

The endodermal cells, which are opposite to the protoxylem elements, are thin walled without casparian strips. These cells are called **passage cells**. Their function is to transport water and dissolved salts from the cortex to the protoxylem.

Water cannot pass through other endodermal cells due to casparian strips. The main function of casparian strips in the endodermal cells is to prevent the re-entry of water into the cortex once water entered the xylem tissue.

The other suberized cells acts as water-tight layer between vascular and non-vascular regions to check the loss of water.

Pericycle

Pericycle is single or few layered parenchymatous found inner to the endodermis. It is the outermost layer of the stele. Rarely thick walled sclerenchymatous. In angiosperms, pericycle gives rise to lateral roots.

Pith or Medulla

The central part of the ground tissue is known as pith or medulla. Generally this is made up of thin walled parenchyma cells with intercellular spaces. The cells in the pith generally stores starch, fatty substances, tannins, phenols, calcium oxalate crystals, etc.

Albuminous Cells: The cytoplasmic nucleated parenchyma, is associated with the sieve cells of Gymnosperms. Albuminous cells in *Conifers* are analogous to companion cells of Angiosperms. It also called as strasburger cells.

9.6 Vascular Tissue System

This section deals with the vascular tissue system of gymnosperms and angiosperms stems and roots.The vascular tissue system consists of xylem and phloem. The elements of xylem and phloem are always organized in groups. They are called **vascular bundles.**

The stems of both groups have an eustele while roots are protostele. In eustelic organization, the stele contains usually a ring of vascular bundles separated by interfascicular region or medullary ray

The structural and organizational variation in vascular bundles is shown below.

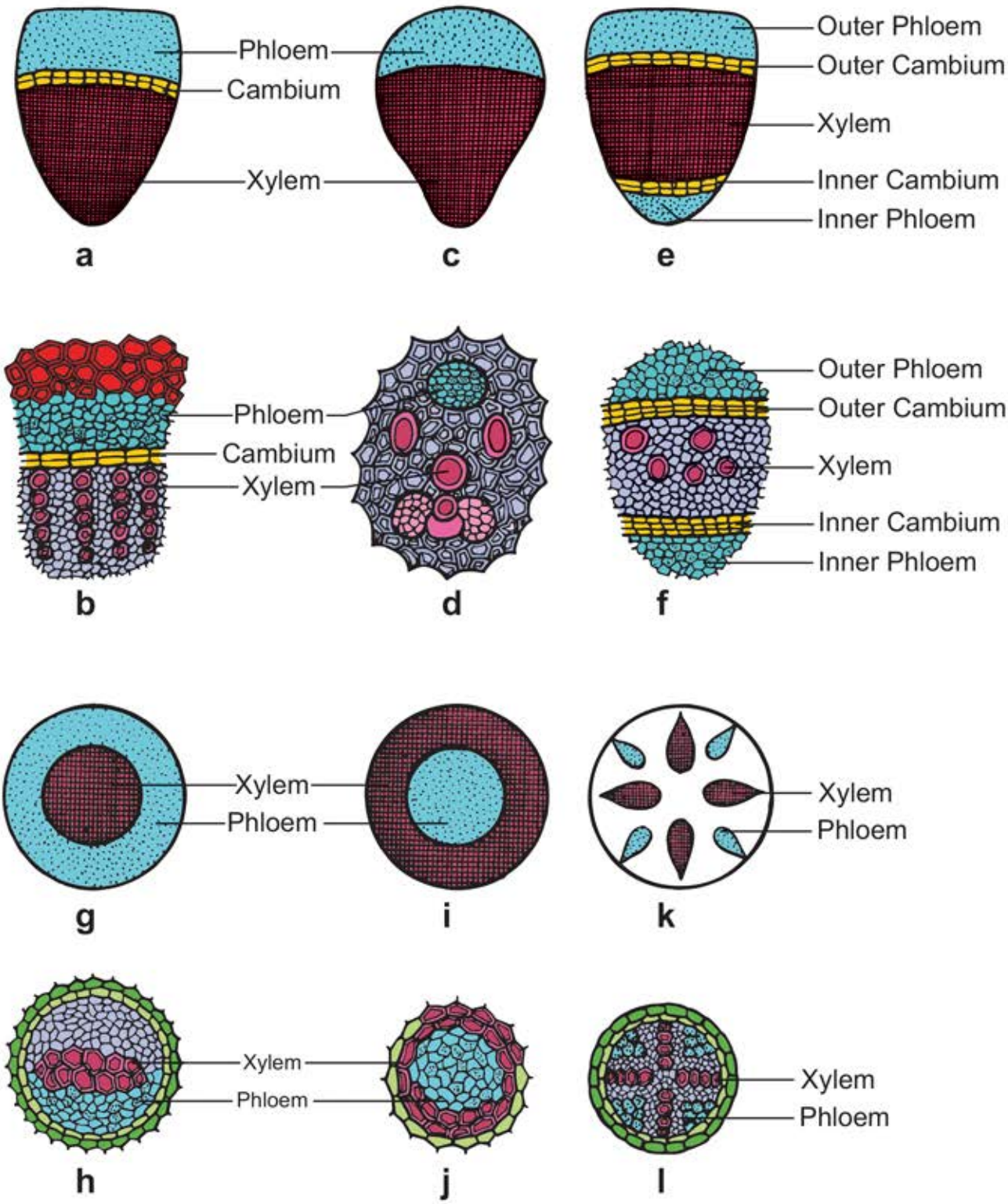


Figure 9.18: Types of vascular bundles

(a) and **(b)** - Conjoint, collateral and open; **(c)** and **(d)** - Conjoint, collateral and closed **(e)** and **(f)** - Conjoint, bicollateral and open; **(g)** and **(h)** - Concentric and amphicribral; **(i)** and **(j)** - Concentric and amphivasal; **(k)** and **(l)** - Radial

Types of vascular Bundles

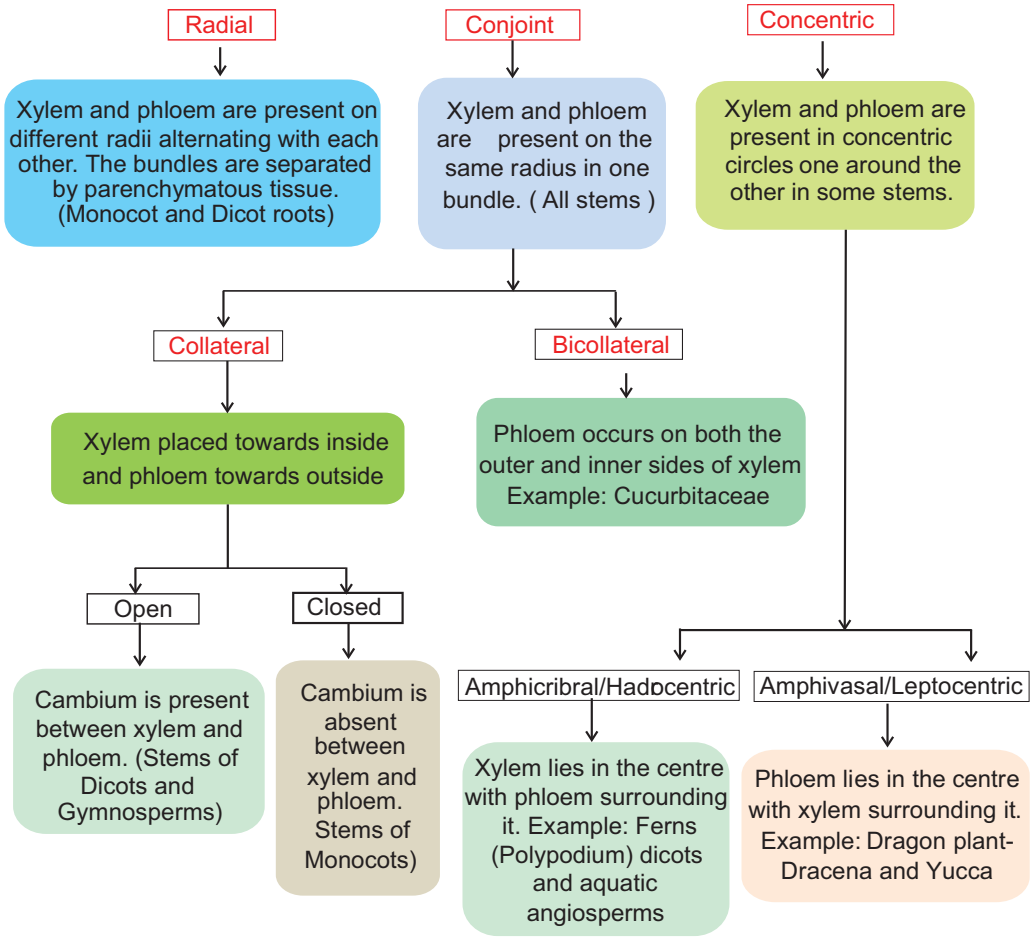


Table 9.3: Comparison of vascular tissues

Proto xylem	**Meta xylem**
• First formed primary xylem • Found in developing organs • Elements relatively smaller in size	• Later formed primary xylem • Found in developed primary organs • Elements relatively larger in size
Proto phloem	**Meta phloem**
• First formed primary phloem • Found in developing organs • Elements relatively smaller in size	• Later formed primary phloem • Found in developed primary organs • Elements relatively larger in size
Primary xylem	**Secondary xylem**
• The primary xylem is derived from the procambium of the apical meristem	• The secondary xylem is derived from the vascular cambium which is a lateral meristem
Primary phloem	**Secondary phloem**
• The primary phloem is derived from the procambium of the apical meristem	• The secondary phloem is derived from the vascular cambium, which is a lateral meristem

9.7 Comparison of Primary Structure – Dicot and Monocot Root, Stem and Leaf

Anatomy of Dicot and Monocot Roots

In different parts of the plants, the various tissues are distributed in characteristic patterns. This is best understood by studying their internal structure by cutting sections (transverse or longitudinal or both) of the part to be studied.

Primary Structure of Dicot Root – Bean Root

The transverse section of the dicot root (Bean) shows the following plan of arrangement of tissues from the periphery to the centre.

Piliferous Layer or Epiblema

The outermost layer of the root is called **piliferous layer or epiblema.** It is made up of single layer of parenchyma cells which are arranged compactly without intercellular spaces. It is devoid of epidermal pores and cuticle. It possesses root hairs which are single celled. It absorbs water and mineral salts from the soil. The chief function of piliferous layer is **protection.**

Cortex

Cortex consists of only parenchyma cells. These cells are loosely arranged with intercellular spaces to make gaseous exchange easier. These cells may store food reserves. The cells are oval or rounded in shape. Sometimes they are polygonal due to mutual pressure. Though chloroplasts are absent in the cortical cells, starch grain are stored in them. The cells also possess leucoplasts. The innermost layer of the cortex is endodermis. Endodermis is made up of single layer of barrel shaped parenchymatous cells. Stele is completely surrounded by endodermis. The radial and the inner tangential walls of endodermal cells are thickened with **suberin and lignin.** This thickening was first noted by **Robert Casparay** in 1965. So these thickenings are called **casparian strips.** But these casparian strips are absent in the endodermis cells which are located opposite the protoxylem elements. These thin-walled cells without casparian strips are called **passage cells** through which water and mineral salts are conducted from the cortex to the xylem elements. Water cannot pass through other endodermal cells due to the presence of casparian thickenings.

Check Your Grasp!

Give the exact location and function of passage cells?

In roots some cells of the endodermis usually the ones opposite to protoxylem, remain thin walled. These cells are called passage cells. They help in radial diffusion of water.

Stele

All the tissues present inside endodermis comprise the stele. It includes pericycle and vascular system.

Pericycle

Pericycle is generally a single layer of parenchymatous cells found inner to the endodermis. It is the outermost layer of the stele. Lateral roots originate from the pericycle. Thus, the lateral roots are endogenous in origin.

Vascular System

Vascular tissues are in **radial arrangement**. The tissue by which xylem and phloem are separated is called **conjunctive tissue**. In bean, the conjuctive tissue is composed of parenchyma tissue. Xylem is in **exarch condition**. The number of protoxylem points is four and so the xylem is called **tetrach**. Each phloem patch consists of sieve tubes, companion cells and phloem parenchyma. Metaxylem vessels are generally polygonal in shape. But in monocot roots they are circular.

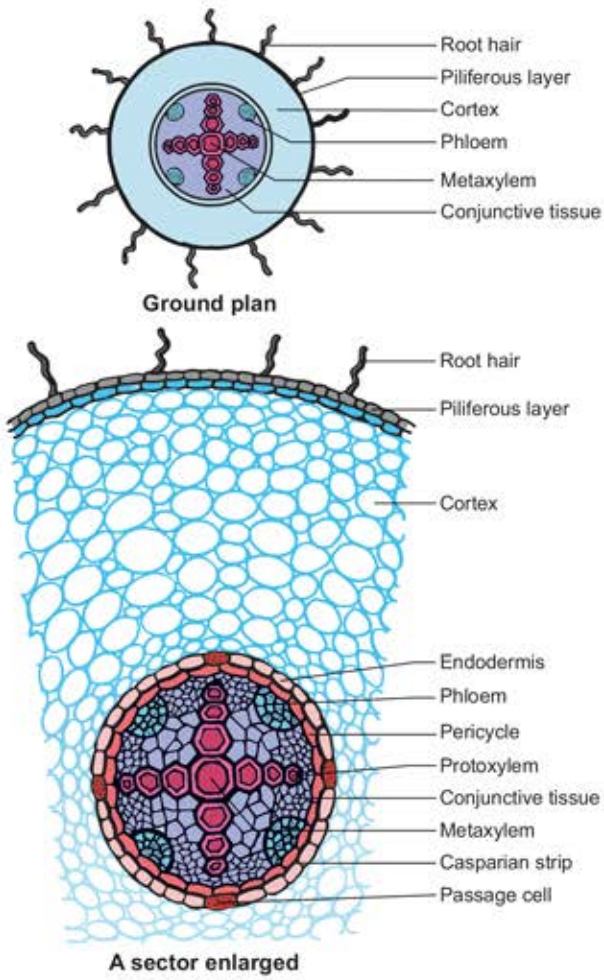


Figure 9.19: T.S. of Dicot root (Bean root)

Primary Structure of Monocot Root-maize Root

The transverse section of the monocot root (maize) shows the following plan of arrangement of tissues from the periphery to the centre.

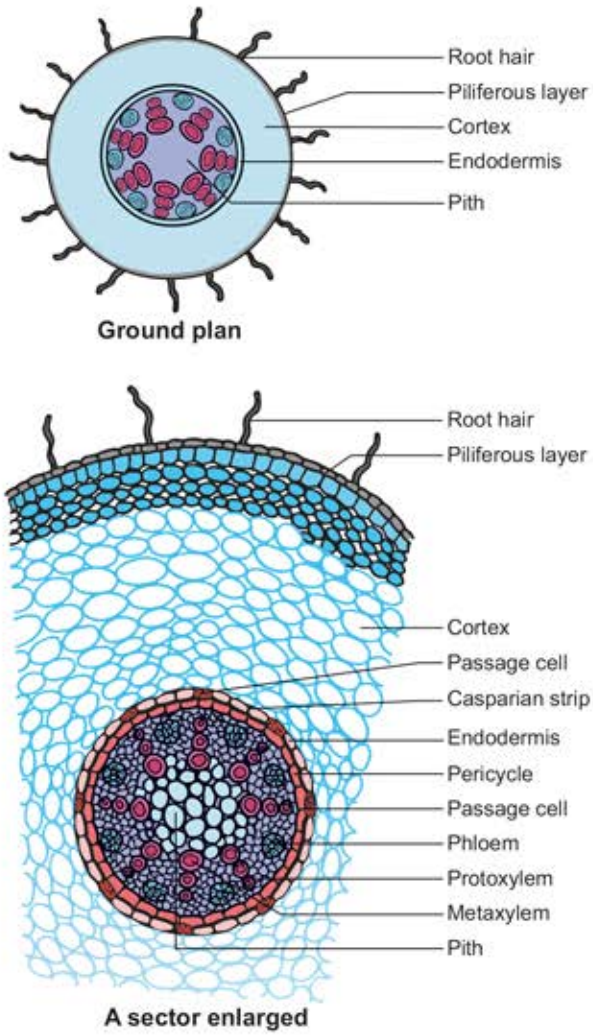


Figure 9.20: T.S of Monocot root (Maize root)

Piliferous Layer or Epiblema

The outermost layer of the root is known as **piliferous layer**. It consists of a single row of thin-walled parenchymatous cells without any intercellular space. Epidermal pores and cuticle are absent in the piliferous layer. Root hairs that are found in the piliferous layers are always unicellular. They absorb water and mineral salts from the soil. Root hairs are generally short lived. The main function of piliferous layer is protection of the inner tissues.

Cortex

The cortex is homogenous. i.e. the cortex is made up of only one type of tissue called parenchyma. It consists of many layers of thin-walled parenchyma cells with lot of intercellular spaces. The function of cortical cells is storage. Cortical cells are generally oval or rounded in shape. Chloroplasts are absent in the cortical cells, but they store starch. The cells are living and possess **leucoplasts.** The inner layer of the cortex is endodermis. It is composed of single layer of barrel shaped parenchymatous cells. This forms a complete ring around the stele. There is a band like structure made of **suberin** and **lignin** present in the radial and inner tangential walls of the endodermal cells. They are called **casparian strips** named after **casparay** who first noted the strips. The endodermal cells, which are opposite the protoxylem elements, are thin walled without casparian strips. These cells are called passage cells. Their function is to transport water and dissolved salts from the cortex to the xylem. Water cannot pass through other endodermal cells due to casparian strips. The main function of casparian strips in the endodermal cells is to prevent the re-entry of water into the cortex once water entered the xylem tissue.

Stele

All the tissues inside the endodermis comprise the stele. This includes pericycle, vascular system and pith.

Pericycle

Pericycle is the outermost layer of the stele and lies inner to the endodermis. It consists of single layer of parenchymatous cells.

Vascular System

Vascular tissues are seen in radial arrangement. The number of protoxylem groups is many. This arrangement of xylem is called polyarch. Xylem is in

Anatomical differences between dicot root and monocot root

S.No.	Characters	Dicot root	Monocot root
1.	Pericyle	Gives rise to lateral roots, phellogen and a part of vascular cambium.	Gives rise to lateral roots only.
2.	Vascular tissue	Usually limited number of xylem and phloem strips.	Usually more number of xylem and phloem strips,
3.	Conjunctive tissue	Parenchymatous; Its cells are differentiated into vascular cambium.	Mostly sclerenchymatous but sometimes parenchymatous. It is never differentiated in to vascular cambium.
4.	Cambium	It appears as a secondary meristem at the time of secondary growth.	It is altogether absent.
5.	xylem	Usually tetrach	Usually polyarch

exarch condition, the tissue which is present between the xylem and the phloem, is called conjunctive tissue. In maize, the conjunctive tissue is made up of sclerenchymatous tissue.

Pith

The central portion is occupied by a large pith. It consists of thin-walled parenchyma cells with intercellular spaces. These cells are filled with abundant starch grains.

Anatomy of Dicot and Monocot Stems

The transverse section of the dicot stem [sunflower] shows the following plan of arrangement of tissues from the periphery to the centre.

Epidermis

It is protective in function and forms the outermost layer of the stem. It is a single layer of parenchymatous rectangular cells. The cells are compactly arranged without intercellular spaces. The outer walls of epidermal cells have a layer called cuticle. The cuticle checks the transpiration. The cuticle is made up of waxy substance known as cutin. Stomata may be present here and there. Epidermal cells are living. Chloroplasts are usually absent. A large number of multicellular hairs occur on the epidermis.

Cortex

Cortex lies below the epidermis. The cortex is differentiated into three zones. Below the epidermis, there are few layers of collenchyma cells. This zone is called **hypodermis.** It gives mechanical strength of the Stem. These cells are living and thickened at the corners.

Inner to the hypodermis, a few layers of collenchyma cells are present. This zone is called hypodermis. It gives mechanical strength to the stem. These cells are living and thickened at the corners. Inner to the hypodermis, a few layers of chlorenchyma cells are present with conspicuous intercellular spaces. This region performs photosynthesis. Some resin ducts also occur here. The third zone is made up of parenchyma cells. These cells store food materials. The innermost layer of the cortex is called **endodermis**. The cells of this layer are barrel shaped and arrange compactly without intercellular spaces. Since starch grains are abundant in these cells, this layer is also known a **starch sheath**. This layer is morphologically homologous to the endodermis found in the root. In most of the dicot stems, endodermis with casparian strips is not developed.

Check Your Grasp!

Why the endodermis in dicot stem is also referred to as the starch sheath?

The cells of the endodermis are rich in starch grains and thus this layer is also referred to as the starch sheath.

Stele

The central part of the stem inner to the endodermis is known as **stele**. It consists of pericyle, vascular bundles and pith. In dicot stem, vascular bundles are arranged in a ring around the pith. This type of stele is called **eustele.**

Pericycle

Pericycle is the layers of cells that occur between the endodermis and vascular bundles. In the stem of **sunflower**

(Helianthus),a few layers of sclerenchyma cell occur in patches outside the phloem in each vascular bundle. This patch of sclerenchyma cell is called **Bundle cap or Hardbast**. The bundle caps and the parenchyma cells between them constitute the pericycle in the stem of sunflower.

Vascular Bundles

The vascular bundles consist of xylem, phloem and cambium. Xylem and phloem in the stem occur together and form the vascular bundles. These vascular bundles are **Wedge shaped**. They are arranged in the form of a ring. Each vascular bundle is **conjoint, collateral, open and endarch**.

Phloem

Primary phloem lies towards the periphery. It consists of **protophloem and metaphloem.** Phloem consists of sieve tubes, companion cells and phloem parenchyma. Phloem fibres are absent in the primary phloem. Phloem conducts organic food materials from the leaves to other parts of the plant body.

Cambium

Cambium consists of **brick shaped** and thin walled meristematic cells. It is one to four layers in thickness. These cells are capable of forming new cells during **secondary growth**.

Xylem

Xylem consists of xylem fibres, xylem parrenchyma vessels and tracheids. Vessels are thick walled and arranged in a few rows.

Xylem conducts water and minerals from the root to the other parts of the plant body.

Pith

The large central portion of the stem is called **pith**. It is composed of parenchyma cells with intercellular spaces. The pith is also known as **medulla**. The pith extends between the vascular bundles. These extensions of the pith between the vascular bundles are called primary pith rays or primary medullary rays. Function of the pith is **storage of food.**

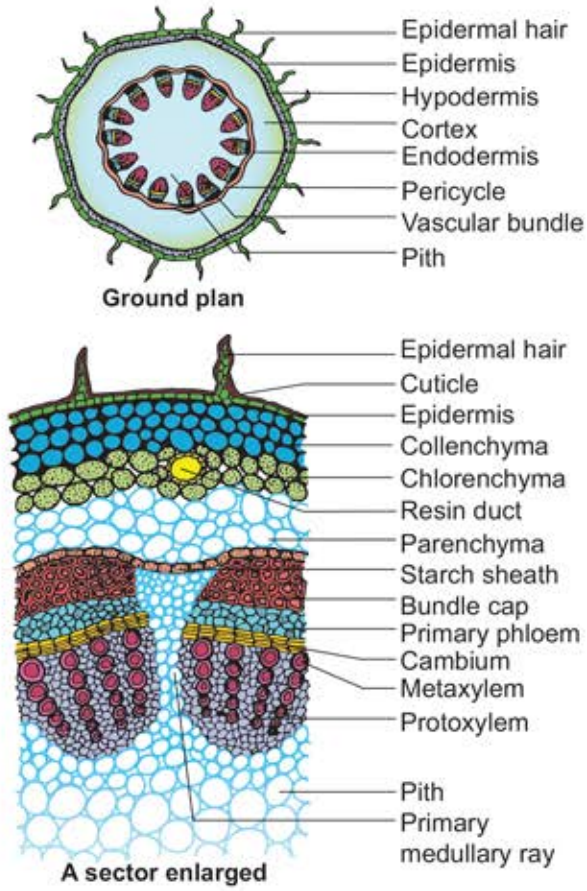


Figure 9.21: T. S of Dicot Stem (Sunflower stem)

Primary Structure of Monocot Stem-maize Stem

The outline of the maize in transverse section is more or less circular. The transverse section of the monocot stem [maize] shows the following plan of arrangement of tissues from the periphery to the centre.

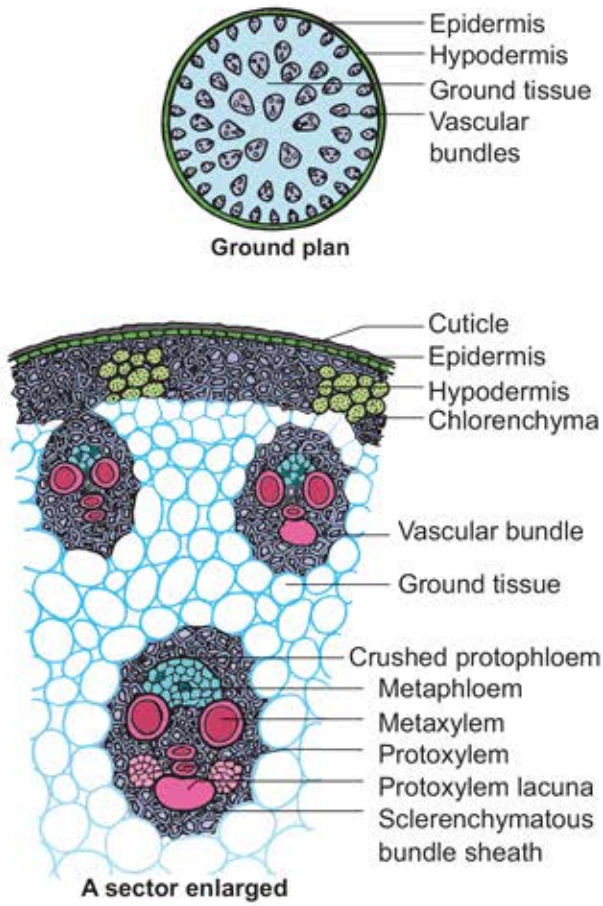


Figure 9.22: T.S. Monocot stem (Maize stem)

Epidermis

It is the outermost layer of the stem. It is made up of single layer of tightly packed parenchymatous cells. Their outer walls are covered with thick cuticle. The continuity of this layer may be broken here and there by the presence of a few stomata. There are no epidermal outgrowths.

Hypodermis

A few layer of sclerenchymatous cells lying below the epidermis constitute the hypodermis. This layer gives mechanical strength to the plant. It is interrupted here and there by chlorenchyma cells.

Ground Tissue

There is no distinction into cortex, endodermis, pericycle and pith. The entire mass of parenchyma cells lying inner to the hypodermis forms the ground tissue.

The cell wall is made up of **cellulose**. The cells contain reserve food material like **starch**. The cells of the ground tissue next to the hypodermis are smaller in size, polygonal in shape and compactly arranged.

Towards the centre, the cells are loosely arranged, rounded in shape and bigger in size. The vascular bundles lie embedded in this tissue. The ground tissue stores food and performs gaseous exchange.

Vascular Bundles

Vascular bundles are **scattered (atactostele)** in the parenchymatous ground tissue. Each vascular bundle is surrounded by a sheath of sclerenchymatous fibres called **bundle sheath**. The vascular bundles are **conjoint, collateral, endarch** and **closed**.Vascular bundles are numerous, small and closely arranged in the peripheral portion. Towards the centre, the bundles are comparatively large in size and loosely arranged. Vascular bundles are **skull or oval shaped.**

Phloem

The phloem in the monocot stem consists of sieve tubes and companion cells. Phloem parenchyma and phloem fibres are absent. It can be distinguished into an outer crushed protophloem and an inner metaphloem.

Xylem

Xylem vessels are arranged in the form of **'Y'** the two metaxylem vessels are located at the upper two arms and one or two protoxylem vessels at the base. In a mature bundle, the lowest protoxylem disintegrates and forms a cavity known as **protoxylem lacuna**.

Table 9.4: Anatomical differences between dicot stem and monocot stem			
S.No.	**Characters**	**Dicot Stem**	**Monocot Stem**
1.	Hypodermis	Collenchymatous	Sclerenchymatous
2.	Ground tissue	Differentiated into cortex, endodermis and pericycle and pith	Not differentiated, but it is a continuous mass of parenchyma.
3.	Starch Sheath	Present	Absent
4.	Medullary rays	Present	Absent
5.	Vascular bundles	(a) Collateral and open	(a) Collateral and closed
		(b) Arranged in a ring	(b) Scattered in ground tissue
		(c) Secondary growth occurs	(c) Secondary growth usually does not occur.

Table 9.5: Anatomical differences between root and stem			
S.No.	**Characters**	**Root**	**Stem**
1.	Epidermis	Absence of cuticle and epidermal pores.	Presence of cuticle and epidermal pores.
		Presence of unicellular root hairs.	Presence of unicellular and multicellular trichomes
2.	Outer Cortical cells	Chlorenchyma absent	Chlorenchyma present
3.	Endodermis	Well defined	ill-defined or absent.
4.	Vascular bundles	Radial arrangement	Conjoint arrangement
5.	Xylem	Exarch	Endarch

Anatomy of a Dicot and Monocot Leaves

Leaves are very important vegetative organs. They are mainly concerned with **photosynthesis and transpiration**. Like stem and roots, leaves also have the three tissue system – dermal, ground and vascular. The dermal tissue system consists of an upper and lower epidermis. The ground tissue system that lies between the epidermal layers of leaf is known as **mesophyll tissue**. Often it is differentiated into **palisade parenchyma** on the adaxial (upper) side and **spongy parenchyma** on the abaxial (lower) side.

In dorsiventral leaves the mesophyll is differentiated into palisade and spongy parenchyma, the former occurring on the upper side and the later on the lower side Example: Sunflower. In isobilateral leaf palisade is present on both sides of the leaf and inbetween them spongy parenchyma is present. Example: Nerium. In some plants Example: Ficus calcium crystals are present. There are also leaves where spongy tissue alone is present in some epidermal cells Example: Grasses.

The presence of air spaces is a special feature of spongy cells. They facilitate the

gaseous exchange between the internal photosynthetic tissue (mesophyll) and the external atmosphere through the stomata.

The vascular tissue system is composed of vascular bundles. They are **collateral** and **closed.** The vascular tissues forms the skeleton of the leaf and are known as **veins**. The veins supply water and minerals to the photosynthetic tissue. Thus the morphological and anatomical features of the leaf help in its physiological functions.

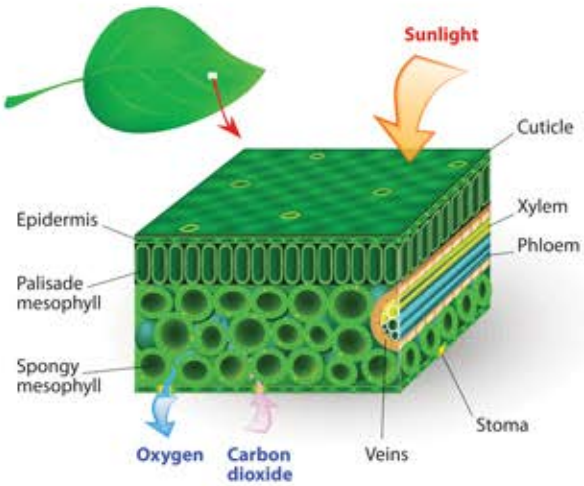


Figure 9.23: Anatomy of Leaf

Anatomy of a Dicot Leaf-sunflower Leaf

Internal structure of dictoyledonous leaves reveal epidermis, Mesophyll and vascular tissues.

Epidermis

This leaf is generally **dorsiventral.** It has upper and lower epidermis. The epidermis is usually made up of a single layer of cells that are closely packed. The cuticle on the upper epidermis is thicker than that of lower epidermis. The minute openings found on the epidermis are called **stomata**. Stomata are more in number on the lower epidermis than on the upper epidermis. A stomata is surrounded by a pair of **bean shaped** cells called guard cells.

Each stoma internally opens into an air chamber. These guard cells contain chloroplasts, whereas other epidermal cells do not contain chloroplasts. The main function of the epidermis is to give protection to the inner tissue called **mesosphyll**. The cuticle helps to check transpiration. Stomata are used for transpiration and gas exchange.

Mesophyll

The entire tissue between the upper and lower epidermis is called the **mesophyll (GK meso = in the middle, phyllome = leaf).** There are two regions in the mesophyll. They are **palisade parenchyma and spongy parenchyma.** Palisade parenchyma cells are seen beneath the upper epidermis. It consists of vertically elongated cylindrical cells in one or more layers. These cells are compactly arranged and are generally without intercellular spaces. Palisade parenchyma cells contain more chloroplasts than the spongy parenchyma cells. The function of palisade parenchyma is **photosynthesis.** Spongy parenchyma lies below the palisade parenchyma. Spongy cells are irregularly shaped. These cells are very loosely arranged with numerous airspaces. As compared to palisade cells, the spongy cells contain lesser number of chloroplasts. Spongy cells facilitate the **exchange of gases** with the help of air spaces. The air space that is found next to the stomata is called **respiratory cavity or substomatal cavity**.

Vascular Tissues

Vascular tissues are present in the veins of leaf. Vascular bundles are **conjoint,**

Collateral and closed. Xylem is present towards the upper epidermis, while the phloem towards the lower epidermis. Vascular bundles are surrounded by a compact layer of parenchymatous cells called **bundle sheath or border parenchyma**.

Xylem consists of metaxylem and protoxylem elements. Protoxylem is present towards the upper epidermis,while the phloem consists of sieve tubes, companion cells and phloem parenchyma. Phloem fibres are absent. Xylem consists of vessels and xylem parenchyma. Tracheids and xylem fibres are absent.

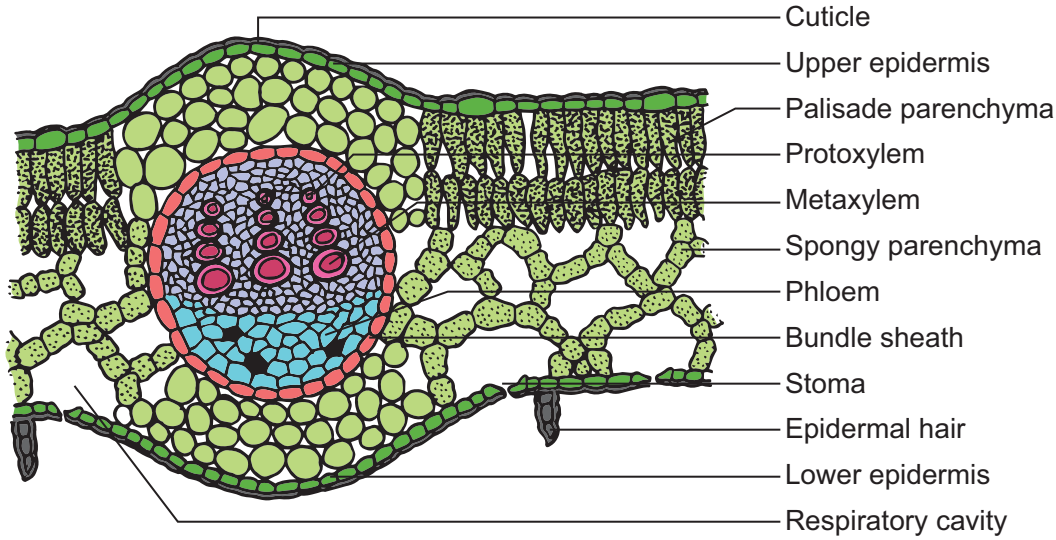


Figure 9.24: T.S. of Dicot Leaf (Sunflower)

Anatomy of a Monocot Leaf – Grass Leaf

A transverse section of a grass leaf reveals the following internal structures.

Epidermis

The leaf has upper and lower epidermis. They are made up of a single layer of thin walled cells. The outer walls are covered by thick cuticle.

The number of stomata is more or less equal on both the epidermis. The stomata is surrounded by **dumb – bell shaped** guard cells. The guard cells-contain chloroplasts, whereas the other epidermal cells do not have them.

Some special cells surround the guard cells. They are distinct from other epidermal cells.

These cells are called **subsidiary cells.**

Some cells of upper epidermis are large and thin walled. They are called **bulliform cells** or motor cells. These cells are helpful for the rolling and unrolling of the leaf according to the weather change.

Some of the epidermal cells of the grass are filled with silica. They are called **silica cells**.

Mesophyll

The ground tissue that is present between the upper and lower epidermis of the leaf is called **mesophyll.** Here, the mesophyll is not differentiated into **palisade and spongy parenchyma.** All the mesophyll cells are nearly isodiametric and thin walled. These cells are compactly arranged

with limited intercellular spaces. They contain numerous chloroplasts.

Vascular Bundles

Vascular bundles differ in size. Most of the vascular bundles are smaller in size. Large bundles occur at regular intervals.Two patches of sclerenchyma are present above and below the large vascular bundles. These sclerenchyma patches give mechanical support to the leaf. The small vascular bundles do not have such sclerenchymatous patches. Vascular bundles are **conjoint, collateral and closed**. Each vascular bundle is surrounded by a parenchymatous bundle sheath. The cells of the bundle sheath generally contain starch grains. The xylem of the vascular bundle is located towards the upper epidermis and the phloem towards the lower epidermis.In C_4 grasses, the bundle sheath cells are living and involve in C_4 photosynthesis. This sheath is called **Kranz sheath**.

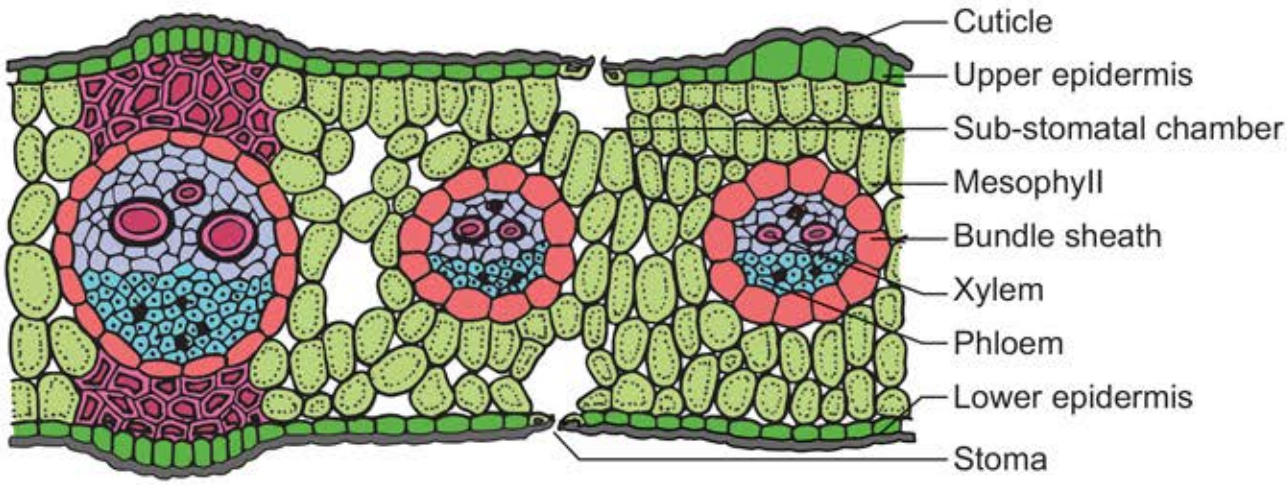


Figure 9.25: T.S. of monocot leaf (Grass)

Water Stomata (or) Hydathodes

A **hydathode** is a type of epidermal pore, commonly found in higher plants.

Structurally, hydathodes are modified stomata, usually located at leaf tips or margins, especially at the teeth.

Hydathodes occur in the leaves of submerged aquatic plants such as **Ranunculus fluitans** as well as in many herbaceous land plants.

Hydathodes are made of a group of living cells with numerous intercellular spaces filled with water, but few or no chloroplasts. These cells open out into one or more sub-epidermal chambers. These, in turn, communicate with the exterior through an open pore. The water stoma structurally resembles an ordinary stoma, but is usually larger and has lost the power of movement.They are connected to the plant vascular system by a tracheid or vessel element.

Hydathodes discharge liquid water with various dissolved substances from the interior of the leaf to its surface. This process is called **guttation**. Example many grasses.

Differences Between Stomata and Hydathodes

Stomata	Hydathodes
Occur in epidermis of leaves, young stems.	Occur at the tip or margin of leaves that are grown in moist shady place.
Stomatal aperture is guarded by two guard cells.	Aperture of hydathodes are surrounded by a ring of cuticularized cells.
The two guard cells are generally surrounded by subsidiary cell.	Subsidiary cells are absent.
Opening and closing of the stomatal aperture is regulated by guard cells.	Hydathode pores remain always open.
These are involved in transpiration and exchange of gases.	These are involved in guttation.

Can mangroove trees grow in salt water?

These amazing trees and shrubs cope with salt. Salt water can kill Plants, so mangroves must extract fresh water from the sea water that surrounds them. Many mangrove species survive by filtering out as much as 90 percent of the salt found in seawater as it enters their roots.

Mangrove excrete salt through glands in their leaves.

Halophiles

- Plants that grow in salty environment are called **Halophiles**.
- Plant growth in **saline habitat** developed numerous adaptations to **salt stress**. The secretion of ions by salt glands is the best known mechanism for regulating the salt content of plant shoots.
- Salt glands typically are found in **halophytes**. (Plants that grow in saline environments)

Figure 9.26: Halophytes

Figure 9.27: Removes excess salts through special salt glands on leaves

Summary

A Tissue is a group of cells that are alike in origin, structure and function.There are two principal groups: (1) Meristematic tissues and (2) Permanent tissues. Meristematic tissues comprise of self-perpetuating cells. Meristems are classified into several types on the basis of position, origin, function and activity. Many anatomists illustrated the root and shoot apical meristems on the basis of the type and arrangement and accordingly proposed many theories. The permanent tissues normally develop from apical meristem. They are classified into two types: 1)Simple permanent tissues and 2)Complex permanent tissues. Simple tissues are composed of a single type of cells only. It is of three types: (1) Parenchyma (2) Collenchyma and (3) Sclerenchyma. A complex tissue is a tissue with several types of cells but all of them function together as a single unit. It is of two types – xylem and phloem. Secretory tissues produce different types of chemicals. Some are in the form of enzymes, hormones, rubber, gum etc.

The tissues can be classified on the basis of their function, structure and location into epidermal tissue system, ground tissue system and vascular tissue system. Epidermal tissue system develops as the outermost covering of the entire plant body. It consists of epidermal cells and associated structures. All tissues except epidermis and vascular tissues constitute the ground tissue. The vascular tissue system is formed of vascular bundles.

In the primary structure, the outermost layer of the root is called piliferous layer. Cortex consists of only parenchyma cells. All the tissues present inside endodermis comprise the stele. In dicot (Example: bean) root, xylem is tetrach. Its phloem patch consists of sieve tubes, companion cells and phloem parenchyma. In monocot (Example: maize) root, xylem is polyarch.

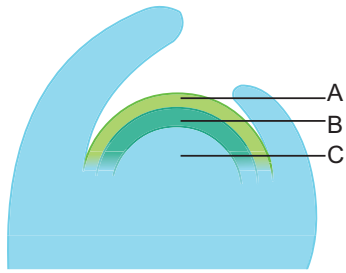
In dicot (Example: sunflower) stem, stele is eustele type and its vascular bundles are wedge shaped, conjoint, collateral, open and endarch. In monocot stem (Example: maize) vascular bundles are scattered and skull shaped, conjoint, collateral, closed and endarch.

In dicot (Example: sunflower) and monocot (Example: grass) leaves vascular bundles are conjoint, collateral and closed.

Hydathodes discharge liquid water with various dissolved substances from the interior of the leaf to its surface. Plants that grow in salty environment are called halophiles. Salt glands typically are found in halophytes.

Evaluation

1. Refer to the given figure and select the correct statement



CLLGQX

i. A, B, and C are histogen of shoot apex

ii. A Gives rise to medullary rays.

iii. B Gives rise to cortex

iv. C Gives rise to epidermis

a. i and ii only

b. ii and iii only

c. i and iii only

d. iii and iv only

2. Read the following sentences and identify the correctly matched sentences.
   i. In exarch condition, the protoxylem lies outside of metaxylem.
   ii. In endarch condition, the protoxylem lie towords the centre.
   iii. In centarch condition, metaxylem lies in the middle of the protoxylem.
   iv. In mesarch condition, protoxylem lies in the middle of the metaxylem.
   a. i, ii and iii only
   b. ii, iii and iv only
   c. i, ii and iv only
   d. All of these
3. In Gymnosperms, the activity of sieve tubes are controlled by
   a. Nearby sieve tube members.
   b. Phloem parenchyma cells
   c. Nucleus of companion cells.
   d. Nucleus of albuminous cells.
4. When a leaf trace extends from a vascular bundle in a dicot stem, what would be the arrangement of vascular tissues in the veins of the leaf?
   a. Xylem would be on top and the phloem on the bottom
   b. Phloem would be on top and the xylem on the bottom
   c. Xylem would encircle the phloem
   d. Phloem would encircle the xylem
5. Grafting is successful in dicots but not in monocots because the dicots have
   a. Vascular bundles arranged in a ring
   b. Cambium for secondary growth
   c. Vessels with elements arranged end to end
   d. Cork cambium
6. Why the cells of sclerenchyma and tracheids become dead?
7. Explain sclereids with their types.
8. What are sieve tubes ?explain.
9. Distinguish the anatomy of dicot root from monocot root.
10. Distinguish the anatomy of dicot stem from monocot stem.

ICT Corner

Plant and Animal Tissues

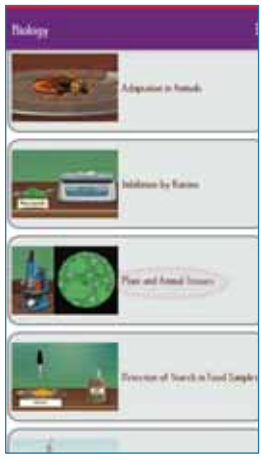
Let's explore **Plant tissues.**

Steps

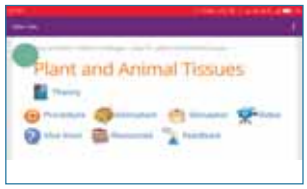
- Scan the QR code or go to Google play store
- Type online labs and install it.
- Select biology and select plant and animal tissues
- Click free sign up and provide your basic information with valid mail-Id
- Login with your registered mail id and password
- Choose theory tab to know the basic about anatomical structure
- Choose animation to view the sectioning process

Activity

- Choose simulation tab and view the section of plant parts under microscope



Step 1



Step 2

Step 4

Step 3

QR code

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Web URL:

https://play.google.com/store/apps/details?id=in.edu.olabs.olabs&hl=en

* Pictures are indicative only

Unit IV: Plant Anatomy (Structural Organisation)

Chapter 10

Secondary Growth

Learning Objectives

The students should be able to,

- *Analyze primary and secondary growth.*
- *Discuss the increase in length and width of the plant.*
- *Explain secondary growth in dicot stems.*
- *Understand the use of wood products to lead comfortable life.*
- *Explain secondary growth in dicot roots.*
- *Discuss anomalous secondary growth in dicots and monocots.*
- *Explain the seasoning, grain, texture and figure of wood.*

Chapter Outline

CLVCSK

How do the trees increase their girth?

Figure 10.1: *Taxus* wood

We have studied in the previous chapters the primary internal structure of monocots and dicots. If you look at the stem of grass (monocot), it is soft, whereas in the neem (dicot), the stem is very hard and woody, why? It is the secondary growth which confers the hardness to wood of dicot stems and roots. In monocots, usually there is no secondary growth and so they are soft.

The increase in girth is called **secondary growth** or **growth in girth** and we shall discuss the details of secondary growth in this chapter.

The plant organs originating from the apical meristems pass through a period of expansion in length and width. The roots and stems grow in length with the help of apical meristems. This is called **primary growth or longitudinal growth.** The gymnosperms and most angiosperms, including some monocots, show an increase in thickness of stems and roots by means of **secondary growth or latitudinal growth.**

The secondary growth in dicots and gymnosperms is brought about by two lateral meristems.

- Vascular Cambium and
- Cork Cambium

Activity

Generally monocots do not have secondary growth, but palms and bamboos have woody stems. Find the reason.

10.1 Secondary Growth in Dicot Stem

Vascular Cambium

The vascular cambium is the lateral meristem that produces the secondary vascular tissues. i.e., secondary xylem and secondary phloem.

Origin and Formation of Vascular Cambium

A strip of vascular cambium that is believed to originate from the procambium is present between xylem and phloem of the vascular bundle. This cambial strip is known as **intrafascicular or fascicular cambium**. In between the vascular bundles, a few parenchymatous cells of the medullary rays that are in line with the fascicular cambium become meristematic and form strips of vascular cambium. It is called **interfascicular cambium**.

This interfascicular cambium joins with the intrafascicular cambium on both sides to form a continuous ring. It is called a **vascular cambial ring.** The differences between interfascicular and intrafascicular cambia are summarised below:

Intrafascicular cambium	**Interfascicular cambium**
Present inside the vascular bundles	Present in between the vascular bundles.
Originates from the procambium.	Originates from the medullary rays.
Initially it forms a part of the primary meristem.	From the beginning it forms a part of the secondary meristem.

Organization of Vascular Cambium

The cells of vascular cambium do not fit into the usual description of meristems which have isodiametric cells, with a dense cytoplasm and large nuclei. While the active vascular cambium possesses cells with large central vacuole (or vacuoles) surrounded by a thin, layers of dense cytoplasm.

Further, the most important character of the vascular cambium is the presence of two kinds of initials, namely, **fusiform initials** and **ray initials**.

Fusiform Initials

These are vertically elongated cells. They give rise to the longitudinal or axial system of the secondary xylem (treachery elements, fibers, and axial parenchyma) and phloem (sieve elements, fibers, and axial parenchyma).

Based on the arrangement of the fusiform initials, two types of vascular cambium are recognized.

Storied (Stratified cambium) and Non-Storied (Non-stratified cambium)

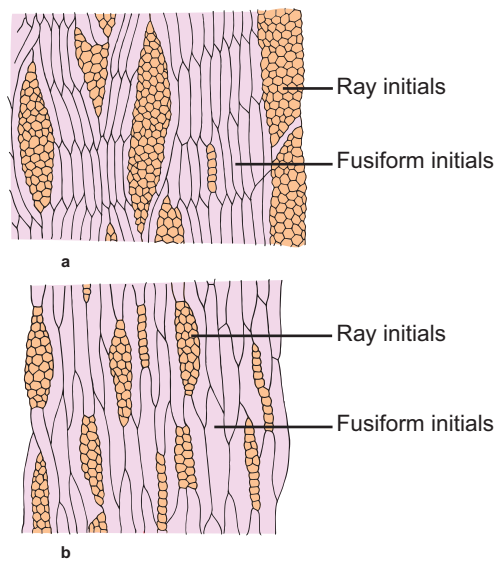


Figure 10.2: Tangential longitudinal section (TLS) of cambium (a) Storied cambium (b) Non-storied cambium

If the fusiform initials are arranged in horizontal tiers, with the end of the cells of one tier appearing at approximately the same level, as seen in tangential longitudinal section (TLS), it is called **storied (stratified) cambium**. It is the characteristic of the plants with short fusiform initials. Whereas in plants with long fusiform initials, they strongly overlap at the ends, and this type of cambium is called **non-storied (non-startified) cambium**.

Ray Initials

These are horizontally elongated cells. They give rise to the ray cells and form the elements of the radial system of secondary xylem and phloem.

Activity of Vascular Cambium

The vascular cambial ring, when active, cuts off new cells both towards the inner and outer side. The cells which are produced outward form secondary phloem and inward secondary xylem.

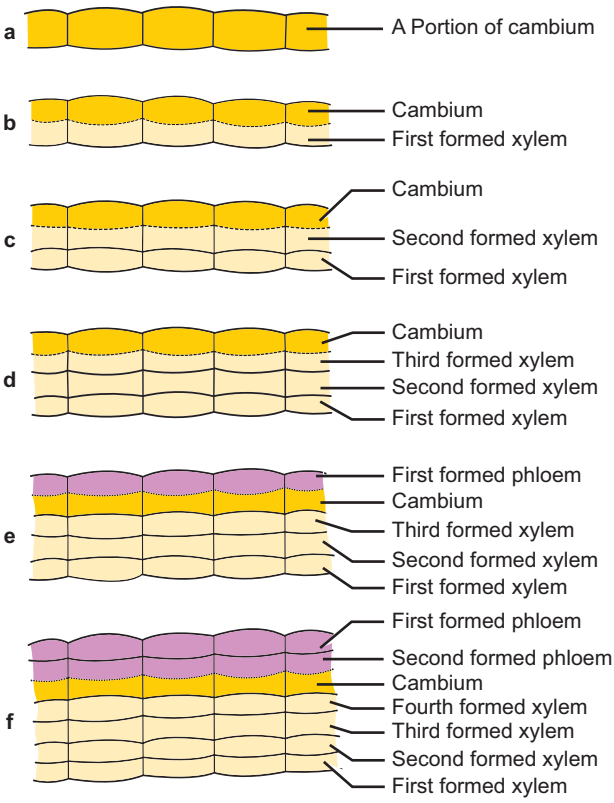


Figure 10.3: Diagrammatic representation of vascular cambial activity (a–f)

At places, cambium forms some narrow horizontal bands of parenchyma which passes through secondary phloem and xylem. These are the rays.

Due to the continued formation of secondary xylem and phloem through vascular cambial activity, both the primary xylem and phloem get gradually crushed.

Secondary Xylem

The secondary xylem, also called **wood**, is formed by a relatively complex meristem, the vascular cambium, consisting of vertically (axial) elongated fusiform initials and horizontally (radially) elongated ray initials.

Xylotomy

The study of wood by preparing sections for microscopic observation.

The axial system consists of vertical files of treachery elements, fibers, and wood parenchyma. Whereas the radial system consists of rows of parenchymatous cells oriented at right angles to the longitudinal axis of xylem elements.

The secondary xylem varies very greatly from species to species with reference to relative distribution of the different cell types, density and other properties. It is of two types.

Porous Wood or Hard Wood

Generally, the dicotyledonous wood, which has vessels is called **porous wood** or **hard wood**. Example: *Morus rubra*.

Non- Porous Wood or Soft Wood

Generally, the gymnosperm wood, which lacks vessels is known as **non- porous wood** or **soft wood**. Example: *Pinus*.

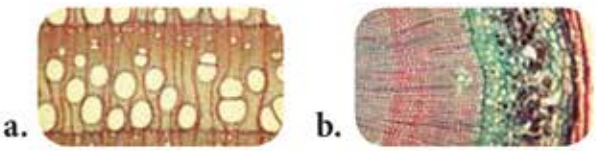


Figure 10.4: a) Structure of porous and b) non-porous wood

Differences between Porous Wood and Non-porous Wood

Porous wood or Hard wood, Example: *Morus*	**Non porous wood or Soft wood, Example: *Pinus***
Common in angiosperms	Common in gymnosperms
Porous because it contains vessels	Non-porous because it does not contain vessels

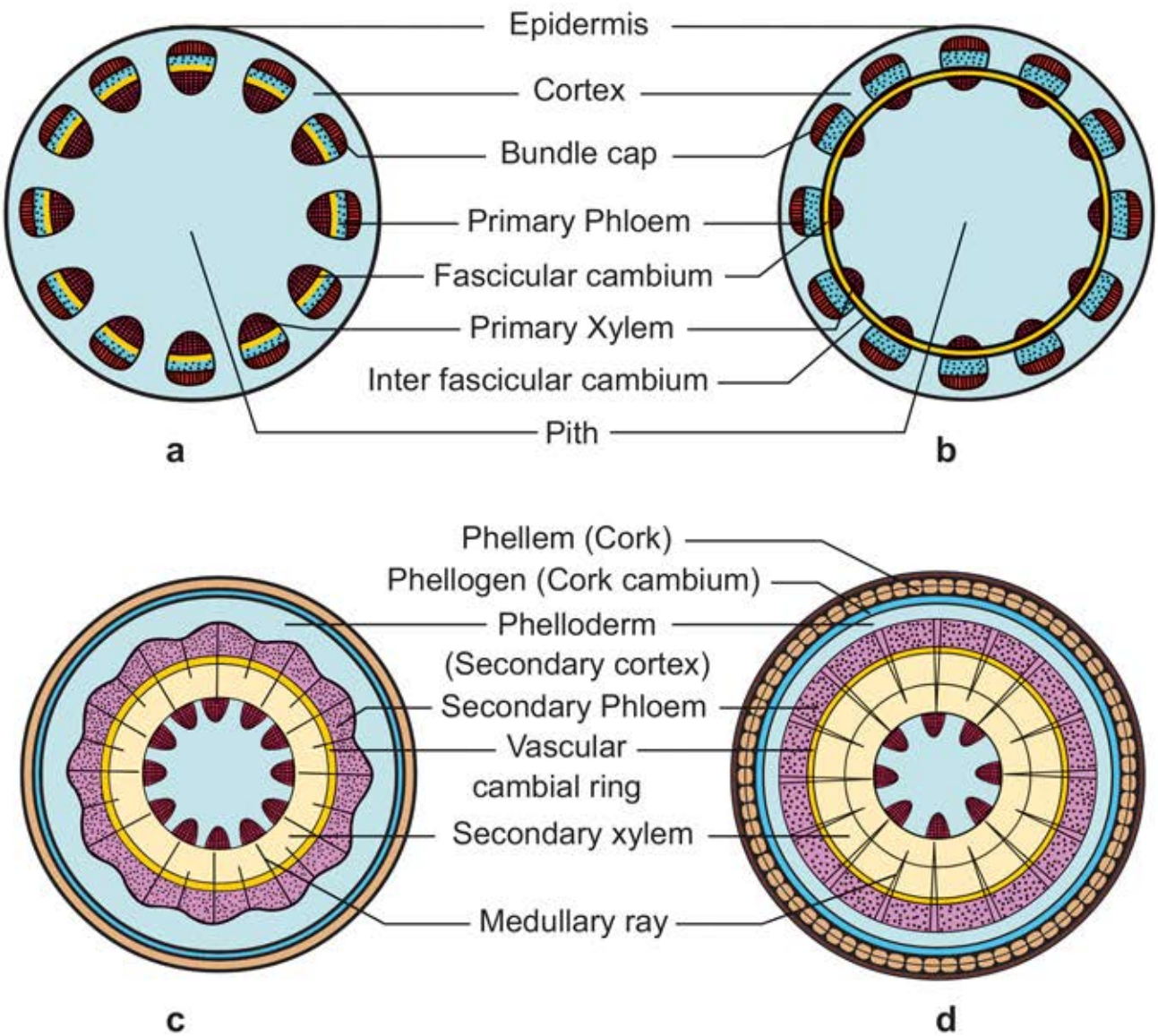


Figure 10.5: Secondary growth in dicot stem (diagrammatic) - stages in transverse section (a–d)

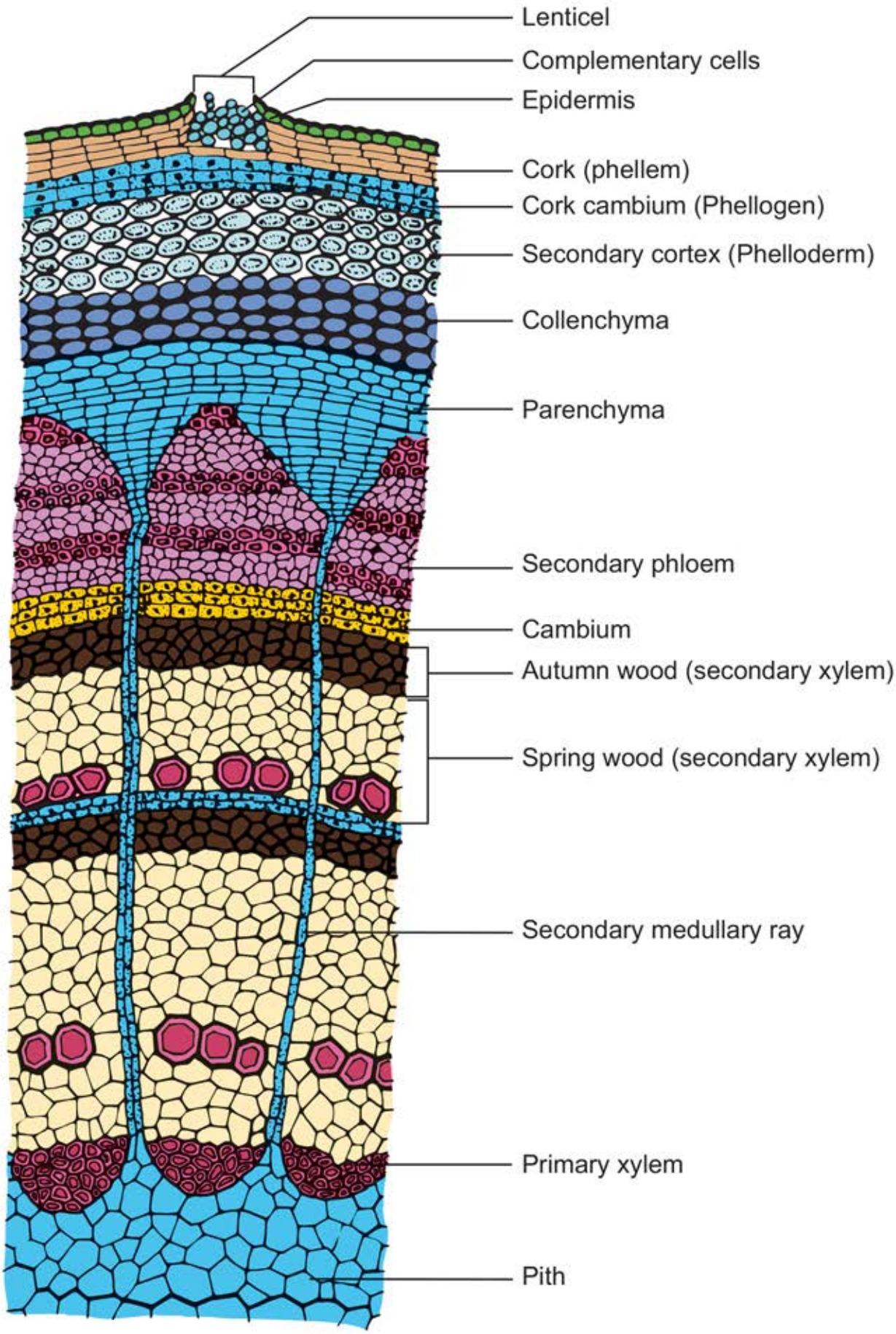
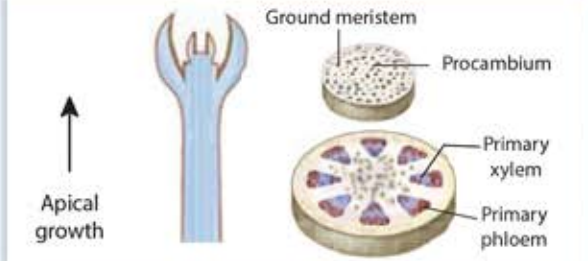


Figure 10.6: Secondary growth in two year old dicot stem – A portion enlarged

Primary and Secondary Growth

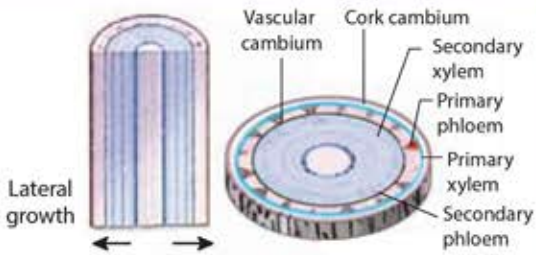
Primary growth in stem

Growth of plant derived from shoot apical meristem increases the length of the stem



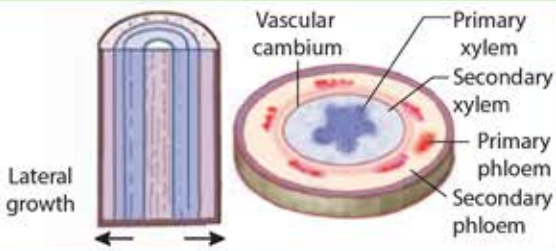
Secondary growth in stem

In gymnosperm and most angiosperm plants, the lateral meristem of stem increases its girth



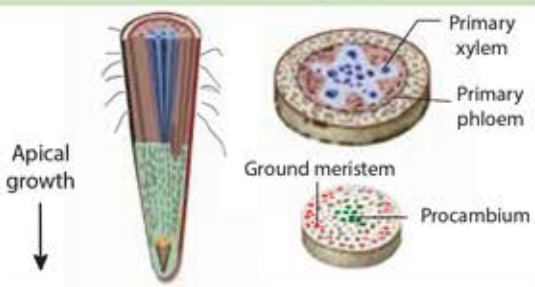
Secondary growth in root

In gymnosperm and most angiosperm plants the lateral meristem of root increases its girth



Primary growth in root

Growth of plant derived from root apical meristem increases length of the root



APICAL AND LATERAL MERISTEMS. Apical meristems produce the primary plant body. In some plants, the lateral meristem increase the girth of a plant. This type of growth is secondary because the lateral meristem are not directly produced by apical meristems. Woody plants have two types of lateral meristems: a vascular cambium that produces xylem, phloem tissues and cork cambium that produces the bark of a tree.

Annual Rings

The activity of vascular cambium is under the control of many physiological and environmental factors. In temperate regions, the climatic conditions are not uniform throughout the year. In the spring season, cambium is very active and produces a large number of xylary elements having vessels/tracheids with wide lumen. The wood formed during this season is called **spring wood or early wood**. The tracheary elements are fairly thin walled. In winter, the cambium is less active and forms fewer xylary elements that have narrow vessels/ tracheids and this wood is called **autumn wood or late wood.**The treachery elements are with narrow lumen, very thick walled.

- Usually more distinct annual rings are formed in the regions where climatic variations are sharp.
- Usually more distinct annual rings are formed in temperate plants and not in tropical plants.
- Usually least distinct annual rings are formed in seashore region because the climatic conditions remain same throughout the year.
- Generally annual rings are also less distinct in desert plants.

The spring wood is lighter in colour and has a lower density whereas the autumn wood is darker and has a higher density.

The annual ring denotes the combination of early wood and late wood and the ring becomes evident to our eye due to the high density of late wood. Sometimes annual rings are called **growth rings** but it should be remembered all the growth rings are not annual. In some trees more than one growth ring is formed with in a year due to climatic changes.

Additional growth rings are developed within a year due to adverse natural calamities like drought, frost, defoliation, flood, mechanical injury and biotic factors during the middle of a growing season,which results in the formation of more than one annual ring. Such rings are called **pseudo-** or **false- annual rings**.

Each annual ring corresponds to one year's growth and on the basis of these rings, the age of a particular plant can easily be calculated. The determination of the age of a tree by counting the annual rings is called **dendrochronology**.

Importance of Studying Growth Rings

- Age of wood can be calculated.
- The quality of timber can be ascertained.
- Radio-Carbon dating can be verified.
- Past climate and archaeological dating can be made.
- Provides evidence in forensic investigation.

Dendroclimatology

It is a branch of dendrochronology concerned with constructing records of past climates and climatic events by analysis of tree growth characteristics, especially growth rings.

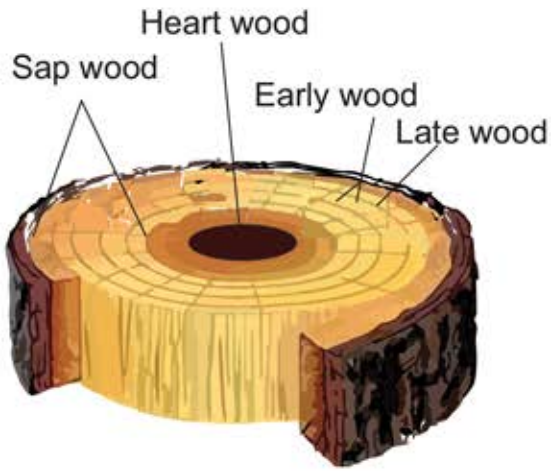


Figure 10.7: Structure of wood – Image shows early wood and late wood

Differences Between Spring Wood and Autumn Wood

Spring wood or Early wood	Autumn wood or Late wood
The activity of cambium is faster.	Activity of cambium is slower
Produces large number of xylem elements.	Produces fewer xylem elements.
Xylem vessels/ trachieds have wider lumen.	Xylem vessels/ trachieds have narrow lumen.
Wood is lighter in colour and has lower density	Wood is darker in colour and has a higher density.

The age of American, *Sequoiadendron* tree is about 3500 years.

Another feature of wood related to seasonal changes is the diffuse porous and ring porous condition. On the basis of diameter of xylem vessels, two main types of angiosperm woods are recognized.

❖ **Diffuse porous woods**

Diffuse porous woods are woods in which the vessels or pores are rather uniform in size and distribution throughout an annual ring.

Example: *Acer*

❖ **Ring porous woods**

The pores of the early wood are distinctly larger than those of the late wood. Thus rings of wide and narrow vessels occur.

Example: *Quercus*

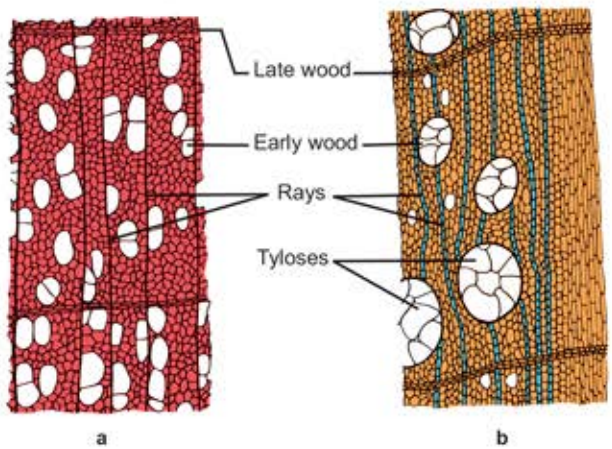


Figure 10.8: Transverse section of wood showing. a) Diffuse porous. b) Ring porous

The word "Porous" is used by the wood anatomists to refer to the appearance of the vessels as pores in transverse section.

Differences Between Diffuse Porous Wood and Ring Porous Wood

Diffuse porous wood	Ring porous wood
This type of wood is formed where the climatic conditions are uniform.	This type of wood is formed where the climatic conditions are not uniform.
The vessels are more or less equal in diameter in any annual ring.	The vessels are wide and narrow within any annual ring.
The vessels are uniformly distributed throughout the wood.	The vessels are not uniformly distributed throughout the wood.

Tyloses

In many dicot plants, the lumen of the xylem vessels is blocked by many balloon-like ingrowths from the neighbouring parenchymatous cells. These balloon-like structures are called **tyloses**.

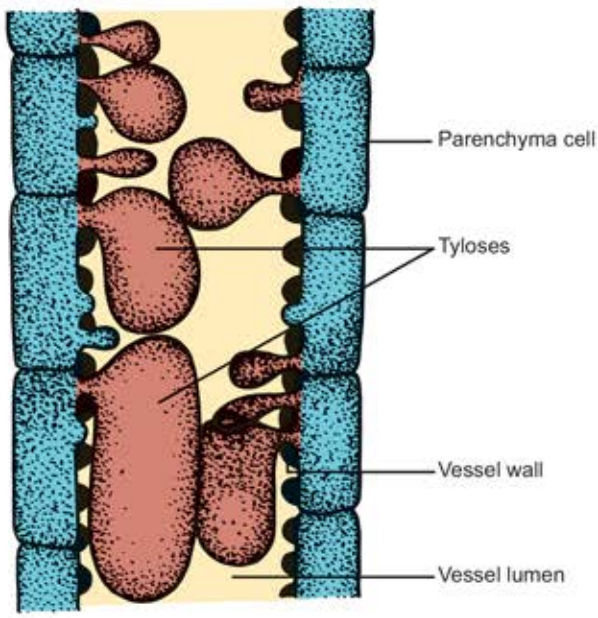


Figure 10.9: Structure of tyloses

Usually, these structures are formed in secondary xylem vessels that have last their function i.e., in heart wood.

In fully developed tyloses, starchy crystals, resins, gums, oils, tannins or coloured substances are found.

There are tylosoids in gymnosperms and angiosperms

In **gymnosperms**, the resin ducts are blocked by tylose-like ingrowths from the neighbouring resin producing parenchyamatous cells. Example: *Pinus*.

In **angiosperms**, the sieve tubes are blocked by tylose- like ingrowths from the neighbouring parenchyamatous cells. Example: *Bombox*.

These are called **tylosoids**

Wood is also classified into **sap wood** and **heart wood**.

Sap Wood and Heart Wood

Sap wood and heart wood can be distinguished in the secondary xylem. In any tree the outer part of the wood, which is paler in colour, is called **sap wood or alburnum.** The centre part of the wood, which is darker in colour is called **heart wood or duramen.** The sap wood conducts water while the heart wood stops conducting water. As vessels of the heart wood are blocked by tyloses, water is not conducted through them. Due to the presence of tyloses and their contents the heartwood becomes coloured, dead and the hardest part of the wood.

From the economic point of view, generally the heartwood is more useful

than the sapwood. The timber from the heartwood is more durable and more resistant to the attack of microorganisms and insects than the timber from sapwood.

Figure 10.10: Cross section of natural wood

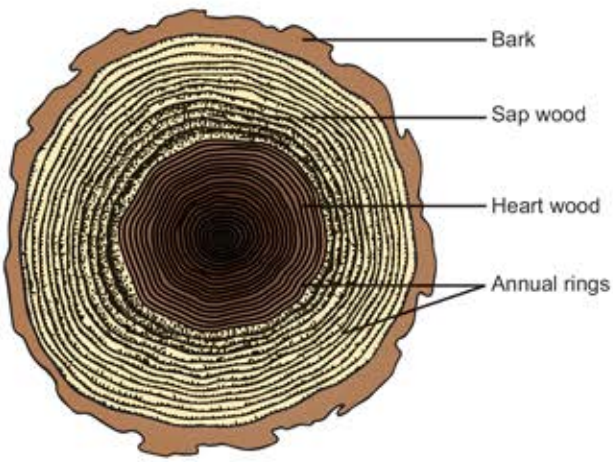


Figure 10.11: Cross - section of wood showing annual ring

When, the heart wood of a tree is destroyed, no vital function of the plant is affected.

When, the sap wood is destroyed, the plant will die because conduction of water will be blocked.

Differences Between Sap Wood (alburnum) and Heart Wood (duramen)

Sap Wood (Alburnum)	Heart Wood (Duramen)
Living part of the wood.	Dead part of the wood.
It is situated on the outer side of wood	It is situated in the centre part of wood
It is less in coloured	It is dark in coloured
Very soft in nature	Hard in nature
Tyloses are absent	Tyloses are present
It is not durable and not resistant to microorganisms	It is more durable and resists microorganisms

The dye, haematoxylin is obtained from the heart wood of *Haematoxylum campechianum* used to stain plant materials for observation under microscope, especially the nucleus of the cell.

a. Haematoxylin

Abies balsamea is a gymnospermic plant. It produces canada balsam, from its resin ducts. It is used as mounting medium for microscopic slide preparation.

b. Canada balsam

c. Microscopic slide

A slide of 60-years-old holotype specimen of a flatworm (*Lethacotyle fijiensis*) permanently mounted in canada balsam.

d. Ant inside blastic amber

Fossil resins-Amber

Plants secrete resins for their protective benefits.Amber is a fossilized tree resin especially from the wood, which has been appreciated for its colour and natural beauty since neolithic times. Much valued from antiquity to the present as a gemstone, amber is made into a variety of decorative objects. Amber is used in jewellery. It has also been used as a healing agent in folk medicine.

Figure 10.12: Economic importance of wood (a–d)

Secondary Phloem

The vascular cambial ring produces secondary phloem or bast on the outer side of the vascular bundle.

Just as the secondary xylem, the secondary phloem also has two tissue systems – the axial (vertical) and the radial (horizontal) systems derived respectively from the vertically elongated fusiform initials and horizontally elongated ray initials of vascular cambium. While sieve elements, phloem fibre, and phloem parenchyma represent the axial system, phloem rays represent the radial system. Life span of secondary phloem is less compared to secondary xylem. Secondary phloem is a living tissue that transports soluble organic compounds made during photosynthesis to various parts of plant.

Some commercially important phloem or bast fibres are obtained from the following plants.

i. Flax-*Linum ustitaissimum*
ii. Hemp-*Cannabis sativa*
iii. Sun hemp-*Crotalaria juncea*
iv. Jute-*Corchorus capsularis*

Be friendly with your environment (Eco friendly)

Why should not we use the natural products which are made by plant fibres like rope, fancy bags, mobile pouch, mat and gunny bags etc., instead of using plastics or nylon?

Periderm

Whenever stems and roots increase in thickness by secondary growth, the periderm, a protective tissue of secondary origin replaces the epidermis and often primary cortex. The periderm consists of phellem, phellogen, and phelloderm.

Phellem (Cork)

It is the protective tissue composed of non-living cells with suberized walls and formed centrifugally (outward) by the phellogen (cork cambium) as part of the periderm. It replaces the epidermis in

older stems and roots of many seed plants. It is characterized by regularly arranged tiers and rows of cells. It is broken here and there by the presence of lenticels.

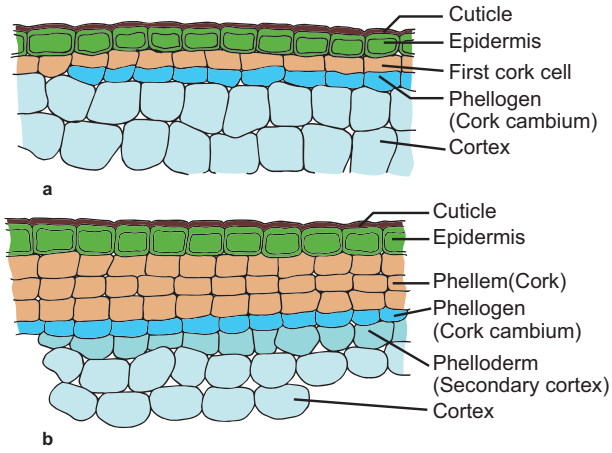


Figure 10.13: The cross section of periderm (a–b)

Phelloids

Phellem (Cork) like cells which lack suberin in their walls.

Phellogen (Cork Cambium)

It is a secondary lateral meristem. It comprises homogenous meristematic cells unlike vascular cambium. It arises from epidermis, cortex, phloem or pericycle (extrastelar in origin). Its cells divide periclinally and produce radially arranged files of cells. The cells towards the outer side differentiate into phellem (cork) and those towards the inside as phelloderm (secondary cortex).

Phelloderm (Secondary cortex)

It is a tissue resembling cortical living parenchyma produced centripetally (inward) from the phellogen as a part of the periderm of stems and roots in seed plants.

Differences Between Phellem and Phelloderm

Phellem (Cork)	Phelloderm (Secondary cortex)
It is formed on the outer side of phellogen.	It is formed on the inner side of phellogen.
Cells are compactly arranged in regular tires and rows without intercellular spaces.	Cells are loosely arranged with intercellular spaces.
Protective in function.	As it contains chloroplast, it synthesises and stores food.
Consists of non-living cells with suberized walls.	Consists of living cells, parenchymatous in nature and does not have suberin.
Lenticels are present.	Lenticels are absent.

Rhytidome is a technical term used for the outer dead bark which consists of periderm and isolated cortical or phloem tissues formed during successive secondary growth. Example: *Quercus*.

Polyderm is found in the roots and underground stems.eg. Rosaceae. It refers to a special type of protective tissues consisting of uniseriate suberized layer alternating with multiseriatenonsuberized cells in periderm.

Differences Between Vascular Cambium and Cork Cambium

Vascular cambium	Cork cambium
Also called cambium	Also called phellogen
It arises from procambium and interfascicular parenchyma in stems and from conjunctive parenchyma in roots	It arises from epidermis, cortex, phloem, or pericyle in both stems and roots
It comprises long fusiform and short ray initials.	It comprises of homogenous cells.
It produces secondary phloem towards the outer side and secondary xylem towards inner side.	It produces phellem(cork) towards outer side and phelloderm (secondary cortex) towards inner side.

Bark

The term 'bark' is commonly applied to all the tissues outside the vascular cambium of stem (**i.e., periderm, cortex, primary phloem and secondary phloem**). Bark protects the plant from parasitic fungi and insects, prevents water loss by evaporation and guards against variations of external temperature. It is an insect repellent, decay proof, fireproof and is used in obtaining drugs or spices. The phloem cells of the bark are involved in conduction of food while secondary cortical cells involved in storage.

If the phellogen forms a complete cylinder around the stem, it gives rise to **ring barks**. Example: *Quercus*. When the bark is formed in overlapping scale like layers, it is known as **scale bark**. Example: Guava. While ring barks normally do not peeled off, scale barks peeled off.

Figure 10.14: *Quercus* Tree-showing ring bark

Figure 10.15: Guava tree showing scale bark

Lenticel

Lenticel is raised opening or pore on the epidermis or bark of stems and roots.

It is formed during secondary growth in stems. When phellogen is more active in the region of lenticels, a mass of loosely arranged thin-walled parenchyma cells are formed. It is called **complementary tissue** or **filling tissue**.

Lenticel is helpful in exchange of gases and transpiration called **lenticular transpiration**.

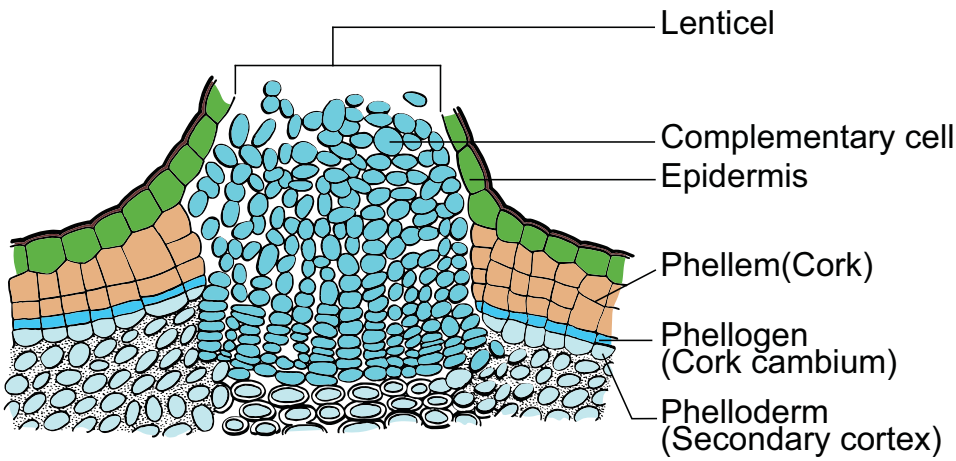


Figure 10.16: Structure of Lenticel

Know your Commercial Barks

 **a. Quinine**	***Cinchona*** bark is medicinally active, containing a variety of alkaloids including the **antimalarial** compound quinine.	 **e. Turpentine**	**Turpentine (Resin)** – obtained from bark of Confiers, is used as thinner for oil based paints and organic solvents. Example: *Pinus*
 **b. Cork**	Cork is an impermeable buoyant material, the phellem layer of bark tissue that is harvested for commercial use primarily from *Quercus suber*. Cork is composed of suberin, a hydrophobic substance and, because of its impermeable, buoyant, elastic, and fire retardant properties, used as a bottle stoppers.	 **f. *Cinnamomum* bark**	**Cinnamon (Oldest Spice)** – Its bark is used as ingredients of curry powder, medicine for cardiac stimulant, diarrhoea and vomiting. Example: *Cinnamomum zeylanicum*
 **c. Shuttle cocks**	Cork is also used as an essential element in the production of badminton shuttle cocks. Example: *Quercus suber*	 **g.** Tree shows gum exudes  **h.** Gum	**Gum Arabic** Transverse incisions are made with a small axe and thin strip of the outer bark are torn off. From that, gum slowly exudes as a viscous liquid, collects in a drop and hardens. Example: *Acacia senegal.*
 **d. Rubber tree**	Rubber is obtained from latex vessels of inner bark. Example: *Hevea brasiliensis*		

10.2 Secondary Growth in Dicot root

Secondary growth in dicot roots is essential to provide strength to the growing aerial parts of the plants. It is similar to that of the secondary growth in dicot stem. However, there is marked difference in the manner of the formation of vascular cambium.

The vascular cambium is completely secondary in origin. It originates from a combination of conjunctive tissue located just below the phloem bundles, and as a portion of pericycle tissue present above the protoxylem to form a complete and continuous wavy ring. This wavy ring later becomes circular and produces secondary xylem and secondary phloem similar to the secondary growth in stems.

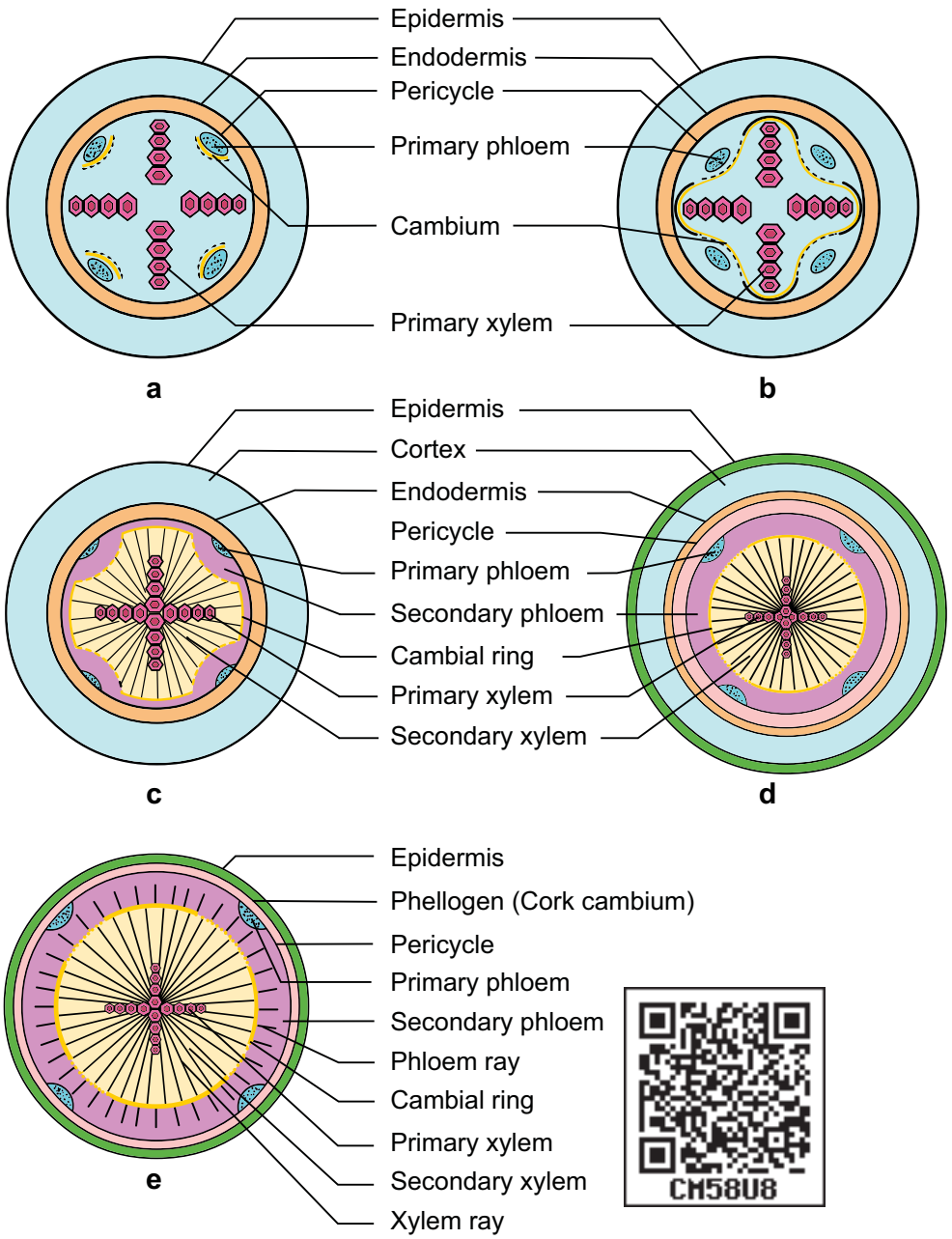
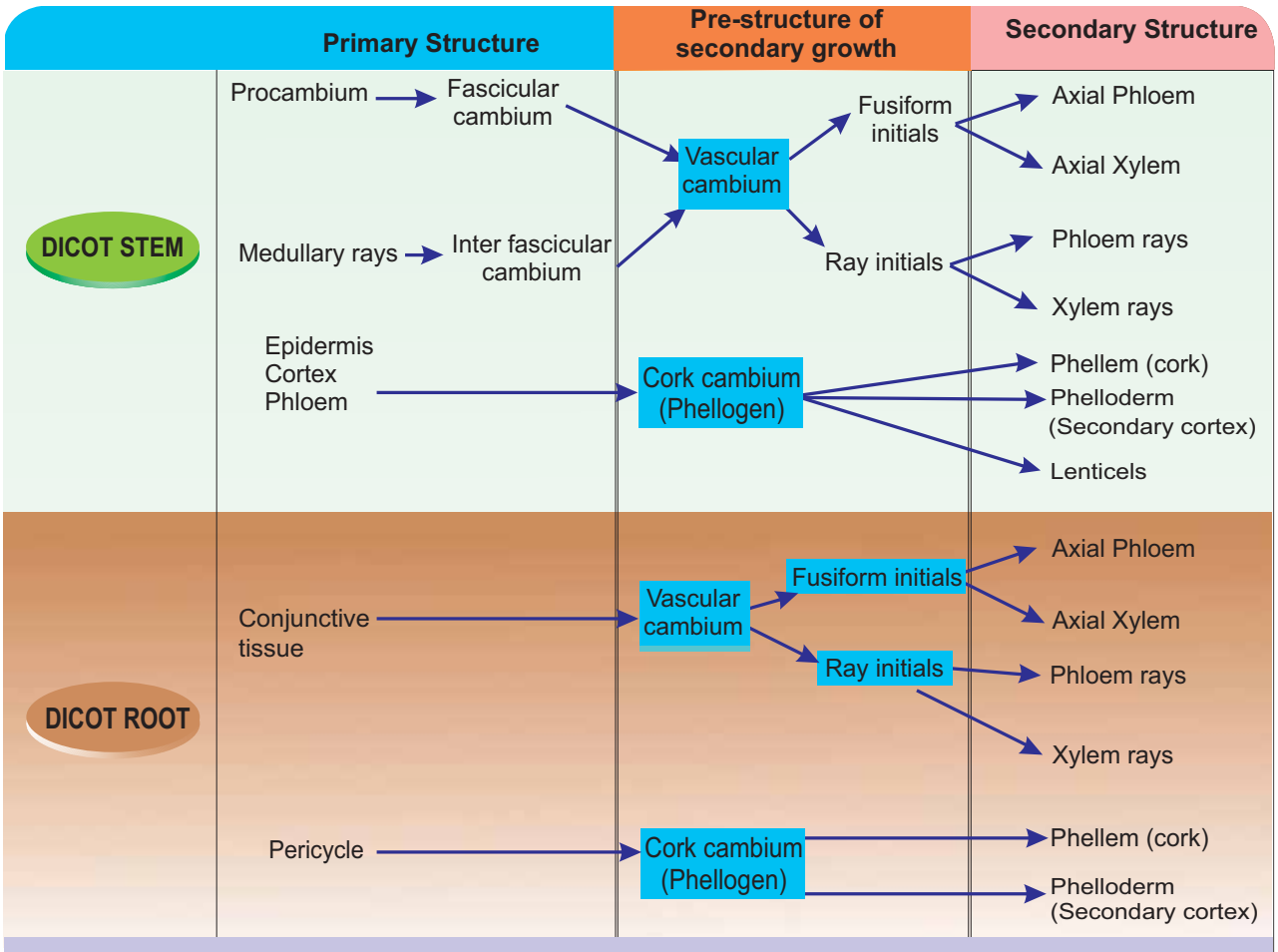


Figure 10.17: Different stages of the secondary growth (diagrammatic) in a typical dicot root (a–e)

Differences Between Secondary Growth in Dicot Stem and Root

Secondary growth in dicot stem	Secondary growth in dicot root
The cambial ring formed is circular in cross section from the beginning.	The cambial ring formed is wavy in the beginning and later becomes circular.
The cambial ring is partially primary (fascicular cambium)and partially secondary (Interfascicular cambium) in origin.	The cambial ring is completely secondary in origin.
Generally, periderm originates from the cortical cells (extrastelar in origin).	Generally, periderm originates from the pericyle. (intrastelar in origin)
More amount of cork is produced as stem is above the ground	Generally, less amount of cork is produced as root is underground.
Lenticels of periderm are prominent.	Lenticels of periderm are not very prominent.



Tissue Lineages During Secondary Growth in Dicot Stem and Root

Summary

Secondary growth deals with the formation of additional vascular tissue by the activities of vascular and cork cambia and secondary thickening meristem (STM). It increases the girth of stem and roots of gymnosperms, most angiosperms, and some monocot plants. Vascular cambium possesses two kinds of initials they are, fusiform and ray initials. Fusiform initials give rise to the axial tissue system whereas ray initials give rise to radial tissue system of stems and roots.

Wood is a very important product of secondary growth. It represents secondary xylem. It is classified in various ways. Based respectively on the presence or absence of vessels, wood is classified into two types. i.e., porous and non-porous wood. Based on the wood formed during seasons, it is classified into spring wood and autumn wood. The spring and autumn wood, together is called **annual ring**. The wood is also classified into sap wood (pale in colour) and heart wood (dark in colour). The lumen of the xylem vessels of heart wood are blocked by many balloon like ingrowths from neighbouring parenchymatous cells called **tyloses**.

The periderm, a secondary protective tissue consists of phellem, phellogen and phelloderm. Secondary growth produces a corky bark around the tree trunk that protects the interior parts from heat, cold, infection etc. Secondary growth of root is different from stem in the method of formation of vascular cambium.

Evaluation

CHE4VV

1. Consider the following statements

   In spring season vascular cambium

   i. is less active

   ii. produces a large number of xylary elements

   iii. forms vessels with wide cavities of these,

   a. (i) is correct but (ii) and (iii) are not correct

   b. (i) is not correct but (ii) and (iii) are correct

   c. (i) and (ii) are correct but (iii) is not correct

   d. (i) and (ii) are not correct but (iii) is correct.

2. Usually, the monocotyledons do not increase their girth, because

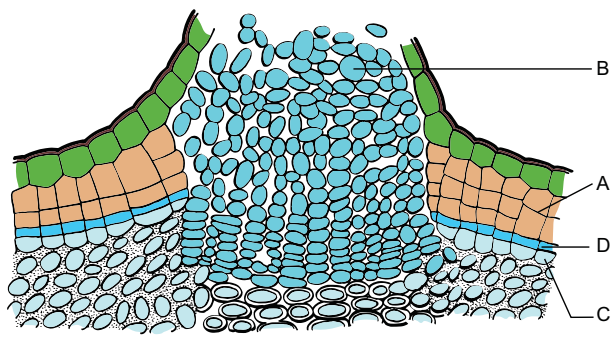
   a. They possess actively dividing cambium

   b. They do not possess actively dividing cambium

   c. Ceases activity of cambium

   d. All are correct

3. In the diagram of lenticel identify the parts marked as A,B,C,D



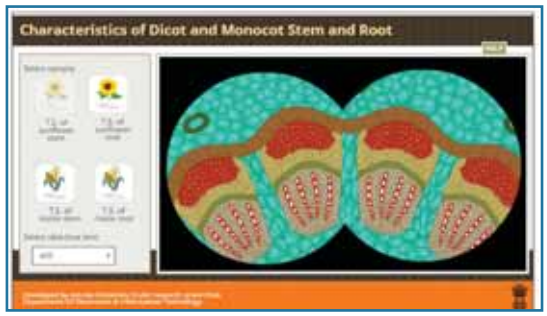
a. A. phellem, B. Complementary tissue, C. Phelloderm, D. Phellogen.
b. A. Complementary tissue, B. Phellem, C. Phellogen, D. Phelloderm.
c. A. Phellogen, B. Phellem, C. Phelloderm, D. complementary tissue
d. A. Phelloderm, B. Phellem, C. Complementary tissue, D. Phellogen

4. The common bottle cork is a product of
   a. Dermatogen
   b. Phellogen
   c. Xylem
   d. Vascular cambium
5. What is the fate of primary xylem in a dicot root showing extensive secondary growth?
   a. It is retained in the center of the axis
   b. It gets crushed
   c. May or may not get crushed
   d. It gets surrounded by primary phloem
6. In a forest, if the bark of a tree is damaged by the horn of a deer, How will the plant overcome the damage?
7. In which season the vessels of angiosperms are larger in size, why?
8. Continuous state of dividing tissue is called meristem. In connection to this, what is the role of lateral meristem?
9. A timber merchant bought 2 logs of wood from a forest & named them A & B, The log A was 50 year old & B was 20 years old. Which log of wood will last longer for the merchant? Why?
10. A transverse section of the trunk of a tree shows concentric rings which are known as growth rings. How are these rings formed? What are the significance of these rings?

ICT Corner

Characteristics of Dicot and Monocot Stem and Root

Let's explore **inside**
Stem and Root



Steps

- Scan the QR code or go to Google play store.
- Type online labs and install it.
- Select biology and select Characteristics of dicot and monocot stem and root.
- Click free sign up and provide your basic information with valid mail-Id.
- Login with your registered mail id and password.
- Choose theory tab to know the basic about anatomical structure of plant parts.
- Choose animation to view the sectioning process.
- Choose simulation tab and view the section of plant parts under microscope.

Activity

- Do the section through simulation and record your observations.

Step 1

Step 2

Step 3

Step 4

Step 5

URL:

https://play.google.com/store/apps/details?id=in.edu.olabs.olabs&hl=en

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* Pictures are indicative only

Unit V: Plant Physiology (Functional Organisation)

Chapter 11

Transport in Plants

Learning Objectives

The learner will be able to,

- *Recall knowledge of basic physical and biological processes studied in previous classes.*
- *Classify, differentiate and compare the process of active and passive transport.*
- *Understand the mechanism of absorption of water.*
- *Analyse the various theories in ascent of sap.*
- *Understand the process of transpiration and Compare the various types of transpiration.*
- *Discuss the mechanism of phloem translocation.*
- *Understand the process behind mineral absorption.*

Chapter Outline

Over 450 million years ago (the Ordovician period in Paleozoic era) plants migrated from their own sophisticated water world to newly formed land. The land had harsh environment; water availability was deeper and so plants struggled for getting water for their very existence. Some of them failed to survive and rest adopted themselves to the new world. The biggest adaptations followed for their survival was building their own water absorbing systems to draw water from deep inside the land. The creation and updating of water absorbing system (vascular tissues) led to the diversity of the plant kingdom. The gregarious growth of prehistoric pteridophytes, gymnosperms and present-day flowering plants led to the biggest challenge in the transport of water from root to several meters high trees against gravity. In this chapter, we will study the events taking place between the gain of water in roots and loss in leaves and the mechanisms behind the basic physical and biological processes in the movement of water, gases and minerals in plants. Further, we study how food material synthesized in the leaf can be transported to various utilizing and storage areas against struggles and challenges.

The Plumbing system of Plants and Humans

Plants and animals evolved separately but developed comparable structures to control transport of water and dissolved chemicals. But whose transport system is optimally designed to offer selective advantage? In plants, transport through xylem has allowed growth in height and colonization of diverse habitats and the system has to be extensive as Photosynthesis requires water. Murray's law predicts the thickness of branches in transport networks, such that the cost for transport and maintenance of the transport medium is minimized. This law is observed in the vascular and respiratory systems of animals, xylem in plants, and the respiratory system of insects. Further research in this area will improve our understanding of natural world.

11.1 Types of Transport

Transport is the process of moving water, minerals and food to all parts of the plant body. Conducting tissues such as xylem and phloem play an important role in this.

What is the need for transport? Water absorbed from roots must travel up to leaves by xylem for food preparation by photosynthesis. Likewise, food prepared from leaves has to travel to all parts of the plant including roots. Both the processes are interconnected and depend on each other.

- Based on the distance travelled by water (sap) or food (solute) they are classified as

  (a) Short distance (Cell to cell transport) and (b) Long distance transport.

  i. **Short-distance (Cell to cell transport):** Involvement of few cells, mostly in the lateral direction. They are the connecting link to xylem and phloem from root hairs or leaf tissues respectively. Examples: Diffusion, Imbibition, and Osmosis.

  ii. **Long-distance transport:** Transport within the network of xylem or phloem is an example for long-distance transport. Examples: Ascent of Sap and Translocation of Solutes.

- Based on energy expenditure during transport, they are classified as **(a) passive transport and (b) active transport.**

  i. **Passive transport:** It is a downhill process which utilizes physical forces like gravity and concentration. No energy expenditure is required. It includes diffusion, facilitated diffusion, imbibition, and osmosis.

ii. **Active transport:** It is a biological process and it runs based on the energy obtained from respiration. It is an uphill process.

11.2 Cell to Cell Transport

Cell to cell or short distance transport covers the limited area and consists of few cells. They are the facilitators or tributaries to the long-distance transport. The driving force for the cell to cell transport can be passive or active (Figure 11.1). The following chart illustrate the various types of cell to cell transport:

Diffusion: The net movement of molecules from a region of their higher concentration to a region of their lower concentration along a concentration gradient until an equilibrium is attained.

Characteristics of diffusion

i. It is a passive process, hence no energy expenditure involved.
ii. It is independent of the living system.
iii. Diffusion is obvious in gases and liquids.

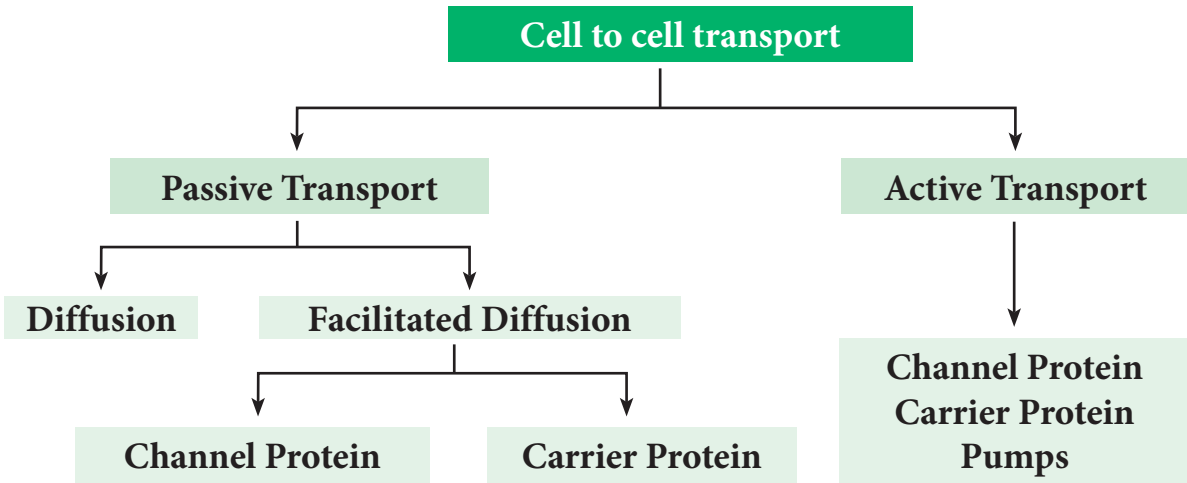


Figure 11.1: Cell to cell transport

11.2.1 Passive Transport

1. Diffusion

When we expose a lightened incense stick or mosquito coil or open a perfume bottle in a closed room, we can smell the odour everywhere in the room. This is due to the even distribution of perfume molecules throughout the room. This process is called **diffusion**.

In **diffusion**, the movement of molecules is continuous and random in order in all directions (Figure 11.2).

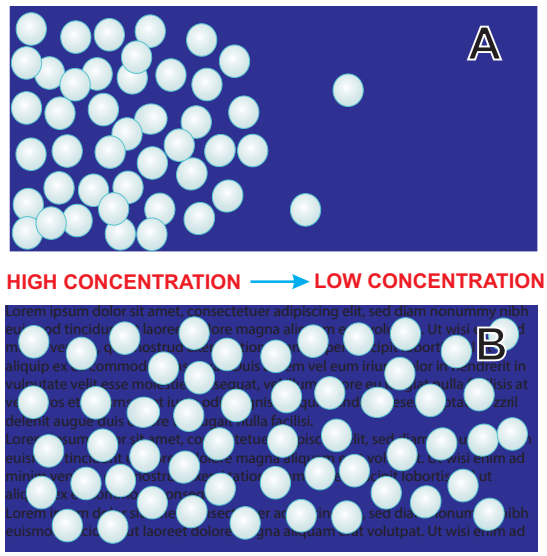


Figure 11.2: Distribution of molecules in diffusion (A) Initial stage (B) Final stage

iv. Diffusion is rapid over a shorter distance but extremely slow over a longer distance.

v. The rate of diffusion is determined by temperature, concentration gradient and relative density.

Significance of diffusion in Plants

i. Gaseous exchange of O_2 and CO_2 between the atmosphere and stomata of leaves takes place by the process of diffusion. O_2 is absorbed during respiration and CO_2 is absorbed during photosynthesis.

ii. In transpiration, water vapour from intercellular spaces diffuses into atmosphere through stomata by the process of diffusion.

iii. The transport of ions in mineral salts during passive absorption also takes place by this process.

Diffusion for sterilization in surgical theatres

Surgical theatres must be free from germs to prevent infection during surgeries. A mixture of Formalin and Potassium permanganate produces enormous fumes which will kill all pathogens in an enclosed area. This method is known as **fumigation** and operates by diffusion.

2. Facilitated Diffusion

Cell membranes allow water and nonpolar molecules to permeate by simple diffusion. For transporting polar molecules such as ions, sugars, amino acids, nucleotides and many cell metabolites is not merely based on concentration gradient. It depends on,

i. Size of molecule: Smaller molecules diffuse faster.

ii. Solubility of the molecule: Lipid soluble substances easily and rapidly pass through the membrane. But water soluble substances are difficult to pass through the membrane. They must be facilitated to pass the membrane.

Types of Membrane Permeability

A solution is made up of solute particles dissolved in a solvent and the permeability of the above components depends on the nature of cell membranes, which is given below:

Impermeable: Inhibit the movement of both solvent and solute molecules. Example: Suberised, cutinesed or liginifid cell walls.

Permeable: They allow diffusion of both solvent and solute molecules through them. Example: Cellulosic cell wall.

Semi permeable: Semi permeable allow diffusion of solvent molecules but do not allow the passage of solute molecule. Example: Parchment paper.

Selectively permeable: All bio membranes allow some solutes to pass in addition to the solvent molecules. Example: Plasmalemma, tonoplast, and membranes of cell organelles.

In facilitated diffusion, molecules cross the cell membrane with the help of special membrane proteins called transport proteins, without the expenditure of ATP.

There are two types of transport proteins present in the cell membrane. They are channel protein and a carrier protein.

I. Channel Protein

Channel protein forms a channel or tunnel in the cell membrane for the easy passage of molecules to enter the cell. The channels are either open or remain closed. They may open up for specific molecules. Some channel proteins create larger pores in the outer membrane. Examples: Porin and Aquaporin.

i. Porin

Porin is a large transporter protein found in the outer membrane of plastids, mitochondria and bacteria which facilitates smaller molecules to pass through the membrane.

ii. Aquaporin

Aquaporin is a water channel protein embedded in the plasma membrane. It regulates the massive amount of water transport across the membrane (Figure 11.3). Plants contain a variety of

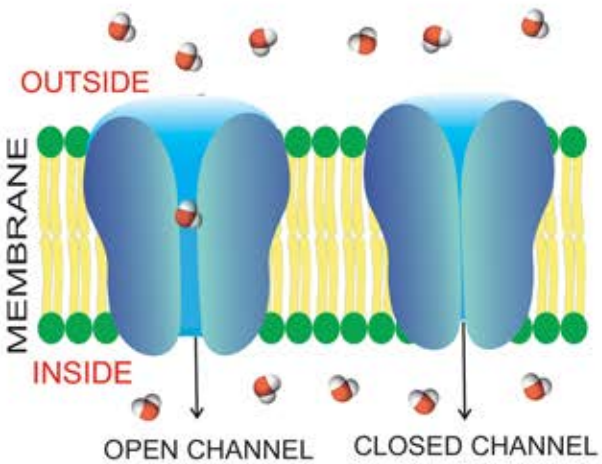


Figure 11.3: Aquaporin

aquaporins. Over 30 types of aquaporins are known from maize. Currently, they are also recognized to transport substrates like glycerol, urea, CO_2, NH_3, metalloids, and **Reactive Oxygen Species** (ROS) in addition to water. They increase the permeability of the membrane to water. They confer drought and salt stress tolerance.

Discovery of Aquaporin

Peter Agre, discovered the "Water Pore" Aquaporin in RBC and received Nobel Prize for chemistry in 2003.

II. Carrier Protein

Carrier protein acts as a vehicle to carry molecules from outside of the membrane to inside the cell and vice versa (Figure 11.4). Due to association with molecules to be transported, the structure of carrier protein gets modified until the dissociation of the molecules.

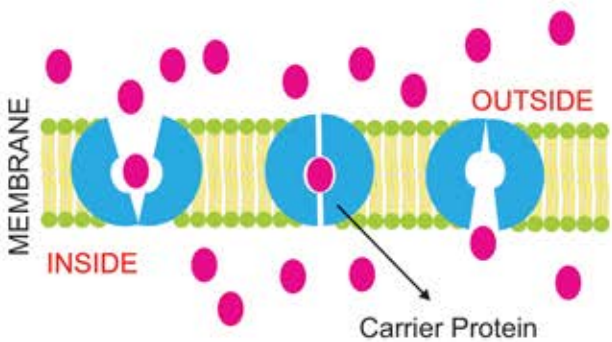


Figure 11.4: Carrier Protein

There are 3 types of carrier proteins classified on the basis of handling of molecules and direction of transport (Figure 11.5). They are, i) **Uniport** ii) **Symport** iii) **Antiport.**

i. ***Uniport***: In this molecule of a single type move across a membrane independent of other molecules in one direction.

ii. ***Symport or co-transport***: The term **symport** is used to denote an integral membrane protein that simultaneously

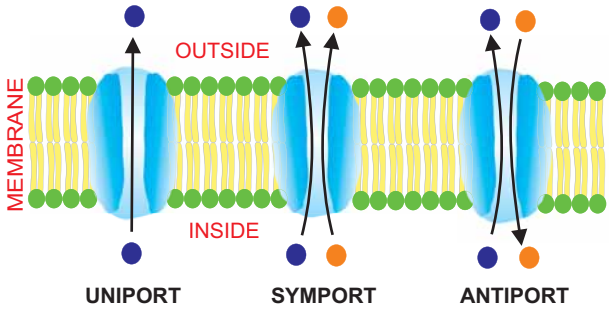


Figure 11.5: Direction of transport

transports two types of molecules across the membrane in the same direction.

iii. ***Antiport or Counter Transport***: An **antiport** is an integral membrane transport protein that simultaneously transports two different molecules, in opposite directions, across the membrane.

11.2.2 Active Transport

The main disadvantage of passive transport processes like diffusion is the lack of control over the transport of selective molecules. There is a possibility of harmful substances entering the cell by a concentration gradient in the diffusion process. But selective permeability of cell membrane has a great control over entry and exit of molecules. Active transport is the entry of molecules against a concentration gradient and an uphill process and it needs energy which comes from ATP. Passive transport uses kinetic energy of molecules moving down a gradient whereas, active transport uses cellular energy to move them against a gradient. The transport proteins discussed in facilitated diffusion can also transport ions or molecules against a concentration gradient with the expenditure of cellular energy as an active process. Pumps use a source of free energy such as ATP or light to drive the thermodynamically uphill transport of ions or molecules. The pump action is an example of active transport. Example: Na^+-K^+-ATPase pump (Table 11.1).

Table 11.1 Comparison of different transport mechanisms

Property	Passive transport		Active transport
	Simple diffusion	Facilitated diffusion	
Nature of process	Physical	Biological	Biological
Requirement for presence of membrane protein	No	Yes	Yes
Selectivity of molecule	No	Yes	Yes
Saturation of transport	No	Yes	Yes
Uphill transport	No	No	Yes
Energy requirement (ATP)	No	No	Yes
Sensitivity to inhibitors	No	Yes	Yes

Check your grasp!

What are the similarities and differences between co- transport and counter transport?

Solution:

Similarity: In both system two molecules are involved for the unidirectional transport.

Difference: In co-transport, two molecules are transported together whereas, in counter transport two molecules are transported in opposite direction to each other.

11.3 Plant Water Relations

Water plays an essential role in the life of the plant. The availability of water influences the external and internal structures of plants as protoplasm is made of 60-80% water. Water is a **universal solvent** since most of the substances get dissolved in it and the high tensile strength of water molecule is helpful in the ascent of sap. Water maintains the internal temperature of the plant as well as the turgidity of the cell.

11.3.1 Imbibition

Colloidal systems such as **gum, starch, proteins, cellulose, agar, gelatin** when placed in water, will absorb a large volume of water and swell up. These substances are called **imbibants** and the phenomenon is **imbibition**.

Examples: 1. The swelling of dry seeds 2.The swelling of wooden windows, tables, doors due to high humidity during the rainy season.

The Power of Imbibition

In olden days, small wooden pegs were inserted into crevices of rocks followed by continuous hydration. Due to imbibition the volume of wooden peg increases and cuts off rocks precisely.

The gluten from wheat can take as much as 300% of its own weight

Significance of imbibition

i. During germination of seeds, imbibition increases the volume of seed enormously and leads to bursting of the seed coat.

ii. It helps in the absorption of water by roots at the initial level.

Activity

Imbibition experiment

Collect 5 gm of gum from Drumstick tree or Babool tree or Almond tree. Immerse in 100ml of water. After 24 hours observe the changes and discuss the results with your teacher.

11.3.2 Water Potential (Ψ)

The concept of water potential was introduced in 1960 by **Slatyer** and **Taylor**. Water potential is potential energy of water in a system compared to pure water when both temperature and pressure are kept the same. It is also a measure of how freely water molecules can move in a particular environment or system. Water potential is denoted by

CHMZXI

the Greek symbol **Ψ** (psi) and measured in **Pascal** (Pa). At standard temperature, the water potential of pure water is **zero**. Addition of solute to pure water decreases the kinetic energy thereby decreasing the water potential. Comparatively a solution always has low water potential than pure water. In a group of cells with different water potential, a water potential gradient is generated. Water will move from higher water potential to lower water potential.

Water potential (**Ψ**) can be determined by,

1. Solute concentration or Solute potential (Ψ_S)
2. Pressure potential (Ψ_P)

By correlating two factors, water potential is written as,

$$\Psi_W = \Psi_S + \Psi_P$$

Water Potential = Solute potential + Pressure potential

1. Solute Potential (Ψ_S)

Solute potential, otherwise known as **osmotic potential** denotes the effect of dissolved solute on water potential. In pure water, the addition of solute reduces its free energy and lowers the water potential value from zero to negative. Thus the value of solute potential is always negative. In a solution at standard atmospheric pressure, water potential is always equal to solute potential ($\Psi_W = \Psi_S$).

2. Pressure Potential (Ψ_P)

Pressure potential is a mechanical force working against the effect of solute potential. Increased pressure potential will increase water potential and water enters cell and cells become **turgid**. This **positive hydrostatic pressure** within the cell is called **Turgor pressure**. Likewise, withdrawal of water from the cell decreases the water potential and the cell becomes **flaccid**.

3. Matric Potential (Ψ_M)

Matric potential represents the attraction between water and the **hydrating colloid or gel-like organic molecules in the cell wall** which is collectively termed as **matric potential**. Matric potential is also known as **imbibition pressure**. The matric potential is maximum (most negative value) in a dry material. **Example**: The swelling of soaked seeds in water.

11.3.3 Osmotic Pressure and Osmotic Potential

When a solution and its solvent (pure water) are separated by a semipermeable membrane, a pressure is developed in the solution, due to the presence of dissolved solutes. This is called **osmotic pressure** (**OP**). Osmotic pressure is increased with the increase of dissolved solutes in the solution. More concentrated solution (low **Ψ** or Hypertonic) has high osmotic pressure. Similarly, less concentrated solution (high **Ψ** or Hypotonic) has low osmotic pressure. The osmotic pressure of pure water is always **zero** and it increases with the increase of solute concentration. Thus osmotic pressure always has a positive value and it is represented as π.

Osmotic potential is defined as the ratio between the number of solute particles and the number of solvent particles in a solution. Osmotic potential and osmotic pressure are numerically equal. Osmotic potential has a negative value whereas on the other hand osmotic pressure has a positive value.

11.3.4 Turgor Pressure and Wall Pressure

When a plant cell is placed in pure water (hypotonic solution) the diffusion of water into the cell takes place by endosmosis. It creates a positive hydrostatic pressure on the rigid cell wall by the cell membrane. Henceforth the pressure exerted by the cell membrane towards the cell wall is **Turgor Pressure (TP).**

The cell wall reacts to this turgor pressure with **equal and opposite force**, and the counter-pressure exerted by the cell wall towards cell membrane is **wall pressure (WP).**

Turgor pressure and wall pressure make the cell fully turgid.

TP + WP = Turgid.

Activity

Find the role of turgor pressure in sudden closing of leaves when we touch the 'touch me not' plant.

11.3.5 Diffusion Pressure Deficit (DPD) or Suction Pressure (SP)

Pure solvent (hypotonic) has higher diffusion pressure. Addition of solute in pure solvent lowers its diffusion pressure. The difference between the diffusion pressure of the solution and its solvent at a particular temperature and atmospheric pressure is called as **Diffusion Pressure Deficit (DPD)** termed by **Meyer (1938)**. DPD is increased by the addition of solute into a solvent system. Increased DPD favours endosmosis or it sucks the water from hypotonic solution; hence **Renner** (1935) called it as **Suction pressure**. It is equal to the difference of osmotic pressure and turgor pressure of a cell. The following three situations are seen in plants:

- **DPD in normal cell:** DPD = OP – TP.
- **DPD in fully turgid cell**: Osmotic pressure is always equal to turgor pressure in a fully turgid cell.
- OP = TP or OP-TP =0. Hence DPD of fully turgid cell is zero.
- **DPD in flaccid cell**: If the cell is in flaccid condition there is no turgor pressure or TP=0. Hence DPD = OP.

11.3.6 Osmosis

Osmosis (Latin: *Osmos*-impulse, urge) is a **special type of diffusion**. It represents the movement of **water or solvent molecules** through a selectively permeable membrane **from the place of its higher concentration (high water potential) to the place of its lower concentration (low water potential).**

Types of Solutions based on concentration

i. ***Hypertonic*** (*Hyper* = High; *tonic* = solute): This is a strong solution (low solvent/ high solute / low **Ψ**) which **attracts solvent** from other solutions.

ii. ***Hypotonic*** (*Hypo* = low; *tonic* = solute): This is a weak solution (high solvent /low or zero solute / high **Ψ**) and it **diffuses water** out to other solutions (Figure 11.7).

iii. ***Isotonic*** (*Iso* = identical; *tonic* = soute): It refers to two solutions having same concentration. In this condition the net movement of water molecule will be zero.

The term hyper, hypo and isotonic are **relative terms** which can be used only

Thistle funnel experiment

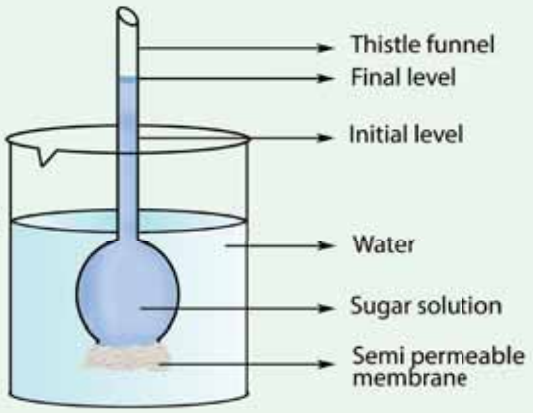


Figure 11.6: Thistle Funnel Experiment

Mouth of a thistle funnel is tied with goat bladder. It acts as a semipermeable membrane. Pour concentrated sugar solution in the thistle funnel and mark the level of solution. Place this in a beaker of water. After some time, water level in the funnel rises up steadily. This is due to the inward diffusion of water molecules through the semipermeable membrane (Figure 11.6).

Conversely, if water in the beaker is replaced by a sugar solution and sugar solution in the thistle funnel replaced by water, what will be happen?

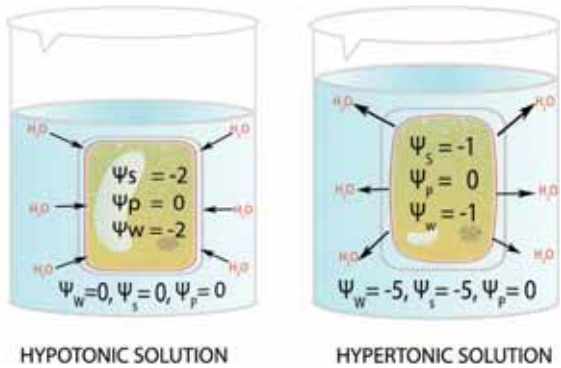


Figure 11.7: Types of solution based on concentration

in comparison with another solution.

1. Types of osmosis

Based on the direction of movement of water or solvent in an osmotic system, two types of osmosis can occur, they are ***Endosmosis*** and ***Exosmosis***.

i. ***Endosmosis***: Endosmosis is defined as the osmotic entry of solvent into a cell or a system when it is placed in a pure water or hypotonic solution.

For example, dry raisins (high solute and low solvent) placed in the water, it swells up due to turgidity.

ii. ***Exosmosis***: Exosmosis is defined as the osmotic withdrawal of water from a cell or system when it is placed in a hypertonic solution. Exosmosis in a plant cell leads to **plasmolysis**.

2. Plasmolysis (*Plasma* = cytoplasm; *lysis* = breakdown)

When a plant cell is kept in a hypertonic solution, water leaves the cell due to **exosmosis**. As a result of water loss, protoplasm shrinks and the cell membrane is pulled away from the cell wall and finally, the cell becomes **flaccid**. This process is named as **plasmolysis**.

Wilting of plants noticed under the condition of water scarcity is an indication of plasmolysis. Three types of plasmolysis occur in plants: i) ***Incipient plasmolysis ii) Evident plasmolysis*** **and** ***iii) Final plasmolysis***. Differences among them are given in table 11.2.

Significance

Plasmolysis is exhibited only by living cells and so it is used to test whether the cell is living or dead.

3. Deplasmolysis

The effect of plasmolysis can be reversed, by transferring them back into water or **hypotonic solution**. Due to endosmosis, the cell becomes turgid again. It regains its original shape and size. This phenomenon of the revival of the plasmolysed cell is called **deplasmolysis**. Example: Immersion of dry raisin in water.

Potato Osmoscope

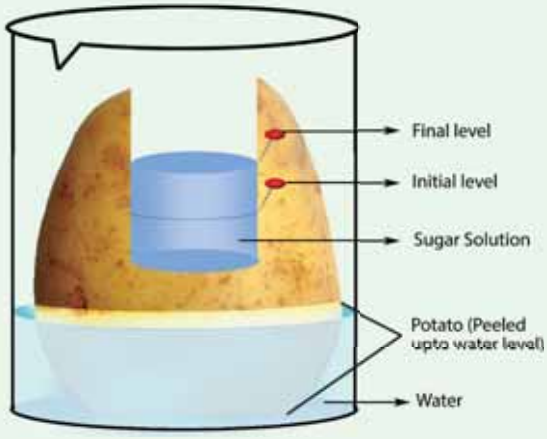


Figure 11.8: Demonstration of Endosmosis by Potato Osmoscope

i. Take a peeled potato tuber and make a cavity inside with the help of a knife.
ii. Fill the cavity with concentrated sugar solution and mark the initial level.
iii. Place this setup in a beaker of pure water.
iv. After 10 minutes observe the sugar solution level and record your findings (Figure 11.8).
v. With the help of your teacher discuss the results.

Instead of potato use beetroot or bottle-guard and repeat the above experiment. Compare and discuss the results.

4. Reverse Osmosis

Reverse Osmosis follows the same principles of osmosis, but in the reverse direction. In this process movement of water is reversed by applying pressure to force the water against a concentration gradient of the solution. In regular osmosis, the water molecules move from the higher concentration (pure water = hypotonic) to lower concentration (salt water = hypertonic). But in reverse osmosis, the water molecules move from the lower concentration (salt water = hypertonic) to higher concentration (pure water = hypotonic) through a selectively permeable membrane (Figure 11.9).

Uses: Reverse osmosis is used for purification of drinking water and desalination of seawater.

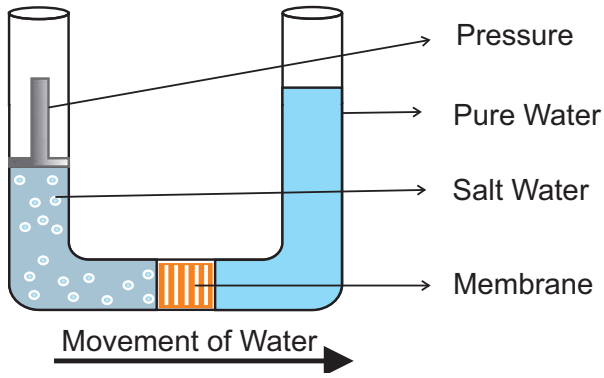
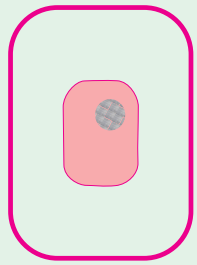


Figure 11.9: Reverse Osmosis

Check your grasp!

If a cell in the cortex with DPD of 5atm is surrounded by hypodermal cells with DPD of 2atm, what will be direction of movement of water?

Solution: Water will move from low DPD to high DPD (hypodermis 2 atm to cortex 5 atm).

Table 11.2: Difference between plasmolysis types.		
Incipient plasmolysis	**Evident plasmolysis**	**Final plasmolysis**
No morphological symptoms appear in plants.	Wilting of leaves appear.	Severe wilting and drooping of leaves appear.
The plasma membrane separates only at the corner from the cell wall of cells.	Plasma membrane completely detaches from the cell wall.	Plasma membrane completely detaches from cell wall with maximum shrinkage of volume.
It is reversible.	It is reversible.	It is irreversible.
		

11.4 Absorption of Water

Terrestrial plants have to absorb water from the soil to maintain turgidity, metabolic activities and growth. Absorption of water from soil takes place in two steps:

1. From soil to root hairs – either actively or passively.

2. From root hairs further transport in the lateral direction to reach xylem, the superhighway of water transport.

11.4.1 Water Absorbing Organs

Usually, absorption of water occurs in plants through young roots. The zone of rapid water absorption is **root hairs**. They are delicate structures which get continuously replaced by new ones. Root hairs are unicellular extensions of epidermal cells without cuticle. Root hairs are extremely thin and numerous and they provide a large surface area for absorption (Figure 11.10).

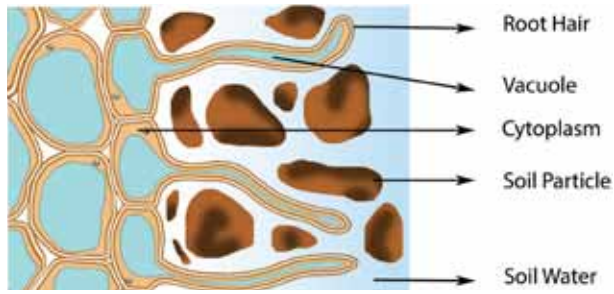


Figure 11.10: Structure of Root Hair

11.4.2 Path of Water Across Root Cells

Water is first absorbed by root hair and other epidermal cells through imbibition from soil and moves radially and centripetally across the cortex, endodermis, pericycle and finally reaches xylem elements osmotically.

There are three possible routes of water (Figure 11.11). They are i) **Apoplast** ii) **Symplast** iii) **Transmembrane route**.

1. Apoplast

The **apoplast** (Greek: ***apo*** = away; ***plast*** = cell) consists of everything external

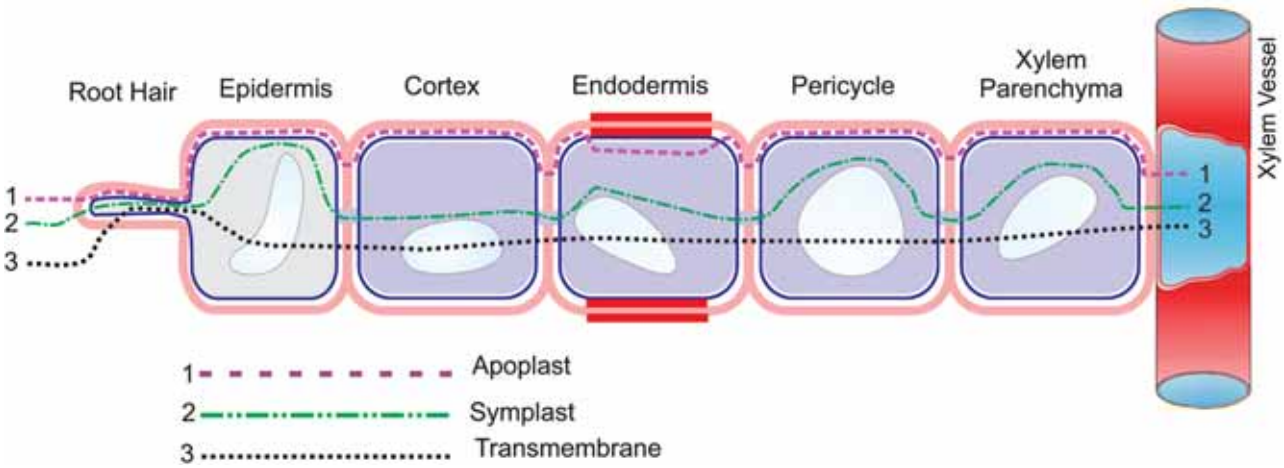


Figure 11.11: Path of water across root cells

to the plasma membrane of the living cell. The apoplast includes cell walls, extra cellular spaces and the interior of dead cells such as vessel elements and tracheids. In the apoplast pathway, water moves exclusively through the cell wall or the non-living part of the plant without crossing any membrane. The apoplast is a continuous system.

2. Symplast

The **symplast** (Greek: ***sym*** = within; ***plast*** = cell) consists of the entire mass of cytosol of all the living cells in a plant, as well as the **plasmodesmata**, the cytoplasmic channel that interconnects them.

In the symplastic route, water has to cross plasma membrane to enter the cytoplasm of outer root cell; then it will move within adjoining cytoplasm through plasmodesmata around the vacuoles without the necessity to cross more membrane, till it reaches xylem.

3. Transmembrane route

In transmembrane pathway water sequentially enters a cell on one side and exits from the cell on the other side. In this pathway, water crosses at least two membranes for each cell. Transport across the **tonoplast** is also involved.

11.4.3 Mechanism of Water Absorption

Kramer (1949) recognized two distinct mechanisms which independently operate in the absorption of water in plants. They are, i) active absorption ii) passive absorption.

1. Active Absorption

The mechanism of water absorption due to forces generated in the root itself is called **active absorption**. Active absorption may be osmotic or non-osmotic.

i. Osmotic active absorption

The theory of osmotic active absorption was postulated by **Atkins** (1916) and **Preistley** (1923). According to this theory, the first step in the absorption is soil water imbibed by cell wall of the root hair followed by osmosis. The soil water is hypotonic and cell sap is hypertonic. Therefore, soil water diffuses into root hair along the concentration gradient (endosmosis). When the root hair becomes fully turgid, it becomes hypotonic and water moves osmotically to the outer most cortical cell. In the same way, water enters into inner cortex, endodermis, pericycle and finally reaches protoxylem. As the

sap reaches the protoxylem a pressure is developed known as **root pressure**. This theory involves the symplastic movement of water.

Objections to osmotic theory: 1.The cell sap concentration in xylem is not always high. 2. Root pressure is not universal in all plants especially in trees.

ii. Non-Osmotic active absorption

Bennet-Clark (1936), **Thimann** (1951) and **Kramer** (1959) observed absorption of water even if the concentration of cell sap in the root hair is lower than that of the soil water. Such a movement requires an expenditure of energy released by respiration (ATP). Thus, there is a link between water absorption and respiration. It is evident from the fact that when respiratory inhibitors like KCN, Chloroform are applied there is a decrease in the rate of respiration and also the rate of absorption of water.

2. Passive Absorption

In passive absorption, roots do not play any role in the absorption of water and is regulated by transpiration only. Due to transpiration, water is lost from leaf cells along with a drop in turgor pressure. It increases DPD in leaf cells and leads to withdrawal of water from adjacent xylem cells. In xylem, a tension is developed and is transmitted downward up to root resulting in the absorption of water from the soil.

In passive absorption (Table 11.3), the path of water may be symplastic or apoplastic. It accounts for about 98% of the total water uptake by plants.

Concept Map - Movement of water in an osmotic system based on various parameters

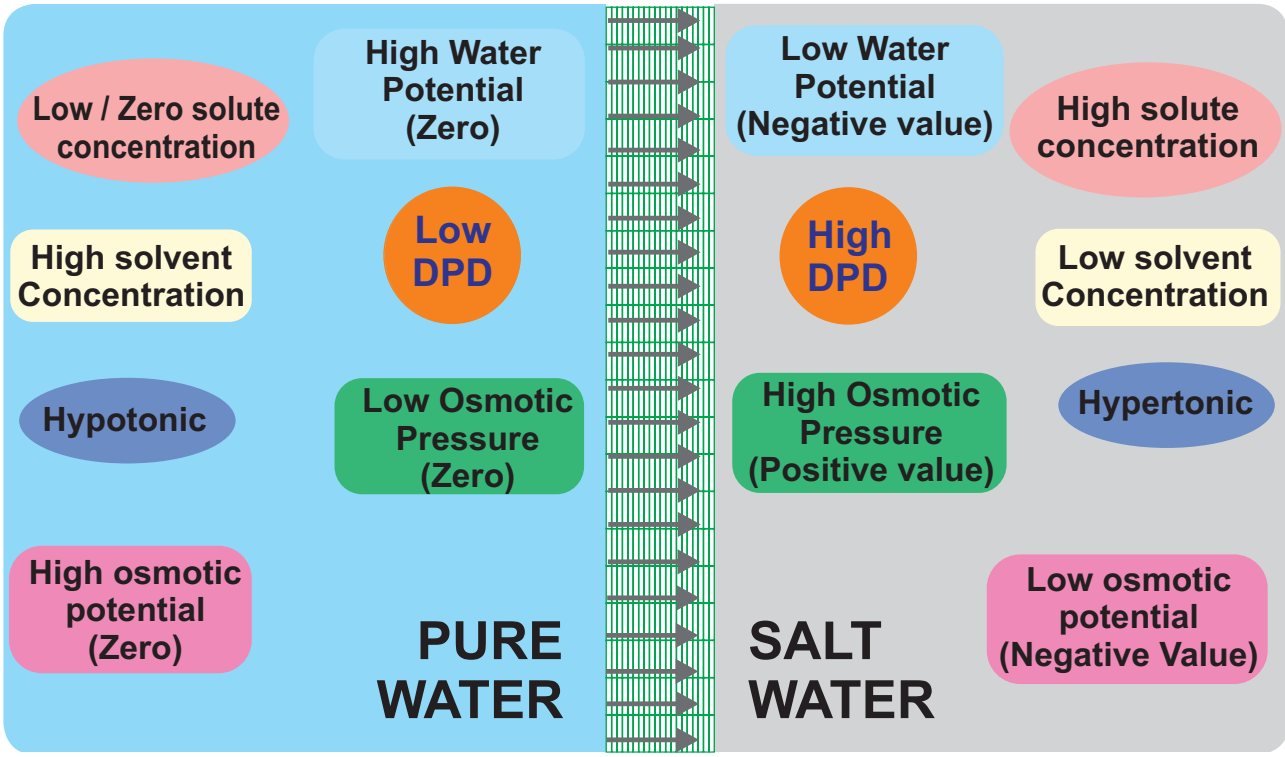


Table: 11.3 Differences between Active Absorption and Passive Absorption

Active absorption	Passive absorption
Active absorption takes place by the activity of root and root hairs	The pressure for absorption is not developed in roots and hence roots play passive role
Transpiration has no effect on active absorption	Absorption regulated by transpiration
The root hairs have high DPD as compared to soil solution and therefore water is taken by tension	The absorption occurs due to tension created in xylem sap by transpiration pull, thus water is sucked in by the tension
Respiratory energy needed	Respiratory energy not required
It involves symplastic movement of water	Both symplast and apoplast movement of water involved

11.5 Ascent of Sap

In the last chapter, we studied about water absorption from roots to xylem in a lateral direction and here we will learn about the mechanism of distribution of water inside the plant. Like tributaries join together to form a river, millions of root hairs conduct a small amount of water and confluence in xylem, the superhighway of water conduction. Xylem handles a large amount of water to conduct to many parts in an upward direction.

The water within the xylem along with dissolved minerals from roots is called **sap** and its upward transport is called **ascent of sap.**

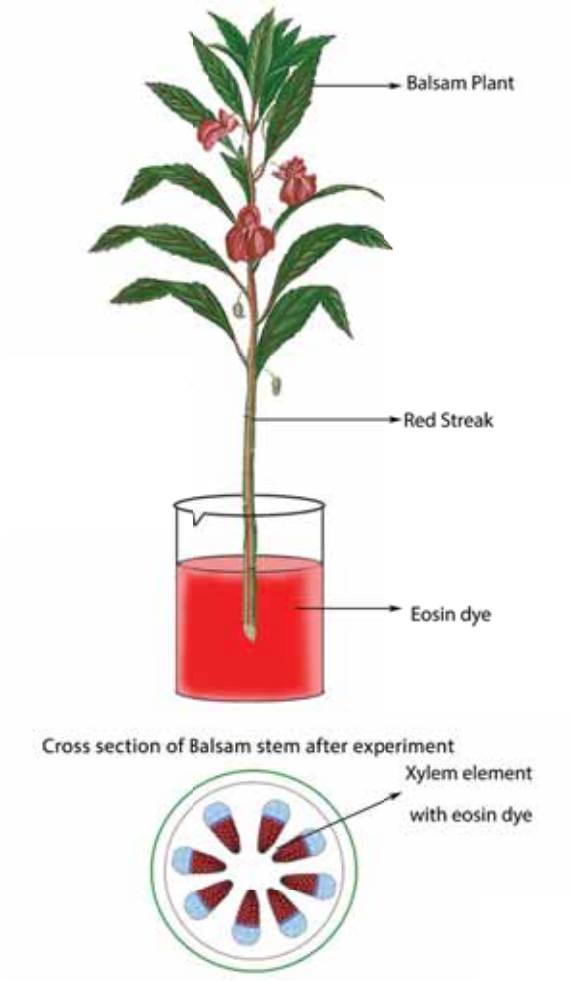


Figure 11.12: Balsam plant and eosin dye experiment

11.5.1 The Path of Ascent of Sap

There is no doubt; water travels up along the vascular tissue. But vascular tissue has two components namely Xylem and Phloem. Of these two, which is responsible for the ascent of sap? The following experiment will prove that xylem is the only element through which water moves up.

Cut a branch of balsam plant and place it in a beaker containing **eosin** (red colour dye) water. After some time, a red streak appears on the stem indicating the ascent of water. Remove the plant from water and cut a transverse section of the stem and observe it under the microscope. Only xylem element is coloured red, which indicates the path

of water is xylem. Phloem is not colored indicating that it has no role in the ascent of sap (Figure 11.12).

Mechanism of Ascent of Sap

In ascent of sap, the biggest challenge is the force required to lift the water to the top of the tallest trees. A number of theories have been put forward to explain the mechanism of the ascent of sap. They are, A. Vital force theories, B. Root pressure theory, and C. Physical force theory.

11.5.2 Vital Force Theories

According to vital force theories, living cells are mandatory for the ascent of sap. Based on this the following two theories derived:

1. **Relay pump theory of Godlewski (1884)**

Periodic changes in osmotic pressure of living cells of the xylem parenchyma and medullary ray act as a pump for the movement of water.

2. **Pulsation theory of J.C.Bose (1923)**

Bose invented an instrument called **Crescograph**, which consists of an electric probe connected to a galvanometer (Figure 11.13). When a probe is inserted into the inner cortex of the stem, the galvanometer showed high electrical activity. Bose believed a rhythmic pulsating movement of inner cortex like a pump (similar to the beating of the heart) is responsible for the ascent of sap. He concluded that cells associated with xylem exhibit pumping action and pumps the sap laterally into xylem cells.

Figure 11.13: J.C. Bose

Objections to vital force theories

i. **Strasburger** (1889) and **Overton** (1911) experimentally proved that living cells are not mandatory for the ascent of sap. For this, he selected an old oak tree trunk which when immersed in **picric acid** and subjected to excessive heat killed all the living cells of the trunk. The trunk when dipped in water, the ascent of sap took place.

ii. Pumping action of living cells should be in between two xylem elements (vertically) and not on lateral sides.

11.5.3 Root Pressure Theory

If a plant which is watered well is cut a few inches above the ground level, sap exudes out with some force. This is called **sap exudation** or **bleeding**. **Stephen Hales**, father of plant physiology observed this phenomenon and coined the term '**Root Pressure'**. **Stoking** (1956) defined root pressure as "*a pressure developing in the tracheary elements of the xylem as a result of metabolic activities of the root*". But the following objections have been raised against root pressure theory:

i. Root pressure is totally absent in gymnosperms, which includes some of the tallest plants.

ii. There is no relationship between the ascent of sap and root pressure. For

example, in summer, the rate of the ascent of sap is more due to transpiration in spite of the fact that root pressure is very low. On the other hand, in winter when the rate of ascent of sap is low, a high root pressure is found.

iii. Ascent of sap continues even in the absence of roots

iv. The magnitude of root pressure is about 2atm, which can raise the water level up to few feet only, whereas the tallest trees are more than 100m high.

11.5.4 Physical Force Theory

Physical force theories suggest that ascent of sap takes place through the dead xylem vessel and the mechanism is entirely physical and living cells are not involved.

1. Capillary theory

Boehm (1809) suggested that the xylem vessels work like a capillary tube. This capillarity of the vessels under normal atmospheric pressure is responsible for the ascent of sap. This theory was rejected because the magnitude of capillary force can raise water level only up to a certain height. Further, the xylem vessels are broader than the tracheid which actually conducts more water and against the capillary theory.

2. Imbibition theory

This theory was first proposed by **Unger** (1876) and supported by **Sachs** (1878). This theory illustrates, that water is imbibed through the cell wall materials and not by the lumen. This theory was rejected based on the ringing experiment, which proved that water moves through the lumen of the cell and not by a cell wall.

3. Cohesion-tension or Cohesion and transpiration pull theory

Cohesion-tension theory was originally proposed by **Dixon** and **Jolly** (1894) and again put forward by **Dixon** (1914, 1924). This theory is based on the following features:

i. **Strong cohesive force or tensile strength of water**

Water molecules have the strong mutual force of attraction called **cohesive force** due to which they cannot be easily separated from one another. Further, the attraction between a water molecule and the wall of the xylem element is called **adhesion**. These cohesive and adhesive force works together to form an unbroken continuous water column in the xylem. The magnitude of the cohesive force is much high (350 atm) and is more than enough to ascent sap in the tallest trees.

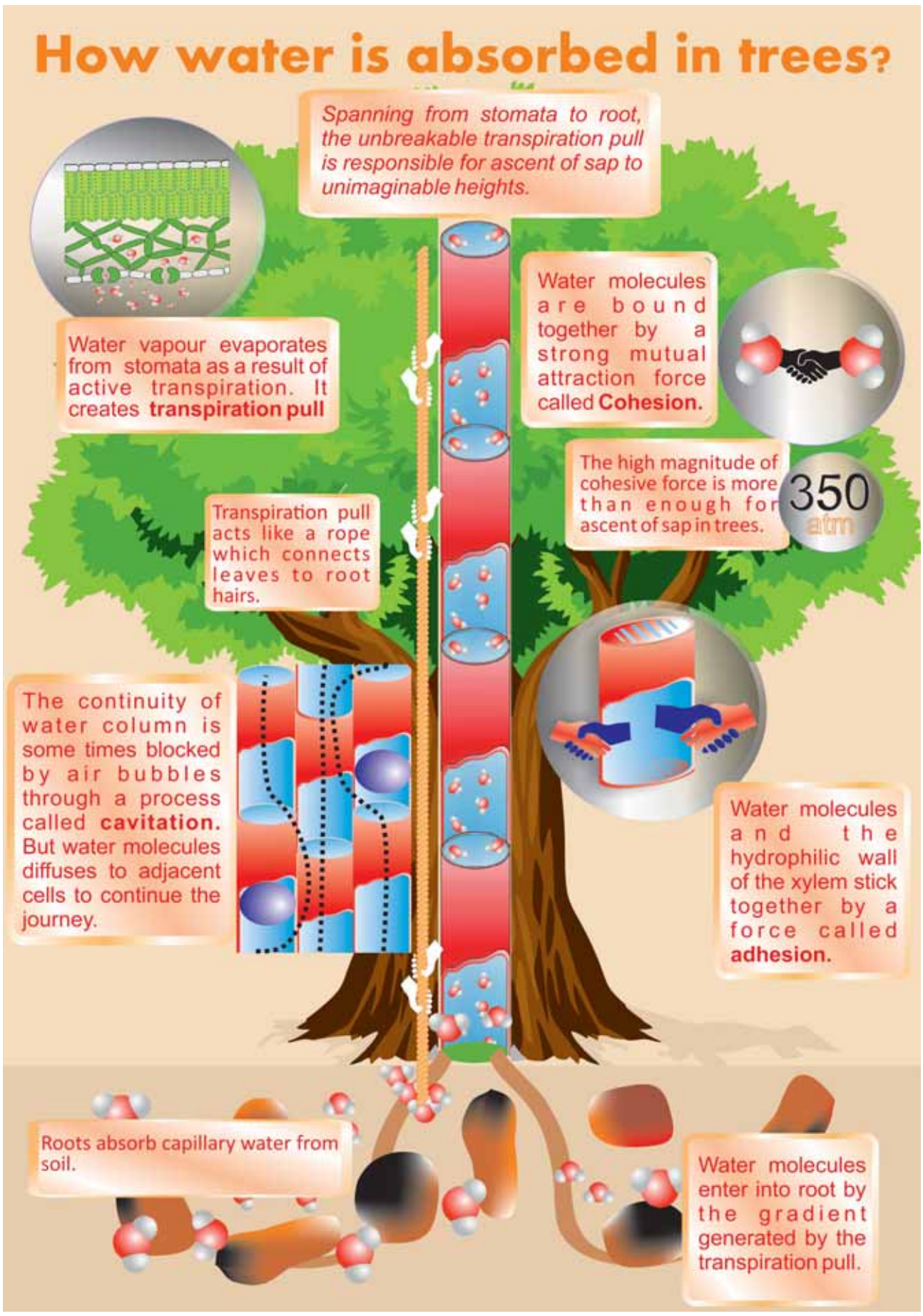
ii. **Continuity of the water column in the plant**

An important factor which can break the water column is the introduction of air bubbles in the xylem. Gas bubbles expanding and displacing water within the xylem element is called **cavitation** or **embolism**. However, the overall continuity of the water column remains undisturbed since water diffuses into the adjacent xylem elements for continuing ascent of sap.

iii. **Transpiration pull or Tension in the unbroken water column**

The unbroken water column from leaf to root is just like a rope. If the rope is pulled from the top, the entire rope will move upward. In plants, such a pull is generated by the process of transpiration which is known as **transpiration pull.**

How water is absorbed in trees?



Water vapour evaporates from mesophyll cells to the intercellular spaces near stomata as a result of active transpiration. The water vapours are then transpired through the stomatal pores. Loss of water from mesophyll cells causes a decrease in water potential. So, water moves as a pull from cell to cell along the water potential gradient. This tension, generated at the top (leaf) of the unbroken water column, is transmitted downwards from petiole, stem and finally reaches the roots. The cohesion theory is the most accepted among the plant physiologists today.

11.6 Transpiration

Water absorbed by roots ultimately reaches the leaf and gets released into the atmosphere in the form of vapour. Only a small fraction of water (less than 5%) is utilized in plant development and metabolic process.

The loss of excess of water in the form of vapour from various aerial parts of the plant is called **transpiration**. Transpiration is a kind of evaporation but differs by the involvement of biological system. The amount of water transpired is astounding (Table 11.4). The water may move through the xylem at a rate as fast as 75cm /min.

Table: 11.4 Rate of Transpiration in some plants

Plant	Transpiration per day
Corn plant	2 Litres
Sunflower	5 Litres
Maple tree	200 Litres
Date palm	450 Litres

Activity

Select a leafy twig of fully grown plant in your school campus. Cover the twig with a transparent polythene bag and tie the mouth of the bag at the base of the twig. Observe the changes after two hours and discuss with your teacher

11.6.1 Types of Transpiration

Transpiration is of following three types:

1. Stomatal transpiration

Stomata are microscopic structures present in high number on the lower epidermis of leaves. This is the most dominant form of transpiration and being responsible for most of the water loss (90 - 95%) in plants.

2. Lenticular transpiration

In stems of woody plants and trees, the epidermis is replaced by periderm because of secondary growth. In order to provide gaseous exchange between the living cells and outer atmosphere, some pores which looks like lens-shaped raised spots are present on the surface of the stem called **Lenticels**. The loss of water from lenticels is very insignificant as it amounts to only 0.1% of the total.

3. Cuticular transpiration

The cuticle is a waxy or resinous layer of **cutin**, a fatty substance covering the epidermis of leaves and other plant parts. Loss of water through cuticle is relatively small and it is only about 5 to 10 % of the total transpiration. The thickness of cuticle increases in xerophytes and transpiration is very much reduced or totally absent.

11.6.2 Structure of Stomata

The epidermis of leaves and green stems possess many small pores called **stomata**. The length and breadth of stomata is about 10-40µ and 3-10µ respectively. Mature leaves contain between 50 and 500 stomata per mm^2. Stomata are made up of two **guard cells**, special semi-lunar or kidney-shaped living epidermal cells in the epidermis. Guard cells are attached to surrounding epidermal cells known as **subsidiary cell**s or **accessory cells**. The guard cells are joined together at each end but they are free to separate to form a pore between them. The inner wall of the guard cell is thicker than the outer wall (Figure 11.14). The stoma opens to the interior into a cavity called **sub-stomatal cavity** which remains connected with the intercellular spaces.

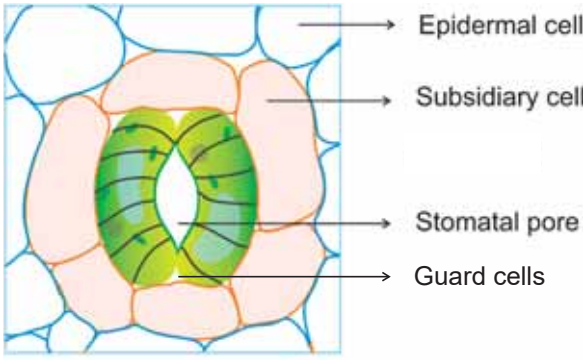


Figure 11.14: Structure of Stomata

11.6.3 Mechanism of Stomatal Movement

Stomatal movements are regulated by the change of turgor pressure in guard cells. When water enters the guard cell, it swells and its unevenly thickened walls stretch up resulting in the opening of stomata. This is due to concave non-elastic nature of inner wall pulled away from each other and stretching of the convex elastic natured outer wall of guard cell.

Different theories have been proposed regarding opening and closing of stomata. The important theories of stomatal movement are as follows,

1. *Theory of Photosynthesis in guard cells*
2. *Starch – Sugar interconversion theory*
3. *Active potassium transport ion concept*

1. Theory of Photosynthesis in guard cells

Von Mohl (1856) observed that stomata open in light and close in the night. According to him, chloroplasts present in the guard cells photosynthesize in the presence of light resulting in the production of carbohydrate (Sugar) which increases osmotic pressure in guard cells. It leads to the entry of water from other cell and stomatal aperture opens. The above process *vice versa* in night leads to closure of stomata.

Demerits

1. Chloroplast of guard cells is poorly developed and incapable of performing photosynthesis.
2. The guard cells already possess much amount of stored sugars.

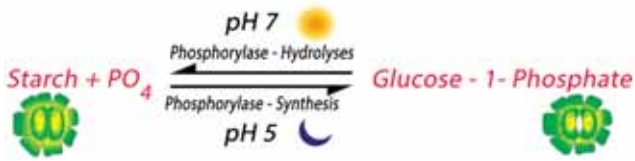
2. Starch – Sugar Interconversion theory

i. According to **Lloyd** (1908), turgidity of guard cell depends on interconversion, of starch and sugar. It was supported by **Loftfield** (1921) as he found guard cells containing sugar during the daytime when they are open and starch during the night when they are closed.

ii. **Sayre** (1920) observed that the opening and closing of stomata depends upon change in pH of guard cells. According to him stomata open at high pH during day time and become closed at low pH at night. Utilization of CO_2

by photosynthesis during light period causes an increase in pH resulting in the conversion of starch to sugar. Sugar increase in cell favours endosmosis and increases the turgor pressure which leads to opening of stomata. Likewise, accumulation of CO_2 in cells during night decrease the pH level resulting in the conversion of sugar to starch. Starch decreases the turgor pressure of guard cell and stomata close.

iii. The discovery of enzyme **phosphorylase** in guard cells by **Hanes** (1940) greatly supports the starch-sugar interconversion theory. The enzyme *phosphorylase* hydrolyses starch into sugar and high pH followed by endosmosis and the opening of stomata during light. The *vice versa* takes place during the night.



iv. **Steward** (1964) proposed a slightly modified scheme of starch-sugar interconversion theory. According to him, Glucose-1-phosphate is osmotically inactive. Removal of phosphate from Glucose-1-phosphate converts to Glucose which is osmotically active and increases the concentration of guard cell leading to opening of stomata (Figure 11.15).

Objections to Starch-sugar interconversion theory

i. In monocots, guard cell does not have starch.

ii. There is no evidence to show the presence of sugar at a time when starch disappears and stomata open.

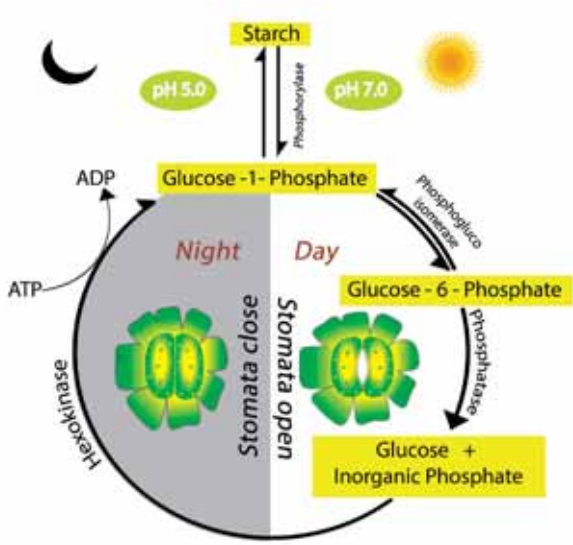


Figure 11.15: Steward Scheme

iii. It fails to explain the drastic change in pH from 5 to 7 by change of CO_2.

3. Theory of K^+ transport

This theory was proposed by **Levit** (1974) and elaborated by **Raschke** (1975). According to this theory, the following steps are involved in the stomatal opening:

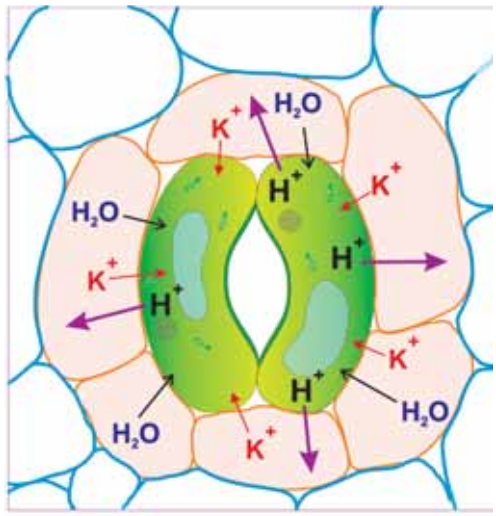


Figure 11.16: Theory of K^+ transport

Opening of stomata

In light

i. In guard cell, starch is converted into organic acid (malic acid).

ii. Malic acid in guard cell dissociates to malate anion and proton (H^+).

iii. Protons are transported through the membrane into nearby subsidiary cells with the exchange of K^+ (Potassium ions) from subsidiary cells to guard cells. This process involves an electrical gradient and is called **ion exchange**.

iv. This ion exchange is an active process and consumes ATP for energy.

v. Increased K^+ ions in the guard cell are balanced by Cl^- ions. Increase in solute concentration decreases the water potential in the guard cell.

vi. Guard cell becomes hypertonic and favours the entry of water from surrounding cells.

vii. Increased turgor pressure due to the entry of water opens the stomatal pore (Figure 11.16).

In Dark

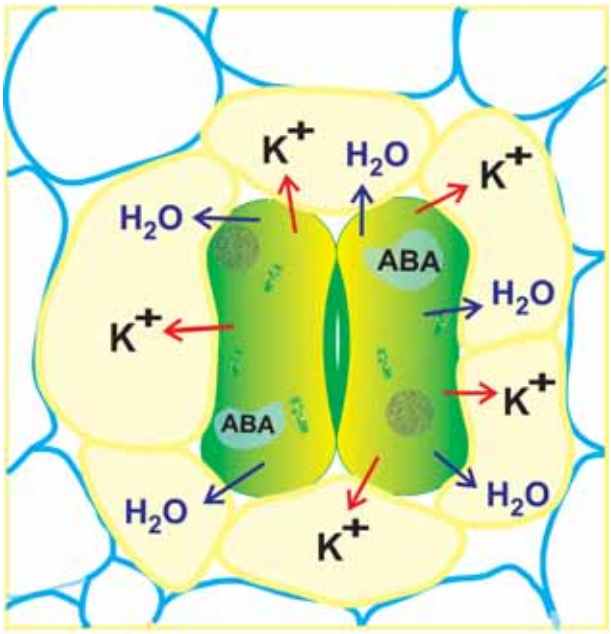


Figure 11.17: Theory of K^+ transport Closing of stomata

i. In dark photosynthesis stops and respiration continues with accumulation of CO_2 in the sub-stomatal cavity.

ii. Accumulation of CO_2 in cell lowers the pH level.

iii. Low pH and a shortage of water in the guard cell activate the stress hormone **Abscisic acid** (ABA).

iv. ABA stops further entry of K^+ ions and also induce K^+ ions to leak out to subsidiary cells from guard cell.

v. Loss of water from guard cell reduces turgor pressure and causes closure of stomata (Figure 11.17).

11.6.4 Factors Affecting Rate of Transpiration

The factors affecting the rate of transpiration can be categorized into two groups. They are 1. External or Environmental factors and 2. Internal or plant factors.

1. External or Environmental factors

i. Atmospheric humidity: The rate of transpiration is greatly reduced when the atmosphere is very humid. As the air becomes dry, the rate of transpiration is also increased proportionately.

ii. Temperature: With the increase in atmospheric temperature, the rate of transpiration also increases. However, at very high-temperatures stomata closes because of flaccidity and transpiration stop.

iii. Light: Light intensity increases the temperature. As in temperature, transpiration is increased in high light intensity and is decreased in low light intensity. Light also increases the permeability of the cell membrane, making it easy for water molecules to move out of the cell.

iv. Wind velocity: In still air, the surface above the stomata get saturated with water vapours and there is no need for more water vapour to come out. If the wind is breezy, water vapour gets carried away near leaf surface and DPD is created to draw more vapour from the leaf cells enhancing transpiration. However, high wind velocity creates an extreme increase in water loss and leads to a reduced rate of transpiration and stomata remain closed.

Activity

What will happen if an indoor plant is placed under fan and AC?

v. Atmospheric pressure: In low atmospheric pressure, the rate of transpiration increases. Hills favour high transpiration rate due to low atmospheric pressure. However, it is neutralized by low temperature prevailing in the hills.

vi. Water: Adequate amount of water in the soil is a pre-requisite for optimum plant growth. Excessive loss of water through transpiration leads to wilting. In general, there are three types of wilting as follows,

a. Incipient wilting: Water content of plant cell decreases but the symptoms are not visible.

b. Temporary wilting: On hot summer days, the freshness of herbaceous plants reduces turgor pressure at the day time and regains it at night.

c. Permanent wilting: The absorption of water virtually ceases because the plant cell does not get water from any source and the plant cell passes into a state of permanent wilting.

2. Internal factors

i. Leaf area: If the leaf area is more, transpiration is faster and so xerophytes reduce their leaf size.

ii. Leaf structure: Some anatomical features of leaves like sunken stomata, the presence of hairs, cuticle, the presence of hydrophilic substances like gum, mucilage help to reduce the rate of transpiration. In xerophytes the structural modifications are remarkable. To avoid transpiration, as in ***Opuntia*** the stem is flattened to look like leaves called **Phylloclade**. **Cladode** or **cladophyll** in ***Asparagus*** is a modified stem capable of limited growth looking like leaves. In some plants, the petioles are flattened and widened, to become **phyllodes** example ***Acacia melanoxylon.***

11.6.5 Plant Antitranspirants

The term **antitranspirant** is used to designate any material applied to plants for the purpose of retarding transpiration. An ideal antitranspirant checks the transpiration process without disturbing the process of gaseous exchange. Plant antitranspirants are two types:

1. To act as a physical barrier above the stomata

Colourless plastics, Silicone oil and **low viscosity waxes** are sprayed on leaves forming a thin film to act as a physical barrier (for transpiration) for water but permeable to CO_2 and O_2. The success rate of a physical barrier is limited.

2. Induction of Stomata closure

Carbon-di-oxide induces stomatal closure and acts as a natural antitranspirant. Further, the advantage of using CO_2 as an antitranspirant is its inhibition of photorespiration. **Phenyl Mercuric Acetate** (PMA), when applied

as a foliar spray to plants, induces partial stomatal closure for two weeks or more without any toxic effect. Use of **abscisic acid** highly induces the closing of stomata. **Dodecenyl succinic acid** also effects on stomatal closure.

Uses:

- Antitranspirants reduce the enormous loss of water by transpiration in crop plants.
- Useful for seedling transplantations in nurseries.

11.6.6 Guttation

During high humidity in the atmosphere, the rate of transpiration is much reduced. When plants absorb water in such a condition root pressure is developed due to excess water within the plant. Thus excess water exudates as liquid from the edges of the leaves and is called **guttation**. Example: Grasses, tomato, potato, brinjal and *Alocasia*. Guttation occurs through stomata like pores called **hydathodes** generally present in plants that grow in moist and shady places. Pores are present over a mass of loosely arranged cells with large intercellular spaces called **epithem** (Figure 11.18). This mass of tissue lies near vein endings (xylem and Phloem). The liquid coming out of hydathode is not pure water but a solution containing a number of dissolved substances.

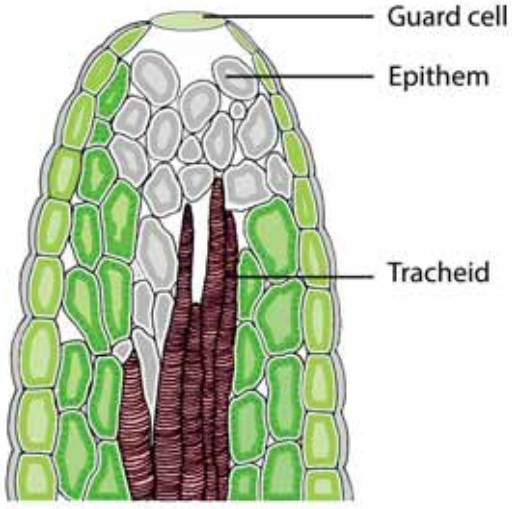


Figure 11.18: Structure of Hydathode

11.6.7 Measurement of Transpiration

1. Ganongs potometer

Ganongs potometer is used to measure the rate of transpiration indirectly. In this, the amount of water absorbed is measured and assumed that this amount is equal to the amount of water transpired.

Apparatus consists of a horizontal graduated tube which is bent in opposite directions at the ends. One bent end is wide and the other is narrow. A reservoir is fixed to the horizontal tube near the wider end. The reservoir has a stopcock to regulate water flow. The apparatus is filled with water from reservoir. A twig or a small plant is fixed to the wider arm through a split cock. The other bent end of the horizontal tube is dipped into a beaker containing coloured water. An air bubble is introduced into the graduated tube at the narrow end (Figure 11.19). keep this apparatus in bright sunlight and observe.As transpiration takes place, the air bubble will move towards the twig. The loss is compensated by water

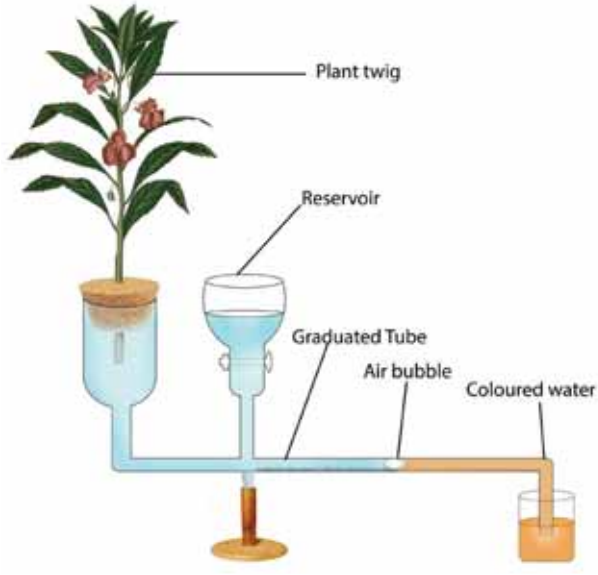


Figure 11.19: Ganongs Potometer

absorption through the xylem portion of the twig. Thus, the rate of water absorption is equal to the rate of transpiration.

2. Cobalt chloride ($CoCl_2$) paper method

Select a healthy dorsiventral leaf and clean its upper and lower surface with dry cotton. Now place a dry Cobalt chloride (**$CoCl_2$**) strips on both surface and immediately cover the paper with glass slides and immobilize them. It will be observed after some time that the $CoCl_2$ strip of lower epidermis turns pink. This indicates that $CoCl_2$ becomes hydrated ($CoCl_2 \cdot 2H_2O$ or $CoCl_2 \cdot 4H_2O$) due to water vapours coming out through stomata. The rate of transpiration is more on the lower surface than in the upper surface of the dorsiventral leaf.

11.6.8 Significance of transpiration

Transpiration leads to loss of water, as stated earlier in this lesson 95% of absorbed water is lost in transpiration. It seems to be an evil process to plants. However, number of process like absorption of water, ascent of sap and mineral absorption directly relay on the transpiration. Moreover plants withstand against scorching sunlight due to transpiration. Hence the transpiration is a "**necessary evil**" as stated by **Curtis**.

11.7 Translocation of Organic Solutes

Leaves synthesize food material through photosynthesis and store in the form of starch grains. When required the starch is converted into simple sugars. They must be transported to various parts of the plant system for further utilization. However, the site of food production (leaves) and site of utilization are separated far apart. Hence, the organic food has to be transported to these areas.

The phenomenon of food transportation from the site of synthesis to the site of utilization is known as **translocation of organic solutes**. The term **solute** denotes food material that moves in a solution.

11.7.1 Path of Translocation

It has now been well established that phloem is the path of translocation of solutes. Ringing or girdling experiment will clearly demonstrate the translocation of solute by phloem.

11.7.2 Ringing or girdling experiment

The experiment involves the removal of all the tissue outside to vascular cambium (bark, cortex, and phloem) in woody stems except xylem. Xylem is the only remaining tissue in the girdled area which connects upper and lower part of the plant. This setup is placed in a beaker of water. After some time, it is observed that a swelling on the upper part of the ring appears as a result of the accumulation of food material (Figure 11.20). If the experiment continues within days, the roots die first. It is because, the supply of food material to the root is cut down by the removal of phloem. The roots cannot synthesize their food and so they die first. As the roots gradually die the upper part (stem), which depends on root for the ascent of sap, will ultimately die.

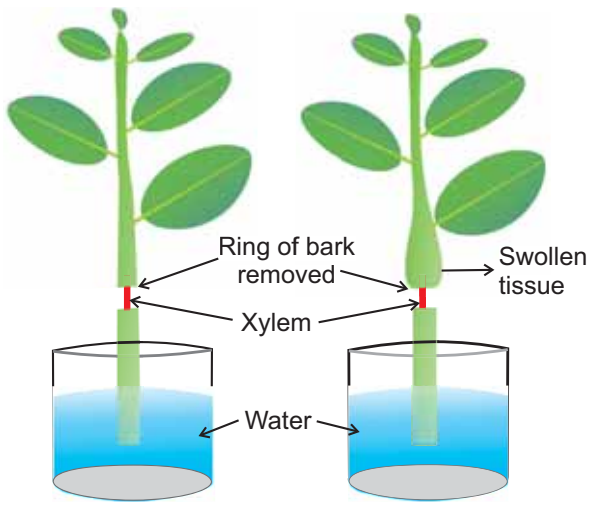


Figure 11.20: Ringing experiment

11.7.3 Direction of Translocation

Phloem translocates the products of photosynthesis from leaves to the area of growth and storage, in the following directions,

Downward direction: From leaves to stem and roots.

Upward direction: From leaves to developing buds, flowers, fruits for consumption and storage. Germination of seeds is also a good example of upward translocation.

Radial direction: From cells of pith to cortex and epidermis, the food materials are radially translocated.

11.7.4 Source and Sink

Source is defined as any organ in plants which are capable of exporting food materials to the areas of metabolism or to the areas of storage. Examples: Mature leaves, germinating seeds.

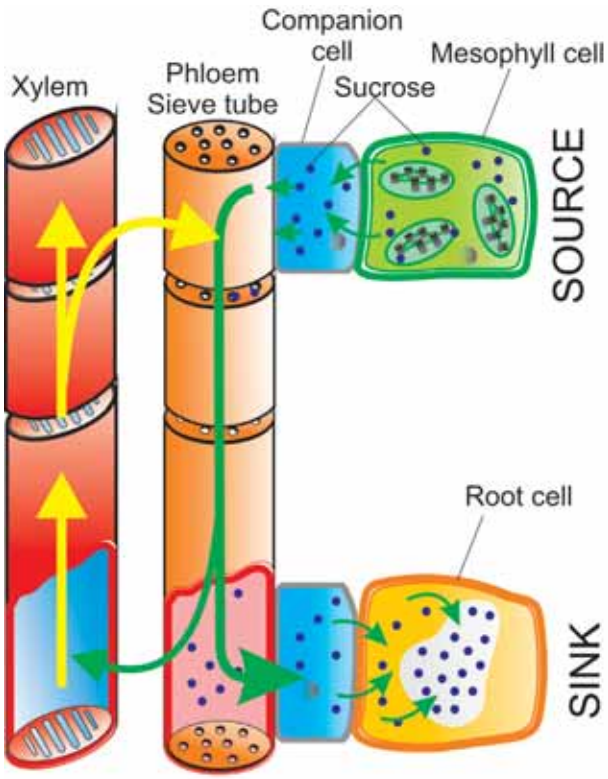


Figure 11.21: Source and Sink

Sink is defined as any organ in plants which receives food from source.Example: Roots, tubers, developing fruits and immature leaves (Figure 11.21).

11.7.5 Phloem Loading

The movement of ***photosynthates*** (products of photosynthesis) from mesophyll cells to phloem sieve elements of mature leaves is known as **phloem loading**. It consists of three steps.

Why plants transport sugars as sucrose and not as starch or glucose or fructose?

Glucose and Fructose are simple monosaccharides, whereas, Sucrose is a disaccharide composed of glucose and fructose. Starch is a polysaccharide of glucose. Sucrose and starch are more efficient in energy storage when compared to glucose and fructose, but starch is insoluble in water. So it cannot be transported via phloem and the next choice is sucrose, being water soluble and energy efficient, sucrose is chosen as the carrier of energy from leaves to different parts of the plant. Sucrose has low viscosity even at high concentrations and has no reducing ends which makes it inert than glucose or fructose.During photosynthesis, starch is synthesized and stored in the chloroplast stroma and sucrose is synthesized in the leaf cytosol from which it diffuses to the rest of the plant.

i. Sieve tube conducts **sucrose** only. But the *photosynthate* in chloroplast mostly in the form of starch or trios-phosphate which has to be transported to the cytoplasm where it will be converted into sucrose for further translocation.

ii. Sucrose moves from mesophyll to nearby sieve elements by short distance transport.

iii. From sieve tube to sink by long-distance transport.

11.7.6 Phloem Unloading

From sieve elements sucrose is translocated into sink organs such as roots, tubers, flowers and fruits and this process is termed as **phloem unloading**. It consists of three steps:

1. ***Sieve element unloading***: Sucrose leave from sieve elements.
2. ***Short distance transport***: Movement of sucrose to sink cells.
3. ***Storage and metabolism***: The final step when sugars are stored or metabolized in sink cells.

11.7.7 Mechanism of Translocation

Several hypotheses have been proposed to explain the mechanism of translocation. Some of them are given below:

1. Diffusion hypothesis

As in diffusion process, this theory states the translocation of food from higher concentration (from the place of synthesis) to lower concentration (to the place of utilization) by the simple physical process. However, the theory was rejected because the speed of translocation is much higher than simple diffusion and translocation is a biological process which any poison can halt.

2. Activated diffusion theory

This theory was first proposed by **Mason** and **Maskell** (1936). According to this theory, the diffusion in sieve tube is accelerated either by activating the diffusing molecules or by reducing the protoplasmic resistance to their diffusion.

3. Electro-Osmotic theory

The theory of electro osmosis was proposed by **Fenson** (1957) and **Spanner** (1958). According to this, an electric-potential across the sieve plate causes the movement of water along with solutes. This theory fails to explain several problems concerning translocation.

4. Munch Mass Flow hypothesis

Mass flow theory was first proposed by **Munch** (1930) and elaborated by **Crafts** (1938). According to this hypothesis, organic substances or solutes move from the region of high osmotic pressure (from mesophyll) to the region of low osmotic pressure along the turgor pressure gradient. The principle involved in this hypothesis can be explained by a simple physical system as shown in figure 11.22.

Two chambers "A" and "B" made up of semipermeable membranes are connected by tube "T" immersed in a reservoir of water. Chamber "A" contains highly concentrated sugar solution while chamber "B" contains dilute sugar solution. The following changes were observed in the system,

i. The high concentration sugar solution of chamber "A" is in a hypertonic state which draws water from the reservoir by endosmosis.

ii. Due to the continuous entry of water into chamber "A", turgor pressure is increased.

iii. Increase in turgor pressure in chamber "A" force, the mass flow of sugar solution to chamber "B" through the tube "T" along turgor pressure gradient.

iv. The movement of solute will continue till the solution in both the chambers attains the state of isotonic condition and the system becomes inactive.

v. However, if new sugar solution is added in chamber "A", the system will start to run again.

A similar analogous system as given in the experiment exists in plants:

Chamber "A" is analogous to mesophyll cells of the leaves which contain a higher concentration of food material in soluble form. In short "A" is the production point called "**source**".

Chamber "B" is analogous to cells of stem and roots where the food material is utilized. In short "B" is consumption end called "**sink**".

Tube "T" is analogous to the sieve tube of phloem.

Mesophyll cells draw water from the xylem (reservoir of the experiment) of the leaf by endosmosis leading to increase in the turgor pressure of mesophyll cell. The turgor pressure in the cells of stem and the roots are comparatively low and hence, the soluble organic solutes begin to flow *en masse* from mesophyll through the phloem to the cells of stem and roots along the gradient turgor pressure.

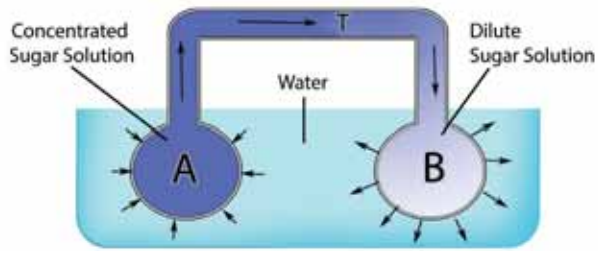


Figure 11.22: A model demonstrating the Mass flow hyphothesis

In the cells of stem and roots, the organic solutes are either consumed or converted into insoluble form and the excess water is released into xylem (by turgor pressure gradient) through cambium.

Merits:

i. When a woody or herbaceous plant is girdled, the sap contains high sugar containing exudates from cut end.

ii. Positive concentration gradient disappears when plants are defoliated.

Objections:

i. This hypothesis explains the unidirectional movement of solute only. However, bidirectional movement of solute is commonly observed in plants.

ii. Osmotic pressure of mesophyll cells and that of root hair do not confirm the requirements.

iii. This theory gives passive role to sieve tube and protoplasm, while some workers demonstrated the involvement of ATP.

11.8 Mineral Absorption

Minerals in soil exist in two forms, either dissolved in soil solution or adsorbed by colloidal clay particle. Previously, it was mistakenly assumed that absorption of mineral salts from soil took place along with absorption of water. But absorption of minerals and ascent of sap are identified as two independent processes. Minerals are absorbed not only by root hairs but also by the cells of epiblema.

Plasma membrane of root cells are not permeable to all ions and also all ions of same salt are not absorbed in equal rate.

Penetration and accumulation of ions into living cells or tissues from surrounding medium by crossing membrane is called **mineral absorption**. Movement of ions into and out of cells or tissues is termed as transport or **flux**. Entry of the ion into cell is called **influx** and exit is called **efflux**. Various theories have been put forward to explain this mechanism. They are categorized under passive mechanisms (without the involvement of metabolic energy) and active mechanisms (involvement of metabolic energy).

11.8.1 Passive Absorption

1. Ion-Exchange:

Ions of external soil solution were exchanged with same charged (anion for anion or cation for cation) ions of the root cells. There are two theories explaining this process of ion exchange namely:

i. Contact exchange and ii. Carbonic acid exchange.

i. **Contact Exchange Theory:**

According to this theory, the ions adsorbed on the surface of root cells and clay particles (or clay micelles) are not held tightly but oscillate within a small volume of space called **oscillation volume**. Due to small space, both ions overlap each other's oscillation volume and exchange takes place (Figure 11.23).

ii. **Carbonic Acid Exchange Theory:**

According to this theory, soil solution plays an important role by acting as a medium for ion exchange. The CO_2 released during respiration of root cells combines with water to form carbonic acid (H_2CO_3). Carbonic acid dissociates into H^+ and HCO_3^- in the soil solution. These H^+ ions exchange with cations adsorbed on clay particles and the cations from micelles get released into soil solution and gets adsorbed on root cells (Figure 11.24).

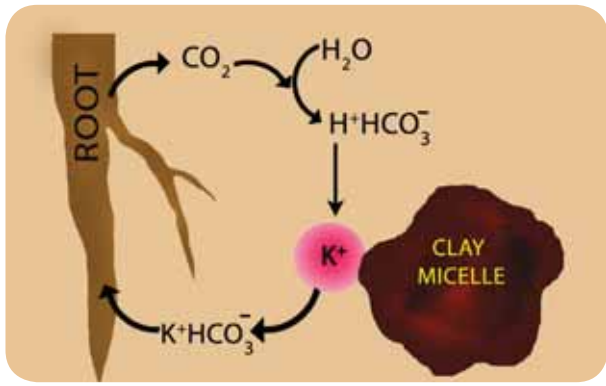


Figure 11.24: Carbonic Acid Exchange theory

Figure 11.23: Contact Exchange theory

11.8.2 Active Absorption

Absorption of ions against the concentration gradient with the expenditure of metabolic energy is called **active absorption**. In plants, the vacuolar sap shows accumulation of anions and cations against the concentration gradient which cannot be explained by theories of passive absorption. Mechanism of active absorption of salts can be explained through Carrier concept.

Carrier Concept:

This concept was proposed by **Van den Honert** in 1937. The cell membrane is largely impermeable to free ions. However, the presence of **carrier molecules** in the membrane acts as a vehicle to pick up or bind with ions to form **carrier-ion-complex,** which moves across the membrane. On the inner surface of the membrane, this complex breaks apart releasing ions into cell while carrier goes back to the outer surface to pick up fresh ions (Figure 11.25).

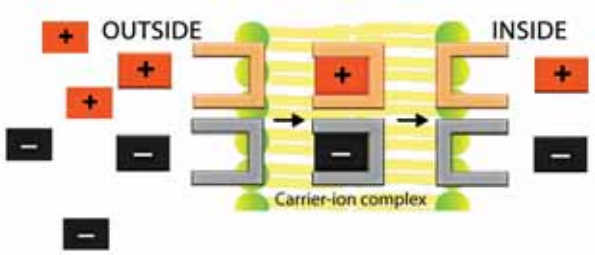


Figure 11.25: Carrier Concept

The concept can be explained using two theories:

1. **Lundegardh's Cytochrome Pump Theory:**

Lundegardh and **Burstrom** (1933) observed a correlation between respiration and anion absorption. When a plant is transferred from water to a salt solution the rate of respiration increases which is called as **anion respiration** or **salt respiration**. Based on this observation **Lundegardh** (1950 and 1954) proposed cytochrome pump theory which is based on the following assumptions:

i. The mechanism of anion and cation absorption are different.

ii. Anions are absorbed through cytochrome chain by an active process, cations are absorbed passively.

iii. An oxygen gradient responsible for oxidation at the outer surface of the membrane and reduction at the inner surface.

According to this theory, the enzyme *dehydrogenase* on inner surface is responsible for the formation of protons (H^+) and electrons (e^-). As electrons pass outward through electron transport chain there is a corresponding inward passage of anions. Anions are picked up by oxidized cytochrome oxidase and are transferred to other members of chain as they transfer the electron to the next component (Figure 11.26).

The theory assumes that cations (C^+) move passively along the electrical gradient created by the accumulation of anions (A^-) at the inner surface of the membrane.

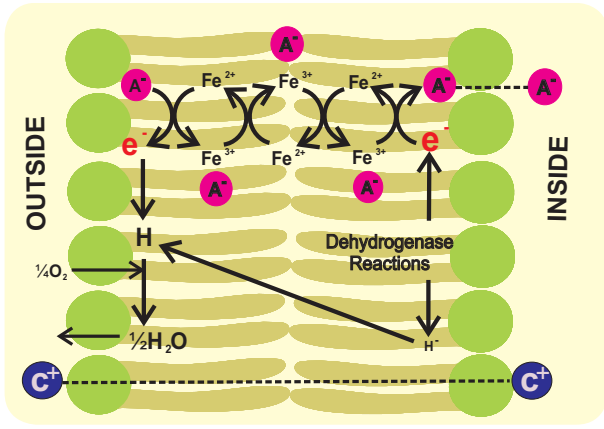


Figure 11.26: Cytochrome Pump theory

Main defects of the above theory are:

(i) Cations also induce respiration.

(ii) Fails to explain the selective uptake of ions.

(iii) It explains absorption of anions only.

2. Bennet-Clark's Protein-Lecithin Theory:

In 1956, **Bennet-Clark** proposed that the carrier could be a protein associated with **phosphatide** called as **lecithin**. The carrier is **amphoteric** (the ability to act either as an acid or a base) and hence both cations and anions combine with it to form **Lecithin-ion complex** in the membrane. Inside the membrane, Lecithin-ion complex is broken down into **phosphatidic acid** and **choline** along with the liberation of ions. Lecithin again gets regenerated from *phosphatidic acid* and *choline* in the presence of the enzyme *choline acetylase* and choline esterase (Figure 11.27). ATP is required for regeneration of lecithin.

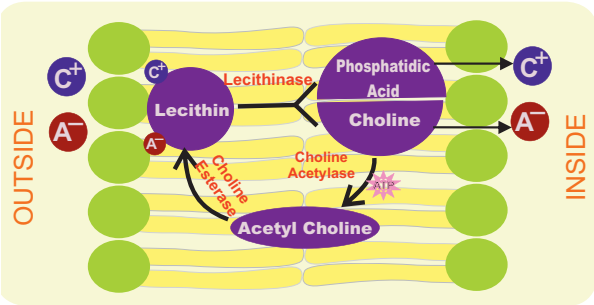


Figure 11.27: Protein-Lecithin theory

11.8.3 Donnan equilibrium

Within the cell, some of the ions never diffuse out through the membrane. They are trapped within the cell and are called fixed ions. But they must be balanced by the ions of opposite charge. Assuming that a concentration of fixed anions is present inside the membrane, more cations would be absorbed in addition to the normal exchange to maintain the equilibrium. Therefore, the cation concentration would be greater in the internal than in the external solution. This electrical balance or equilibrium controlled by electrical as well as diffusion phenomenon is known as the **Donnan equilibrium**.

Summary

There are two types of transports namely short and long distance in plants to translocate sap and solutes. Based on energy requirement, the transport may either be passive or active. The process of diffusion, facilitated diffusion, imbibition and osmosis are driven by concentration gradient like a ball rolling down to a slope and hence, no energy is needed. The water absorbed (either active or passive) from the soil by root hairs must reach the xylem for further transportation. There are three possible routes to reach the xylem from root hairs. They are i) apoplast ii) symplast and/or iii) transmembrane. Various theories explain the path of sap in the xylem and Dixon's Cohesion-tension theory is the most accepted one. Transpiration is mostly carried out by stomata, which has guard cells. The general mechanism of stomatal movement is based on entry and exit of water molecules in guard cells. Many theories are there to explain how water enters and exits from guard cells. The theory of potassium transport enumerates two different reactions separately run for opening and closing of stomata. Contrary to ascent of sap by xylem in an upward direction, the path of solute which consists of the photosynthetic products is always in phloem and translocate multidirectional. The point of origin of translocation is photosynthetic leaves which are the source. On the other

hand, point of utilization is called sink. According to Munch mass flow hypothesis, the solutes move along the concentration gradient in a bulk flow.

Although minerals are dissolved in soil water, they do not tend together with water to enter the root hairs during absorption of water. Mineral absorption is independent of water absorption. Minerals are absorbed either actively or passively.

Evaluation

1. In a fully turgid cell
   a. DPD = 10 atm; OP = 5 atm; TP = 10 atm
   b. DPD = 0 atm; OP = 10 atm; TP = 10 atm
   c. DPD = 0 atm; OP = 5 atm; TP = 10 atm
   d. DPD = 20 atm; OP = 20 atm; TP = 10 atm
2. Which among the following is correct?
   i. apoplast is fastest and operate in nonliving part
   ii. Transmembrane route includes vacuole
   iii. symplast interconnect the nearby cell through plasmadesmata
   iv. symplast and transmembrane route are in living part of the cell

   a. i and ii b. ii and iii
   c. iii and iv d. i, ii, iii, iv
3. What type of transpiration is possible in the xerophyte *Opuntia*?
   a. Stomatal b. Lenticular
   c. Cuticular d. All the above
4. Stomata of a plant open due to
   a. Influx of K^+ b. Efflux of K^+
   c. Influx of Cl^- d. Influx of OH^-
5. Munch hypothesis is based on
   a. Translocation of food due to TP gradient and imbibition force
   b. Translocation of food due to TP
   c. Translocation of food due to imbibition force
   d. None of the above
6. If the concentration of salt in the soil is too high and the plants may wilt even if the field is thoroughly irrigated. Explain
7. How phosphorylase enzyme open the stomata in starch sugar interconversion theory?
8. List out the non-photosynthetic parts of a plant that need a supply of sucrose?
9. What are the parameters which control water potential?
10. An artificial cell made of selectively permeable membrane immersed in a beaker (in the figure). Read the values and answer the following questions?

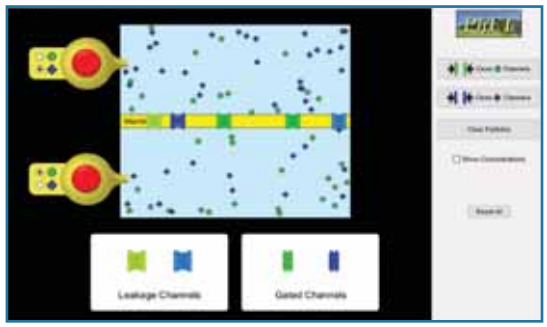
CMHVZ6

   a. Draw an arrow to indicate the direction of water movement
   b. Is the solution outside the cell isotonic, hypotonic or hypertonic?
   c. Is the cell isotonic, hypotonic or hypertonic?
   d. Will the cell become more flaccid, more turgid or stay in original size?
   e. With reference to artificial cell state, the process is endosmosis or exosmosis? Give reasons

ICT Corner

Membrane transport

Let's play with **membrane proteins.**



Steps

- Open PhET:
  Method 1: By scanning the QR Code given
  Method 2: Through Google – Open PhET by typing PhET
- Select play with simulation & enter
- Click Biology – select Membrane Channels & run
- Select Membrane channel in PhET
- Select round molecule and pump it by pressing red button in one column
- Select square molecule and pump it by pressing the same action
- Observe the movement of molecules across membrane

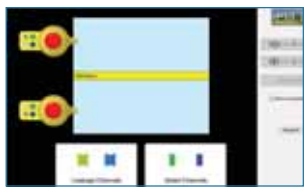
Activity

- Use leakage channel and gated channel in closed and open position and observe the molecules movement.

Step 1

Step 2

Step 3



Step 4

URL:

https://phet.colorado.edu/

* Pictures are indicative only

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Unit V: Plant Physiology (Functional Organisation)

Chapter 12

Mineral Nutrition

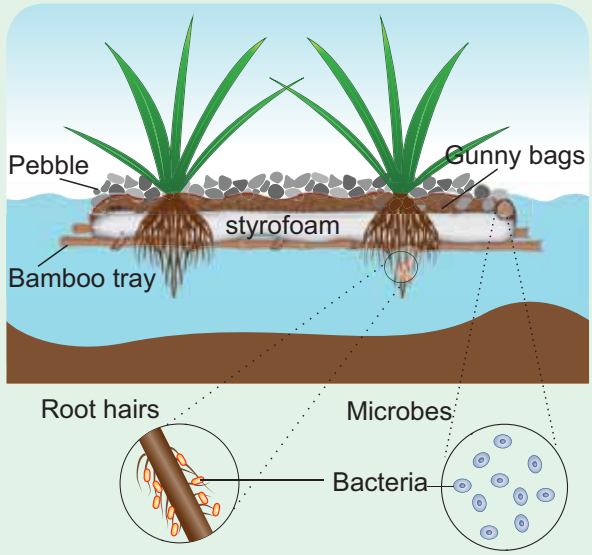
Learning Objectives

The learner will be able to,

- *Recognise the need of mineral nutrition.*
- *Analyse the classification and criteria for essential minerals.*
- *Learn the techniques of Hydroponics and Aeroponics.*
- *Correlate different types of special modes of nutrition.*
- *Ability to recall and analyse nitrogen fixation.*

Chapter Outline

A solution to Pollution



A new solution has come up for high nutrient pollution and eutrophication in surface waters. Floating Treatment Wetlands (FTWs) offer promising solution and it is a built structure which measures around 3,000 sq.ft and comprises four layers: floatable bamboo at base, styrofoam second layer, a third layer of gunny bags with gravels and final layer to support cleaning agents (plants). Native plants including Vetivers, *Citronella*, Tulsi and *Withania* are being researched for use as cleaning agents. FTW works on the principle of Hydroponics which is explained in this chapter. Microbes grown on the roots of these plants break down and consume organic matter in water and reduce pollution.

As a traveller you would have got a chance to observe the plants. It is an interesting fact that all plants are not unique. Just spend some time to listen to nature. You can notice plants with attractive leaves, flowers and fruits.

Can you say all plants are healthy and uniform in growth? Some plants are not healthy and show symptoms like texture changes, stunted growth, chlorosis, necrosis and so on. Can you tell what is the reason for all these symptoms? It may be due to infection of microbial pathogens or climatic factors or due to mineral deficiency.

In this chapter we are going to learn about classification of minerals, their functions, deficiency diseases and symptoms, nitrogen metabolism and special modes of nutrition. Further, how can these ideas help us to improve productivity in agriculture?

Plants naturally obtain nutrients from atmosphere, water and soil. Carbon, hydrogen and oxygen are called as skeletal elements and constitute about 94% of dry weight. These elements play an important role in the formation of organic compounds such as carbohydrates, fats and protein. These non-mineral elements are obtained from air and water. Minerals are classified based on essentiality. **Arnon** and **Stout** (1939) gave criteria required for essential minerals:

1. Elements necessary for growth and development.
2. They should have direct role in the metabolism of the plant.
3. It cannot be replaced by other elements.
4. Deficiency makes the plants impossible to complete their vegetative and reproductive phase.

12.1 Classification of minerals

12.1.1 Classification of minerals based on their quantity

Essential elements are classified as **Macronutrients, Micronutrients** and **Unclassified minerals** based on their requirements. Essential minerals which are required in higher concentration are called **Macronutrients**. Essential minerals which are required in less concentration called are as **Micronutrients**.

Minerals like Sodium, Silicon, Cobalt and Selenium are not included in the list

Historical events in mineral nutrition

Van Helmont (1648) – made first observation of mineral nutrition, noticed over a period of 5 years soil lost only 56 g in nourishing a seedling into tree. Increase in organic substance comes from water alone.

Wood word (1699) – Soil provides mineral nutrients required for their growth.

De Saussure (1804) – plant growth depends on nitrogen and other elements absorbed by roots from soil.

Liebig (1840) – gave the "law of minimum" which states that productivity of soil depends on amount of essential elements present in minimum quantity.

Julius Von Sachs (1860) – Demonstrated growing a plant in a defined nutrient solution.

William Frederick Goerick (1940) – Gave the term Hydroponics and commercial technique.

Table 12.1: Mineral Types		
Macro nutrients	**Micro nutrients**	**Unclassified minerals**
Excess than 10 mmole Kg-1 in tissue concentration or 0.1 to 10 mg per gram of dry weight.	Less than 10 mmole Kg-1 in tissue concentration or equal or less than 0.1 mg per gram of dry weight.	Required for some plants in trace amounts and have some specific functions.
Example: C, H, O, N, P, K, Ca, Mg and S	Example: Fe, Mn, Cu, Mo, Zn, B, Cl and Ni	Example: Sodium, Cobalt, Silicon and Selenium

of essential nutrients but are required by some plants, these minerals are placed in the list of unclassified minerals. These minerals play specific roles for example, Silicon is essential for pest resistance, prevent water lodging and aids cell wall formation in Equisetaceae (*Equisetum*), Cyperaceae and Gramineae (Table 12. 1).

12.1.2 Classification of minerals based on mobility

If you observe where the deficiency symptoms appear first, you can notice differences in old and younger leaves. It is mainly due to mobility of minerals. Based on this, they are classified into 1. Actively mobile minerals and 2. Relatively immobile minerals (Figure 12.1).

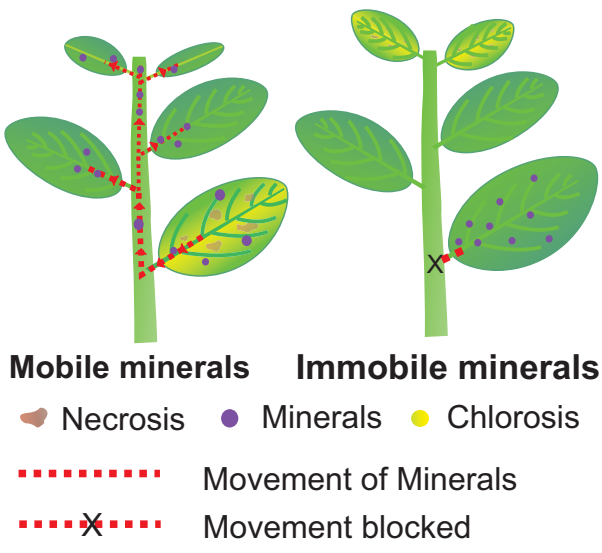


Figure 12.1: Mobility of Minerals

a. Actively mobile minerals

Nitrogen, Phosphorus, Potassium, Magnesium, Chlorine, Sodium, Zinc and Molybdenum.

Deficiency symptoms first appear on old and senescent leaves due to active movement of minerals to younger leaves.

b. Relatively immobile minerals

Calcium, Sulphur, Iron, Boron and Copper shows deficiency symptoms first that appear on young leaves due to the immobile nature of minerals

12.1.3 Classification of minerals based on their functions

a. Structural component minerals: Minerals like Carbon, Hydrogen, Oxygen and Nitrogen

b. Enzyme function: Molybdenum (Mo) is essential for nitrogenase enzyme during reduction of atmospheric nitrogen into ammonia. Zinc (Zn) is an important activator for alcohol dehydrogenase and carbonic anhydrase. Magnesium (Mg) is the activator for RUBP carboxylase-oxygenase and PEP carboxylase.

Nickel (Ni) is a constituent of urease and hydrogenase.

c. **Osmotic Potential:** Potassium (K) plays a key role in maintaining osmotic potential of the cell. The absorption of water, movement of stomata and turgidity are due to osmotic potential.

d. **Energy components**: Magnesium (Mg) in chlorophyll and phosphorous (P) in ATP.

12.2 Functions, mode of absorption and deficiency symptoms of macronutrients

Macronutrients, their functions, their mode of absorption, deficiency symptoms and deficiency diseases are discussed here:

1. **Nitrogen (N):** It is required by the plants in greatest amount. It is an essential component of proteins, nucleic acids, amino acids, vitamins, hormones, alkaloids, chlorophyll and cytochrome. It is absorbed by the plants as nitrates (NO_3).

   Deficiency symptoms: Chlorosis, stunted growth, anthocyanin formation.

2. **Phosphorus (P):** Constituent of cell membrane, proteins, nucleic acids, ATP, NADP, phytin and sugar phosphate. It is absorbed as $H_2PO_4^+$ and HPO_4^- ions.

   Deficiency symptoms: Stunted growth, anthocyanin formation, necrosis, inhibition of cambial activity, affect root growth and fruit ripening.

3. **Potassium (K):** Maintains turgidity and osmotic potential of the cell, opening and closure of stomata, phloem translocation, stimulate activity of enzymes, anion and cation balance by ion-exchange. It is absorbed as K^+ ions.

   Deficiency symptoms: Marginal chlorosis, necrosis, low cambial activity, loss of apical dominance, lodging in cereals and curled leaf margin.

4. **Calcium (Ca):** It is involved in synthesis of calcium pectate in middle lamella, mitotic spindle formation, mitotic cell division, permeability of cell membrane, lipid metabolism, activation of phospholipase, ATPase, amylase and activator of adenyl kinase. It is absorbed as Ca^{2+} exchangeable ions.

   Deficiency symptoms: Chlorosis, necrosis, stunted growth, premature fall of leaves and flowers, inhibit seed formation, Black heart of Celery, Hooked leaf tip in Sugar beet, *Musa* and Tomato.

5. **Magnesium (Mg):** It is a constituent of chlorophyll, activator of enzymes of carbohydrate metabolism (RUBP Carboxylase and PEP Carboxylase) and involved in the synthesis of DNA and RNA. It is essential for binding of ribosomal sub units. It is absorbed as Mg^{2+} ions.

   Deficiency symptoms: Inter veinal chlorosis, necrosis, anthocyanin (purple) formation and Sand drown of tobacco.

6. **Sulphur (S):** Essential component of amino acids like cystine, cysteine and methionine, constituent of coenzyme A, Vitamins like biotin and thiamine, constituent of proteins and ferredoxin.plants utilise sulphur as sulphate (SO_4^-) ions.

Deficiency symptoms: Chlorosis, anthocyanin formation, stunted growth, rolling of leaf tip and reduced nodulation in legumes.

NPK Fertilizers

It consists of nitrogen, phosphate with potassium in different proportions. The number labelled on the bags as 15-15-15 indicates N, P & K in equal proportions.

Chelating Agents

EDTA (Chemical Chelating Agent)

Plants which are growing in alkaline soil when supplied with all nutrients including iron will show iron deficiency. To rectify this, we have to make iron into a soluble complex by adding a chelating agent like EDTA (Ethylene Diamine Tetra Acetic acid) to form Fe-EDTA.

Siderophores (Biological Chelating agent)

Siderophores (iron carriers) are Iron chelating agents produced by bacteria. They are used to chelate ferric Iron (Fe^{3+}) from environment and host.

12.3 Functions, mode of absorption and deficiency symptoms of micronutrients

Micronutrients even though required in trace amounts are essential for the metabolism of plants. They play key roles in many plants. Example: Boron is essential for translocation of sugars, molybdenum is involved in nitrogen metabolism and zinc is needed for biosynthesis of auxin. Here, we will study about the role of micro nutrients, their functions, their mode of absorption, deficiency symptoms and deficiency diseases.

1. **Iron (Fe):** Iron is required lesser than macronutrient and larger than micronutrients, hence, it can be placed in any one of the groups. Iron is an essential element for the synthesis of chlorophyll and carotenoids. It is the component of cytochrome, ferredoxin, flavoprotein, formation of chlorophyll, porphyrin, activation of catalase, peroxidase enzymes. It is absorbed as ferrous (Fe^{2+}) and ferric (Fe^{3+}) ions. Mostly fruit trees are sensitive to iron.

   Deficiency: Interveinal Chlorosis, formation of short and slender stalk and inhibition of chlorophyll formation.

2. **Manganese (Mn):** Activator of carboxylases, oxidases, dehydrogenases and kinases, involved in splitting of water to liberate oxygen (photolysis). It is absorbed as manganous (Mn^{2+}) ions.

   Deficiency: Interveinal chlorosis, grey spot on oats leaves and poor root system.

3. **Copper (Cu):** Constituent of plastocyanin, component of phenolases, tyrosinase, enzymes involved in redox reactions, synthesis of ascorbic acid, maintains carbohydrate and nitrogen balance, part of oxidase and cytochrome oxidase. It is absorbed as cupric (Cu^{2+}) ions.

Deficiency: Die back of citrus, Reclamation disease of cereals and legumes, chlorosis, necrosis and Exanthema in *Citrus*.

4. **Zinc (Zn):** Essential for the synthesis of Indole acetic acid (Auxin) activator of carboxylases, alcohol dehydrogenase, lactic dehydrogenase, glutamic acid dehydrogenase, carboxy peptidases and tryptophan synthetase. It is absorbed as Zn^{2+} ions.

   Deficiency: Little leaf and mottle leaf due to deficiency of auxin, Inter veinal chlorosis, stunted growth, necrosis and Khaira disease of rice.

5. **Boron (B):** Translocation of carbohydrates, uptake and utilisation of Ca^{++}, pollen germination, nitrogen metabolism, fat metabolism, cell elongation and differentiation. It is absorbed as borate BO^{3-} ions.

   Deficiency: Death of root and shoot tips, premature fall of flowers and fruits, brown heart of beet root, internal cork of apple and fruit cracks.

6. **Molybdenum (Mo):** Component of nitrogenase, nitrate reductase, involved in nitrogen metabolism, and nitrogen fixation. It is absorbed as molybdate (Mo^{2+}) ions.

   Deficiency: Chlorosis, necrosis, delayed flowering, retarded growth and whip tail disease of cauliflower.

7. **Chlorine (Cl):** It is involved in Anion – Cation balance, cell division, photolysis of water. It is absorbed as Cl^- ions.

   Deficiency: Wilting of leaf tips

8. **Nickel (Ni):** Cofactor for enzyme urease and hydrogenase.

   Deficiency: Necrosis of leaf tips.

Calmodulin

Calmodulin is a Ca^{2+} modulating protein in eukaryotic cells. It is a heat stable protein involved in fine metabolic regulations.

12.4 Deficiency diseases and symptoms

The following table (Table 12.2) gives you an idea about Minerals and their Deficiency symptoms:

Activity

Collect leaves showing mineral deficiency. Tabulate the symptoms like Marginal Chlorosis, Interveinal Chlorosis, Necrotic leaves, Anthocyanin formation in leaf, Little leaf and Hooked leaf. (Discuss with your teacher about the deficiency of minerals)

12.5 Critical concentration and toxicity of minerals

12.5.1 Critical Concentration

To increase the productivity and also to avoid mineral toxicity knowledge of critical concentration is essential. Mineral nutrients lesser than critical concentration cause deficiency symptoms. Increase of mineral nutrients more than the normal concentration causes toxicity. A concentration, at which 10 % of the dry weight of tissue is reduced, is considered as toxic. Figure 12.2 explains about Critical Concentration.

Table 12.2: Deficiency diseases and Symptoms	
Name of the deficiency disease and symptoms	**Deficiency minerals**
1. Chlorosis (Overall)	Nitrogen, Potassium, Magnesium, Sulphur, Iron, Manganese, Zinc and Molybdenum.
a. Interveinal chlorosis	Magnesium, Iron, Manganese and Zinc
b. Marginal chlorosis	Potassium
2. Necrosis (Death of the tissue)	Magnesium, Potassium, Calcium, Zinc, Molybdenum and Copper.
3. Stunted growth	Nitrogen, Phosphorus, Calcium, Potassium and Sulphur.
4. Anthocyanin formation	Nitrogen, Phosphorus, Magnesium and Sulphur
5. Delayed flowering	Nitrogen, Sulphur and Molybdenum
6. Die back of shoot, Reclamation disease, Exanthema in citrus (gums on bark)	Copper
7. Hooked leaf tip	Calcium
8. Little Leaf	Zinc
9. Brown heart of turnip and Internal cork of apple	Boron
10. Whiptail of cauliflower and cabbage	Molybdenum
11. Curled leaf margin	Potassium

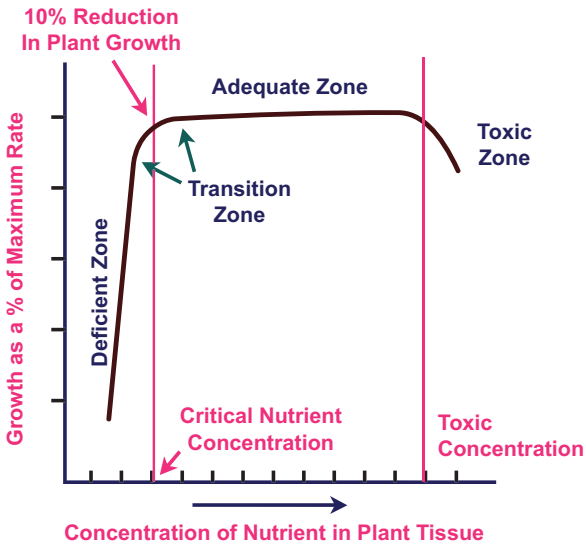


Figure 12.2: Critical Concentration

12.5.2 Mineral Toxicity

a. Manganese toxicity

Increased Concentration of Manganese will prevent the uptake of Fe and Mg, prevent translocation of Ca to the shoot apex and cause their deficiency. The symptoms of manganese toxicity are appearance of brown spots surrounded by chlorotic veins.

b. Aluminium Toxicity

Aluminium toxicity causes precipitation of nucleic acid, inhibition of ATPase,

Iron and Manganese toxicity

Iron and Manganese exhibit competitive behaviour. Deficiency of Fe and Mn shows similar symptoms. Iron toxicity will affect absorption of manganese. The possible reason for iron toxicity is excess usage of chelated iron in addition with increased acidity of soil (PH less than 5.8) Iron and manganese toxicity will be solved by using fertilizer with balanced ratio of Fe and Mn.

inhibition of cell division and binding of plasma membrane with Calmodulin.

For theories regarding, translocation of minerals please refer Chapter- 11.

12.6 Hydroponics and Aeroponics

1. **Hydroponics or Soilless culture:** **Von Sachs** developed a method of growing plants in nutrient solution. The commonly used nutrient solutions are **Knop solution** (1865) and **Arnon** and **Hoagland Solution** (1940). Later the term Hydroponics was coined by **Goerick** (1940) and he also introduced commercial techniques for hydroponics. In hydroponics roots are immersed in the solution containing nutrients and air is supplied with help of tube (Figure 12.3).

Aeroponics: This technique was developed by **Soifer Hillel** and **David Durger**. It is a system where roots are suspended in air and nutrients are sprayed over the roots by a motor driven rotor (Figure 12.4).

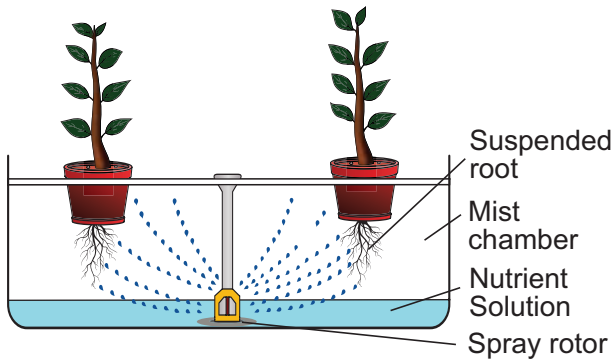


Figure 12.4: Aeroponics

12.7 Nitrogen Fixation

Inspiring act of nature is self-regulation. As all living organisms act as tools for bio geo chemical cycles, nitrogen cycle is highly regulated. Life on earth depends on nitrogen cycle. Nitrogen occurs in atmosphere in the form of N_2 (N≡N), two nitrogen atoms joined together by strong

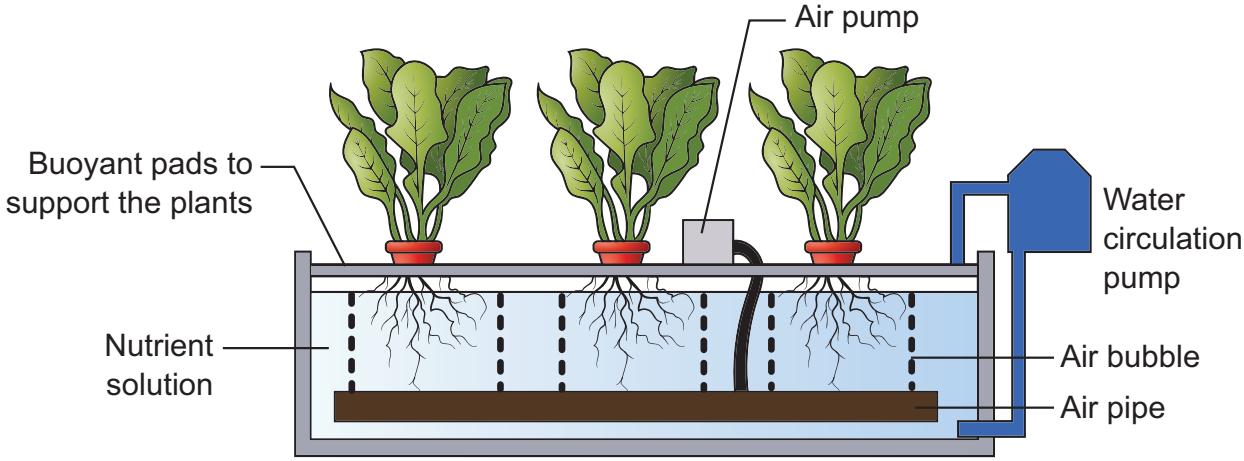


Figure 12.3: Hydroponics

Activity

Preparation of Solution Culture to find out Mineral Deficiency

1. Take a glass jar or polythene bottle and cover with black paper (to prevent algal growth and roots reacting with light).
2. Add nutrient solution.
3. Fix a plant with the help of split cork.
4. Fix a tube for aeration.
5. Observe the growth by adding specific minerals.

triple covalent bonds. The process of converting atmospheric nitrogen (N_2) into ammonia is termed as nitrogen fixation. Nitrogen fixation can occur by two methods: 1. Biological; 2. Non-Biological (Figure 12.5).

12.7.1 Non – Biological nitrogen fixation

- Nitrogen fixation by chemical process in industry.
- Natural electrical discharge during lightening fixes atmospheric nitrogen.

12.7.2 Biological nitrogen fixation

Symbiotic bacterium like *Rhizobium* fixes atmospheric nitrogen. Cyanobacteria found in Lichens, *Anthoceros, Azolla* and coralloid roots of *Cycas* also fix nitrogen. non-symbiotic (free living bacteria) like *Clostridium* also fix nitrogen.

a. Symbiotic nitrogen fixation

i. Nitrogen fixation with nodulation

Rhizobium bacterium is found in leguminous plants and fix atmospheric nitrogen. This kind of symbiotic association is beneficial for both the bacterium and plant. Root nodules are formed due to bacterial infection. *Rhizobium* enters into the host cell and proliferates, it remains separated from the host cytoplasm by a membrane (Figure 12.6).

Stages of Root nodule formation:

1. Legume plants secretes phenolics which attracts *Rhizobium*.
2. *Rhizobium* reaches the rhizosphere and enters into the root hair, infects the root hair and leads to curling of root hairs.
3. Infection thread grows inwards and separates the infected tissue from normal tissue.

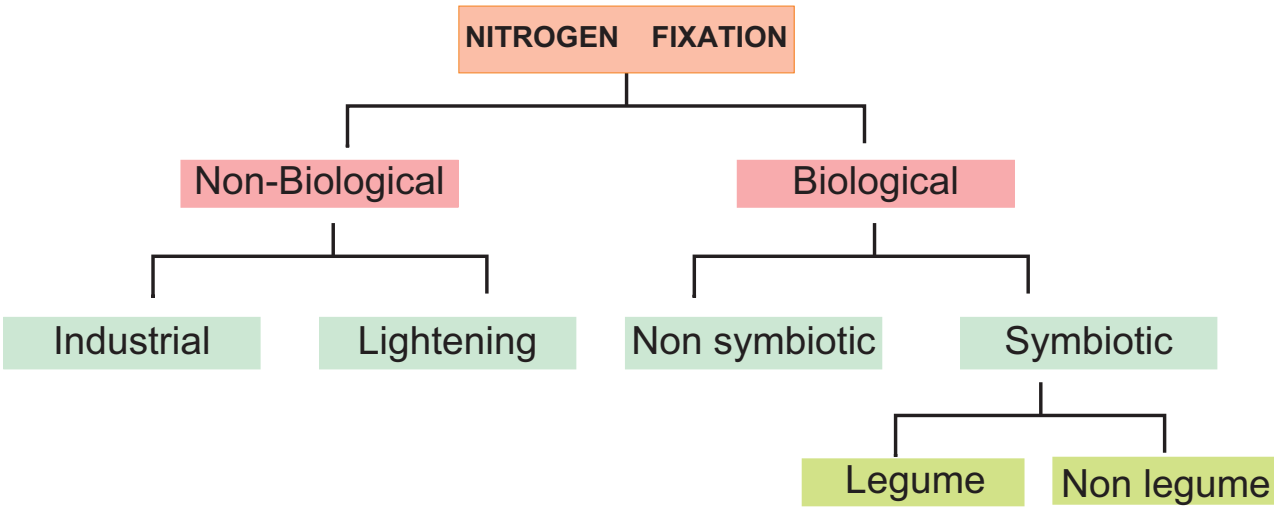


Figure 12.5: Nitrogen fixation

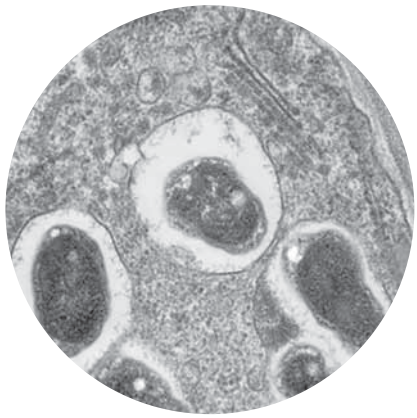


Figure 12.6: Rhizobium (Bacteroid) in root nodule

4. A membrane bound bacterium is formed inside the nodule and is called **bacteroid**.
5. Cytokinin from bacteria and auxin from host plant promotes cell division and leads to nodule formation

Activity

- Collect roots of legumes with root nodules.
- Take cross section of the root nodule.
- Observe under microscope. Discuss your observations with your teacher.

Non-Legume

Alnus and Casuarina contain the bacterium *Frankia*. *Psychotria* contains the bacterium *Klebsiella*.

ii. Nitrogen fixation without nodulation

The following plants and prokaryotes are involved in nitrogen fixation.

Lichens - *Anabaena* and *Nostoc*

Anthoceros - *Nostoc*

Azolla - *Anabaena azollae*

Cycas - *Anabaena* and *Nostoc*

b. Non-symbiotic Nitrogen fixation

Free living bacteria and fungi also fix atmospheric nitrogen.

Aerobic	*Azotobacter, Beijerneckia and Derxia*
Anaerobic	*Clostridium*
Photosynthetic	*Chlorobium and Rhodospirillum*
Chemosynthetic	*Disulfovibrio*
Free living fungi	Yeast and *Pullularia*
Cyanobacteria	*Nostoc, Anabaena and Oscillatoria.*

12.8 Nitrogen cycle and nitrogen metabolism

12.8.1 Nitrogen cycle

This cycle consists of following stages:

1. Fixation of atmospheric nitrogen

Di-nitrogen molecule from the atmosphere progressively gets reduced by addition of a pair of hydrogen atoms. Triple bond between two nitrogen atoms (N≡N) are cleaved to produce ammonia (Figure 12.7).

nitrogen fixation process requires Nitrogenase enzyme complex, Minerals (Mo, Fe and S), anaerobic condition, ATP, electron and glucose 6 phosphate as H^+ donor. Nitrogenase enzyme is active only in anaerobic condition. To create this anaerobic condition a pigment known as **leghaemoglobin** is synthesized in the nodules which acts as oxygen scavenger and removes the oxygen. Nitrogen fixing bacteria in root nodules appears pinkish due to the presence of this leghaemoglobin pigment.

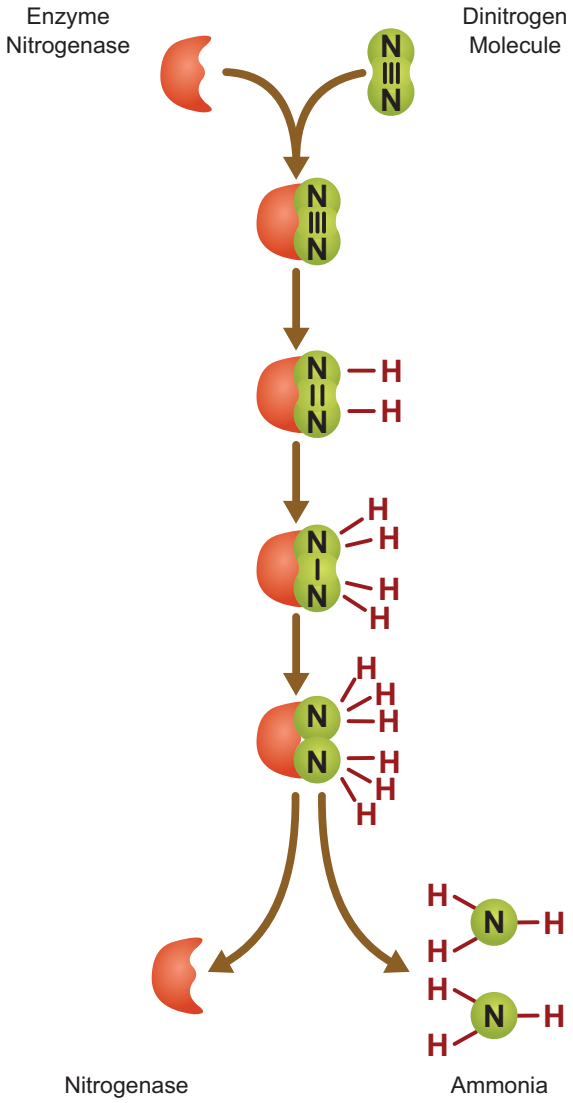


Figure 12.7: Nitrogenase enzyme function

Overall equation:

$$N_2 + 8e^- + 8H^+ + 16ATP \longrightarrow 2NH_3^+ + H_2 + 16ADP + 16\ Pi$$

2. Nitrification

Ammonia (NH_3^+) is converted into Nitrite (NO_2^-) by *Nitrosomonas* bacterium. Nitrite is then converted into Nitrate (NO_3^-) by *Nitrobacter* bacterium.

Plants are more adapted to absorb nitrate (NO_3^-) than ammonium ions from the soil.

$$2\ NH_3^+ + 3\ O_2 \xrightarrow{Nitrosomonas} 2\ NO_2^- + 2\ H^+ + 2H_2O$$

$$2\ NO_2^- + O_2 \xrightarrow{Nitrobacter} 2\ NO_3^-$$

3. Nitrate Assimilation

The process by which nitrate is reduced to ammonia is called **nitrate assimilation** and occurs during nitrogen cycle.

$$NO_3^- \xrightarrow[Mo]{\text{Nitrate reductase}} NO_2^-$$

$$NO_2^- \xrightarrow[Cu,\ Fe]{\text{Nitrite reductase}} NH_3^+$$

4. Ammonification

Decomposition of organic nitrogen (proteins and amino acids) from dead plants and animals into ammonia is called **ammonification**. Organisim involved in this process are *Bacillus ramosus* and *Bacillus vulgaris*.

5. Denitrification

Nitrates in the soil are converted back into atmospheric nitrogen by a process called **denitrification**. Bacteria involved in this process are *Pseudomonas*, *Thiobacillus* and *Bacillus subtilis*.

$$\underset{(NO_3^-)}{\text{Nitrate}} \xrightarrow{Pseudomonas} \underset{(N_2)}{\text{Molecular Nitrogen}}$$

The overall process of nitrogen cycle is given in Figure 12.8.

12.8.2 Nitrogen Metabolism

Ammonium Assimilation (Fate of Ammonia)

Ammonia is converted into amino acids by the following processes:

1. Reductive amination

Glutamic acid or glutamate is formed by reaction of ammonia with α-ketoglutaric acid.

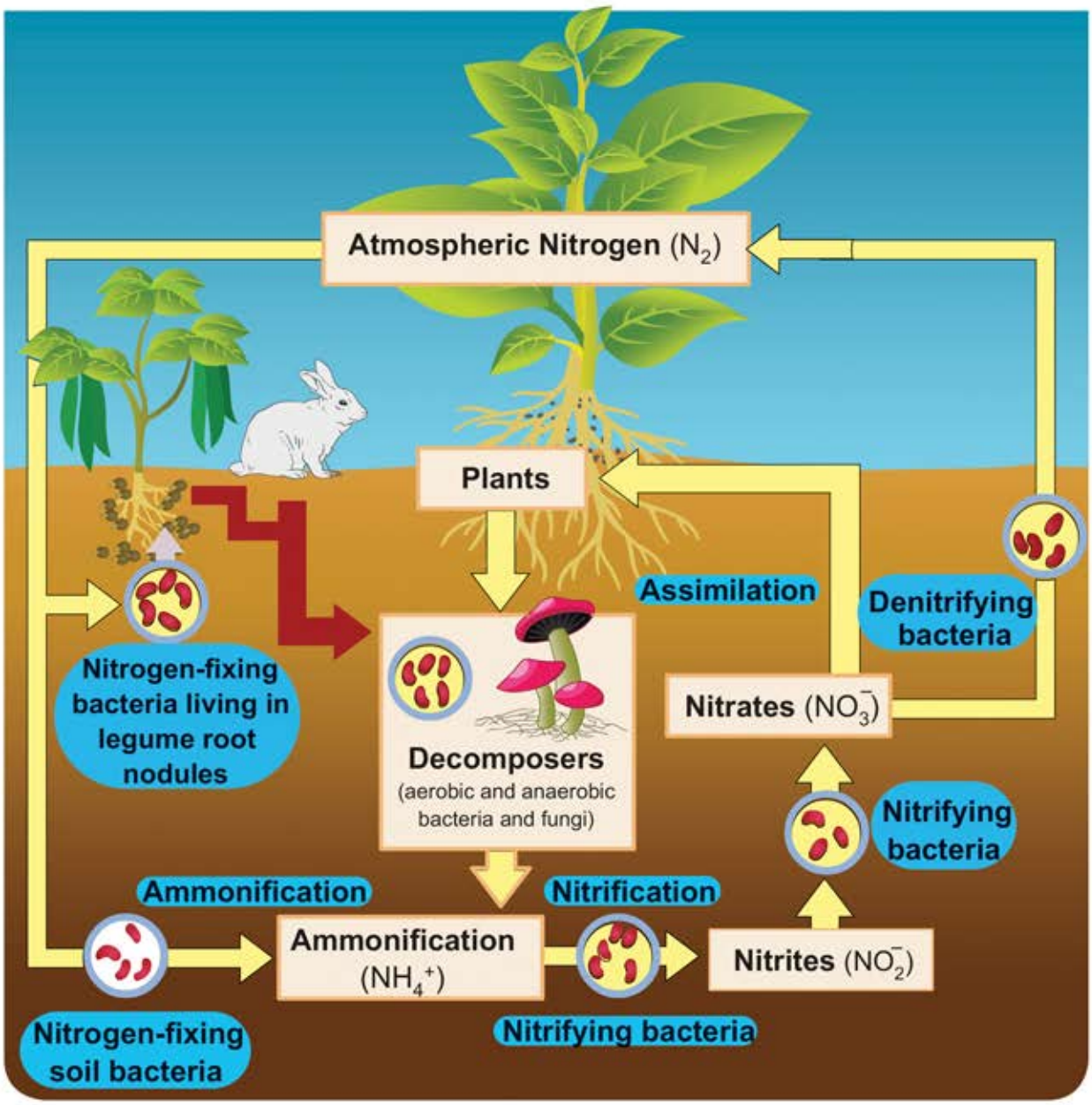
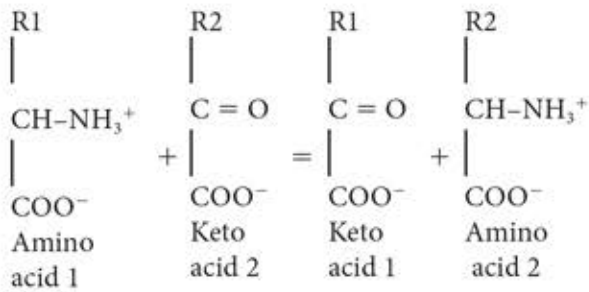


Figure 12.8: Nitrogen Cycle

$$\alpha\text{-Ketoglutaric acid} + NH_4^+ \xrightarrow[NADPH+H^+ \;\; NADP^+]{\text{Glutamate dehydrogenase (GDH)}} \text{Glutamate} + H_2O$$

2. Transamination

Transfer of amino group (NH_3^+) from glutamic acid glutamate to keto group of keto acid. Glutamic acid is the main amino acid from which other amino acids are synthesised by transamination. Transamination requires the enzyme transaminase and co enzyme pyridoxal phosphate (derivative of vitamin B6 -pyridoxine)



3. Catalytic Amination: (GS/GOGAT Pathway)

Glutamate amino acid combines with ammonia to form the amide glutamine.

$$\text{Glutamate} + NH_4^+ \xrightarrow[\text{ATP}\quad\text{ADP + Pi}]{\text{Glutamine Synthetase (GS)}} \text{Glutamine.}$$

Glutamine reacts with α ketoglutaric acid to form two molecules of glutamate.

$$\text{Glutamine} + \underset{\text{(2- oxoglutarate)}}{\text{α Ketoglutaric acid}} \xrightarrow[NADH+H^+\quad NAD^+]{\text{GOGAT (enzyme)}} 2\ \text{Glutamate}$$

(GOGAT- Glutamine-2-Oxoglutarate aminotransferase)

12.9 Special modes of nutrition

Nutrition is the process of uptake and utilization of nutrients by living organisms. There are two main types such as **autotrophic** and **heterotrophic** nutrition. Autotrophic nutrition is further divided into **photosynthetic** and **chemosynthetic** nutrition. Heterotrophic nutrition is further divided into saprophytic, parasitic, symbiotic and insectivorous type. In this topic you are going to learn about special mode of nutrition.

12.9.1 Saprophytic mode of nutrition in angiosperms

Saprophytes derive nutrients from dead and decaying matter. Bacteria and fungus are main saprophytic organisms. Some angiosperms also follow saprophytic mode of nutrition. Example: *Neottia*. Roots of *Neottia* (Bird's Nest Orchid) associate with mycorrhizae and absorb nutrients as a saprophyte. *Monotropa* (Indian Pipe) grow on humus rich soil found in thick forests. It absorbs nutrient through mycorrhizal association (Figure 12.9).

Neottia (Bird's Nest Orchid) ***Monotropa*** (Indian Pipe)

Figure 12.9: Saprophytic Mode of nutrition

12.9.2 Parasitic mode of nutrition in angiosperms

Organisms deriving their nutrient from another organism (host) and causing disease to the host are called parasites.

a. Obligate or Total parasite - Completely depends on host for their survival and produces haustoria.

i. **Total stem parasite**: The leafless stem twine around the host and produce haustoria. Example: *Cuscuta* (Dodder), a rootless plant growing on *Zizyphus*, *Citrus* and so on.

ii. **Total root parasite**: They do not have stem axis and grow in the roots of host plants produce haustoria. Example: *Rafflesia*, *Orobanche* and *Balanophora*.

b. Partial parasite - Plants of this group contain chlorophyll and synthesize carbohydrates. Water and mineral requirements are dependent on host plant.

i. **Partial Stem Parasite**: Example: *Loranthus* and *Viscum* (Mistletoe)

Loranthus grows on fig and mango trees and absorb water and minerals from xylem.

Figure 12.10: Parasitic Mode of Nutrition

ii. **Partial root parasite**: Example: *Santalum album* (Sandal wood tree) in its juvenile stage produces haustoria which grows on roots of many plants (Figure 12.10).

12.9.3 Symbiotic mode of Nutrition

a. **Lichens**: It is a mutual association of Algae and Fungi. Algae prepares food and fungi absorbs water and provides thallus structure.

b. **Mycorrhizae**: Fungi associated with roots of higher plants including Gymnosperms. Example: *Pinus*.

c. ***Rhizobium* and Legumes**: This symbiotic association fixes atmospheric nitrogen

d. **Cyanobacteria and Coralloid Roots**: This association is found in *Cycas* where

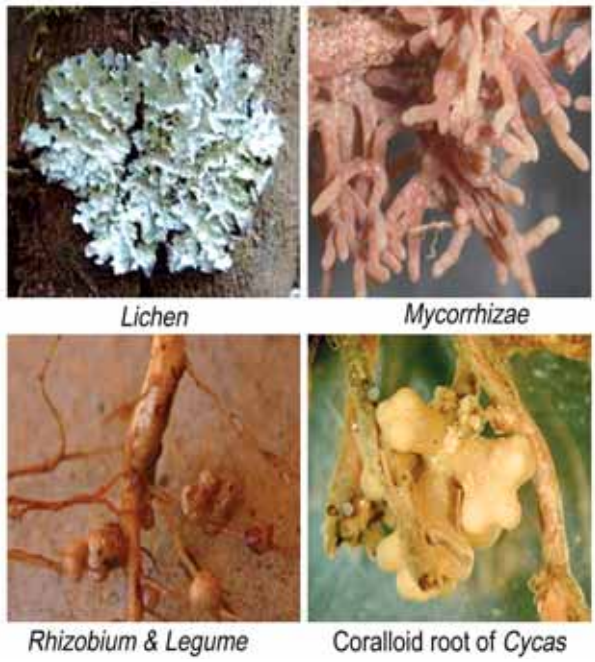


Figure 12.11: Symbiotic mode of nutrition

Nostoc associates with its coralloid roots. (Figure 12.11).

12.9.4 Insectivorous mode of nutrition

Plants which are growing in nitrogen deficient areas develop insectivorous habit to resolve nitrogen deficiency.

a. ***Nepenthes*** (Pitcher plant): Pitcher is a modified leaf and contains digestive enzymes. Rim of the pitcher is provided with nectar glands and acts as an attractive lid. When insect is trapped, proteolytic enzymes will digest the insect.

b. ***Drosera*** (Sundew): It consists of long club shaped tentacles which secrete sticky digestive fluid which looks like a sundew.

c. ***Utricularia*** (Bladder wort): Submerged plant in which leaf is modified into a bladder to collect insect in water.

d. ***Dionaea*** (Venus fly trap): Leaf of this plant modified into a colourful trap. Two folds of lamina consist of sensitive trigger hairs and when insects touch the hairs it will close (Figure 12.12).

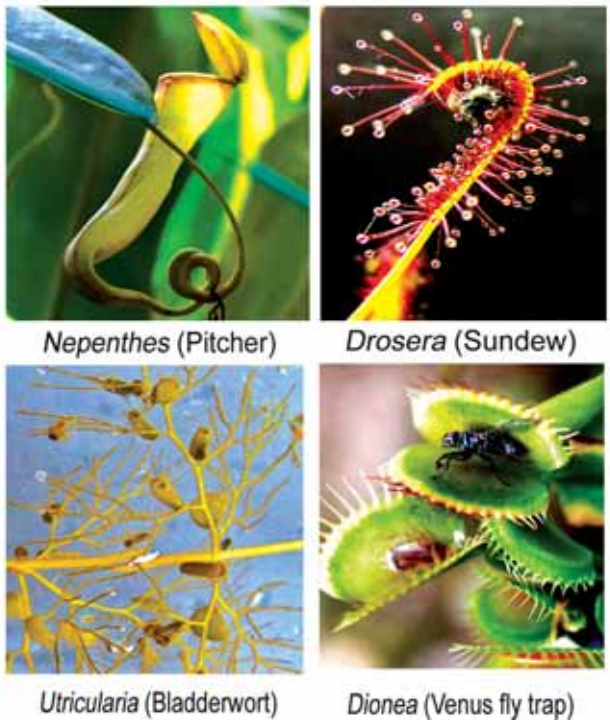


Figure 12.12: Insectivorous mode of nutrition

Lichens are indicators of SO_2 pollution and a pioneer species in xeric succession.

Check your grasp!

Mineral X required for the activation of enzyme nitrogenase, Mineral Y involved in transport of sugar and Mineral Z required for maintaining ribosome structure. Identify X, Y and Z.

Summary

Sources of minerals for plants are atmosphere, water and soil. Minerals are classified based on their quantity, mobility and functions. Macro nutrients (C, H, O, N, P, K, Ca, Mg and S) are required in higher concentration and micro nutrients (Fe, Mn, Cu, Zn, B, Mo, Cl and Ni) are required in lesser concentration. Minerals like Sodium, Cobalt, Silicon and Selenium are required by some plants for specific functions and such minerals are grouped as unclassified minerals. Actively mobile elements are N, P, K, Mg, Cl, Na, Zn and Mo. The deficiency symptoms for these minerals first appear on old and senescent leaves due to active movement of minerals to younger leaves. Relatively immobile elements are Ca, S, Fe, B and Cu. In such minerals, deficiency symptoms first appear on young leaves due to immobile nature. Minerals and their deficiency symptoms include chlorosis (loss of chlorophyll pigments), necrosis (death of tissue), anthocyanin formation, die back of shoot, exanthema, hooked leaf tip, whiptail and so on. A concentration at which 10% of dry weight is reduced is considered as critical concentration. Minerals used in excess concentration become toxic.

Soil less cultivation alleviates problems due to mineral deficiency. It includes hydroponics and aeroponics. Hydroponics is a method of growing plants in a nutrient solution. Aeroponics is the technique in which roots are suspended over the nutrient medium in air and nutrient sprayed over the roots by motor driven rotor. Nitrogen is an important requirement for normal growth and functioning of a plant. Nitrogen fixing organisms fix nitrogen from atmosphere naturally through symbiotic and non-symbiotic modes. Special modes of nutrition are seen in plant which grew in nutrient deficient soils and the character becomes permanent.

Evaluation

1. Identify correct match.

   1. Die back disease of citrus - (i) Mo
   2. Whip tail disease - (ii) Zn
   3. Brown heart of turnip - (iii) Cu
   4. Little leaf - (iv) B

   a. 1 (iii) 2 (ii) 3 (iv) 4 (i)

   b. 1 (iii) 2 (i) 3 (iv) 4 (ii)

   c. 1 (i) 2 (iii) 3 (ii) 4 (iv)

   d. 1 (iii) 2 (iv) 3 (ii) 4 (i)

2. If a plant is provided with all mineral nutrients but, Mn concentration is increased, what will be the deficiency?

   a. Mn prevent the uptake of Fe, Mg but not Ca

   b. Mn increase the uptake of Fe, Mg and Ca

   c. Only increase the uptake of Ca

   d. Prevent the uptake Fe, Mg, and Ca

3. The element which is not remobilized?

   a. Phosphorous b. Potassium

   c. Calcium d. Nitrogen

4. Match the correct combination.

	Minerals		Role
A	Molybdenum	1	Chlorophyll
B	Zinc	2	Methionine
C	Magnesium	3	Auxin
D	Sulphur	4	Nitrogenase

   a. A-1 B-3 C-4 D-2

   b. A-2 B-1 C-3 D-4

   c. A-4 B-3 C-1 D-2

   d. A-4 B-2 C-1 D-3

5. Identify the correct statement

   i. Sulphur is essential for amino acids Cystine and Methionine

   ii. Low level of N, K, S and Mo affect the cell division

   iii. Non-leguminous plant Alnuswhich contain bacterium *Frankia*

   iv. Denitrification carried out by nitrosomonas and nitrobacter.

   a. I, II are correct

   b. I, II, III are correct

   c. I only correct

   d. all are correct

6. The nitrogen is present in the atmosphere in huge amount but higher plants fail to utilize it. Why?

7. Why is that in certain plants deficiency symptoms appear first in younger parts of the plants while in others, they do so in mature organs?

8. Plant A in a nutrient medium shows whiptail disease plant B in a nutrient medium shows a little leaf disease. Identify mineral deficiency of plant A and B?

9. Write the role of nitrogenase enzyme in nitrogen fixation?

10. Explain the insectivorous mode of nutrition in angiosperms?

ICT Corner

Role of minerals in plant growth

Let's try to make the **plant blossom**

Steps

- Scan the QR code
- Start a new game
- Add lime
- Test the Soil pH by test the sample press grows
- Do it for combination of minerals

Activity

- Change the combination of minerals and test the soil samples
- Find the correct proportion of chemical and specific pH for flowering
- Conclude your observations.

Step 1

Step 2

Step 3

Step 4

Web URL:

http://www.glencoe.com/sites/common_assets/science/virtual_labs/BL04/BL04.html

* Pictures are indicative only

B166_11_BOT_EM

Unit V: Plant Physiology (Functional Organisation)

Chapter 13

Photosynthesis

Learning Objectives

The learner will be able to,

- *Learn the ultra structure of Chloroplast .*
- *Realise the importance of solar energy and properties of light.*
- *Acquire knowledge of Quantum, Quantum yield and Quantum requirement.*
- *Develop curiosity for photosynthetic experiments like Red drop, Emerson Enhancement effect and Hill's Reaction.*
- *Analyse the pathway of electron- PS I and PS II.*
- *Recognise the Photo-Oxidative and Photo Chemical Pathway.*
- *Develop skill in Photosynthetic pathways and ability to draw C_3, C_4, C_2 and CAM cycle.*

CNYF6R

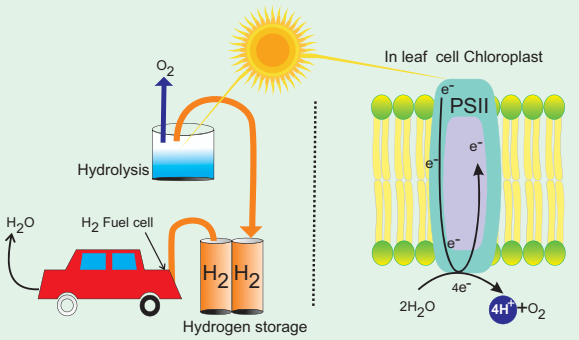
Chapter Outline

Life on earth is made up of organic compounds. How do we get these organic compounds? Ultimately, plants are the main source of all kinds of carbon compounds in this planet. We directly or indirectly depend on plants for this. Plants are the major machinery which produce organic compounds like carbohydrates, lipids, proteins, nucleic acids and other biomolecules.

Though man has reached the glory of achievements still he is not able to imitate

A quest for future energy

Hydrogen is considered as a promising energy vector for the next generation. It can be used for "green" electricity production or developing cogeneration systems such as fuel cells. The sustainability of its employment depends on the energy source used to synthesize it from hydrogen-rich compounds such as water or biomass. The splitting of water in hydrogen and oxygen by means of solar radiation in Photolysis is common in plants. Water splitting is not an easy process to mimic artificially but preliminary success is achieved so far. If young minds take up this as their research ambition a revolution can be made in green energy.



the metabolic activities of plants which produces energy resources and other biomolecules.

The plants get energy from sun by converting solar or radiant energy into chemical energy by the process of Photosynthesis, which acts as a driving force for both biotic and abiotic world. Photosynthesis produces 1700 million tonnes of dry matter per year by fixing 75×10^{12} Kg of carbon every year. Photosynthetic organisms use only 0.2 % of incident solar light on earth. Carbohydrates produced by photosynthesis are the basic raw material for respiration and also to produce many organic compounds. It maintains atmospheric oxygen and carbon dioxide level. Photosynthesis consumes atmospheric carbon dioxide which is continuously added by the respiration of organisms. Photosynthesis is the major endergonic reaction. In this chapter, we will study about the energy yielding process of photosynthesis and various types of energy utilization processes to produce carbohydrates.

13.1 Historical Events in Photosynthesis

- **Van Helmont** (1648) – Increase in organic substances comes from water alone by growing a Willow tree that gains weight but soil loses only 2 ounces of the original weight.
- **Stephen Hales** (1727) – Father of Plant Physiology, Plants obtain nourishment from air and light.
- **Joseph Priestley** (1772) – Performed experiments with candle, mice and Mint plant and concluded that vegetation purifies the air.
- **Jean-Ingen-Housz** (1779) – Confirmed Priestley's experiment that oxygen released by the plants is possible only in light.
- **Lavoisier** (1783) – Purifying gas produced by plants in sunlight is Oxygen (*Phlogiston*) and noxious gas produced by burning of candle (*de Phlogiston*) is Carbon di oxide.
- **Desaussure** (1804)- Explained the importance of water in the process of photosynthesis.
- **Dutrochet** (1837) – Explained the importance of Chlorophyll in Photosynthesis.

- **Von Mayer** (1845) – Green plants convert solar energy into chemical energy of organic matter.

$$CO_2 + H_2O \longrightarrow \text{Organic matter} + O_2$$

- **Liebig** (1845) – Organic matter of plants was derived from CO_2.
- **Julius Von Sachs** (1854) – Discovered that product of photosynthesis was starch. Green substance (chlorophyll) is located in special structures (Chloroplast).
- **T.W. Engelmann** (1888)- Plotted action spectrum of photosynthesis
- **Blackman** (1905) – Proposed Law of Limiting factors.
- **Warburg** (1920) – Used unicellular green algae *Chlorella* for the study of Photosynthesis.
- **Van Neil** (1931) – Oxygen released during photolysis comes from water and not from CO_2. He also conducted experiments in Purple green bacteria and demonstrated Photosynthesis.

$$2H_2A + CO_2 \xrightarrow[\text{Chlorophyll}]{\text{Light}} (CH_2O)_n + H_2O + 2A$$

In Green Sulphur bacteria H_2S is the Hydrogen donor which releases Sulphur instead of oxygen.

- **Emerson and Arnold** (1932) – Existence of light and dark reaction by flashing light experiments.
- **R. Hill** (1937) – Explained photolysis with the help of isolated chloroplasts and electron acceptors in the presence of light.
- **Ruben and Kamen** (1941) – Used ^{18}O radioactive Oxygen to prove that oxygen evolves from water.
- **Arnon, Allen and Whatley** (1954) – Used radioactive $^{14}CO_2$ to show fixation of CO_2 by isolated chloroplast.
- **Melvin Calvin** (1954) – Used radioactive $^{14}CO_2$ and traced path of carbon in the dark phase of photosynthesis or C_3 Cycle.
- **Emerson** *et al.*, (1957) – Reported existence of two photosystems
- **Hatch and Slack** (1965) – Reported C_4 pathway and CO_2 fixation in C_4 plants
- **Huber, Michel and Dissenhofer** (1985) – Crystalized photosynthetic reaction centre of *Rhodobacter* and received the Nobel Prize in 1988.

13.2 Definition, Significance and Site of Photosynthesis

13.2.1 Definition of Photosynthesis

Photosynthesis is referred as photochemical oxidation and reduction reactions carried out with help of light, converting solar energy into Chemical energy. It is the most important anabolic process. Plants and photosynthetic bacteria use simple raw materials like carbon dioxide water and with the help of light energy synthesize carbohydrates and evolve oxygen. The overall chemical equation for photosynthesis is:

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

Ruben and **Kamen** (1941) demonstrated six molecules of water as insufficient for the evolution of 6 molecules of O_2 and modified the equation as:

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

Photosynthesis is a collection of oxidation and reduction reactions (Redox reaction).

Oxidation- Water is oxidised into oxygen (loss of electrons).

Reduction – CO_2 is reduced into Carbohydrates (gain of electrons).

In some bacteria, oxygen is not evolved and is called as **non-oxygenic** and **anaerobic photosynthesis**. Examples: Green sulphur, Purple sulphur and green filamentous bacteria.

13.2.2 Significance of Photosynthesis

1. Photosynthetic organisms provide food for all living organisms on earth either directly or indirectly.
2. It is the only natural process that liberates oxygen in the atmosphere and balances the oxygen level.
3. Photosynthesis balances the oxygen and carbon cycle in nature.
4. Fuels such as coal, petroleum and other fossil fuels are from preserved photosynthetic plants.
5. Photosynthetic organisms are the primary producers on which all consumers depend for energy.
6. Plants provide fodder, fibre, fire wood, timber, useful medicinal products and these sources come by the act of photosynthesis.

13.2.3 Site of Photosynthesis

Chloroplasts are the main site of photosynthesis and both energy yielding process (Light reaction) and fixation of carbon dioxide (Dark reaction)that takes place in chloroplast. It is a double wall membrane bounded organelle, discoid or lens shaped, 4–10 µm in diameter and 1–33 µm in thickness. The membrane is a unit membrane and space between them is 100 to 200 Å. A colloidal and proteinaceous matrix called stroma is present inside.

Bioluminescence is the production and emission of light by a living organism. Bioluminescence is rare in true plants.

A team of MIT engineers have created living bioluminescent lamps out of watercress plants with the goal of one day replacing conventional electrical lighting with the glowing greenery.

A sac like membranous system called **thylakoid** or **lamellae** is present in stroma and they are arranged one above the other forming a stack of coin like structure called **granum** (plural grana). Each chloroplast contains 40 to 80 grana and each granum consists of 5 to 30 thylakoids.

Thylakoids found in granum are called grana lamellae and in stroma are called stroma lamellae. Thylakoid disc size is 0.25 to 0.8 micron in diameter. A thinner lamella called Fret membrane connects grana. Pigment system I is located on outer thylakoid membrane facing stroma and Pigment system II is located on inner membrane facing lumen of thylakoid. Grana lamellae have both PS I and PS II whereas stroma lamellae have only PS I. Chloroplast contains 30–35% Proteins, 20–30% phospholipids, 5–10% chlorophyll, 4–5% Carotenoids, 70S ribosomes, circular DNA and starch grains. Inner surface of lamellar membrane consists of small spherical structure called as **Quantasomes**. Presence of 70S ribosome and DNA gives them status of semi-autonomy and proves endosymbiotic hypothesis which says chloroplast evolved from bacteria. Thylakoid contains pigment systems which produces ATP and NADPH + H^+ using

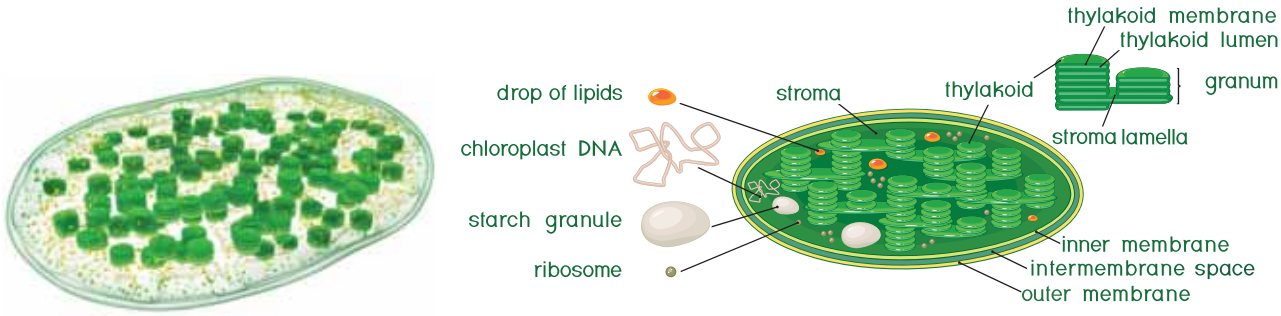


Figure 13.1: (a) 3D view of chloroplast (b) Sectional view of chloroplast

solar energy. Stroma contains enzyme which reduces carbondioxide into carbohydrates. In Cyanobacteria thylakoid lies freely in cytoplasm without envelope (Figure 13.1).

13.3 Photosynthetic Pigments

A photosynthetic pigment is a pigment that is present in chloroplasts or photosynthetic bacteria which captures the light energy necessary for photosynthesis (Table 13.1).

13.3.1 Chlorophyll

Chlorophyll 'a' is the primary pigment which acts as a reaction centre and all other pigments act as accessory pigments and trap solar energy and then transfer it to chlorophyll 'a'. Chlorophyll molecules

Table 13.1: Types of Photosynthetic pigments

Chlorophyll	Carotenoids	Phycobilins
1. Chlorophyll 'a' ($C_{55}H_{72}O_5N_4Mg$) – Green plants and Cyanobacteria	1. Carotene ($C_{40}H_{56}$) – Lycopene (Red)	1. Phycocyanin – Cyanobacteria
2. Chlorophyll 'b' ($C_{55}H_{70}O_6N_4Mg$) – Green algae and all higher plants	2. Xanthophyll ($C_{40}H_{56}O_2$)- Yellow colour – Violaxanthin, Fucoxanthin (Brown Algae) and Lutein	2. Phycoerythrin – Red Algae
3. Chlorophyll 'c' ($C_{55}H_{32}O_5N_4Mg$) – Dinoflagellates, Diatoms and Brown Algae		
4. Chlorophyll 'd' – Red Algae		
5. Chlorophyll 'e' – Xathophycean Algae		
6. Bacteriochlorophyll 'a'		
7. Bacteriochlorophyll 'b'		
8. Chlorobium Chlorophyll 650		
9. Chlorobium Chlorophyll 666		

have a tadpole like structure. It consists of Mg-Porphyrin head (Hydrophilic Head) and (Lipophilic tail) Phytol tail. The Porphyrin head consists of four pyrrol rings linked together by C-H bridges. Each pyrrole ring comprises of four carbons and one nitrogen atom. Porphyrin ring has several side groups which alter the properties of the pigment. Different side groups are indicative of various types of chlorophyll. The Phytol tail made up of 20 carbon alcohol is attached to carbon 7 of the Pyrrole ring IV. It has a long propionic acid ester bond. Long lipophilic tail helps in anchoring chlorophyll to the lamellae (Figure 13.2).

i. Biosynthesis of Chlorophyll

Chlorophyll is synthesized from intermediates of respiration and photosynthesis. Succinic acid an intermediate of Krebs cycle is activated by the addition of coenzyme A and it reacts with a simple amino acid glycine and the reaction goes on to produce chlorophyll 'a'. Bio synthesis of chlorophyll 'a' requires Mg, Fe, Cu, Zn, Mn, K and nitrogen. The absence of any one of these minerals leads to chlorosis (Recall what you have studied in '*Mineral Nutrition*').

ii. Comparison of Chlorophyll – 'a' with other pigments

1. Chlorophyll 'b' differs from Chlorophyll 'a' in having CHO (aldehyde) group instead of CH_3 (Methyl) group at the 3rd C atom in II Pyrrol ring (Figure 13.2).
2. Chlorophyll 'c' differs from Chlorophyll 'a' by lacking phytol tail.

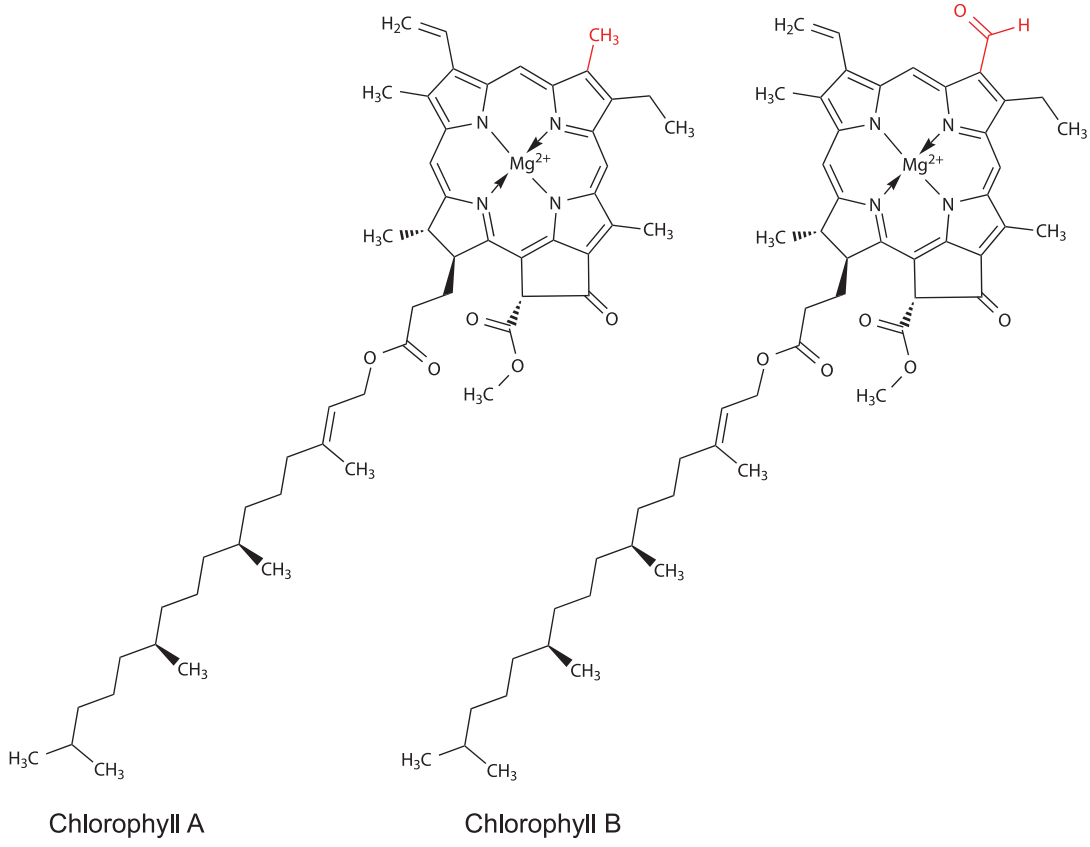


Figure 13.2: Structures of Chlorophyll 'a' and 'b'

3. Chlorophyll 'd' differs from Chlorophyll 'a' in having O-CHO group instead of CH-CH_2 group at 2nd Carbon in the 1st Pyrrol ring.
4. Pheophytin resembles Chlorophyll 'a' except that it lacks Mg atom. Instead it has two H atoms.
5. Phycobilins have open tetra pyrrols and they have neither Mg nor phytol chain.

13.3.2 Carotenoids

Carotenoids are yellow to orange pigments, mostly tetraterpens and these pigments absorb light strongly in the blue to violet region of visible spectrum. These pigments protect chlorophyll from photo-oxidative damage. Hence, they are called as **shield pigments**. These pigments absorb light and transfer these to chlorophyll. Almost all carotenoid pigments have 40 carbon atoms. Ripening of fruits, floral colours and leaf colour change during autumn is due to Carotenoids (Carotene and Xanthophyll) (Figure 13.3).

i. Carotenes:

Orange, Red, Yellow and Brownish pigments, hydrocarbons (Lipids) and most of them are tetraterpenes ($C_{40}H_{56}$).

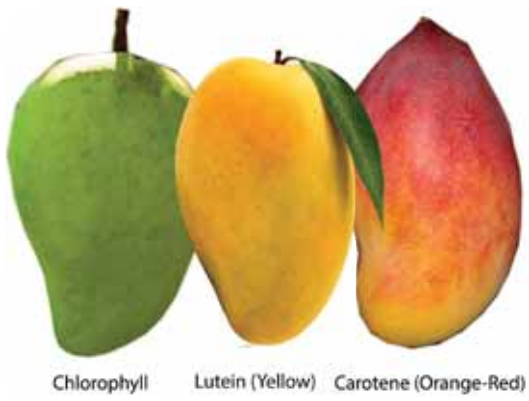


Figure 13.3: Changes in Fruit colour due to difference in pigmentation

Separation of Chloroplast pigments by paper Chromatography method

Step 1. Extract chlorophyll pigment from the leaves using 80% Acetone.

Step 2. Allow to concentrate by evaporation.

Step 3. Apply few drops on one end above 2 cm from the edge of a chromatographic paper.

Step 4. A solvent with mixture of Petroleum ether and acetone in the ratio of 9:1 is prepared and poured into development chamber.

Step 5. Place the strip above the solvent by placing one end of the strip touching the solvent.

Observation

After one hour observe the chromatographic paper. You can find the pigments being separated into four distinct spots (Figure 13. 4).

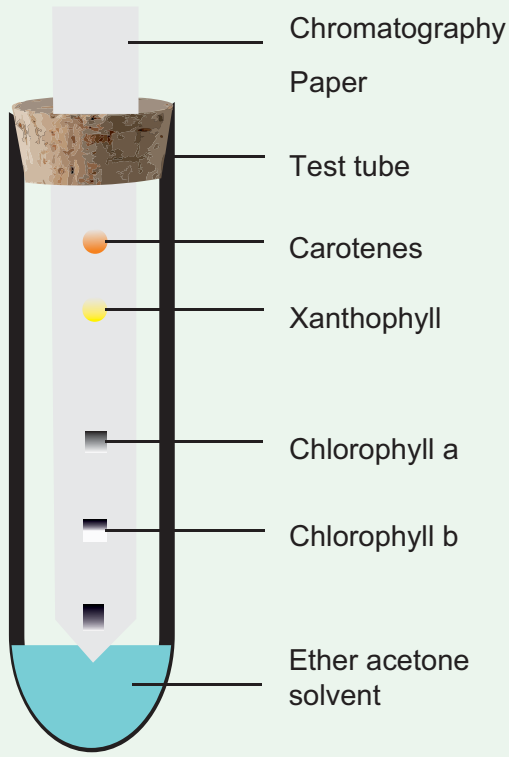


Figure 13.4: Paper Chromatography

Carotene is the most abundant Carotene in plants and it is a precursor of Vitamin A. Lycopene is the red pigment found in the fruits of tomato, red peppers and roses.

ii. Xanthophylls:

Yellow ($C_{40}H_{56}O_2$) pigments are like carotenes but contain oxygen. Lutein is responsible for yellow colour change of leaves during autumn season. Examples: Lutein, Violaxanthin and Fucoxanthin.

13.3.3 Phycobilins

They are proteinaceous pigments, soluble in water, and do not contain Mg and Phytol tail. They exist in two forms such as 1. Phycocyanin found in cyanobacteria 2. Phycoerythrin found in rhodophycean algae (Red algae).

13.4 Spectrum of Electromagnetic Radiation

In the total electromagnetic spectrum,visible light is the smallest part. The entire life on earth depends on light and is the driving force for all organisms. Plants have natural potential to utilize solar energy directly. In the given picture electromagnetic radiation spectrum and components of visible spectrum are mentioned. The wavelength of solar radiation which reaches the earth is between 300 to 2600 nm. The visible spectrum ranges between 390 to 763 nm (3900 Å to 7630 Å). The colour of the light is determined by the wavelength. Energy of the quantum is inversely proportional to wavelength. Shorter wavelength has

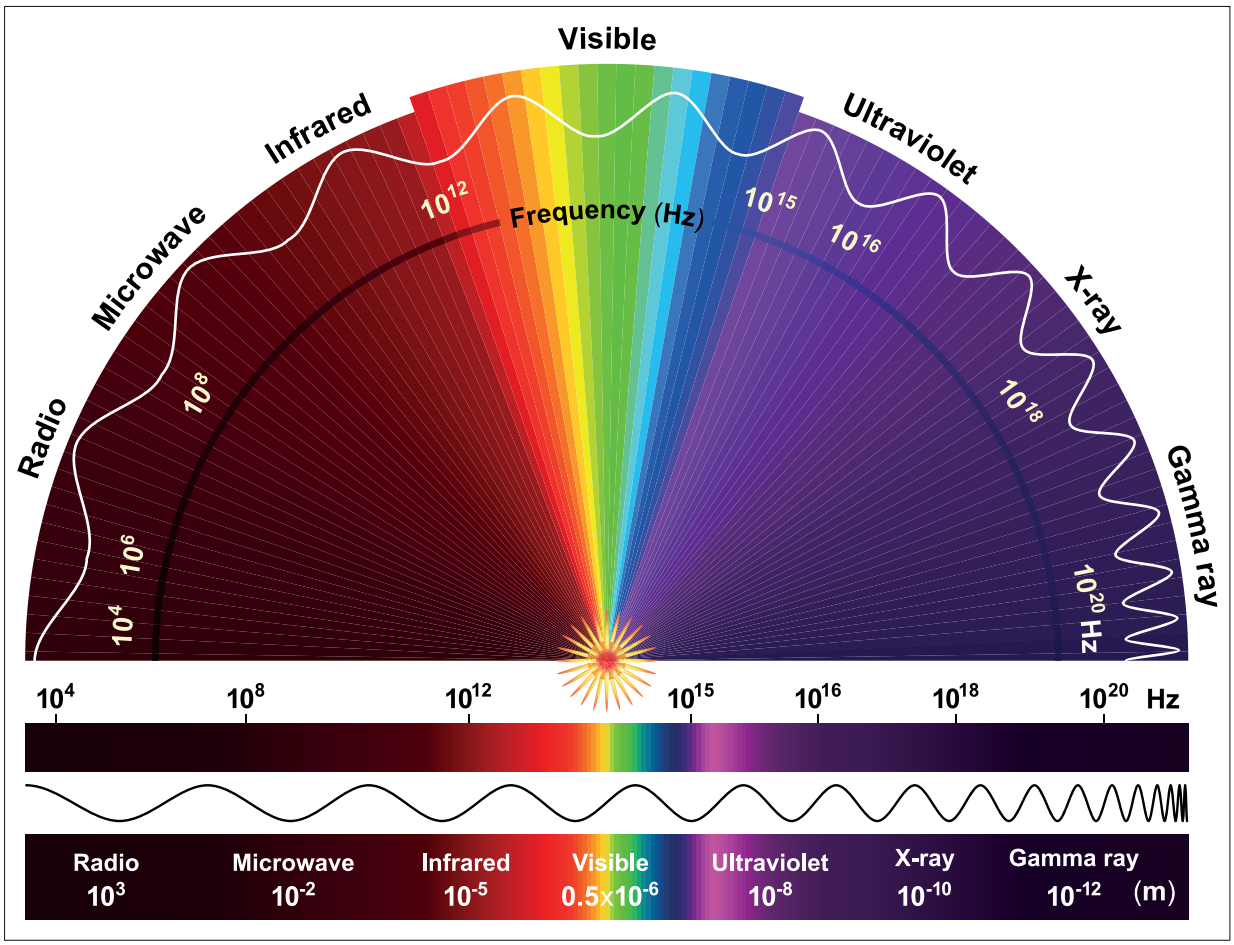


Figure 13.5: Electromagnetic Spectrum

more energy than longer wavelength. Electromagnetic spectrum consists of 8 types of radiations such as cosmic rays, gamma rays, X rays, U-V rays, Visible light spectrum, infrared rays, electric rays and radio rays (Figure 13. 5).

Light is extremely variable and if radiation is evenly distributed over the globe it is sufficient to melt 35 m thick ice layer.

Properties of Light

1. Light is a transverse electromagnetic wave.
2. It consists of oscillating electric and magnetic fields that are perpendicular to each other and perpendicular to the direction of propagation of the light.
3. Light moves at a speed of 3×10^8 ms^{-1}
4. Wavelength is the distance between successive crests of the wave.
5. Light as a particle is called **photon**. Each photon contains an amount of energy known as **quantum**.
6. The energy of a photon depends on the frequency of the light (Figure 13. 6).

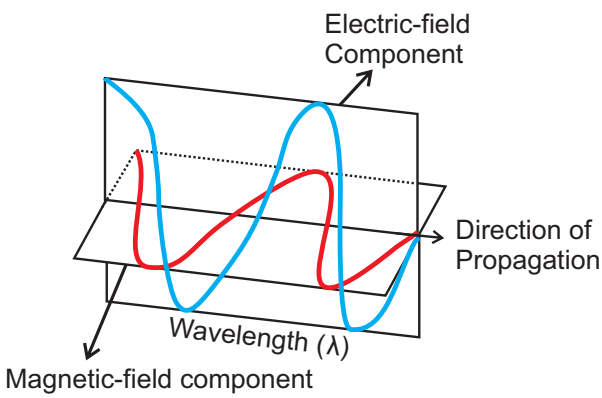


Figure 13.6: Oscillation of electric and magnetic vectors in light

13.5 Photosynthetic Unit (Quantasome)

Quantasomes are the morphological expression of physiological photosynthetic units, located on the inner membrane of thylakoid lamellae. Each quantasome measures about 180 Å × 160 Å and 100 Å thickness. In 1952, **Steinman** observed granular structures in chloroplast lamellae under electron microscope. Later, **Park** and **Biggins** (1964) confirmed these granular structures as physiological units of photosynthesis and coined the term **Quantasome**. According to them one quantasome contains about 230 chlorophyll molecules. A minimum number of chlorophyll and other accessory pigments act together in a photochemical reaction to release one oxygen or to reduce one molecule of CO_2. It constitutes a photosynthetic unit. (Figure 13.7) **Emerson** and **Arnold** (1932) based on flashing light experiment found 2500 chlorophyll molecules are required to fix one molecule of CO_2. However, the reduction or fixation of one CO_2 requires 10 quanta of light and so each unit would contain 1/10 of 2500 i.e. 250 molecules. Usually 200 to 300 chlorophyll molecules are considered as a physiological unit of photosynthesis. According to Emerson 8 quanta of light are required for the release of one oxygen molecule or reduction of one Carbon dioxide molecule. The quantum yield is 1/8 or 12 %.

13.6 Absorption Spectrum and Action Spectrum

13.6.1 Absorption Spectrum

The term absorption refers to complete retention of light, without reflection or

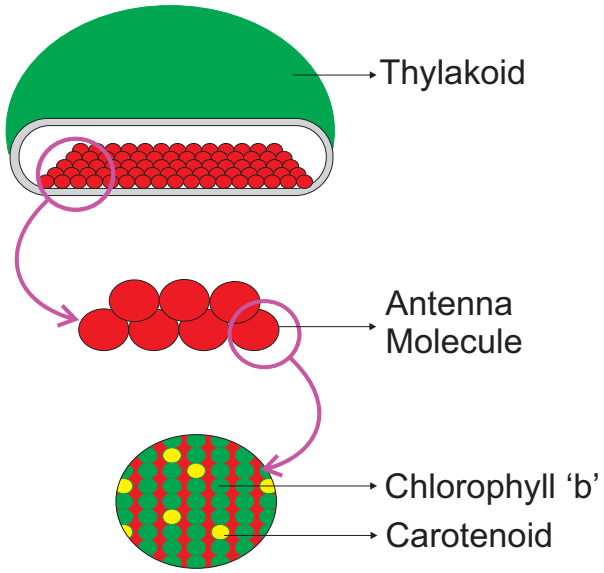


Figure 13.7: Quantasome

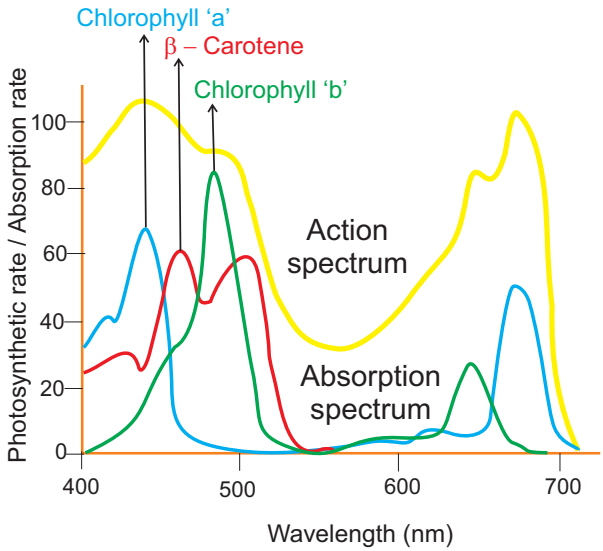


Figure 13. 8: Absorption and action spectrum

transmission. Pigments absorb different wavelengths of light. A curve obtained by plotting the amount of absorption of different wavelengths of light by a pigment is called its **absorption spectrum**.

- Chlorophyll 'a' and chlorophyll 'b' absorb quanta from blue and red region
- Maximum absorption peak for different forms of chlorophyll 'a' is 670 to 673, 680 to 683 and 695 to 705nm.
- Chlorophyll 'a' 680 (P680) and Chlorophyll 'a' 700 (P700) function as trap centre for PS II and PS I respectively.

13.6.2 Action Spectrum

The effectiveness of different wavelength of light on photosynthesis is measured by plotting against quantum yield. The curve showing the rate of photosynthesis at different wavelengths of light is called **action spectrum**. From the graph showing action spectrum, it can be concluded that maximum photosynthesis takes place in blue and red region of the spectrum. This wavelength of the spectrum is the absorption maxima for Chlorophyll (a) and Chlorophyll (b). The Action Spectrum is instrumental in the discovery of the existence of two photosystems in O_2 evolving photosynthesis (Figure 13. 8).

13.7 Emerson's Experiments and Hill's Reaction

13.7.1 Red Drop or Emerson's First Effect

Emerson conducted experiment in *Chlorella* using only one wavelength of light (monochromatic light) at a time and he measured quantum yield. He plotted a graph of the quantum yield in terms of O_2 evolution at various wavelengths of light. His focus was to determine at which wavelength the photochemical yield of oxygen was maximum. He found that in the wavelength of 600 to 680 the yield was constant but suddenly dropped in the region above 680 nm (red region). The fall in the photosynthetic yield beyond red region of the spectrum is referred as **Red drop or Emerson's first effect.**

13.7.2 Emerson's Enhancement Effect

Emerson modified his first experiment by supplying shorter wavelength of light (red light) along with longer wavelength of light (far red light). He found that the monochromatic light of longer wavelength (far red light) when supplemented with shorter wavelength of light (red light) enhanced photosynthetic yield and recovered red drop. This enhancement of photosynthetic yield is referred to as Emerson's Enhancement Effect (Figure 13.9).

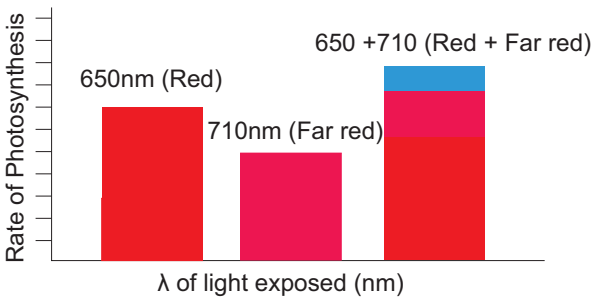


Figure 13.9: Emerson's Enhancement Effect

Photosynthetic rate at far red light (710 nm) = 10

Photosynthetic rate at red light (650 nm) = 43.5

Photosynthetic rate at red + far red (650 + 710 nm) = 72.5 (Enhancement effect).

13.7.3 Hill's Reaction

R. Hill (1937) isolated chloroplasts and when they were illuminated in the presence of suitable electron acceptors such as ferricyanide, they were reduced to ferrocyanide and oxygen is evolved. Hill's Reaction is now considered to be equivalent to Light Reaction.

Conclusions of Hill's Reaction:

1. During photosynthesis oxygen is evolved from water.
2. Electrons for the reduction of CO_2 are obtained from water.
3. Reduced substance produced, later helps to reduce CO_2

$$2H_2O + 2A \longrightarrow 2\,AH_2 + O_2$$

A is the Hydrogen acceptor, the common *in vitro* hydrogen acceptors are ferricyanide, benzoquinone and Di Chloro Phenol Indole Phenol (DCPIP).

13.8 Modern Concept of Photosynthesis

Photosynthesis is an Oxidation and Reduction process. Water is oxidised to release O_2 and CO_2 is reduced to form sugars. The first phase requires light and is called **light reaction or Hill's reaction**.

1. Light reaction: It is a photochemical reaction whereas dark reaction is a thermochemical reaction.

Solar energy is trapped by chlorophyll and stored in the form of chemical energy (assimilatory power)as ATP and reducing power NADPH + H^+. NADPH + H^+ alone are known as **reducing powers**. This reaction takes place in thylakoid membrane of the chloroplast. Oxygen is evolved as a result of splitting of water molecules by light.

Light reaction is discussed in two phases:

i. Photo-oxidation Phase:

- Absorption of light energy.
- Transfer of energy from accessory pigments to reaction centre.
- Activation of Chlorophyll 'a' molecule.

ii. Photo Chemical Phase:

- Photolysis of water and oxygen evolution
- Electron transport and synthesis of assimilatory power.

2. Dark reaction (Biosynthetic phase): Fixation and reduction of CO_2 into carbohydrates with the help of assimilatory power produced during light reaction. This reaction does not require light and is not directly light driven. Hence, it is called as **Dark reaction or Calvin-Benson cycle** (Figure 13.10).

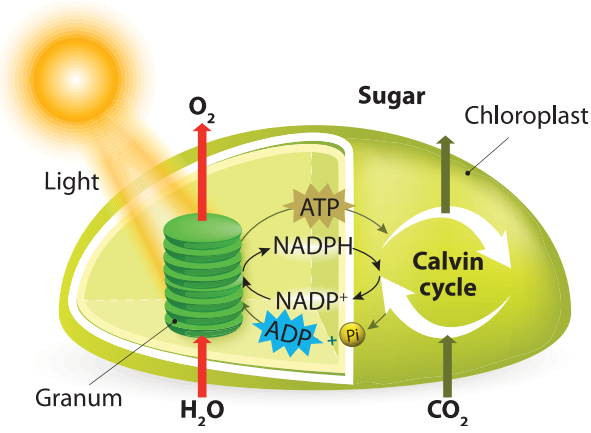


Figure 13.10: Light and Dark Reaction

13.9 Photo-Oxidation Phase of Light Reaction

The action of photon plays a vital role in excitation of pigment molecules to release an electron. When the molecules absorb a photon, it is in excited state. When the light source turned off, the high energy electrons return to their normal low energy orbitals as the excited molecule goes back to its original stable condition known as **ground state**. When molecules absorb or emit light they change their electronic state. Absorption of blue light excites the chlorophyll to higher energy state than absorption of Red light, because the energy of photon is higher when their wavelength is shorter. When the pigment molecule is in an excited state, this excitation energy is utilised for the phosphorylation. Phosphorylation takes place with the help of light generated electron and hence it is known as **photophosphorylation**.

13.9.1 Fluorescence and Phosphorescence

Normal state of an atom or molecule is called **ground state**. When a photon of light collides with the chlorophyll molecule, an electron from outer most orbit is moved to higher energy orbit causing excitation of chlorophyll. This is known as **excited state**. There are three excited states such as:

1. First singlet state (S_1)
2. Second singlet state (S_2)
3. First Triplet Sate (T_1)

When a red light strikes chlorophyll molecule, one electron is released from its ground level (S_0) to first singlet state (S_1). It is in unstable state having half-life period of 10^{-9} seconds. When a blue light strikes chlorophyll molecule, one electron is released from its ground level (S_0) to second singlet state (S_2). It is because blue light has shorter wavelength and more energy than red light. This state is also unstable having half-life period of less than 10^{-12} seconds. Both S_1 and S_2 states being unstable move to ground state S_0 by releasing energy through the several possible ways.

i. Fluorescence

The electron from first singlet state (S_1) returns to ground state (S_0) by releasing energy in the form of radiation energy (light) in the red region and this is known as **fluorescence**. Fluorescence is the immediate emission of absorbed radiations (Figure 13.11). Pathway of

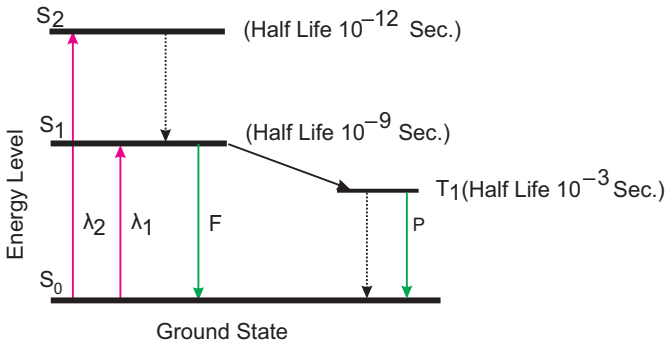


Figure 13.11: Fluorescence (F) and Phosphorescence (P)

electron during fluorescence: $S_1 \rightarrow S_0$

ii. Phosphorescence

Electron from Second Singlet State (S_2) may return to next higher energy level (S_1) by losing some of its extra energy in the form of heat. From first singlet state (S_1) electron further drops to first triplet state (T_1). Triplet State is unstable having half life time of 10^{-3} seconds and electrons returns to ground state with emission of light in red region called as **phosphorescence** (Figure 13.11). Phosphorescence is the delayed emission of absorbed radiations. Pathway of electron during Phosphorescence: $S_2 \rightarrow S_1 \rightarrow T_1 \rightarrow S_0$

13.9.2 Photosystem and Reaction Centre

- Thylakoid membrane contains Photosystem I (PS I) and Photosystem II (PS II).
- PS I is in unstacked region of granum facing stroma of chloroplast.
- PS II is found in stacked region of thylakoid membrane facing lumen of thylakoid.
- Each Photosystem consists of central core complex (CC) and light harvesting Complex (LHC) or Antenna molecules(Figure 13.12).

CPR3BP

- The core complex consists of respective reaction centre associated with proteins, electron donors and acceptors.
- PS I – CC I consists of reaction centre P700 and LHC I.
- PS II – CC II consists of reaction centre P680 and LHC II (Table 13.2).

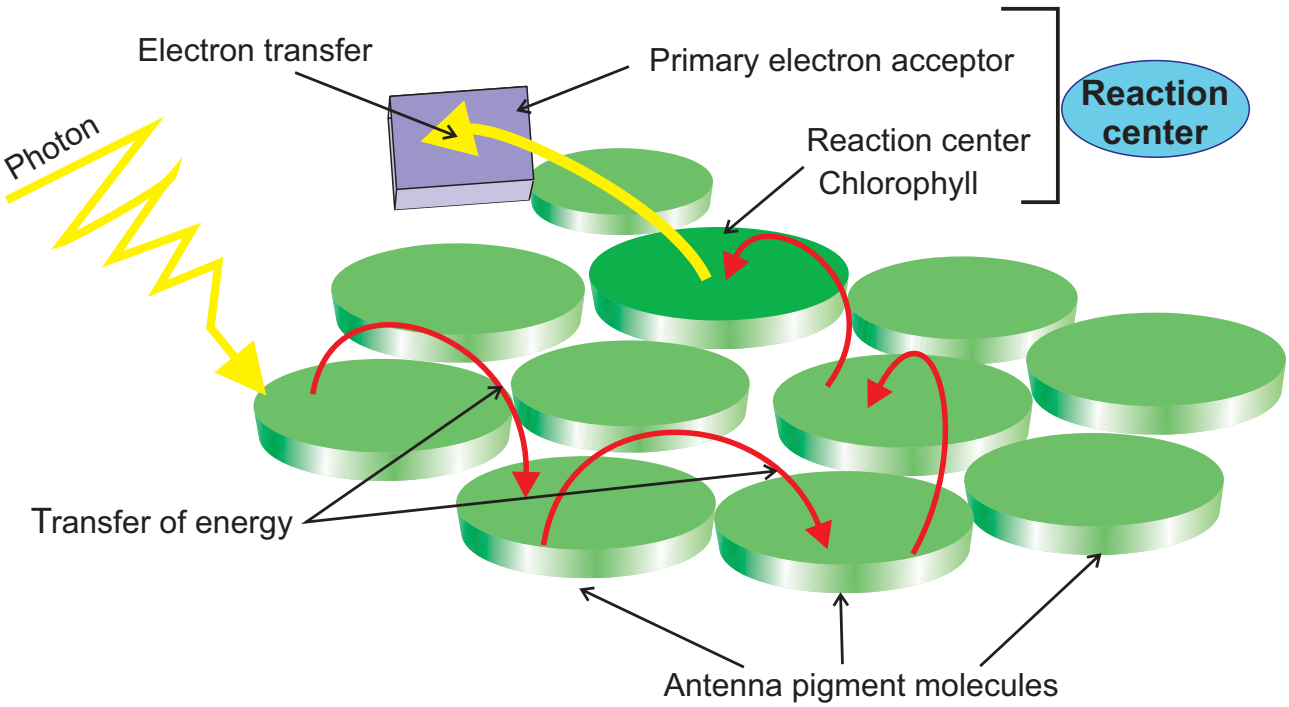


Figure 13.12: Photosystem

Table 13.2: Differences between Photosystem I and Photosystem II	
Photosystem I	**Photosystem II**
1. The reaction centre is P700	1. Reaction centre is P680
2. PS I is involved in both cyclic and non-cyclic.	2. PS II participates in Non-cyclic pathway
3. Not involved in photolysis of water and evolution of oxygen	3, Photolysis of water and evolution of oxygen take place.
4. It receives electrons from PS II during non-cyclic photophosphorylation	4. It receives electrons by photolysis of water
5. Located in unstacked region granum facing chloroplast stroma	5. Located in stacked region of thylakoid membrane facing lumen of thylakoid.
6. Chlorophyll and Carotenoid ratio is 20 to 30:1	6. Chlorophyll and Carotenoid ratio is 3 to 7:1

- Light Harvesting Complex consists of several chlorophylls, carotenoids and xanthophyll molecules.
- The main function of LHC is to harvest light energy and transfer it to their respective reaction centre.

13.10 Photochemical phase of light reaction

In this phase electrons pass through electron carrier molecules and generate assimilatory powers ATP and NADPH + H^+. Splitting of water molecule generates electrons replacing electrons produced by the light.

13.10.1 Photolysis of Water

The process of Photolysis is associated with **Oxygen Evolving Complex** (OEC) or water splitting complex in pigment system II and is catalysed by the presence of Mn^{++} and Cl^-. When the pigment system II is active it receives light and the water molecule splits into OH^- ions and H^+ ions. The OH^- ions unite to form water molecules again and release O_2 and electrons. Photolysis of water is due to strong oxidant which is yet unknown and designated as Z or Yz. Widely accepted theory proposed by **Kok** *et al.*,(1970) explaining photo-oxidation of water is **water oxidising clock** (or) **S' State Mechanism.** It consists of a series of 5 states called as S_0, S_1, S_2, S_3 and S_4. Each state acquires positive charge by a photon (*hv*) and after the S_4 state it acquires 4 positive charges, four electrons and evolution of oxygen. Two molecules of water go back to the S_0. At the end of photolysis 4 H^+,4 e^- and O_2 are evolved from water (Figure 13.13).

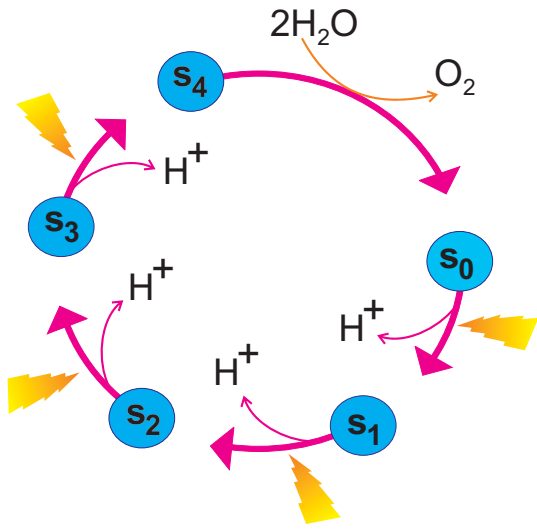


Figure 13.13: Oxygen Evolving Complex (OEC)

$$4\ H_2O \longrightarrow 4\ H^+ + 4\ OH^-$$
$$4\ OH^- \longrightarrow 2\ H_2O + O_2 + 4\ e^-$$
$$2H_2O \longrightarrow 4\ H^+ + O_2 + 4\ e^-$$

13.10.2 Electron Transport Chain of Chloroplast

shuttle between PS II and Cytochrome b_6- f complex and PC connects

- Cytochrome b_6-f and PS I complex.
- *ATPase complex or Coupling factor:* It is found in the surface of thylakoid membrane. This complex is made up of CF_1 and CF_0 factors. This complex

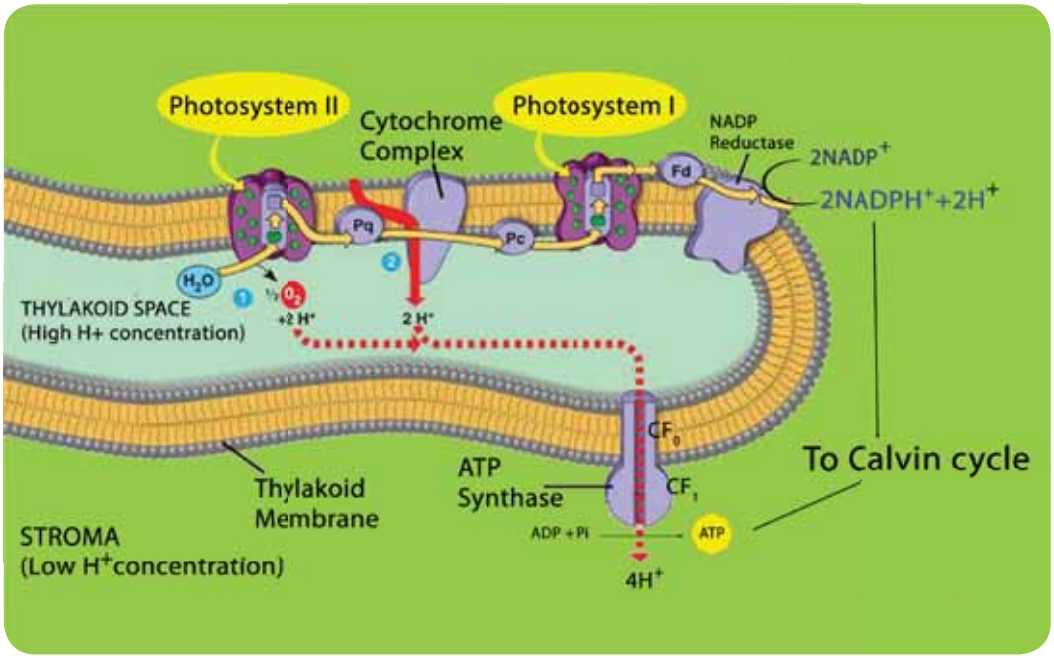


Figure 13.14: Electron Transport Chain in Chloroplast

Electron transport chain in each photosystem involves four complexes:

- *Core Complex (CC):* CC I in PS I the reaction centre is P700, CC II in PS II the reaction centre is P680
- Light Harvesting Complex or Antenna complex (LHC):
- Two types: LHC I in PS I and LHC II in PS II.
- Cytochrome b6 f complex: It is the non-pigmented protein complex connecting PS I and PS II. Plastoquinone (PQ) and Plastocyanin (PC) are intermediate complexes acting as mobile or shuttle electron carriers of Electron Transport Chain. PQ acts as

utilizes energy from ETC and converts ADP and inorganic phosphate (P_i) into ATP (Figure 13.14).

13.11 Photophosphorylation

Phosphorylation taking place during respiration is called as **oxidative phosphorylation** and ATP produced by the breakdown of substrate is known as **substrate level phosphorylation**. In this topic, we are going to learn about phosphorylation taking place in chloroplast with the help of light. During the movement of electrons through carrier molecules ATP and NADPH + H^+ are produced. Phosphorylation is the process

of synthesis of ATP by the addition of inorganic phosphate to ADP. The addition of phosphate here takes place with the help of light generated electron and so it is called as **photophosphorylation**. It takes place in both cyclic and non-cyclic electron transport.

13.11.1 Cyclic Photophosphorylation

Cyclic photophosphorylation refers to the electrons ejected from the pigment system I (Photosystem I) and again cycled back to the PS I. When the photons activate P700 reaction centre photosystem II is activated. Electrons are raised to the high energy level. The primary electron acceptor is Ferredoxin Reducing Substance (FRS) which transfers electrons to Ferredoxin (Fd), Plastoquinone (PQ), cytochrome b6-f complex, Plastocyanin (PC) and finally back to chlorophyll P700 (PS I). During this movement of electrons Adenosine Di Phosphate (ADP) is phosphorylated, by the addition of inorganic phosphate and generates Adenosine Tri Phosphate (ATP). Cyclic electron transport produces only ATP and there is no NADPH + H^+ formation. At each step of electron transport, electron loses potential energy and is used by the transport chain to pump H^+ ions across the thylakoid membrane. The proton gradient triggers ATP formation in ATP synthase enzyme situated on the thylakoid membrane. Photosystem I need light of longer wave length (> P700 nm). It operates under low light intensity, less CO_2 and under anaerobic conditions which makes it considered as earlier in evolution (Figure 13.15).

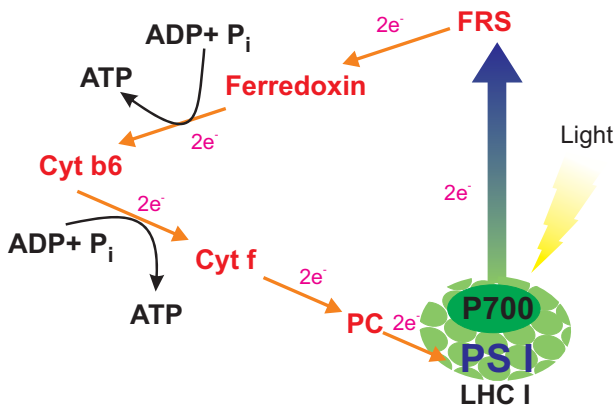


Figure 13.15: Cyclic Photophosphorylation

13.11.2 Non-Cyclic Photophosphorylation

When photons are activated reaction centre of pigment system II(P680), electrons are moved to the high energy level. Electrons from high energy state passes through series of electron carriers like pheophytin, plastoquinone, cytochrome complex, plastocyanin and finally accepted by PS I (P700). During this movement of electrons from PS II to PS I ATP is generated (Figure 13. 16). PS I (P700) is activated by light, electrons are moved to high energy state and accepted by electron acceptor molecule ferredoxin reducing Substance (FRS). During the downhill movement through ferredoxin, electrons are transferred to $NADP^+$ and reduced into NADPH + H^+ (H^+ formed from splitting of water by light).

Electrons released from the photosystem II are not cycled back. It is used for the reduction of $NADP^+$ in to NADPH + H^+. During the electron transport it generates ATP and hence this type of photophosphorylation is called **non-cyclic photophosphorylation**. The electron flow looks like the appearance of letter 'Z' and so known as **Z scheme**. When there is availability of $NADP^+$ for reduction and when there is splitting of

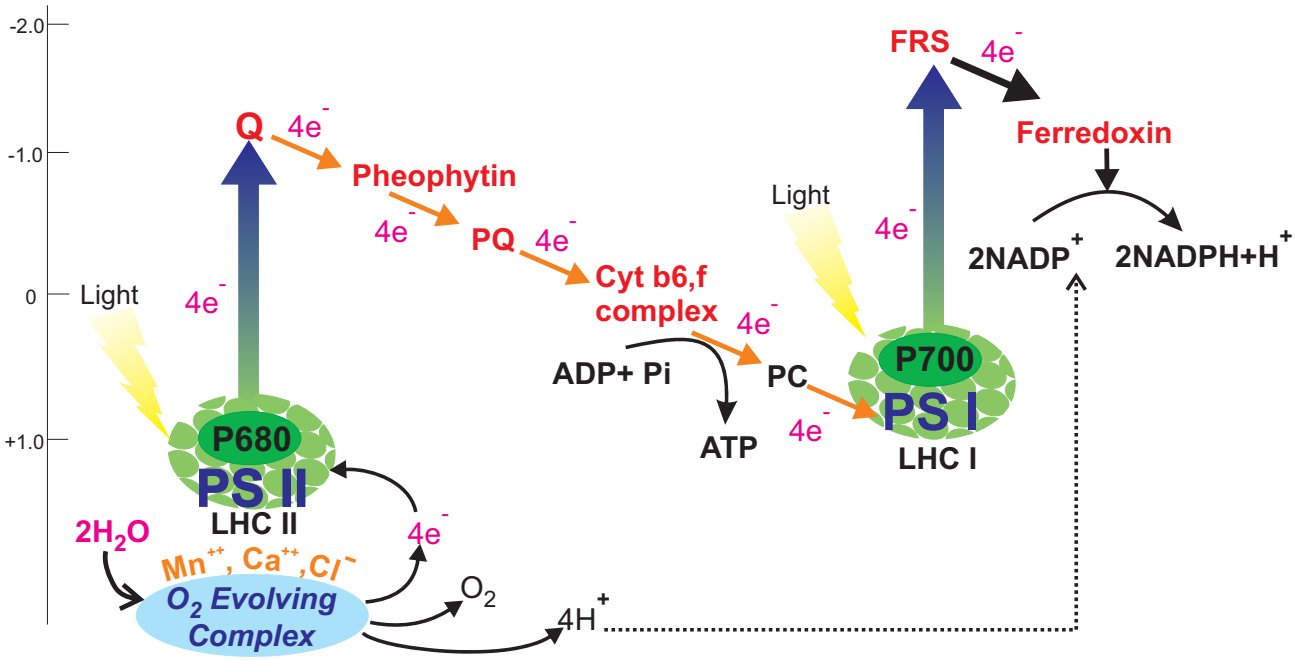


Figure 13.16: Non-Cyclic Photophosphorylation

water molecules both PS I and PS II are activated (Table 13.3). Non-cyclic electron transport PS I and PS II both are involved co-operatively to transport electrons from water to $NADP^+$ (Figure 13.6). In oxygenic species non-cyclic electron transport takes place in three stages.

i. Electron transport from water to P680:

Splitting of water molecule produce electrons, protons and oxygen. Electrons lost by the PS II (P680) are replaced by electrons from splitting of water molecule.

ii. Electron transport from P680 to P700:

Electron flow starts from P680 through a series of electron carrier molecules like pheophytin, plastoquinone (PQ), cytochrome b_6-f complex, plastocyanin (PC) and finally reaches P700 (PS I).

iii. Electron transport from P700 to $NADP^+$

PS I(P700) is excited now and the electrons pass to high energy level. When electron travels downhill through ferredoxin, $NADP^+$ is reduced to NADPH + H^+.

13.11.3 Bio energetics of light reaction

- To release one electron from pigment system it requires two quanta of light.
- One quantum is used for transport of electron from water to PS I.
- Second quantum is used for transport of electron from PS I to $NADP^+$
- Two electrons are required to generate one NADPH + H^+.
- During Non-Cyclic electron transport two NADPH + H^+ are produced and it requires 4 electrons.
- Transportation of 4 electrons requires 8 quanta of light.

Check your grasp!

Name the products produced from Non-Cyclic photophosphorylation?

Why does PS II require electrons from water?

Can you find the difference in the Pathway of electrons during PS I and PS II?

Table 13.3 Differences between Cyclic Photophosphorylation and Non-Cyclic Photophosphorylation	
Cyclic Photophosphorylation	**Non-Cyclic Photophosphorylation**
1. PS I only involved	1. PS I and PS II involved
2. Reaction centre is P700	2. Reaction centre is P680
3. Electrons released are cycled back	3. Electron released are not cycled back
4. Photolysis of water does not take place	4. Photolysis of water takes place
5. Only ATP synthesized	5. ATP and NADPH + $H^+$are synthesized
6. Phosphorylation takes place at two places	6. Phosphorylation takes place at only one place
7. It does not require an external electron donor	7. Requires external electron donor like H_2O or H_2S
8. It is not sensitive to dichloro dimethyl urea (DCMI)	8. It is sensitive to DCMI and inhibits electron flow

13.12 Chemiosmotic Theory

Chemiosmotic theory was proposed by **P. Mitchell** (1966). According to this theory electrons are transported along the membrane through PS I and PS II and connected by Cytochrome b6-f complex. The flow of electrical current is due to difference in electrochemical potential of protons across the membrane. Splitting of water molecule takes place inside the membrane. Protons or H^+ ions accumulate within the lumen of the thylakoid (H^+ increase 1000 to 2000 times). As a result, proton concentration is increased inside the thylakoid lumen. These protons move across the membrane because the primary acceptor of electron is located outside the membrane. Protons in stroma less in number and creates a proton gradient. This gradient is broken down due to the movement of proton across the membrane to the stroma through CF_O of the ATP synthase enzyme. The proton motive force created inside the lumen of thylakoid or chemical gradient of H^+ ion across the membrane stimulates ATP generation (Figure 13.17).

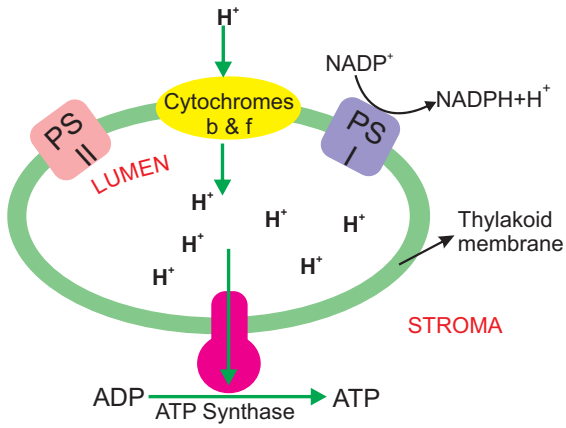


Figure 13.17: Chemiosmotic Theory

The evolution of one oxygen molecule (4 electrons required) requires 8 quanta of light. C_3 plants utilise 3 ATPs and 2 NADPH + H^+ to evolve one Oxygen molecule. To evolve 6 molecules of Oxygen 18 ATPs and 12 NADPH + H^+ are utilised. C_4 plants utilise 5 ATPs and 2 NADPH + H^+ to evolve one oxygen molecule. To evolve 6 molecules of Oxygen 30 ATPs and 12 NADPH + H^+ are utilised.

Check your grasp!

What will be the quanta requirement for complete light reaction which releases 6 oxygen molecules?

Solution: Complete light reaction releases 6 oxygen molecules. If one molecule of oxygen evolution requires 8 quanta means, for 6 oxygen molecules 6 × 8 = 48 quanta of light required for complete light reaction.

13.13 Dark Reaction or C_3 Cycle or Biosynthetic Phase or Photosynthetic Carbon Reduction (PCR)Cycle

Biosynthetic phase of photosynthesis utilises assimilatory powers(ATP and NADPH + H^+) produced during light reaction are used to fix and reduce carbon dioxide into carbohydrates. This reaction does not require light. Therefore, it is named Dark reaction. Ribulose 1,5 bisphosphate (RUBP) act as acceptor molecule of carbon dioxide and fix the CO_2 by RUBISCO enzyme. The first product of the pathway is a 3- carbon compound (Phospho Glyceric Acid) and so it is also called as C_3 Cycle. It takes place in the stroma of the chloroplast. **M. Melvin Calvin, A.A. Benson** and their co-workers in the year 1957 found this path way of carbon fixation. Melvin Calvin was awarded Nobel Prize for this in 1961 and this pathway named after the discoverers as **Calvin-Benson** Cycle. Dark reaction is temperature dependent and so it is also called thermo-chemical reaction.

Dark reaction consists of three phases: (Figure 13.18).

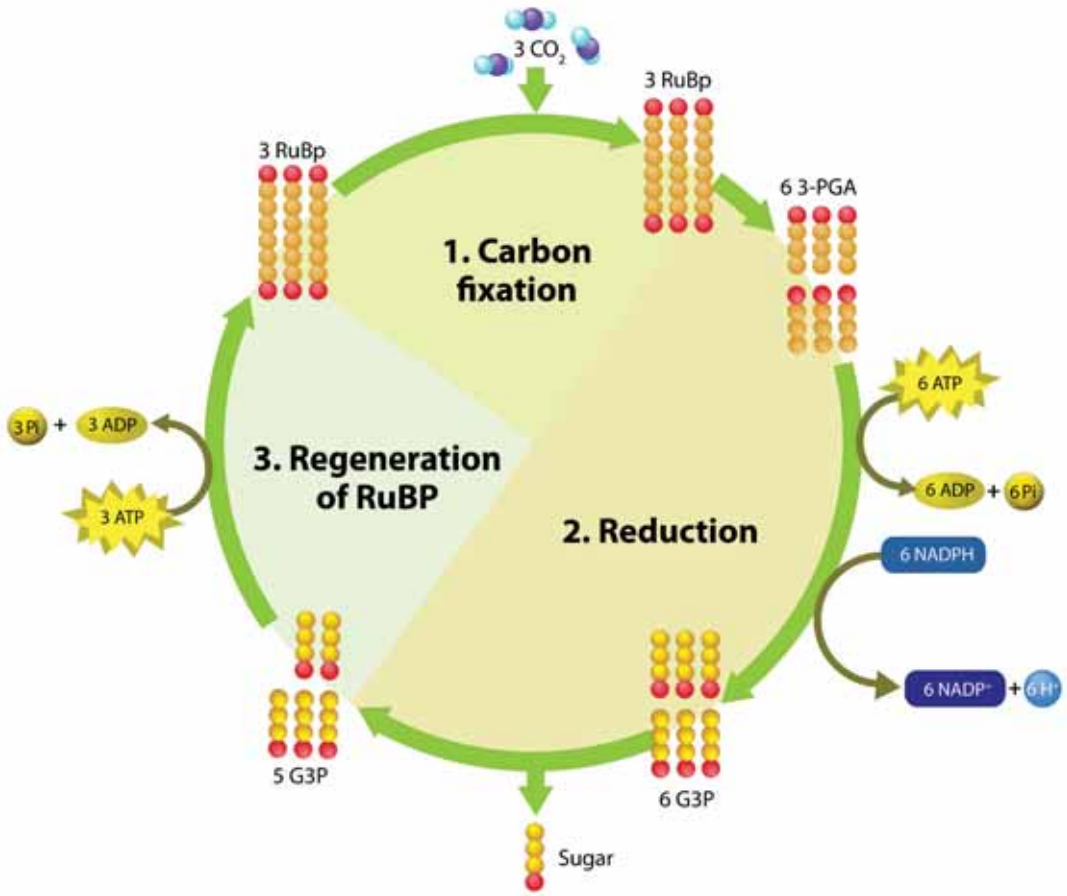


Figure 13.18: Phases of Calvin Cycle

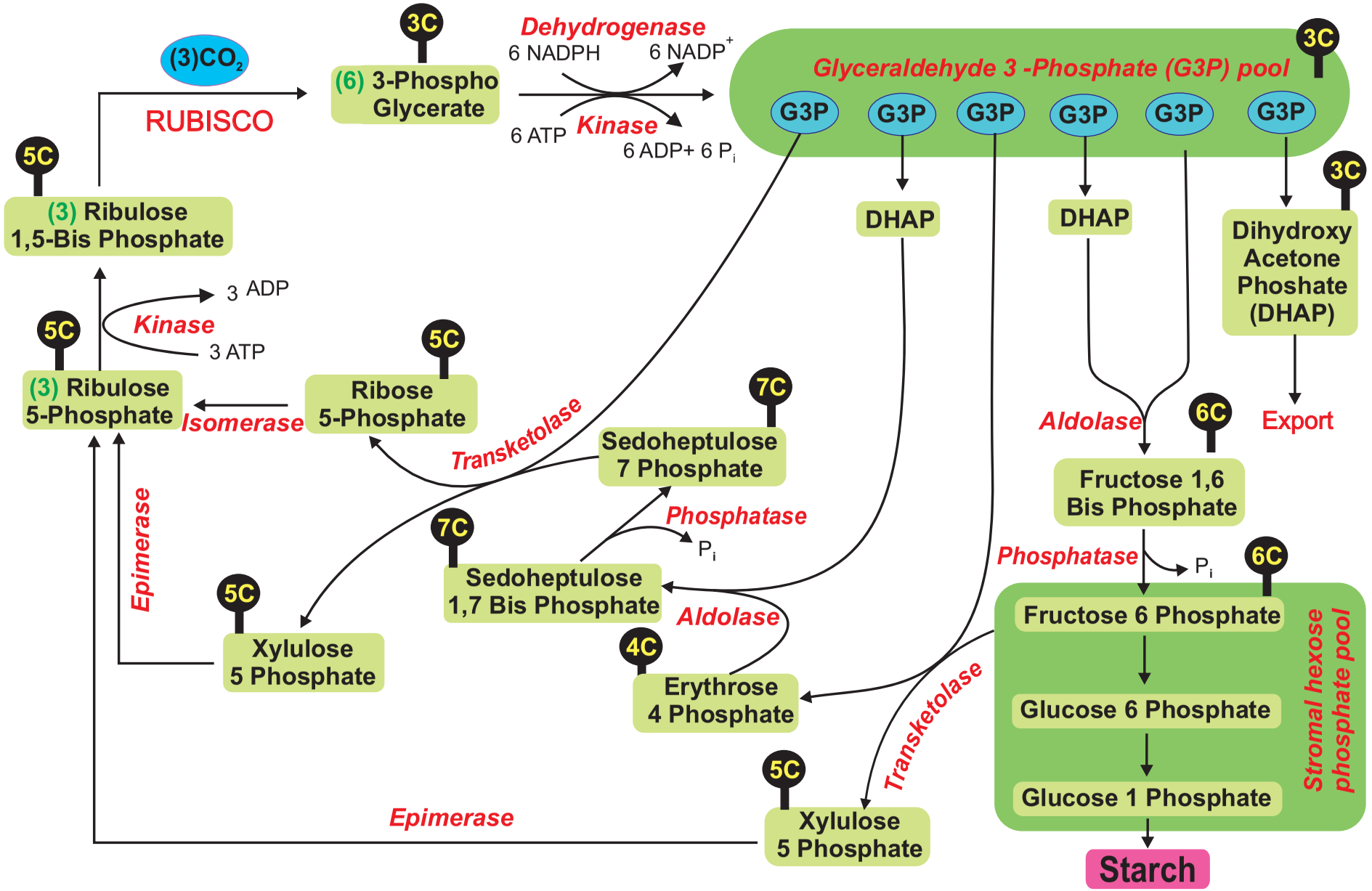


Figure 13.19: Calvin Cycle

1. Carboxylation (fixation)
2. Reduction (Glycolytic Reversal)
3. Regeneration

Phase 1- Carboxylation (Fixation)

The acceptor molecule Ribulose 1,5 Bisphosphate (RUBP) a 5 carbon compound with the help of RUBP carboxylase oxygenase (RUBISCO) enzyme accepts one molecule of carbon dioxide to form an unstable 6 carbon compound. This 6C compound is broken down into two molecules of 3-carbon compound phospho glyceric acid (PGA) (Figure 13.19).

$$RUBP + CO_2 \xrightarrow{Rubisco} 2 \text{ molecules PGA}$$

Phase 2 – Glycolytic Reversal / Reduction

Phospho glyceric acid is phosphorylated by ATP and produces 1,3 bis phospho glyceric acid by PGA kinase. 1,3 bis phospho glyceric acid is reduced to glyceraldehyde 3 Phosphate (G-3-P) by using the reducing power NADPH + H^+. Glyceraldehyde 3 phosphate is converted into its isomeric form dihydroxy acetone phosphate (DHAP).

$$PGA \xrightarrow[ATP \quad ADP]{PGA\ Kinase} 1,3\ bisphosphoglyceric\ acid$$

$$1,3\ bisphosphoglceric\ acid \xrightarrow[]{NADPH + H^+ \quad NADP^+} Glyceraldehyde\text{-}3\text{-}Phosphate$$

Phase 3 – Regeneration

Regeneration of RUBP involves the formation of several intermediate compounds of 6-carbon, 5-carbon, 4-carbon and 7- carbon skeleton. Fixation of one carbon dioxide requires 3 ATPs and 2 NADPH + H^+, and for the fixation of 6 CO_2 requires 18 ATPs and 12 NADPH + H^+ during C_3 cycle. One 6 carbon compound is the net gain to form hexose sugar.

$$RU5P \xrightarrow[ATP \quad ADP]{} RUBP$$

Overall equation for dark reaction:

$$6CO_2 + 18ATP + 12NADPH + H^+ \longrightarrow C_6H_{12}O_6 + 6H_2O + 18ADP + 18Pi + 12NADP^+$$

RUBISCO – RUBP Carboxylase Oxygenase enzyme, is the most abundant protein found on earth. It constitutes 16 % of the chloroplast protein. It acts as carboxylase in the presence of CO_2 and oxygenase in the absence of CO_2.

13.14 Hatch & Slack Pathway or C_4 Cycle or Dicarboxylic Acid Pathway or Dicarboxylation Pathway

Till 1965, Calvin cycle is the only pathway for CO_2 fixation. But in 1965, **Kortschak**, **Hart** and **Burr** made observations in sugarcane and found C_4 or dicarboxylic acid pathway. Malate and aspartate are the major labelled products. This observation was confirmed by **Hatch** & **Slack** in 1967. This alternate pathway for the fixation of CO_2 was found in several tropical and sub-tropical grasses and some dicots. C_4 cycle is discovered in more than 1000 species. Among them 300 species belong to dicots and rest of them are monocots. C_4 plants represent about 5% of

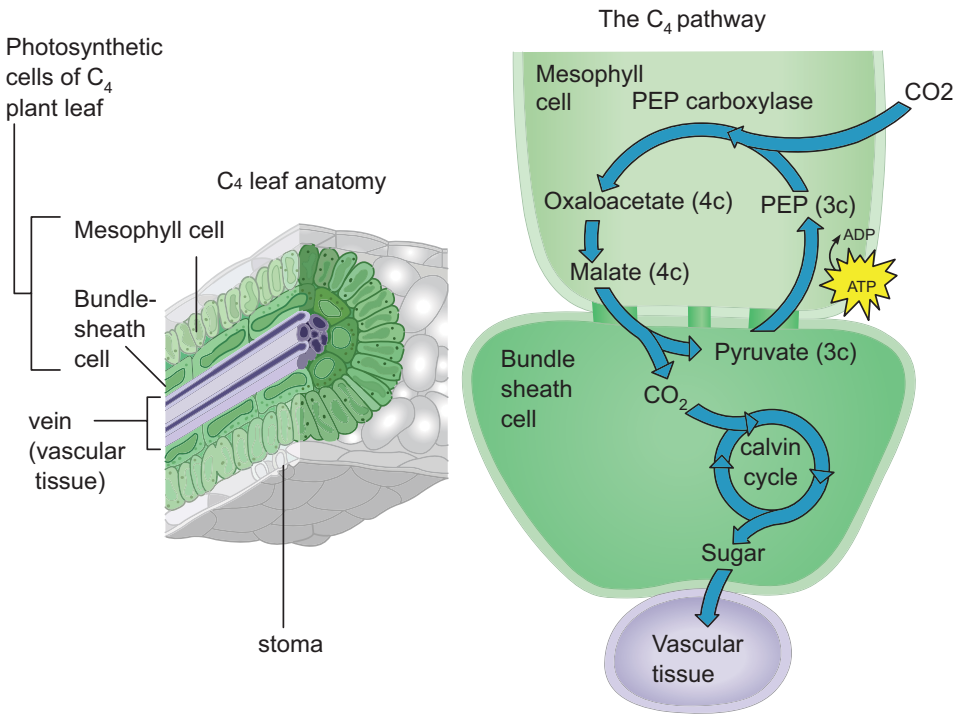


Figure 13.20: C_4 Cycle

Earth's plant biomass and 1% of its known plant species. Despite this scarcity, they account for about 30% of terrestrial carbon fixation. Increasing the proportion of C_4 plants on earth could assist biosequestration of CO_2 and represent an important climate change avoidance strategy.

C_4 pathway is completed in two phases, first phase takes place in stroma of mesophyll cells, where the CO_2 acceptor molecule is 3-Carbon compound, phospho enol pyruvate (PEP) to form 4-carbon Oxalo acetic acid (OAA). The first product is a 4-carbon and so it is named as C_4 cycle. oxalo acetic acid is a dicarboxylic acid and hence this cycle is also known as **dicarboxylic acid pathway** (Figure 13.20). Carbon dioxide fixation takes place in two places one in mesophyll and another in bundle sheath cell (dicarboxylation pathway). It is the adaptation of tropical and sub tropical plants growing in warm and dry conditions. Fixation of CO_2 with minimal loss is due to absence of photorespiration. C_4 plants require 5 ATP and 2 NADPH + H^+ to fix one molecule of CO_2.

13.14.1 Stage: I Mesophyll Cells

Phosphoenol Pyruvate + CO_2
(PEP) (3C)
PEP carboxylase
↓
Oxaloacetic acid (OAA) (4C)

Oxaloacetic acid (OAA) is converted into malic acid or aspartic acid and is transported to the bundle sheath cells through plasmodesmata.

13.14.2 Stage: II Bundle Sheath Cells

Malic acid undergoes decarboxylation and produces a 3 carbon compound Pyruvic acid and CO_2. The released CO_2 combines with RUBP and follows the calvin cycle and finally sugar is released to the phloem. Pyruvic acid is transported to the mesophyll cells.

$$\underset{(5C)}{RUBP} + CO_2 \xrightarrow{\text{Rubisco}} \underset{(3C)}{2\ PGA}$$

Activity

- Collect the leaves of Paddy (C_3) and Sugar cane (C_4).
- Take the cross section.
- Observe the sections under the microscope.
- See the difference in their anatomy (Dimorphic chloroplast and Kranz anatomy).

Kranz Anatomy: It is the German term meaning a halo or wreath. In C_4 plants vascular bundles are surrounded by a layer of bundle sheath. Bundle sheath is surrounded by a ring of mesophyll cells. The characteristic feature of C_4 plants is the presence of dimorphic chloroplast:

Bundle sheath chloroplast: Larger chloroplast, thylakoids not arranged in granum and rich in starch.

Mesophyll Chloroplast: Smaller chloroplast, thylakoids arranged in granum and less starch.

Table 13.4: Differences between C_3 and C_4 plants

C_3 Plants	C_4 Plants
1. CO_2 fixation takes place in mesophyll cells only	1. CO_2 fixation takes place mesophyll and bundle sheath
2. CO_2 acceptor is RUBP only	2. PEP in mesophyll and RUBP in bundle sheath cells
3. First product is 3C- PGA	3. First product is 4C- OAA
4. Kranz anatomy is not present	4. Kranz anatomy is present
5. Granum is present in mesophyll cells	5. Granum present in mesophyll cells and absent in bundle sheath
6. Normal Chloroplast	6. Dimorphic chloroplast
7. Optimum temperature 20° to 25°C	7. Optimum temperature 30° to 45°C
8. Fixation of CO_2 at 50 ppm	8. Fixation of CO_2 even less than 10 ppm
9. Less efficient due to higher photorespiration	9. More efficient due to less photorespiration
10. RUBP carboxylase enzyme used for fixation	10. PEP carboxylase and RUBP carboxylase used
11. 18 ATPs used to synthesize one glucose	11. Consumes 30 ATPs to produce one glucose.
12. Efficient at low CO_2	12. Efficient at higher CO_2
13. Example: Paddy, Wheat, Potato and so on	13. Example: Sugar cane, Maize, *Sorghum*, *Amaranthus* and so on

Check your grasp!

C_4 plants requires 30 ATPs and 12 NADPH + H^+ to synthesize one glucose, but C_3 plants requires only 18 ATPs and 12 NADPH + H^+ to synthesize one glucose molecule. If then, how can you say C_4 plants are more advantageous?

Solution: C_4 plants are more advantageous than C_3 plants because most of the energy lost during photo respiration in C_3 plants.

13.14.3 Significance of C_4 cycle

1. Plants having C_4 cycle are mainly of tropical and sub-tropical regions and are able to survive in environment with low CO_2 concentration.
2. C_4 plants are partially adapted to drought conditions.
3. Oxygen has no inhibitory effect on C_4 cycle since PEP carboxylase is insensitive to O_2.
4. Due to absence of photorespiration, CO_2 Compensation Point for C_4 is lower than that of C_3 plants.

Differences between C_3 Plants (C_3 Cycle) and C_4 Plants (C_4 Cycle) are given in table 13.4.

13.15 Crassulacean Acid Metabolism or CAM cycle

It is one of the carbon pathways identified in succulent plants growing in semi-arid or xerophytic condition. This was first observed in crassulaceae family plants like *Bryophyllum*, *Sedum*, *Kalanchoe* and is the reason behind the name of this cycle. It is also noticed in plants from other families Examples: *Agave*, *Opuntia*, Pineapple and Orchids. The stomata are closed during day and are open during night (Scotoactive). This reverse stomatal rhythm helps to conserve water loss through transpiration and will stop the fixation of CO_2 during the day time. At night time CAM plants fix CO_2

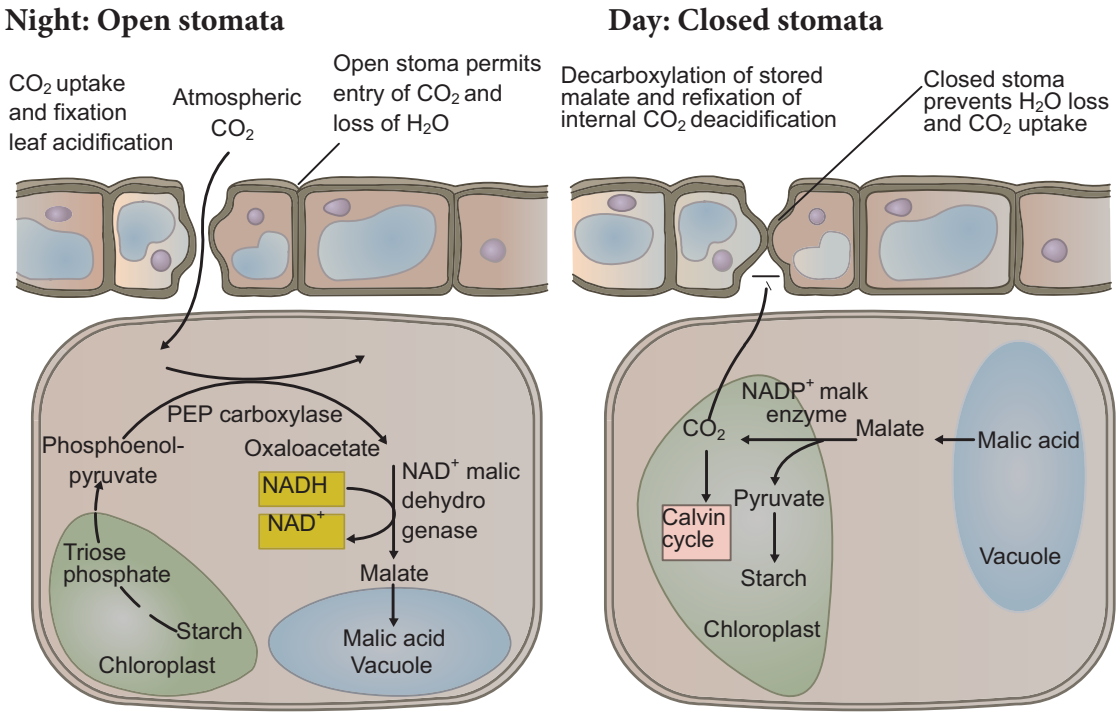


Figure 13.21: CAM cycle

with the help of Phospho Enol Pyruvic acid (PEP) and produce oxalo acetic acid (OAA). Subsequently OAA is converted into malic acid like C_4 cycle and gets accumulated in vacuole increasing the acidity. During the day time stomata are closed and malic acid is decarboxylated into pyruvic acid resulting in the decrease of acidity. CO_2 thus formed enters into Calvin Cycle and produces carbohydrates (Figure13.21).

Significance of CAM Cycle

1. It is advantageous for succulent plants to obtain CO_2 from malic acid when stomata are closed.
2. During day time stomata are closed and CO_2 is not taken but continue their photosynthesis.
3. Stomata are closed during the day time and help the plants to avoid transpiration and water loss.

13.16 Photorespiration or C_2 Cycle or Photosynthetic Carbon Oxidation (PCO) Cycle

Respiration is a continuous process for all living organisms including plants. **Decker** (1959) observed that rate of respiration is more in light than in dark. Photorespiration is the excess respiration taking place in photosynthetic cells due to absence of CO_2 and increase of O_2(Table 13.5). This

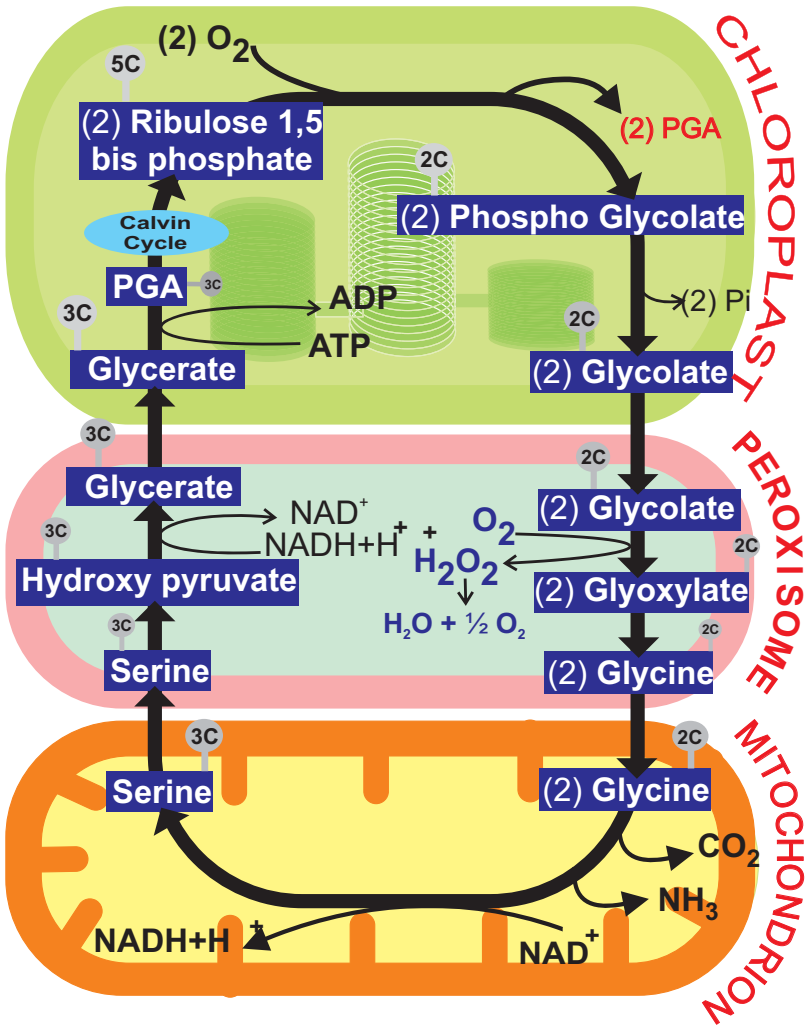


Figure 13.22: Photorespiration

condition changes the carboxylase role of RUBISCO into oxygenase. C_2 Cycle takes place in chloroplast, peroxisome and mitochondria. RUBP is converted into PGA and a 2C-compound phosphoglycolate by Rubisco enzyme in chloroplast. Since the first product is a 2C-compound, this cycle is known as **C_2 Cycle**. Phosphoglycolate by loss of phosphate becomes glycolate. Glycolate formed in chloroplast enters into peroxisome to form glyoxylate and hydrogen peroxide. Glyoxylate is converted into glycine and transferred into mitochondria. In mitochondria, two molecules of glycine combine to form serine. Serine enters into peroxisome to form hydroxy pyruvate. Hydroxy pyruvate with help of NADH + H^+ becomes glyceric acid. Glyceric acid is cycled back to chloroplast utilising ATP and becomes Phosphoglyceric acid (PGA) and enters into the Calvin cycle (PCR cycle). Photorespiration does not yield any free energy in the form of ATP. Under certain conditions 50% of the photosynthetic potential is lost because of Photorespiration (Figure 13.22).

13.16.1 Significance of photorespiration

1. Glycine and Serine synthesised during this process are precursors of many biomolecules like chlorophyll, proteins, nucleotides.
2. It consumes excess NADH + H^+ generated.
3. Glycolate protects cells from Photo oxidation.

13.16.2 Carbon Dioxide Compensation Point

When the rate of photosynthesis equals the rate of respiration, there is no exchange of oxygen and carbon dioxide and this is called as carbon dioxide **compensation point**. This will happen at particular light intensity when exchange of gases becomes zero. When light is not a limiting factor and atmospheric CO_2 concentration is between 50 to 100 ppm the net exchange is zero.

Table 13.5: Differences between Photorespiration and Dark Respiration

Photorespiration	Dark respiration
1. It takes place in photosynthetic green cells	1. It takes place in all living cells
2. It takes place only in the presence of light	2. It takes place all the time
3. It involves chloroplast, peroxisome and mitochondria	3. It involves only mitochondria
4. It does not involve Glycolysis, Kreb's Cycle, and ETS	4. It involves glycolysis, Kreb's Cycle and ETS
5. Substrate is glycolic acid	5. Substrate is carbohydrates, protein or fats
6. It is not essential for survival	6. Essential for survival
7. No phosphorylation and yield of ATP	7. Phosphorylation produces ATP energy
8. $NADH_2$ is oxidised to NAD^+	8. NAD^+ is reduced to $NADH_2$
9. Hydrogen peroxide is produced	9. Hydrogen peroxide is not produced
10. End products are CO_2 and PGA	10. End products are CO_2 and water

13.17 Factors affecting Photosynthesis

In 1860, **Sachs** gave three cardinal points theory explaining minimum, optimum and maximum factors that control photosynthesis. In 1905, **Blackman** put forth the importance of smallest factor. **Blackman's law of limiting factor** is actually a modified Law proposed by **Liebig's Law of minimum**. According to Blackman, *"When a process is conditioned as to its rapidity by a number of separate factors, the rate of the process is limited by the pace of the lowest factor"*. To conclude in an easy way *"at any given point of time the lowest factor among essentials will limit the rate of photosynthesis"*. For example, when even sufficient light intensity is available, photosynthesis may be low due to low CO_2 in the atmosphere. Here, CO_2 acts as a limiting factor. If CO_2 is increased in the atmosphere the rate of photosynthesis also increases. Further increase in photosynthesis is possible only if the available light intensity is also increased proportionately (Figure 13.23).

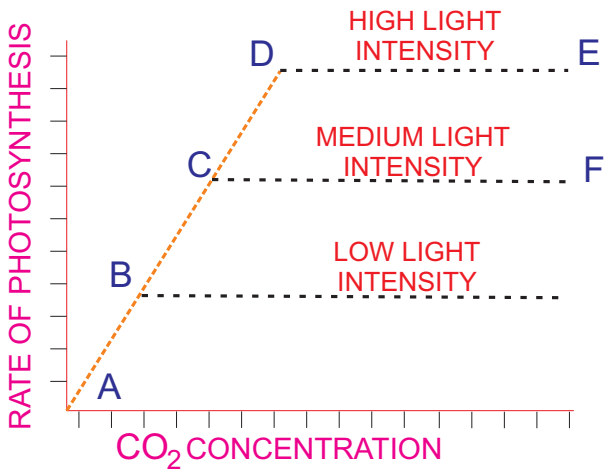


Figure 13.23: Blackman's Law of Limiting Factors

Factors affecting photosynthesis are further grouped into External or Environmental factors and Internal factors.

I. **External factors:** Light, carbon dioxide, temperature, water, mineral and pollutants.

II. **Internal factors:** Pigments, protoplasmic factor, accumulation of carbohydrates, anatomy of leaf and hormones.

13.17.1. External factors

1. Light

Energy for photosynthesis comes only from light. Photooxidation of water and excitation of pigment molecules are directly controlled by light. Stomatal movement leading to diffusion of CO_2 is indirectly controlled by light.

a. Intensity of Light:

Intensity of light plays a direct role in the rate of photosynthesis. Under low intensity the photosynthetic rate is low and at higher intensity photosynthetic rate is higher. It also depends on the nature of plants. Heliophytes (Bean Plant) require higher intensity than Sciophytes (*Oxalis*).

b. Quantity of Light:

In plants which are exposed to light for longer duration (Long day Plants) photosynthetic rate is higher.

c. Quality of light:

Different wavelengths of light affect the rate of photosynthesis because pigment system does not absorb all the rays equally. Photosynthetic rate is maximum in blue and red light. **Photosynthetically Active Radiation** (PAR) is between 400 to 700 nm. Red light induces highest rate of photosynthesis and green light induces lowest rate of photosynthesis.

2. Carbon dioxide

CO_2 is found only 0.3 % in the atmosphere but plays a vital role. Increase in concentration of CO_2 increases the rate of photosynthesis (CO_2 concentration in the atmosphere is 330 ppm). If concentration is increased beyond 500ppm, rate of photosynthesis will be affected showing the inhibitory effect.

3. Oxygen

The rate of photosynthesis decreases when there is an increase of oxygen concentration. This Inhibitory effect of oxygen was first discovered by **Warburg** (1920) using green algae *Chlorella.*

4. Temperature

The optimum temperature for photo synthesis varies from plant to plant. Temperature is not uniform in all places. In general, the optimum temperature for photosynthesis is 25°C to 35°C. This is not applicable for all plants. The ideal temperature for plants like *Opuntia* is 55°C, Lichens 20°C and Algae growing in hot spring photosynthesis is 75°C. Whether high temperature or low temperature it will close the stomata as well as inactivate the enzymes responsible for photosynthesis (Figure 13. 24).

5. Water

Photolysis of water provides electrons and protons for the reduction of NADP, directly. Indirect roles are stomatal movement and hydration of protoplasm. During water stress, supply of NADPH + H^+ is affected.

6. Minerals

Deficiency of certain minerals affect photosynthesis e.g. mineral involved in the synthesis of chlorophyll (Mg, Fe and N), Phosphorylation reactions (P), Photolysis of water (Mn and Cl), formation of plastocyanin (Cu).

7. Air pollutants

Pollutants like SO_2, NO_2, O_3 (Ozone) and Smog affects rate of photosynthesis.

13.17.2 Internal Factors

1. Photosynthetic Pigments

It is an essential factor and even a small quantity is enough to carry out photosynthesis.

2. Protoplasmic factor

Hydrated protoplasm is essential for photosynthesis. It also includes enzymes responsible for Photosynthesis.

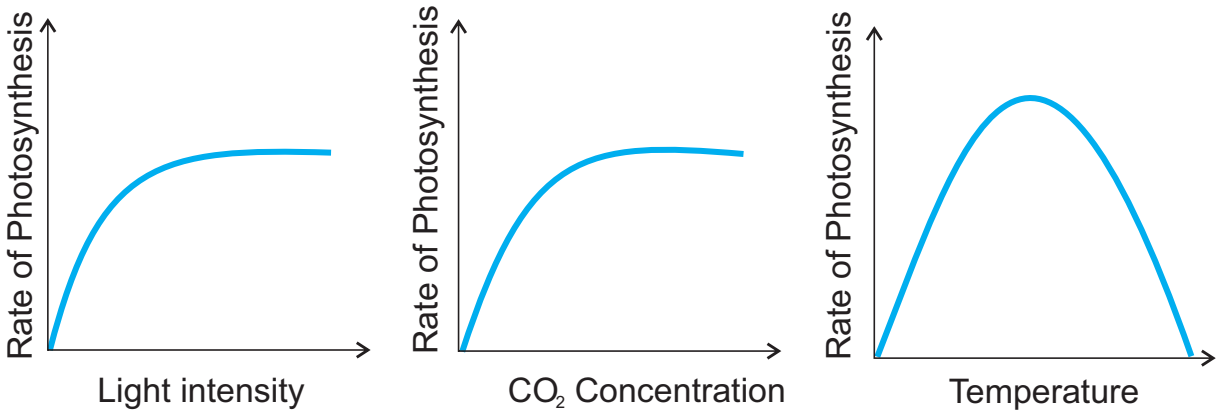


Figure 13.24: Factors affecting Photosynthesis

Experiment to determine rate of photosynthesis by Wilmott's bubbler

Wilmott's bubbler consists of a wide mouth bottle fitted with single holed cork, a glass tube with lower end having wider opening to insert *Hydrilla* plant, the upper end fitted to a narrow bottle with water (Figure 13.25).

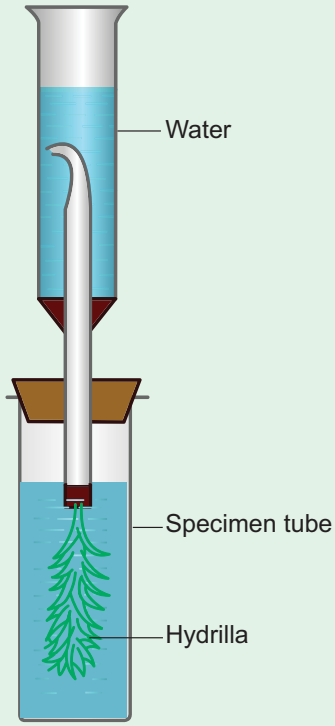


Figure 13.25: Wilmott's Bubbler

1. Fill the bottle with water and insert *Hydrilla* twig into the wider part of the tube
2. *Hydrilla* plant should be cut inside the water to avoid entry of air bubbles
3. Fix the tube with jar which acts as water reservoir
4. Keep the apparatus in sunlight
5. Count the bubbles when they are in same size.

3. Accumulation of Carbohydrates

Photosynthetic end products like carbohydrates are accumulated in cells and if translocation of carbohydrates is slow then this will affect the rate of photosynthesis.

4. Anatomy of leaf

Thickness of cuticle and epidermis, distribution of stomata, presence or absence of Kranz anatomy and relative proportion of photosynthetic cells affect photosynthesis.

5. Hormones

Hormones like gibberellins and cytokinin increase the rate of photosynthesis.

Test tube funnel experiment or Experiment to prove oxygen evolved during Photosynthesis

1. Place *Hydrilla* plant at the bottom of a beaker containing water.
2. Cover the plant with an inverted funnel.
3. Invert a test tube over the funnel.
4. Keep this setup in sunlight.

Note your observations (Figure 13. 26).

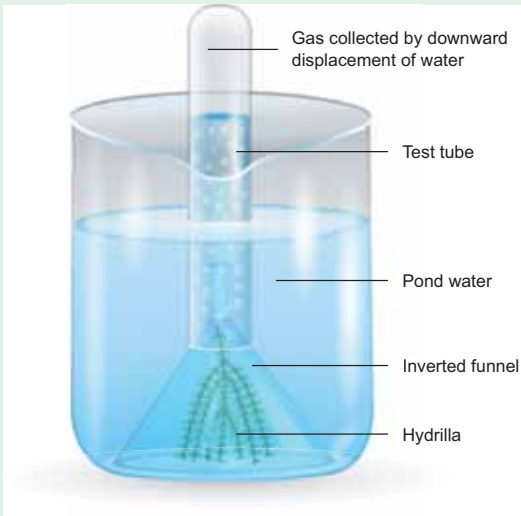


Figure 13.26: Test tube funnel experiment

Table 13.6: Difference between photosynthesis in plants and photosynthesis in bacteria	
Photosynthesis in Plants	**Photosynthesis in Bacteria**
1. Cyclic and non-cyclic phosphorylation takes place	1. Only cyclic phosphorylation takes place
2. Photosystem I and II involved	2. Photosystem I only involved
3. Electron donor is water	3. Electron donor is H_2S
4. Oxygen is evolved	4. Oxygen is not evolved
5. Reaction centres are P700 and P680	5. Reaction centre is P_{870}
6. Reducing agent is NADPH + H^+	6. Reducing agent is NADH + H^+
7. PAR is 400 to 700 nm	7. PAR is above 700 nm
8. Chlorophyll, carotenoid and xanthophyll	8. Bacterio chlorophyll and bacterio viridin
9. Photosynthetic apparatus – chloroplast	9. It is chlorosomes and chromatophores

13.18 Photosynthesis in bacteria

Though we study about bacterial photosynthesis as the last part, bacterial photosynthesis formed first and foremost in evolution. Bacteria does not have specialized structures like chloroplast. It has a simple type of photosynthetic apparatus called chlorosomes and chromatophores (Table 13.6). **Van Neil** (1930) discovered a bacterium that releases sulphur instead of oxygen during photosynthesis. Here, electron donor is hydrogen sulphide (H_2S) and only one photosystem is involved (PS I) and the reaction centre is P_{870}. Pigments present in bacteria are bacteriochlorophyll a, b, c, d, e and g and carotenoids. Photosynthetic bacteria are classified into three groups:

1. Green sulphur bacteria. Example: *Chlorobacterium* and *Chlorobium.*
2. Purple sulphur bacteria. Example: *Thiospirillum* and *Chromatium.*
3. Purple non-sulphur bacteria. Example: *Rhodopseudomonas* and *Rhodospirillum*.

Summary

Photosynthesis is an oxidation and reduction process. It has two phases: the light reaction and dark reaction. During light reaction water is oxidised to release O_2 and during dark reaction $CO_2$is reduced to form sugars. Solar energy is trapped by pigment system I and pigment system II. P700 and P680 act as reaction centres for PS I and PS II respectively. Splitting of water molecule (Photolysis) produces electrons, protons and oxygen. Photophosphorylation takes place through cyclic and non-cyclic mechanisms and generates energy and reducing power. Dark reaction or biosynthetic phase of photosynthesis use the products of light energy (ATP and NADPH + H^+) and carbon dioxide is reduced to Carbohydrates. Carbon pathway in C_3 cycle has RUBP as the acceptor molecule and the first product is PGA (3C). Carbon pathway in C_4 plants involves mesophyll and bundle sheath cells, Kranz anatomy. Dimorphic chloroplast, no photorespiration, acceptor molecule as PEP and first product as OAA (4C) are some of the unique characters of C_4 cycle. C_2 Cycle or photorespiration is operated when less amount of CO_2 is used for reduction and O_2 increases.

Rubisco starts to play oxygenase role. Succulent and xerophytic plants show reverse stomatal rhythm as they open during night time and close during day time and follow CAM cycle. Night time produces malic acid and during day time malate is converted into pyruvate and produces CO_2 which is reduced to carbohydrates. Photosynthesis is affected by internal and external factors. Bacterial photosynthesis is the primitive type of photosynthesis and it involves only photosystem I.

Evaluation

1. **Assertion (A):** Increase in Proton gradient inside lumen responsible for ATP synthesis

   Reason (R): Oxygen evolving complex of PS I located on thylakoid membrane facing Stroma, releases H+ ions

   a. Both Assertion and Reason are True.

   b. Assertion is True and Reason is False.

   c. Reason is True and Assertion is False.

   d. Both Assertion and Reason are False.

2. Which chlorophyll molecule does not have a phytol tail?

   a. Chl- a b. Chl-b c. Chl- c d. Chl -d

3. The correct sequence of flow of electrons in the light reaction is

   a. PS II, plastoquinone, cytochrome, PS I, ferredoxin.

   b. PS I, plastoquinone, cytochrome, PS II ferredoxin.

   c. PS II, ferredoxin, plastoquinone, cytochrome, PS I.

   d. PS I, plastoquinone, cytochrome, PS II, ferredoxin.

4. For every CO_2 molecule entering the C_3 cycle, the number of ATP & NADPH required

   a. 2ATP + 2NADPH

   b. 2ATP + 3NADPH

   c. 3ATP + 2NADPH

   d. 3ATP + 3NADPH

5. Identify true statement regarding light reaction of photosynthesis?

   a. Splitting of water molecule is associate with PS I.

   b. PS I and PS II involved in the formation of NDPH+H^{+}.

   c. The reaction center of PS I is Chlorophyll a with absorption peak at 680 nm.

   d. The reaction center of PS II is Chlorophyll a with absorption peak at 700 nm.

6. Two groups (A & B) of bean plants of similar size and same leaf area were placed in identical conditions. Group A was exposed to light of wavelength 400-450nm & Group B to light of wavelength of 500-550nm. Compare the photosynthetic rate of the 2 groups giving reasons.

7. A tree is believed to be releasing oxygen during night time. Do you believe the truthfulness of this statement? Justify your answer by giving reasons?

8. Grasses have an adaptive mechanism to compensate photorespiratory losses- Name and describe the mechanism.

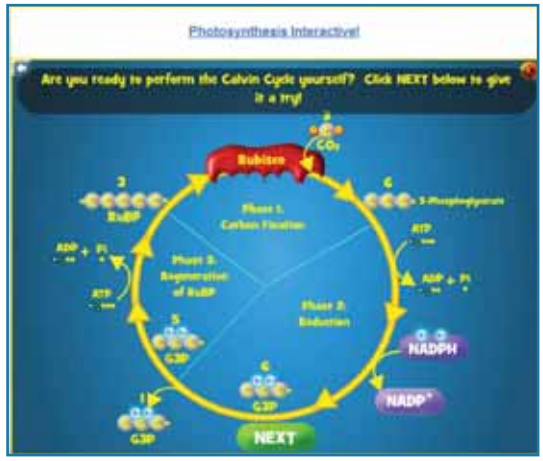
9. In Botany class, teacher explains, Synthesis of one glucose requires 30 ATPs in C_4 plants and only 18 ATPs in C_3plants. The same teacher explains C_4 plants are more advantageous than C_3 plants. Can you identify the reason for this contradiction?

10. When there is plenty of light and higher concentration of O_2, what kind of pathway does the plant undergo? Analyse the reasons.

ICT Corner

Photosynthesis

Let's play
photosynthesis



Steps

- Scan the QR code
- Start a new game and tap
- Click light dependent reaction and follow the steps
- After completion – move back and Click Calvin cycle reaction and follow the steps

Activity

- Observe the cycle and record it
- Check your grasp by click the Quiz tap
- Conclude your observations.

Step 1


Step 2


Step 3


Step 4

Web URL:

https://biomanbio.com/HTML5GamesandLabs/PhotoRespgames/photointeractivehtml5page.html

* Pictures are indicative only

B166_11_BOT_EM

Unit V: Plant Physiology (Functional Organisation)

Chapter 14

Respiration

Learning Objectives

The learner will be able to,

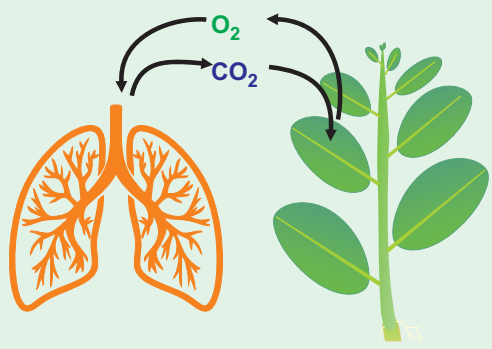
- *Recognize the stages of glucose breakdown and its redox system.*
- *Differentiate aerobic respiration from anaerobic respiration.*
- *Describe the conditions under which respiration occurs.*
- *Realize the role of mitochondria as power house of the cell.*
- *Understand, how ATP molecules are generated during respiration.*

Chapter Outline

CQ9UEZ

Plant and Animal Interdependence

In biosphere, plants and animals are complementary systems which are integrated to sustain life. In plants, oxygen enters through the stomata and it is transported to cells, where oxygen is utilized for energy production. Plants require carbon dioxide to survive, to produce carbohydrates and to release oxygen through photosynthesis. These oxygen molecules are inhaled by human through the nose, which reaches the lungs where oxygen is transported through the blood and it reaches cells. Cellular respiration takes place inside the cell. A specialized respiratory system is present in animals but is absent in plants for delivering oxygen inside the cell. But the cellular respiration stages are similar in both plants and animals which hint at evolutionary divergence.



If you are sleeping under a tree during night time you will feel difficulty in breathing. During night, plants take up oxygen and release carbon dioxide and as a result carbon dioxide will be abundant around the tree. This process of CO_2 evolution is called **respiration**. This process takes place during day time also (Figure 14.1). It is accompanied by breakdown of substrates and release of energy. In this chapter, respiration process in plants at cellular level will be dealt with.

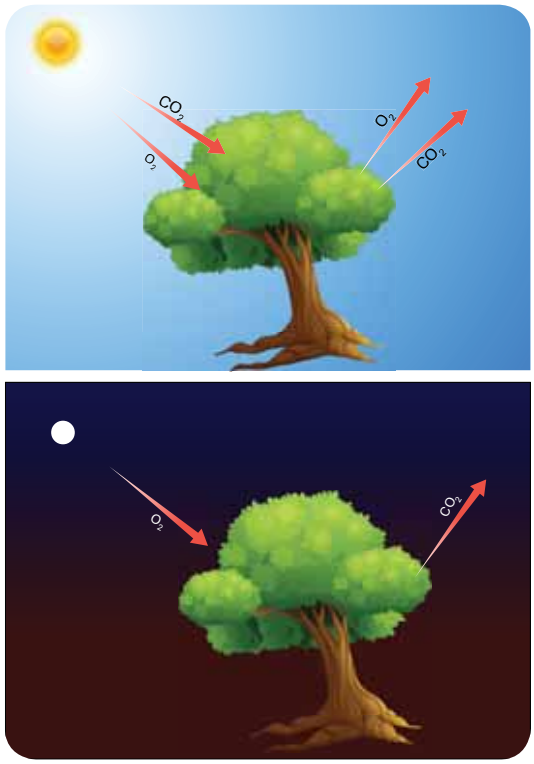


Figure 14.1: Gaseous exchange in plants

14.1 Gaseous Exchange

14.1.1 Respiration

The term respiration was coined by **Pepys** (1966). Respiration is a biological process in which oxidation of various food substances like carbohydrates, proteins and fats take place and as a result of this, energy is produced where O_2 is taken in and CO_2 is liberated. The organic substances which are oxidised during respiration are called respiratory substrates. Among these, glucose is the commonest respiratory substrate. Breaking of C-C bonds of complex organic compounds through oxidation within the cells leads to energy release. The energy released during respiration is stored in the form of **ATP** (Adenosine Tri Phosphate) as well as liberated heat. Respiration occurs in all the living cells of organisms. The overall process of respiration corresponds to a reversal of photosynthesis.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

(686 K cal or 2868 KJ)

Depending upon the nature of respiratory substrate, **Blackman** divided respiration into,

1. Floating respiration
2. Protoplasmic respiration

When carbohydrate or fat or organic acid serves as respiratory substrate and it is called **floating respiration.** It is a common mode of respiration and does not produce any toxic product. Whereas respiration utilizing protein as a respiratory substrate, it is called **protoplasmic respiration**. Protoplasmic respiration is rare and it depletes structural and functional proteins of protoplasm and liberates toxic ammonia.

14.1.2 Compensation point

At dawn and dusk the intensity of light is low. The point at which CO_2 released in respiration is exactly compensated by CO_2 fixed in photosynthesis that means no net gaseous exchange takes place, it is called **compensation point**. At this moment, the amount of oxygen released from photosynthesis is equal to the

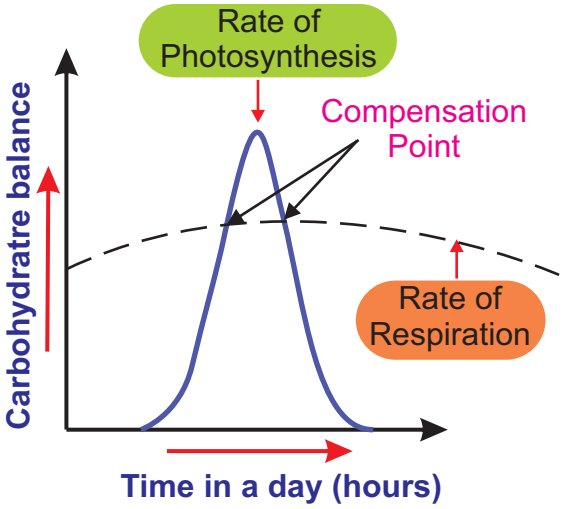


Figure 14.2: Compensation point

amount of oxygen utilized in respiration. The two common factors associated with compensation point are CO_2 and light (Figure 14.2). Based on this there are two types of compensation point. They are CO_2 compensation point and light compensation point. C_3 plants have compensation points ranging from 40-60 ppm (parts per million) CO_2 while those of C_4 plants ranges from 1-5 ppm CO_2.

14.2 Structure of ATP

Respiration is responsible for generation of ATP. The discovery of ATP was made by **Karl Lohman** (1929). ATP is a nucleotide consisting of a base-adenine, a pentose sugar-ribose and three phosphate groups. Out of three phosphate groups the last two are attached by high energy rich bonds (Figure 14.3). On hydrolysis, it releases energy (7.3 K cal or 30.6 KJ/ATP) and it is found in all living cells and hence it is called **universal energy currency of the cell**. ATP is an instant source of energy within the cell. The energy contained in ATP is used in synthesis carbohydrates, proteins and lipids. The energy transformation concept was established by **Lipman** (1941).

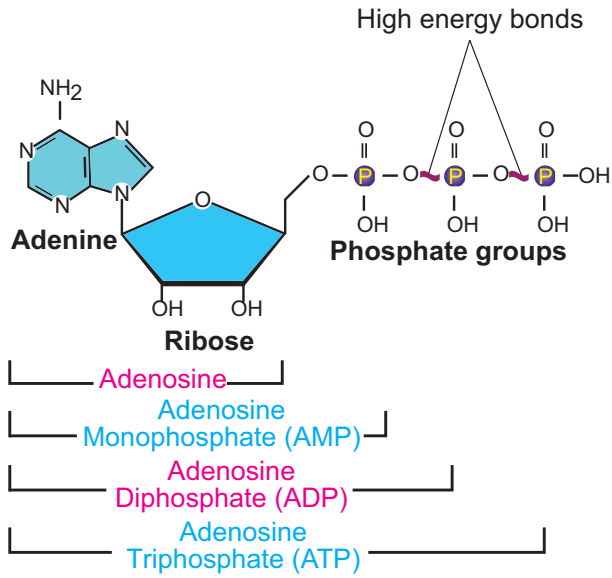


Figure 14.3: Molecular structure of ATP

ATP is not only higher energy compound present in a cell. There are other higher energy compounds also present. Example GTP (Guanosine Tri Phosphate) and UTP (Uridine Tri Phosphate).

14.3 Redox Reactions

$$NAD^+ + 2e^- + 2H^+ \longrightarrow NADH + H^+$$
$$FAD + 2e^- + 2H^+ \longrightarrow FADH_2$$

When NAD^+ (Nicotinamide Adenine Dinucleotide-oxidised form) and FAD (Flavin Adenine Dinucleotide) pick up electrons and one or two hydrogen ions (protons), they get reduced to $NADH + H^+$ and $FADH_2$ respectively. When they drop electrons and hydrogen off they go back to their original form. The reaction in which NAD^+ and FAD gain (reduction) or lose (oxidation) electrons are called **redox reaction** (Oxidation reduction reaction). These reactions are important in cellular respiration.

Handy mnemonic

LEO the lion says GER

LEO - Loss of Electrons is Oxidation

GER - Gain of Electrons is Reduction

14.4 Types of Respiration

Respiration is classified into two types as aerobic and anaerobic respiration (Figure 14.4)

14.4.1 Aerobic respiration

Respiration occurring in the presence of oxygen is called **aerobic respiration**. During aerobic respiration, food materials like carbohydrates, fats and proteins are completely oxidised into CO_2, H_2O and energy is released. Aerobic respiration is a very complex process and is completed in four major steps:

1. Glycolysis
2. Pyruvate oxidation (Link reaction)
3. Krebs cycle (TCA cycle)
4. Electron Transport Chain (Terminal oxidation).

14.4.2 Anaerobic respiration

In the absence of molecular oxygen glucose is incompletely degraded into either ethyl alcohol or lactic acid (Table 14.1). It includes two steps:

1. Glycolysis
2. Fermentation

14.5 Stages of Respiration

1. Glycolysis-conversion of glucose into pyruvic acid in cytoplasm of cell.
2. Link reaction-conversion of pyruvic acid into acetyl coenzyme-A in mitochondrial matrix.
3. Krebs cycle-conversion of acetyl coenzyme A into carbon dioxide and water in the mitochondrial matrix.

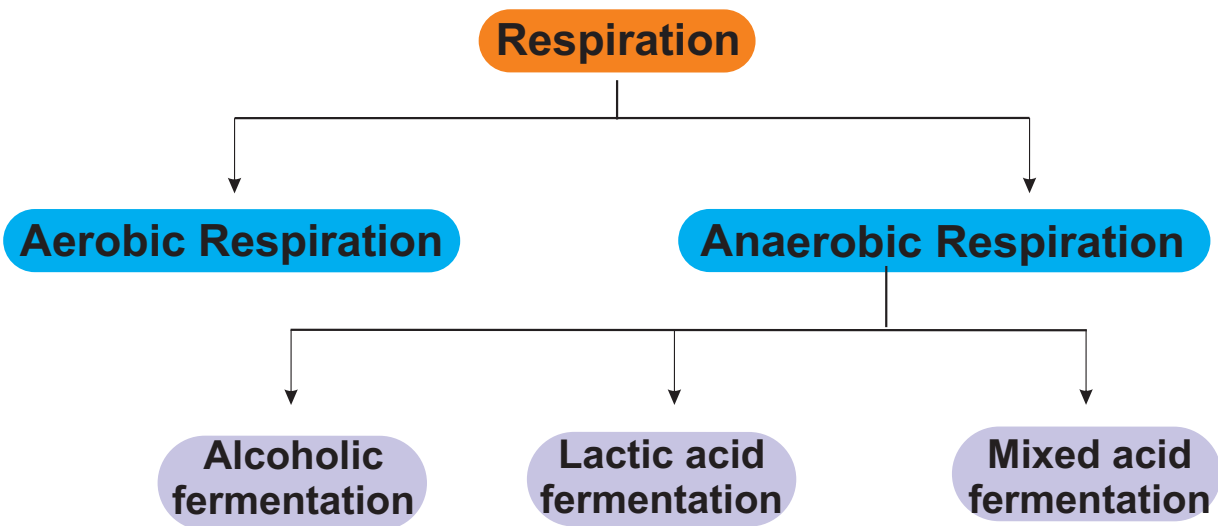


Figure 14.4: Types of Respiration

Table 14.1: Differences between aerobic and anaerobic respiration	
Aerobic respiration	**Anaerobic Respiration**
1. It occurs in all living cells of higher organisms.	It occurs yeast and some bacteria.
2. It requires oxygen for breaking the respiratory substrate.	Oxygen is not required for breaking the respiratory substrate.
3. The end products are CO_2 and H_2O.	The end products are alcohol, and CO_2 (or) lactic acid.
4. Oxidation of one molecule of glucose produces 36 ATP molecules.	Only 2 ATP molecules are produced.
5. It consists of four stages-glycolysis, link reaction, TCA cycle and electron transport chain.	It consists of two stages-glycolysis and fermentation.
6. It occurs in cytoplasm and mitochondria.	It occurs only in cytoplasm.

4. Electron transport chain and oxidative phosphorylation remove hydrogen atoms from the products of glycolysis, link reaction and Krebs cycle release water molecule with energy in the form of ATP in mitochondrial inner membrane (Figure 14.5).

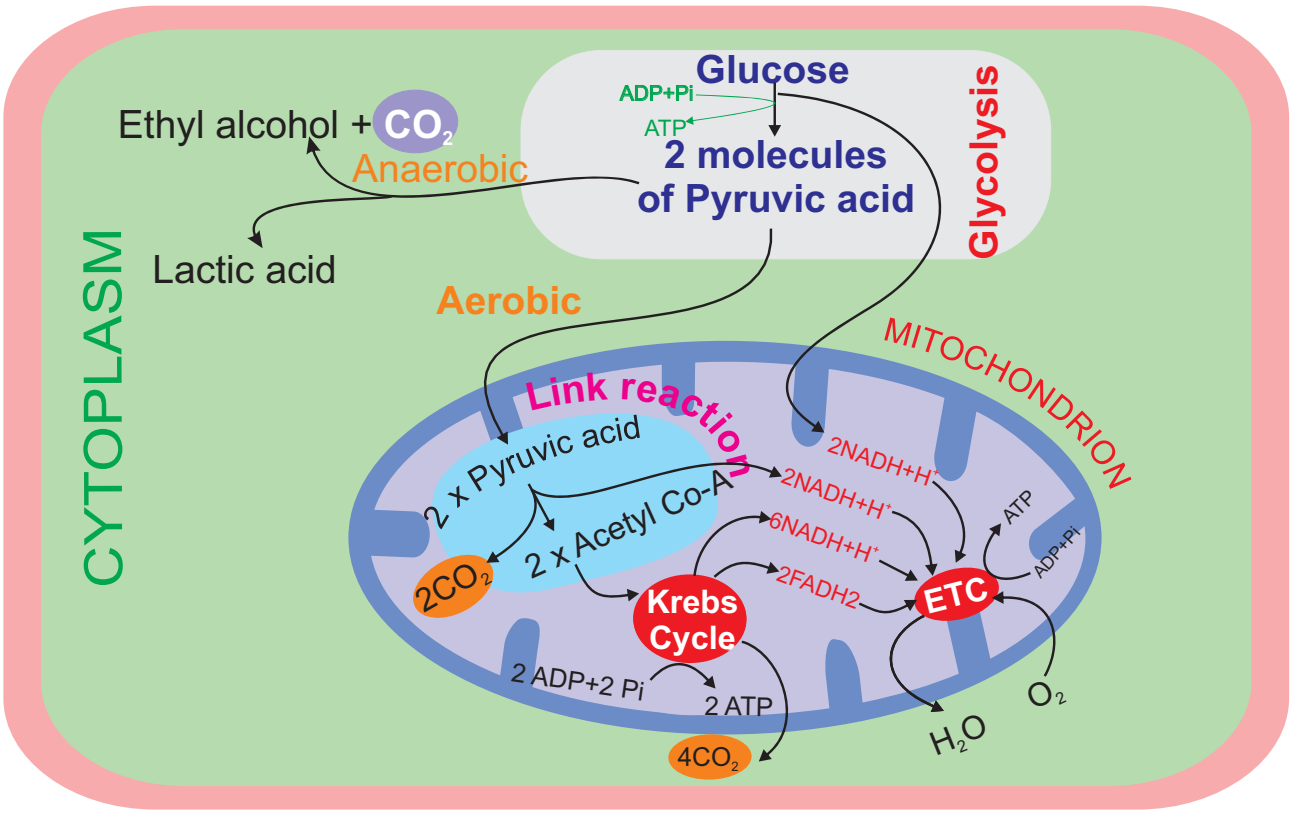


Figure 14.5: Overall stages of Respiration

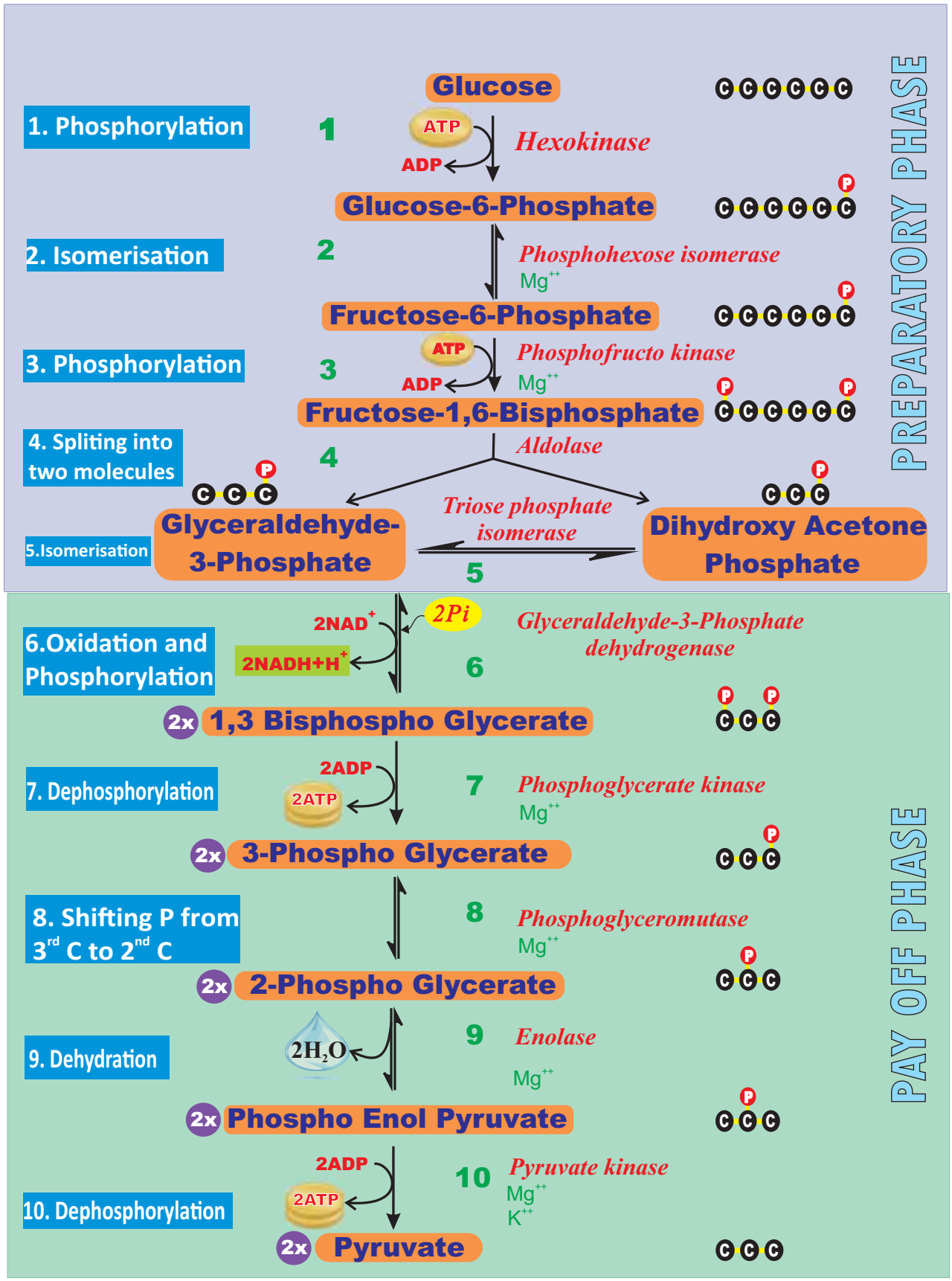


Figure 14.6: Glycolysis or EMP pathway

14.5.1 Glycolysis

(*Gr: Glykos* = Glucose, *Lysis* = Splitting) Glycolysis is a linear series of reactions in which 6-carbon glucose is split into two molecules of 3-carbon pyruvic acid. The enzymes which are required for glycolysis are present in the cytoplasm (Figure 14.6). The reactions of glycolysis were worked out in yeast cells by three scientists **Gustav Embden** (German), **Otto Meyerhoff** (German) and **J Parnas** (Polish) and so it is also called as **EMP pathway**. It is the first and common stage for both aerobic and anaerobic respiration. It is divided into two phases.

1. **Preparatory phase** or endergonic phase or hexose phase (steps 1-5).
2. **Pay off phase** or oxidative phase or exergonic phase or triose phase (steps 6-10).

1. Preparatory phase

Glucose enters the glycolysis from sucrose which is the end product of photosynthesis. Glucose is phosphorylated into glucose-6-phosphate by the enzyme hexokinase, and subsequent reactions are carried out by different enzymes (Figure 14.6). At the end of this phase fructose-1, 6 - bisphosphate is cleaved into glyceraldehyde-3- phosphate and dihydroxy acetone phosphate by the enzyme aldolase. These two are isomers. Dihydroxy acetone phosphate is isomerised into glyceraldehyde-3- phosphate by the enzyme triose phosphate isomerase, now two molecules of glyceraldehyde 3 phosphate enter into pay off phase. During preparatory phase two ATP molecules are consumed in step-1 and step-3 (Figure 14.6).

Check your grasp!

How many ATP molecules are produced from one sucrose molecule?

2. Pay off phase

Two molecules of glyceraldehyde-3-phosphate oxidatively phosphorylated into two molecules of 1,3 - bisphospho glycerate. During this reaction $2NAD^+$ is reduced to $2NADH + H^+$ by glyceraldehyde-3- phosphate dehydrogenase at step 6. Further reactions are carried out by different enzymes and at the end two molecules of pyruvate are produced. In this phase, 2ATPs are produced at step 7 and 2 ATPs at step10 (Figure 14.6). Direct transfer of phosphate moiety from substrate molecule to ADP and is converted into ATP is called **substrate phosphorylation** or **direct phosphorylation** or **trans phosphorylation**. During the reaction at step 9, 2phospho glycerate dehydrated into Phospho enol pyruvate a water molecule is removed by the enzyme enolase. As a result, enol group is formed within the molecule. This process is called **Enolation.**

3. Energy Budget

In the pay off phase totally 4ATP and $2NADH + H^+$ molecules are produced. Since 2ATP molecules are already consumed in the preparatory phase, the net products in glycolysis are 2ATPs and $2NADH + H^+$.

The overall net reaction of glycolysis

$$C_6H_{12}O_6 + 2ADP + 2Pi + 2NAD^+ \downarrow$$
$$2x\ CH_3COCOOH + 2ATP + 2NADH + 2H^+$$

14.5.2 Pyruvate Oxidation (Link reaction)

Two molecules of pyruvate formed by glycolysis in the cytosol enters into the mitochondrial matrix. In aerobic respiration this pyruvate with coenzyme A is oxidatively decarboxylated into acetyl CoA by pyruvate dehydrogenase complex. This reaction is irreversible and produces two molecules of NADH + H^+ and $2CO_2$. It is also called **transition reaction** or **Link reaction**. The reaction of pyruvate oxidation is

$$2x\ CH_3COCOOH + 2NAD^+ + 2CoA$$

$$\downarrow \text{ Pyruvate dehydrogenase complex/ } Mg^{++}$$

$$2xCH_3CO.CoA + 2NADH + 2H^+ + 2CO_2\uparrow$$

Pyruvate dehydrogenase complex consist of three distinct enzymes, such as

1. Pyruvate dehydrogenase
2. Dihydrolipoyil transacetylase
3. Dihydrolipoyil dehydrogenase

and five different coenzymes, TPP (Thymine Pyro Phosphate), NAD^+, FAD, CoA and lipoate.

14.5.3 Krebs cycle or Citric acid cycle or TCA cycle:

Two molecules of acetyl CoA formed from link reaction now enter into Krebs cycle. It is named after its discoverer, German Biochemist **Sir Hans Adolf Krebs** (1937). The enzymes necessary for TCA cycle are found in mitochondrial matrix except succinate dehydrogenase enzyme which is found in mitochondrial inner membrane (Figure 14.7).

Sir Hans Adolf Krebs was born in Germany on 25th August 1900. He was awarded Nobel Prize for his discovery of Citric acid cycle in Physiology in 1953.

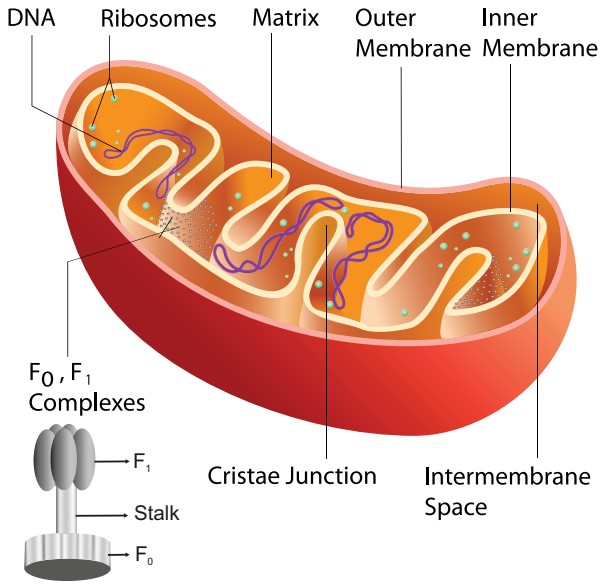


Figure 14.7: Structure of Mitochondrion

TCA cycle starts with condensation of acetyl CoA with oxaloacetate in the presence of water to yield citrate or citric acid. Therefore, it is also known as **Citric Acid Cycle (CAC)** or **Tri Carboxylic Acid (TCA) cycle**. It is followed by the action of different enzymes in cyclic manner. During the conversion of succinyl CoA to succinate by the enzyme succinyl CoA synthetase or succinate thiokinase, a molecule of ATP synthesis from substrate without entering the electron transport chain is called **substrate level phosphorylation.** In animals a molecule of GTP is synthesized from GDP+Pi. In a coupled reaction GTP is converted to GDP with simultaneous synthesis of ATP from ADP+Pi. In three

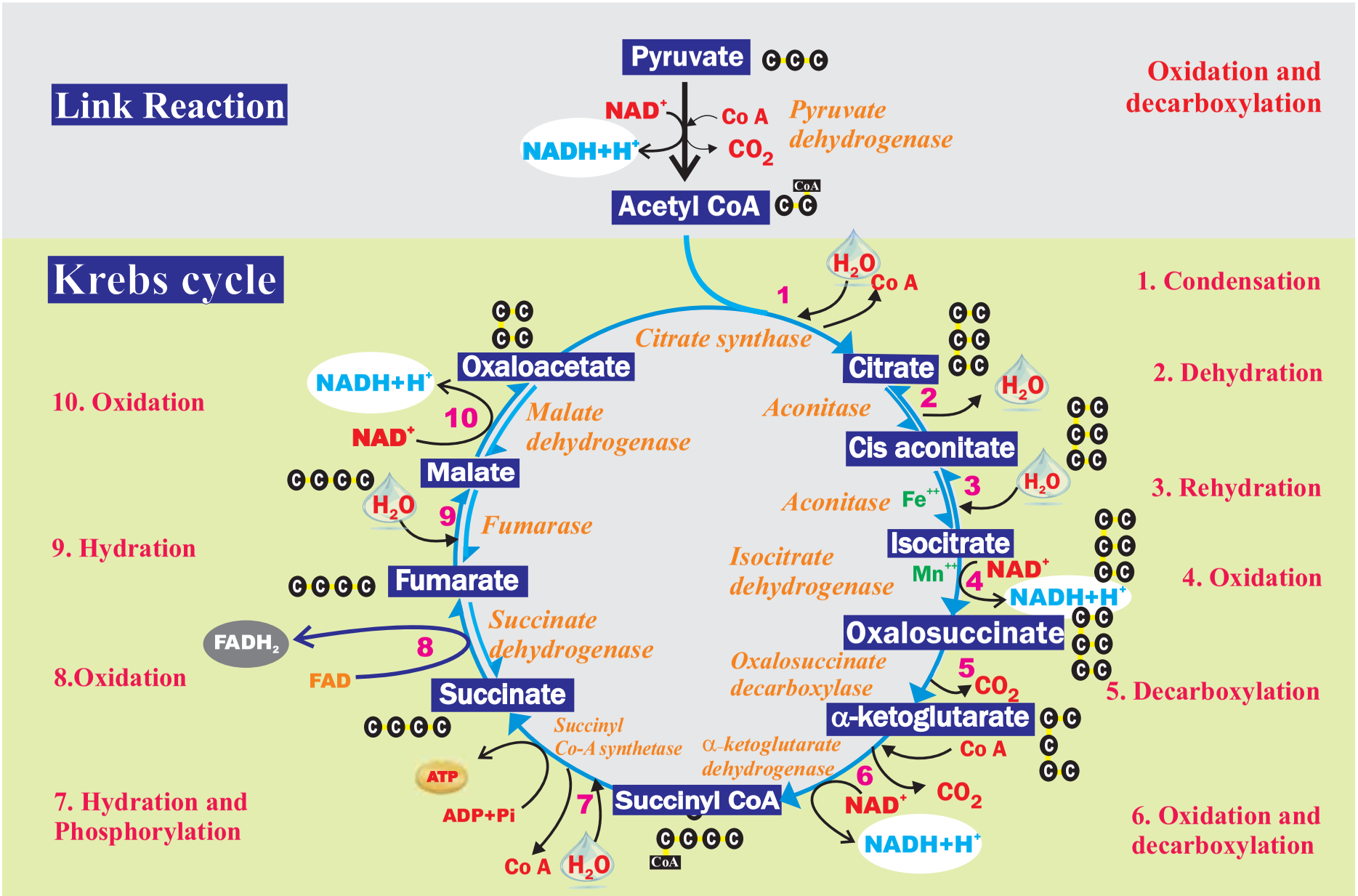


Figure 14.8: Krebs cycle or Citric acid cycle

steps (4, 5, 9) in this cycle NAD^+ is reduced to NADH+ H^+ and at step 7 (Figure14.8) where FAD is reduced to $FADH_2$.

The summary of link reaction and Krebs cycle in Mitochondria is

Pyruvic acid + $4NAD^+$ + FAD + $4H_2O$ + ADP+Pi

↓ Mitochondrial matrix.

$3CO_2$+ 4NADH+$4H^+$ +$FADH_2$ +H_2O+ATP.

Two molecules of pyruvic acid formed at the end of glycolysis enter into the mitochondrial matrix. Therefore, Krebs cycle is repeated twice for every glucose molecule where two molecules of pyruvic acid produces six molecules of CO_2, eight molecules of NADH + H^+, two molecules of $FADH_2$ and two molecules of ATP.

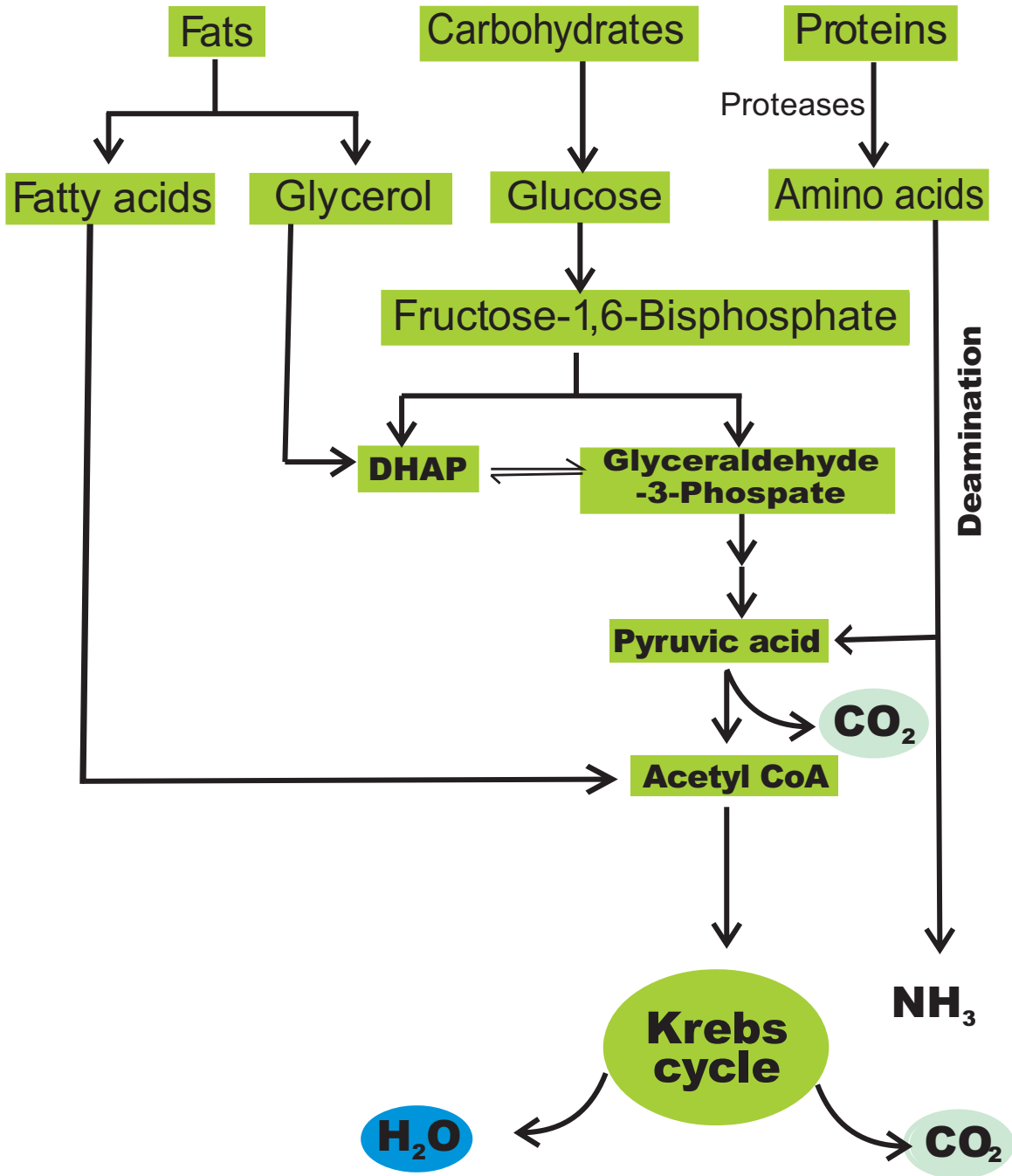


Figure 14.9: Alternative substrates for respiration

1. Significance of Krebs cycle:

1. TCA cycle is to provide energy in the form of ATP for metabolism in plants.
2. It provides carbon skeleton or raw material for various anabolic processes.
3. Many intermediates of TCA cycle are further metabolised to produce amino acids, proteins and nucleic acids.
4. Succinyl CoA is raw material for formation of chlorophylls, cytochrome, phytochrome and other pyrrole substances.
5. α-ketoglutarate and oxaloacetate undergo reductive amination and produce amino acids.
6. It acts as metabolic sink which plays a central role in intermediary metabolism.

2. Amphibolic nature

Krebs cycle is primarily a catabolic pathway, but it provides precursors for various biosynthetic pathways there by an anabolic pathway too. Hence, it is called **amphibolic pathway**. It serves as a pathway for oxidation of carbohydrates, fats and proteins. When fats are respiratory substrate they are first broken down into glycerol and fatty acid. Glycerol is converted into DHAP and acetyl CoA. This acetyl CoA enter into the Krebs cycle. When proteins are the respiratory substrate they are degraded into amino acids by proteases. The amino acids after deamination enter into the Krebs cycle through pyruvic acid or acetyl CoA and it depends upon the structure. So respiratory intermediates form the link between synthesis as well as breakdown. The citric acid cycle is the final common pathway for oxidation of fuel molecules like amino acids, fatty acids and carbohydrates. Therefore, respiratory pathway is an amphibolic pathway (Figure 14.9).

The synthesis of glucose from certain non-carbohydrate carbon substrates such as proteins and lipids are called **gluconeogenesis.**

14.5.4 Electron Transport Chain (ETC) (Terminal oxidation)

During glycolysis, link reaction and Krebs cycle the respiratory substrates are oxidised at several steps and as a result many reduced coenzymes NADH + H^+ and $FADH_2$ are produced. These reduced coenzymes are transported to inner membrane of mitochondria and are converted back to their oxidised forms produce electrons and protons. In mitochondria, the inner membrane is folded in the form of finger projections towards the matrix called cristae. In cristae many oxysomes (F_1 particles) are present which have electron transport carriers are present. According to **Peter Mitchell's Chemiosmotic theory** this electron transport is coupled to ATP synthesis. Electron and hydrogen(proton) transport takes place across four multiprotein complexes(I-IV). They are

1. Complex-I (NADH dehydrogenase). It contains a flavoprotein(FMN) and associated with non-heme iron Sulphur protein (Fe-S). This complex is responsible for passing electrons and protons from mitochondrial NADH **(Internal)** to Ubiquinone(UQ).

$NADH + H^+ + UQ \rightleftharpoons NAD^+ + UQH_2$

In plants, an additional NADH dehydrogenase (**External)** complex is present on the outer surface of inner membrane of mitochondria which can oxidise cytosolic NADH + H^+.

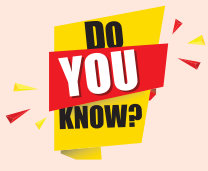
Ubiquinone (UQ) or Coenzyme Quinone(Co Q) is a small, lipid soluble electron, proton carrier located within the inner membrane of mitochondria.

2. Complex-II (Succinic dehydrogenase) It contains FAD flavoprotein is associated with non-heme iron Sulphur (Fe-S) protein. This complex receives electrons and protons from succinate in Krebs cycle and is converted into fumarate and passes to ubiquinone.

Succinate + UQ $\rightarrow$ Fumarate + UQH_2

3. Complex-III (Cytochrome bc_1 complex) This complex oxidises reduced ubiquinone (ubiquinol) and transfers the electrons through Cytochrome bc_1 Complex (Iron Sulphur center bc_1 complex) to cytochrome c. Cytochrome c is a small protein attached to the outer surface of inner membrane and act as a mobile carrier to transfer electrons between complex III to complex IV.

$UQH_2 + 2Cyt\ c_{oxidised} \rightleftharpoons UQ + 2Cyt\ c_{reduced} + 2H^+$



Ubiquinone and cytochrome bc_1 complex are structurally and functionally similar to plastoquinone and cytochrome b_6f complex respectively in the photosynthetic electron transport chain.

4. Complex IV (Cytochrome c oxidase) This complex contains two copper centers (A and B) and cytochromes a and a_3. Complex IV is the terminal oxidase and brings about the reduction of 1/2 O_2 to H_2O.Two protons are needed to form a molecule of H_2O (terminal oxidation).

$2Cyt\ c_{oxidised} + 2H^+ + 1/2\ O_2 \rightleftharpoons 2Cyt\ c_{reduced} + H_2O$

The transfer of electrons from reduced coenzyme NADH to oxygen *via* complexes I to IV is coupled to the synthesis of ATP from ADP and inorganic phosphate (Pi) which is called **Oxidative phosphorylation**. The F_0F_1-ATP synthase (also called complex V) consists of F_0 and F_1. F_1 converts ADP and Pi to ATP and is attached to the matrix side of the inner membrane. F_0 is present in inner membrane and acts as a channel through which protons come into matrix.

Oxidation of one molecule of NADH + H^+ gives rise to 3 molecules of ATP and oxidation of one molecule $FADH_2$ produces 2 molecules of ATP within a mitochondrion. But cytoplasmic NADH + H^+ yields only two ATPs through external NADH dehydrogenase. Therefore, two reduced coenzyme (NADH + H^+) molecules from glycolysis being extra mitochondrial will yield $2 \times 2 = 4$ ATP molecules instead of 6 ATPs (Figure 14.10). The Mechanism of mitochondrial ATP synthesis is based on Chemiosmotic hypothesis. According to this theory electron carriers present in the inner mitochondrial membrane allow for the transfer of protons (H^+). For the production of single ATP, 3 protons (H^+) are needed. The terminal oxidation of external NADH bypasses the first phosphorylation site and hence only two ATP molecules are produced per external NADH oxidised through

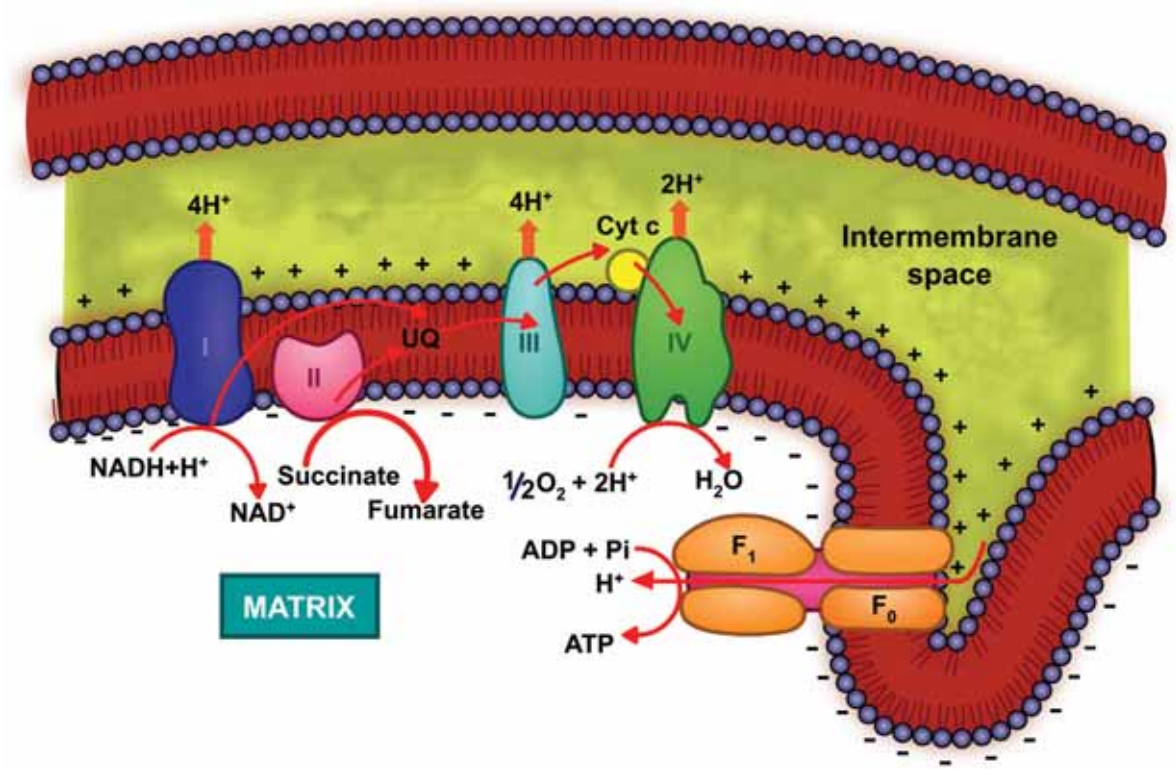


Figure 14.10: Electron Transport Chain and Terminal Oxidation

mitochondrial electron transport chain. However, in those animal tissues in which malate shuttle mechanism is present, the oxidation of external NADH will yield almost 3 ATP molecules.

Abnormal rise in respiratory rate of ripening in fruits is called **Climacteric**. Examples are apple, banana, mango, papaya, pear.

Complete oxidation of a glucose molecule in aerobic respiration results in the net gain of **36 ATP molecules in plants** as shown in table 14.2. Since huge amount of energy is generated in mitochondria in the form of ATP molecules they are called ***'power house of the cell'.*** In the case of aerobic prokaryotes due to lack of mitochondria each molecule of glucose produces 38 ATP molecules.

Recent view

When the cost of transport of ATPs from matrix into the cytosol is considered, the number will be **2.5 ATPs for each NADH + H^+ and 1.5 ATPs for each $FADH_2$** oxidised during electron transport system. Therefore, in plant cells net yield of 30 ATP molecules for complete aerobic oxidation of one molecule of glucose. But in those animal cells (showing malate shuttle mechanism) net yield will be 32 ATP molecules.

Electron transport chain inhibitors

1. **2,4 DNP (Dinitrophenol)** - It prevents synthesis of ATP from ADP, as it directs electrons from Co Q to O_2
2. **Cyanide** - It prevents flow of electrons from Cytochrome a_3 to O_2
3. **Rotenone** - It prevents flow of electrons from NADH + H^+/$FADH_2$ to Co Q
4. **Oligomycin** – It inhibits oxidative phosphorylation

Peter Mitchel, a British Biochemist received Nobel prize for Chemistry in 1978 for his work on the coupling of oxidation and phosphorylation in mitochondria.

Cyanide resistant respiration is believed to be responsible for the climacteric in fruits

Cyanide resistant respiration is known to generate heat in thermogenic tissues.

The amount of heat produced in thermogenic tissues may be as high as 51°C.

14.6 Respiratory Quotient (RQ)

The ratio of volume of carbon dioxide given out and volume of oxygen taken in during respiration is called **Respiratory Quotient or Respiratory ratio**. RQ value depends upon respiratory substrates and their oxidation.

$$RQ = \frac{\text{Volume of } CO_2 \text{ liberated}}{\text{Volume of } O_2 \text{ consumed}}$$

1. The respiratory substrate is a carbohydrate, it will be completely oxidised in aerobic respiration and the value of the RQ will be equal to unity.

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + 6O_2 \longrightarrow 6CO_2 \uparrow + 6H_2O + \text{Energy}$$

$$\text{RQ of glucose} = \frac{6 \text{ molecules of } CO_2}{6 \text{ molecules of } O_2}$$

$$= 1 \text{ (unity)}$$

2. If the respiratory substrate is a carbohydrate it will be incompletely oxidised when it goes through anaerobic respiration and the RQ value will be infinity.

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \longrightarrow 2CO_2\uparrow + \underset{\text{Ethyl alcohol}}{2C_2H_5OH} + \text{Energy}$$

$$\left.\begin{matrix}\text{RQ of glucose} \\ \text{Anaerobically}\end{matrix}\right\} = \frac{2 \text{ molecules of } CO_2}{\text{zero molecule of } O_2}$$

$$= \infty \text{ (infinity)}$$

3. In some succulent plants like O*puntia, Bryophyllum* carbohydrates are partially oxidised to organic acid, particularly malic acid without corresponding release of CO_2 but O_2 is consumed hence the RQ value will be zero.

Table 14.2: Net Products gained during aerobic respiration per glucose molecule.

Stages	CO_2	ATP	Reduced NAD^+	Reduced FAD	Total ATP Production
Glycolysis	0	2	2 ($2 \times 2 = 4$)	0	6
Link reaction	2	0	2 ($2 \times 3 = 6$)	0	6
Krebs cycle	4	2	6 ($6 \times 3 = 18$)	2 ($2 \times 2 = 4$)	24
Total	**6**	**4 ATPs**	**28 ATPs**	**4 ATPs**	**36 ATPs**

$$2C_6H_{12}O_6 + 3O_2 \longrightarrow 3C_4H_6O_5 + 3H_2O + \text{Energy}$$
Glucose — Malic acid

$$\text{RQ of glucose in succulents} = \frac{\text{zero molecule of } CO_2}{\text{3 molecules of } O_2}$$

$$= 0 \text{ (zero)}$$

4. When respiratory substrate is protein or fat, then RQ will be less than unity.

$$2(C_{51}H_{98}O_6) + 145O_2 \longrightarrow 102CO_2\uparrow + 98H_2O + \text{Energy}$$
Tripalmitin(Fat)

$$\text{RQ of Tripalmitin} = \frac{\text{102 molecules of } CO_2}{\text{145 molecules of } O_2}$$

$$= 0.7 \text{ (less than unity)}$$

5. When respiratory substrate is an organic acid the value of RQ will be more than unity.

$$C_4H_6O_5 + 3O_2 \longrightarrow 4CO_2\uparrow + 3H_2O + \text{Energy}$$
Malic acid

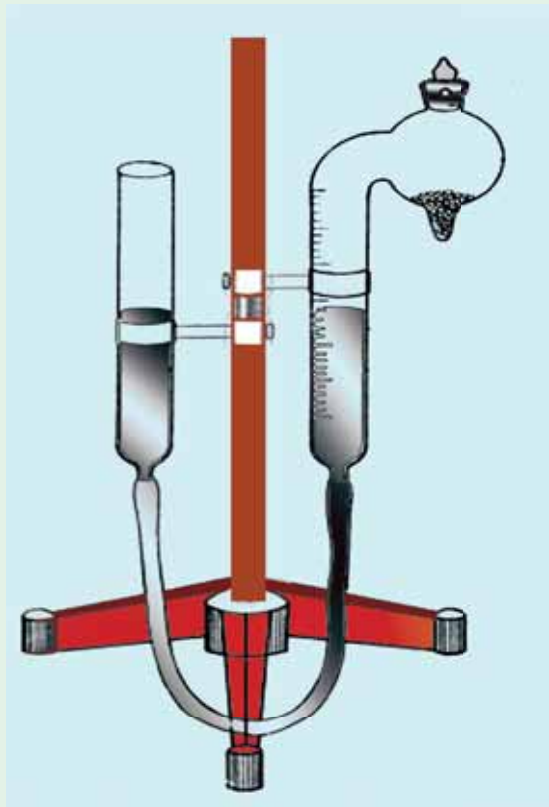
$$\text{RQ of malic acid} = \frac{\text{4 molecules of } CO_2}{\text{3 molecules of } O_2}$$

$$= 1.33 \text{ (more than unity)}$$

Significance of RQ

1. RQ value indicates which type of respiration occurs in living cells, either aerobic or anaerobic.
2. It also helps to know which type of respiratory substrate is involved.

Red colour in various parts of plants is due to the presence of anthocyanin, synthesis of which require more O_2 than CO_2 evolved. RQ will be less than one.



The apparatus used for determining respiration and RQ is called Ganong's Respirometer.

Respiratory quotients of some other substances

Proteins	:	0.8–0.9
Oleic acid (Fat)	:	0.71
Palmitic acid (Fat)	:	0.36
Tartaric acid	:	1.6
Oxalic acid	:	4.0

Experiment to demonstrate the production of CO_2 in aerobic respiration

Take small quantity of any seed (groundnut or bean seeds) and allow them to germinate by imbibing them. While they are germinating place them in a conical flask. A small glass tube containing 4 ml of freshly prepared

Potassium hydroxide (KOH) solution is hung into the conical flask with the help of a thread and tightly close the one holed cork (Figure 14.11). Take a bent glass tube, the shorter end of which is inserted into the conical flask through the hole in the cork, while the longer end is dipped in a beaker containing water. Observe the position of initial water level in bent glass tube. This experimental setup is kept for two hours and the seeds were allowed to germinate. After two hours, the level of water rises in the glass tube. It is because, the CO_2 evolved during aerobic respiration by germinating seeds will be absorbed by KOH solution and the level of water will rise in the glass tube.

$$CO_2 + 2KOH \text{ —> } K_2CO_3 + H_2O$$

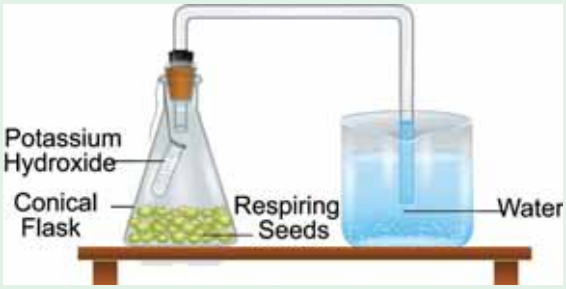


Figure 14.11: Demonstration of production of CO_2 during respiration

In the case of groundnut or bean seeds, the rise of water is relatively lesser because these seeds use fat and proteins as respiratory substrate and release a very small amount of CO_2. But in the case of wheat grains, the rise in water level is greater because they use carbohydrate as respiratory substrate. When carbohydrates are used as substrate, equal amounts of CO_2 and O_2 are evolved and consumed.

Activity

Take a test tube with some germinated seeds and fill with water. Keep this test tube after some time until liberation of CO_2. When the carbon dioxide from respiration is mixed to water, carbonic acid (H_2CO_3) is produced. Therefore, as more carbon dioxide is released, the solution becomes more acidic. You will see changes in pH as an indicator using blue litmus paper changed into red that respiration has occurred

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

14.7 Anaerobic Respiration

14.7.1 Fermentation

Some organisms can respire in the absence of oxygen. This process is called **fermentation or anaerobic respiration** (Figure 14.12). There are three types of fermentation:

1. Alcoholic fermentation
2. Lactic acid fermentation
3. Mixed acid fermentation

1. Alcoholic fermentation

The cells of roots in water logged soil respire by alcoholic fermentation because of lack of oxygen by converting pyruvic acid into ethyl alcohol and CO_2. Many species of yeast (*Saccharomyces*) also respire anaerobically. This process takes place in two steps:

$$\text{(i) } 2CH_3COCOOH \xrightarrow[TPP]{\text{Pyruvate decarboxylase}} 2CH_3CHO + 2CO_2\uparrow$$

Pyruvic acid — Acetaldehyde

$$\text{(ii) } 2CH_3CHO + 2NADH + 2H^+ \xrightarrow{\text{Alcohol dehydrogenase}} 2CH_3CH_2OH + 2NAD^+$$

Acetaldehyde — Ethyl alcohol

Table 14.3: Comparison of alcoholic fermentation and lactic acid fermentation	
Alcoholic fermentation	**Lactic acid fermentation**
1. It produces alcohol and releases CO_2 from pyruvic acid.	It produces lactic acid and does not release CO_2 from pyruvic acid.
2. It takes place in two steps.	It takes place in single step.
3. It involves two enzymes, pyruvate decarboxylase with Mg^{++} and alcohol dehydrogenase.	It uses one enzyme, lactate dehydrogenase with Zn^{++}.
4. It forms acetaldehyde as intermediate compound.	Does not form any intermediate compound.
5. It commonly occurs in yeast.	Occurs in bacteria, some fungi and vertebrate muscles.

Industrial uses of alcoholic fermentation:

1. In bakeries, it is used for preparing bread, cakes, biscuits.
2. In beverage industries for preparing wine and alcoholic drinks.
3. In producing vinegar and in tanning, curing of leather.
4. Ethanol is used to make gasohol (a fuel that is used for cars in Brazil).

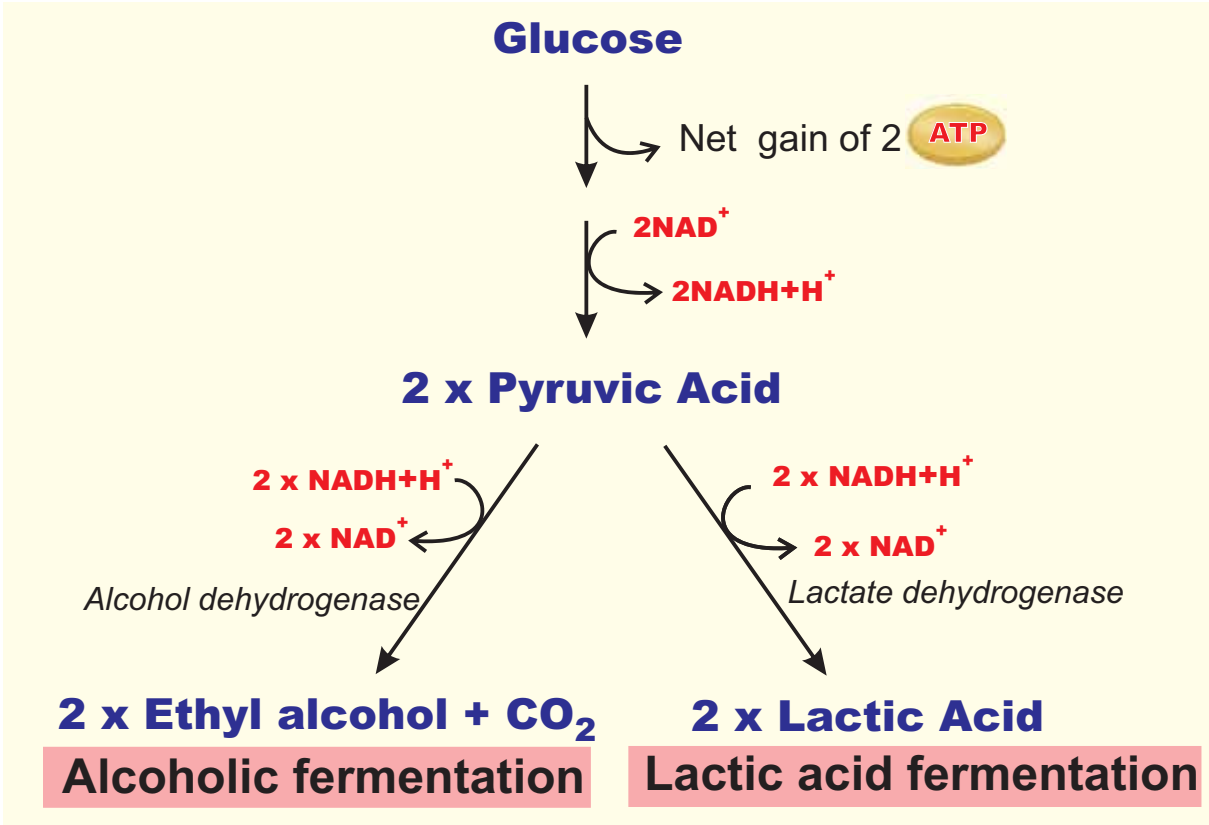


Figure 14.12: Anaerobic Respiration

2. Lactic acid fermentation

Some bacteria (*Bacillus*), fungi and muscles of vertebrates produce lactic acid from pyruvic acid (Table 14.3).

$$2CH_3COCOOH + 2NADH + 2H^+ \xrightarrow[\text{Lactate dehydrogenase}]{\text{Pyruvic acid}} 2CH_3CHOHCOOH + 2NAD^+$$

Lactic acid

3. Mixed acid fermentation

This type of fermentation is a characteristic feature of Enterobacteriaceae and results in the formation of lactic acid, ethanol, formic acid and gases like CO_2 and H_2.

Characteristics of Anaerobic Respiration

1. Anaerobic respiration is less efficient than the aerobic respiration (Figure 14. 12) (Table 14.4).
2. Limited number of ATP molecules is generated per glucose molecule (Table 14.5).
3. It is characterized by the production of CO_2 and it is used for Carbon fixation in photosynthesis.

Table 14.4: Comparison between glycolysis and fermentation

Glycolysis	Fermentation
1. Glucose is converted into pyruvic acid.	Starts from pyruvic acid and is converted into alcohol or lactic acid.
2. It takes place in the presence or absence of oxygen.	It takes place in the absence of oxygen.
3. Net gain is 2ATP.	No net gain of ATP molecules.
4. 2NADH + H^+ molecules are produced.	2NADH + H^+ molecules are utilised.

Table 14.5: Net products from one molecule of Glucose under Glycolysis and Anaerobic respiration.

Stage	Substrate level ATP production	Reduced NAD^+	Total ATP
Glycolysis	2	2*	8
Anaerobic respiration	2	2 reduced NAD^+ re-oxidised	2

*One reduced NAD^+ equivalent to 3 ATPs

Check your grasp!

- Why Microorganisms respire anaerobically?
- Does anaerobic respiration take place in higher plants?

Demonstration of alcoholic fermentation

Take a Kuhne's fermentation tube which consists of an upright glass tube with side bulb. Pour 10% sugar solution mixed with baker's yeast into the fermentation tube the side tube is filled plug the mouth with lid. After some time, the glucose solution will be fermented. The solution will give out an alcoholic smell and level of solution in glass column will fall due to the accumulation of CO_2 gas. It is due to the presence of zymase enzyme in yeast which converts the glucose solution into alcohol and CO_2. Now introduce a pellet of KOH into the tube, the KOH will absorb CO_2 and the level of solution will rise in upright tube (Figure 14.13).

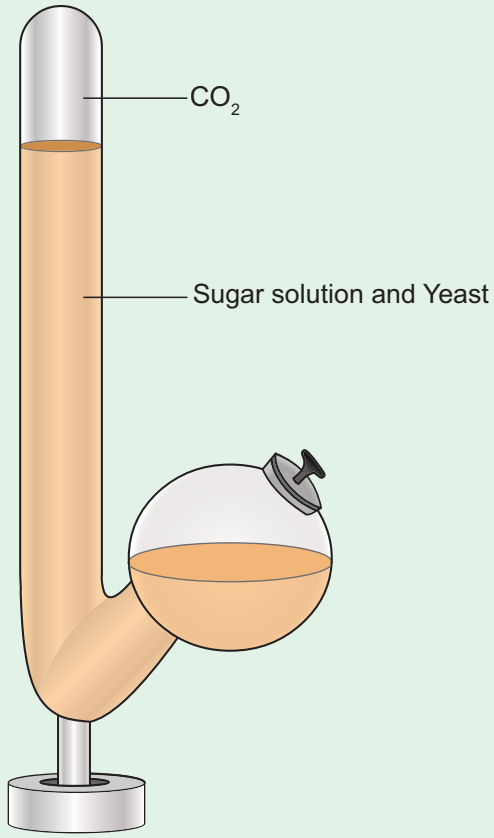


Figure 14.13: Kuhne's fermentation experiment

Activity

Take a bottle filled with warm water mixed with baker's yeast and sugar. After some time, you will notice water bubbling as yeast produces carbon dioxide. Attach a balloon to the mouth of the bottle. After 30 minutes you'll notice balloon standing upright (Figure 14.14).

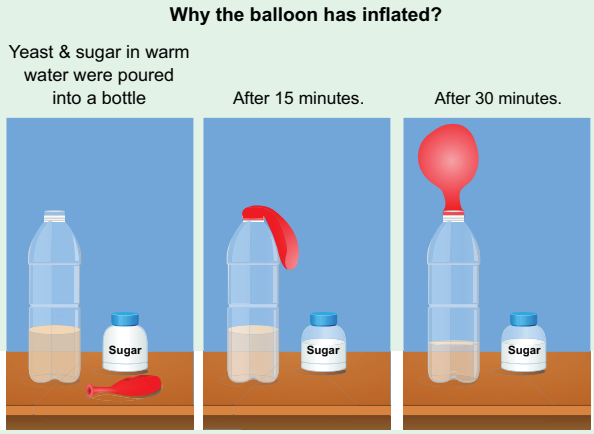
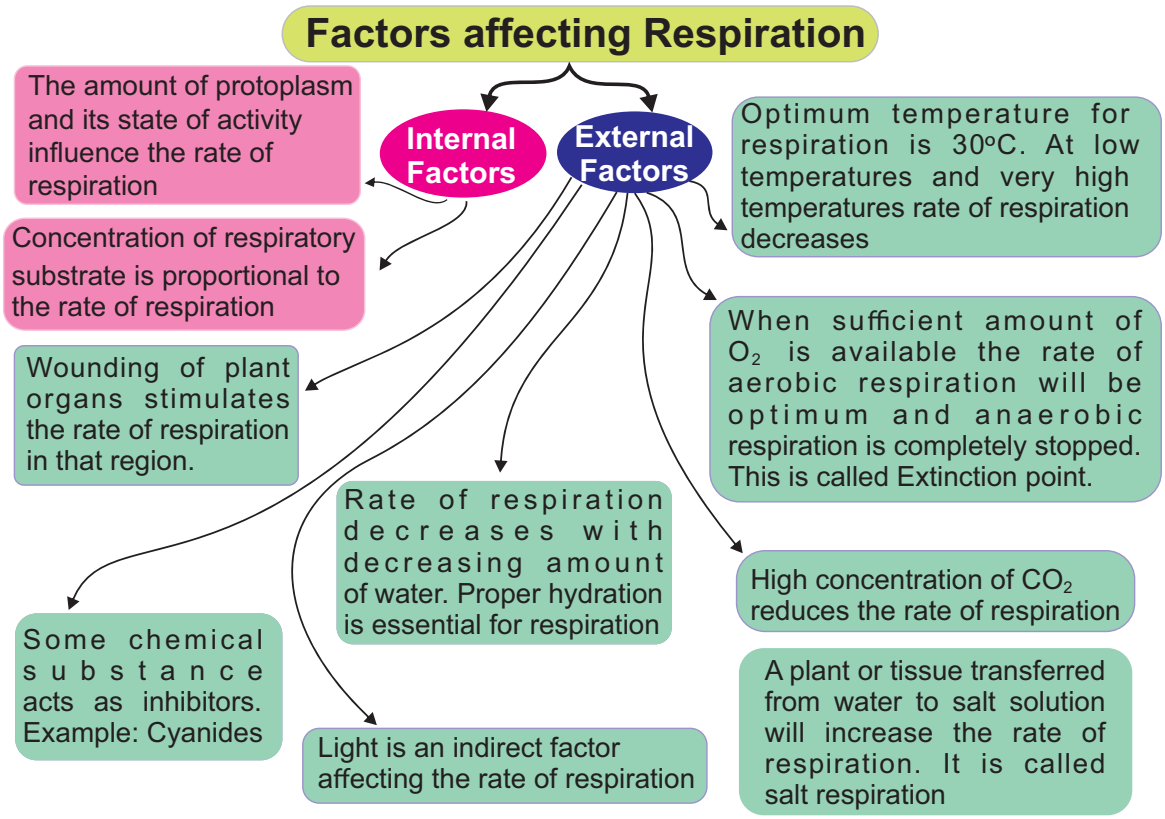


Figure: 14.14: Air balloon activity

14.8 Factors Affecting Respiration



How alcoholic beverages like beer and wine is made?

The conversion of pyruvate to ethanol takes place in malted barley and grapes through fermentation. Yeasts carryout this process under anaerobic conditions and this conversion increases ethanol concentration. If the concentration increases, it's toxic effect kills yeast cells and the left out is called beer and wine respectively.

14.9 Pentose Phosphate Pathway (Phospho Gluconate Pathway)

During respiration breakdown of glucose in cytosol occurs both by glycolysis (about 2/3) as well as by oxidative pentose phosphate pathway (about 1/3). Pentose phosphate pathway was described by **Warburg**, **Dickens** and **Lipmann** (1938). Hence, it is also called **Warburg-Dickens-Lipmann pathway**. It takes place in cytoplasm of mature plant cells. It is an alternate way for breakdown of glucose (Figure 14.15).

It is also known as **Hexose monophosphate shunt (HMP Shunt)** or **Direct Oxidative Pathway**. It consists of two phases, oxidative phase and non-oxidative phase. The oxidative events convert six molecules of six carbon Glucose-6-phosphate to 6 molecules of five carbon sugar Ribulose-5 phosphate with loss of $6CO_2$ molecules and generation of 12 NADPH + H^+ (not NADH). The remaining reactions known as **non-oxidative pathway**, convert Ribulose-5-phosphate molecules to various intermediates such as Ribose-5-phosphate(5C),Xylulose-5-phosphate(5C), Glyceraldehyde-3-phosphate(3C), Sedoheptulose-7-Phosphate(7C), and Erythrose-4-phosphate(4C). Finally, five molecules of glucose-6-phosphate is regenerated (Figure 14.16). The overall reaction is:

6 x Glucose-6-Phosphate + 12NADP$^+$ + 6H_2O

↓

5 x Glucose-6-Phosphate + 6CO_2 + Pi + 12NADPH +12H$^+$

The net result of complete oxidation of one glucose-6-phosphate yield $6CO_2$ and 12NADPH + H^+. The oxidative pentose phosphate pathway is controlled by glucose-6-phosphate dehydrogenase enzyme which is inhibited by high ratio of NADPH to NADP$^+$.

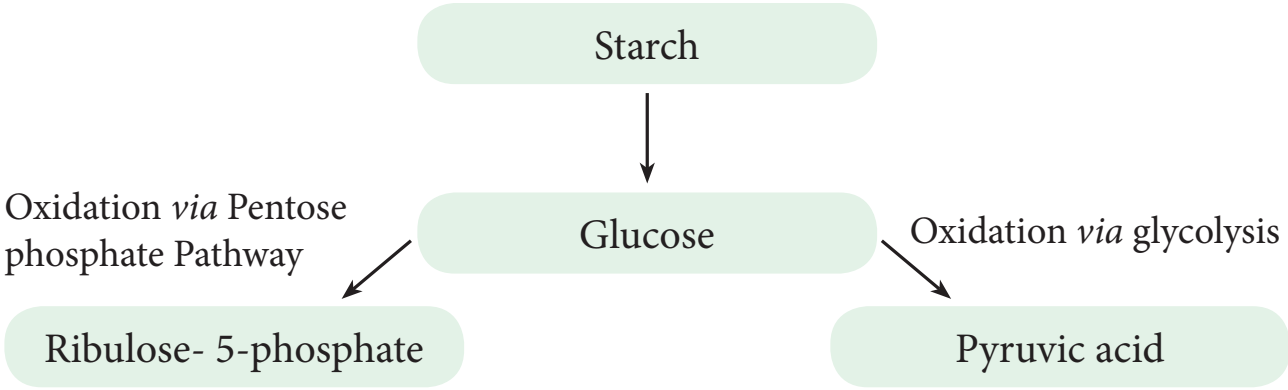


Figure 14.15: Fate of Glucose in HMP shunt and Glycolysis

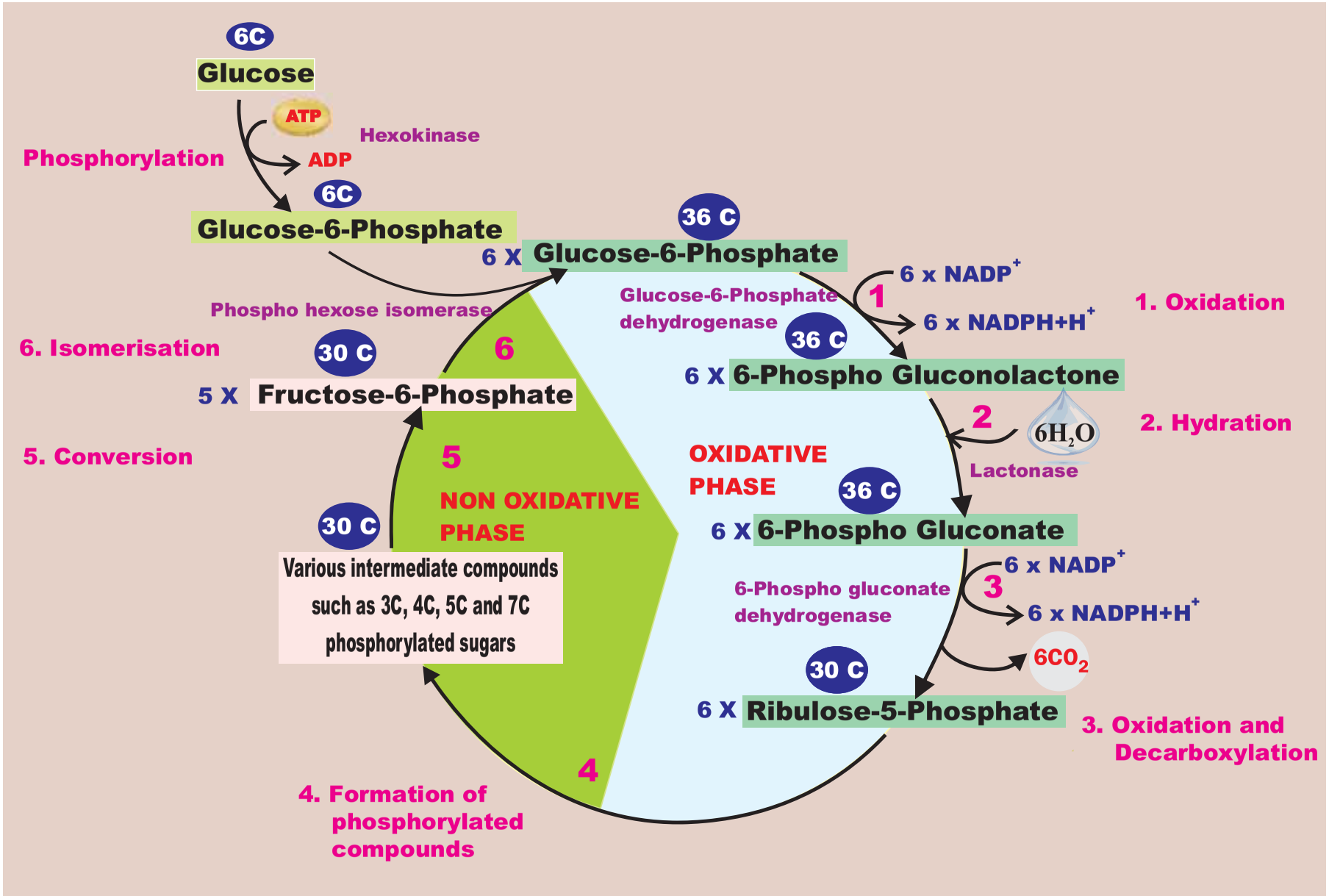


Figure 14.16: Pentose phosphate pathway or HMP shunt

Significance of pentose phosphate pathway

1 HMP shunt is associated with the generation of two important products, NADPH and pentose sugars, which play a vital role in anabolic reactions.

2 Coenzyme NADPH generated is used for reductive biosynthesis and counter damaging the effects of oxygen free radicals

3 Ribose-5-phosphate and its derivatives are used in the synthesis of DNA, RNA, ATP, NAD^+, FAD and Coenzyme A.

4 Erythrose is used for synthesis of anthocyanin, lignin and other aromatic compounds.

Summary

Respiration is a biological process in which energy is released by breaking down of complex organic substances into simple compounds. The respiratory substrates may be carbohydrate, protein or fats. Respiration is of two types, aerobic (with O_2) and anaerobic (without O_2). All plants, animals and most of the microbes derive energy from aerobic respiration. Some bacteria and fungi like yeast show anaerobic respiration. Aerobic respiration consists of four stages and they are glycolysis, link reaction, TCA cycle and ETS. Glycolysis is the first stage which occurs in cytosol and common for both aerobic and anaerobic respiration and it involves breaking down of

glucose into two molecules of pyruvic acid. Acetyl CoA formed from pyruvic acid, acts as a link between glycolysis and Krebs cycle. Krebs cycle takes place in matrix of mitochondria and also called as citric acid cycle in which CO_2 and H_2O were produced. Hydrogen removed from the substrates is received by coenzymes which get reduced. They are again oxidised by removal of hydrogen. This hydrogen splits into protons and electrons. The electrons transferred through various electron transport carriers present in inner membrane of mitochondria is used for the synthesis of ATP with the help of ATP synthase. This process is called **oxidative phosphorylation**.

Anaerobic respiration involves incomplete breaking down of the substrate glucose into ethyl alcohol or lactic acid. In aerobic respiration 36 ATP molecules are produced in plant mitochondria but in animals 38 ATP molecules are produced per glucose molecule. During anaerobic respiration only 2 ATP molecules are produced, therefore anaerobic respiration is less efficient than aerobic respiration. The respiratory quotient (RQ) is the ratio of carbon dioxide production to oxygen consumption and reflects the relative contributions of fat, carbohydrate, and protein to the oxidation. Pentose phosphate pathway is an alternative pathway to glycolysis and TCA cycle for oxidation of glucose. It occurs in cytoplasm of both prokaryotes and eukaryotes.

Evaluation

CR2HJX

1. The number of ATP molecules formed by complete oxidation of one molecule of pyruvic acid is

   a. 12 b. 13 c. 14 d. 15

2. During oxidation of two molecules of cytosolic NADH + H^+, number of ATP molecules produced in plants are

   a. 3 b. 4 c. 6 d. 8

3. The compound which links glycolysis and Krebs cycle is

   a. succinic acid b. pyruvic acid
   c. acetyl CoA d. citric acid

4. Assertion (A): Oxidative phosphorylation takes place during the electron transport chain in mitochondria.
   Reason (R): Succinyl CoA is phosphorylated into succinic acid by substrate phosphorylation.

   a. A and R is correct. R is correct explanation of A
   b. A and R is correct but R is not the correct explanation of A
   c. A is correct but R is wrong
   d. A and R is wrong.

5. Which of the following reaction is not involved in Krebs cycle.

   a. Shifting of phosphate from 3C to 2C
   b. Splitting of Fructose 1,6 bisphosphate of into two molecules 3C compounds.
   c. Dephosphorylation from the substrates
   d. All of these

6. What are enzymes involved in phosphorylation and dephosphorylation reactions in EMP pathway?
7. Respiratory quotient is zero in succulent plants. Why?
8. Explain the reactions taking place in mitochondrial inner membrane.
9. What is the name of alternate way of glucose breakdown? Explain the process involved in it?
10. How will you calculate net products of one sucrose molecule upon complete oxidation during aerobic respiration as per recent view?

ICT Corner

Rate of respiration

Let's estimate **rate of respiration**

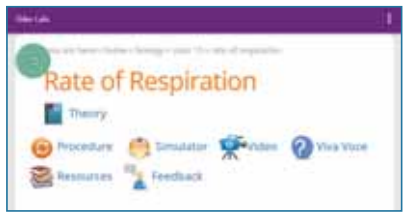
Steps

- Scan the QR code or go to google play store
- Type online labs and install it.
- Select biology and select rate of respiration
- Click theory to know the basic about respiration
- Register yourself with mail-id and create password to access online lab simulations

Activity

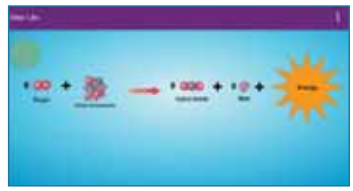
- Press simulation to do the rate of respiration.
- Conclude your observations.

Step 1



Step 2

Step 3



Step 4

URL:
https://play.google.com/store/apps/details?id=in.edu.olabs.olabs&hl=en

Alternate web:
http://www.sumanasinc.com/webcontent/animations/content/cellularrespiration.html

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* Pictures are indicative only

Unit V: Plant Physiology (Functional Organisation)

Chapter 15

Plant Growth and Development

Learning Objectives

The learner will be able to,

- *Define growth.*
- *List out and differentiate the phases of growth.*
- *Understand the ways of measuring growth.*
- *Explain the structure, precursor, bioassay and physiological effects of plant growth regulators.*

Chapter Outline

CRBDLK

The Banyan tree continues to grow for thousands of years and some others particularly annual plants cease growth within a season or within a year. Can you understand the reasons? How does a zygote give rise to an embryo and an embryo to a seedling? How does a new plant structure arise from the pre-existing structure? Growth is defined as an irreversible permanent increase in size, shape, number,volume and dry weight. Plant growth occurs by cell division, cell enlargement, differentiation and maturation.

DO YOU KNOW?

Bamboos are evergreen grasses and certain species of it can grow at the rate of growth 91 cm per day. The Saguaro Cactus is a tree like cactus and is a slow growing plant. The rate of growth is one inch in the first ten years and it does not begin to flower until it is about 60 years old. It's lifespan exceeds 150 years and takes 75–100 years to grow a side arm.

15.1 Characteristics of Growth

- Growth increases in protoplasm at cellular level.
- Stem and roots are indeterminate in growth due to continuous cell division and is called **open form of growth**.

Growth is measurable, it is amazing to know that one single maize root apical meristem can give rise to more than 17,500 new cells per hour and cells in a watermelon may increase in size upto 3,50,000 times.

- The primary growth of the plant is due to the activity of apical meristem where, new cells are added to root and shoot apex causing linear growth of plant body.
- The secondary vascular cambium and cork cambium add new cells to cause increase in girth.
- Leaves, flowers and fruits are limited in growth or of determinate or **closed form growth.**
- Monocarpic annual plants produce flowers only once during lifetime and dies. Example: Paddy and Bean
- Monocarpic perennials produce flowers only once during life time but the plants survive for many years. Example: Bamboo.
- Polycarpic perennials produce flowers every year during life time. Example: Coconut.

15.1.1 Indication of growth

Growth in plants can be measured in terms of,

i. Increase in length or girth (roots and stems)
ii. Increase in fresh or dry weight
iii. Increase in area or volume (fruits and leaves)
iv. Increase in number of cells produced.

15.1.2 Phases of growth

There are three phases of growth,

1. Formative phase
2. Elongation phase
3. Maturation phase

1. Formative phase: Growth in this phase occurs in meristematic cells of shoot and root tips. These cells are small in size, have dense protoplasm, large nucleus and small vacuoles. Cells divide continuously by mitotic cell division. Some cells retain capability of cell division while other cells enter the next phase of growth (Figure 15.1).

2. Elongation Phase: Newly formed daughter cells are pushed out of the meristematic zone and increases the volume. It requires auxin and food supply, deposition of new cell wall materials (intussusception), addition of protoplasm and development of central vacuole take place.

3. Maturation Phase: During this stage cells attain mature form and size. Thickening and differentiation takes place. After differentiation, the cells do not grow further.

Activity

Demonstration of phases of growth

To demonstrate and study the phases of growth, germinate a few seeds of bean on a circular filter paper soaked with water in a petridish. After two days of growth, select a few seedlings with straight radical of 2 to 3 cm length. Dry the surface of radical with a blotting paper and mark the radical from tip to base with at least 2 mm gap using water proof ink. Replace the seedlings in filter paper and observe further growth.

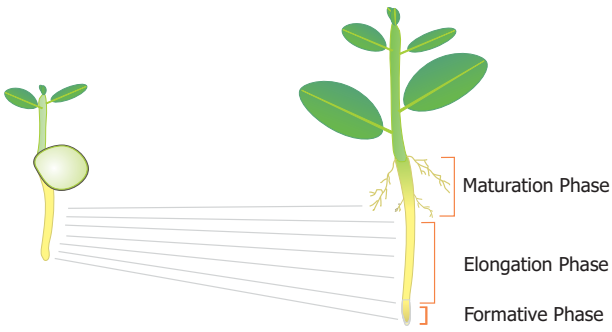


Figure 15.1: Phases of growth in root

15.1.3 Kinetics of growth

It is an analysis of the motion of cells or expansion.

1. Stages in Growth rate

The total period from initial to the final stage of growth is called the **grand period of growth.** The total growth is plotted against time and 'S' shaped sigmoid curve (Grand period curve) is obtained. It consists of four phases (Figure 15.2). They are:

i. Lag phase
ii. Log phase
iii. Decelerating phase
iv. Maturation phase

i. Lag phase

In this phase new cells are formed from pre-existing cells slowly. It is found in the tip of the stem, root and branches. It is the initial stage of growth. In other words, growth starts from this period (Figure 15.2).

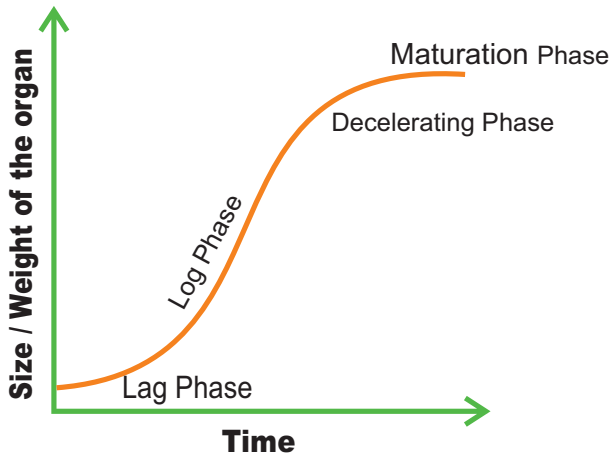


Figure 15.2: Stages in growth rate

ii. Log phase or exponential growth

Here, the newly formed cell increases in size rapidly by deposition of cell wall material. Growth rate is maximum and reaches top because of cell division and physiological processes are quite fast. The volume of protoplasm also increases. It results in rapid growth and causes elongation of internode in the stem.

iii. Decelerating phase or Decline phase or slow growth phase

The rate of growth decreases and becomes limited owing to internal and external or both the factors because the metabolic process becomes slow.

iv. Steady state period or maturation phase

In this phase cell wall thickening due to new particle deposition on the inner surface of the cell wall takes place. The overall growth ceases and becomes constant. The growth rate becomes zero.

2. Types of growth rate

The increased growth per unit time is termed as growth rate. An organism or part of an organism can produce more cells through arithmetic growth or geometric growth or both.

i. Arithmetic Growth Rate

If the length of a plant organ is plotted against time, it shows a linear curve and this growth is called **arithmetic growth**.

- The rate of growth is constant and it increases in an arithmetic manner.

- Only one cell is allowed to divide between the two-resulting progeny cell.
- One continues to divide but the other undergoes cell cycle arrest and begins to develop, differentiate and mature.
- After each round of cell division, only a single cell remains capable of division and one new body cell forms.

For example, starting with a single cell after round 1 of cell division there is one dividing cell and one body cell. After round 2 there are two body cells, after round 3 there are three and so on (Figure 15.3).

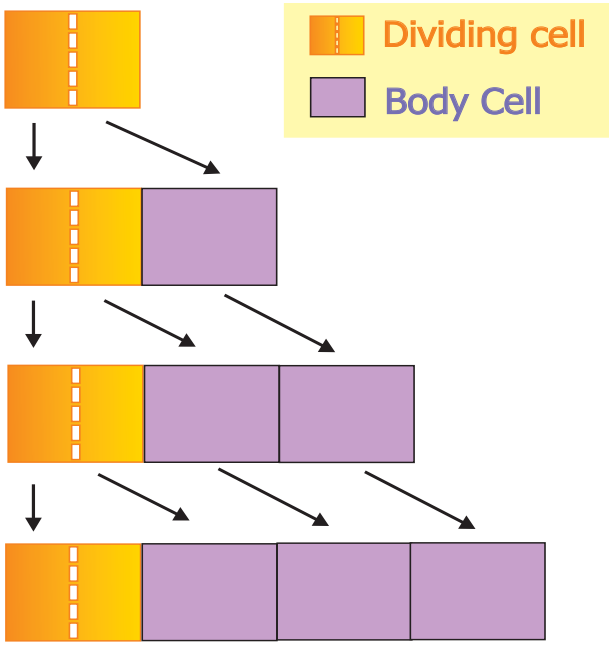


Figure 15.3: Arithmetic Growth Rate

The plants single dividing cell would undergo one million rounds of nuclear and cellular division. If each round requires one day, this type of arithmetic increase would require one million days or 2739.7 years. This arithmetic rate is capable of producing small number of cells present in very small parts of plants. For example the hair on many leaves and stems consists of just a single row of cells produced by the division of the basal cell, the cell at the bottom of the

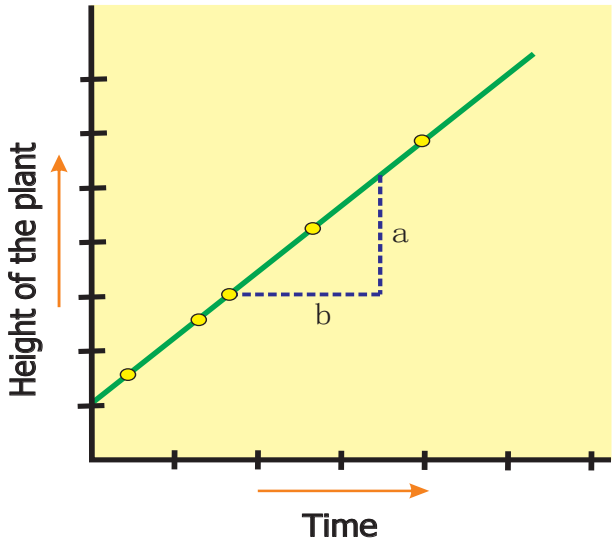


Figure 15.4: Constant Linear Growth

hair next to other epidermal cells. Hair may contain 5 to 10 cells by the division of the basal cell. So, all its cells could be produced in just five to ten days. In the figure 15.4, on plotting the hight of the plant against time a linear curve is obtained. Mathematically it is expressed as:

$L_t = L_o + rt$

L_t = length at time 't'

L_o = length at time zero

r = growth rate of elongation per unit

ii. Geometric growth rate:

This growth occurs in many higher plants and plant organs and is measured in size or weight. In plant growth, geometric cell division results if all cells of an organism or tissue are active mitotically. Example: Round three in the given figure 15.5, produces 8 cells as $2^3 = 8$ and after round 20 there are $2^{20} = 1{,}048{,}576$ cells.

The large plant or animal parts are produced this way. In fact, it is common in animals but rare in plants except when they are young and small. Exponential growth curve can be expressed as,

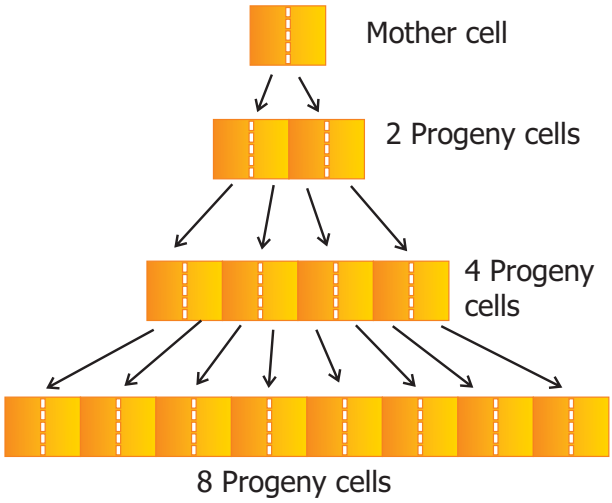


Figure 15.5: Geometric growth

$W_1 = W_0 e^{rt}$

W_1 = Final size (weight, height and number)

W_0 = Initial size at the beginning of the period

r = Growth rate

t = Time of growth

e = Base of the natural logarithms

Here '*r*' is the relative growth rate and also a measure of the ability of the plant to produce new plant material, referred to as efficiency index. Hence, the final size of W_1 depends on the initial size W_0.

iii. Arithmetic and Geometric Growth of Embryo

Plants often grow by a combination of arithmetic and geometric growth patterns. A young embryonic plant grows geometrically and cell division becomes restricted to certain cells at the tips of roots and shoots. After this point, growth is of the slower arithmetic type, but some of the new cells that are produced can develop into their mature condition and begin carrying out specialized types of metabolism (Figure 15. 6). Plants are thus a mixture of older, mature cells and young, dividing cells.

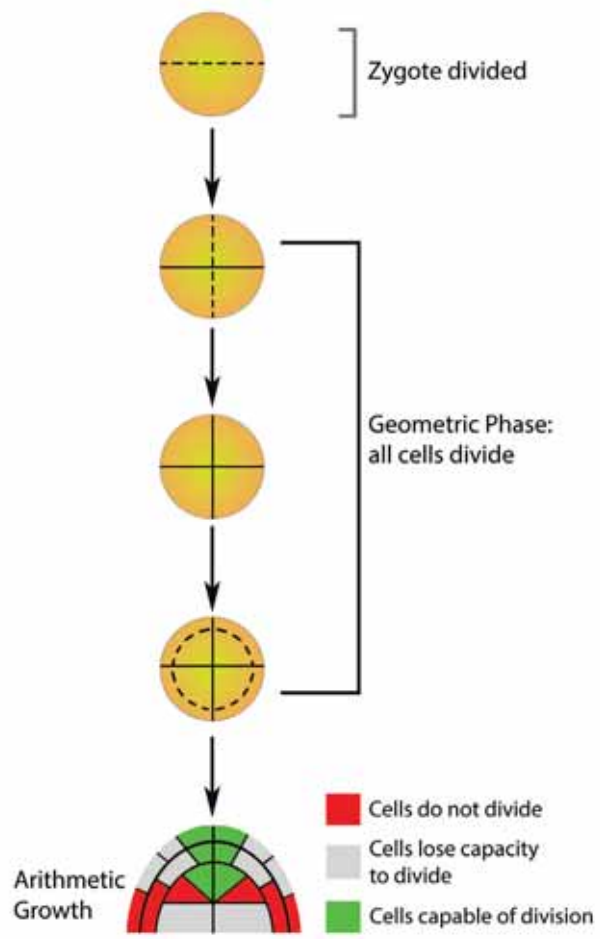


Figure 15.6: Arithmetic and geometric growth of embryo

Quantitative comparisons between the growth of living system can also be made in two ways and is explained in the table 1.

In figure 15.7, two leaves A and B are drawn at a particular time. Then $A^1$and B^1 are drawn after a given time. A and B = Area of leaves at a particular time. A^1 and B^1 = Area of leaves after a given time. (A^1-A) and (B^1-B) represents an absolute increase in area in the given time. Leaf A

Table 1: Comparison between absolute and relative growth rates

Absolute growth rate	Relative growth rate
Increase in total growth of two organs measured and compared per unit time is called absolute growth rate.	The growth of the given system per unit time expressed per unit initial parameter is called relative growth rate.

increases from 5 cm^2 to 10 cm^2; 5 cm^2 in a given time. Leaf B increases from 50 cm^2 to 55 cm^2 ; 5 cm^2 in a given time. Hence, both leaves A and B increase their area by 5 cm^2 in a given time. This is absolute growth. Relative growth is faster in leaf A because of initial small size. It decreases with time (Figure 15.7).

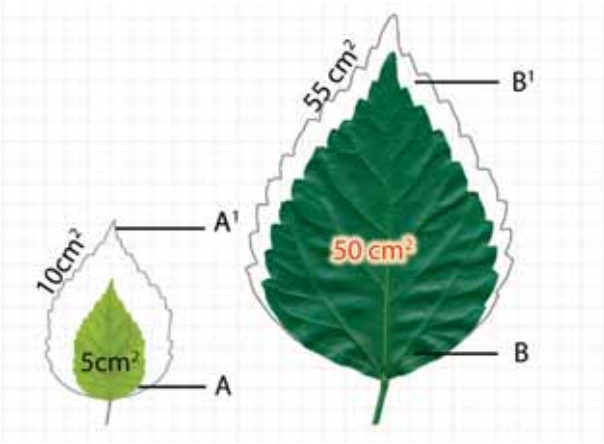


Figure 15.7: Diagrammatic comparision of absolute and relative growth rates

3.Conditions of growth

Plant growth is influenced by a variety of external and internal factors. A brief account of these factors is given below:

I. External Factors

a. Water

Water is essential for cell enlargement as well as growth in the size of the cell. Turgidity of cells helps in growth extension. Water provides the medium for enzymatic activities needed for growth.

b. Nutrition

Nutrition plays an important role in the formation of protoplasm. Macro and micro elements are very important as sources of energy. For example, carbon and oxygen in carbon-di-oxide and hydrogen in water are assimilated in photosynthesis.

c. Temperature

Temperature plays a significant role in the growth of the plant. Proper growth of a plant occurs at a about 28° C to 30° C temperature and above 45° C will damage the protoplasm and hinders the growth.

d. Oxygen

Oxygen has a vital role in the growth of the plant. It helps in releasing metabolic energy essential for growth activities. It is necessary for respiration.

e. Light

Light has its own contribution in the growth of the plant. Light is important for growth and photosynthesis. Light stimulates healthy growth. Absence of light may lead to yellowish in colour. This is called **etiolation**.

II. Internal Factors

a. Genes are intracellular factors for growth.

b. Phytohormones are intracellular factors for growth. Example: auxin, gibberellin, cytokinin.

c. C/N ratio.

The ratio of carbohydrates and nitrogenous compounds regulate the specific pattern of growth in plants. For example, if a plant contains more nitrogenous compounds as compared to carbohydrates it produces more protoplasm less mechanical tissues and vigorous vegetative growth. On the other hand, less nitrogenous compounds and more carbohydrates favour the synthesis of more wall material, less protoplasm, and more mechanical tissues.

4. Measurement of growth

Activity

Measurement of growth by direct method.

Step 1: Take ordinary scale.

Step 2: Measure ground stem up to the growing point of the plant.

Step 3: Use Indian ink and mark at regular intervals to measure the length of root, stem, and girth of the trunk.

5. Sequence of developmental process in a plant cell

Development is a term that includes all the changes that an organism goes through during life cyle from germination of a seed to senescence. Diagrammatic representation of the sequence of processes which constitute the development of a cell of a higher plant is given in the figure. It is also applicable to tissues/organ.

Experiment: 1. Arc auxanometer:

The increase in the length of the stem tip can easily be measured by an arc auxanometer which consists of a small pulley to the axis of which is attached a long pointer sliding over a graduated arc. A thread one end of which is tied to the stem tip and another end to a weight passes over the pulley tightly. As soon as the stem tip increases in length, the pulley moves and the pointer slide over the graduated arc (Figure 15.8). The reading is taken. The actual increase in the length of the stem is then calculated by knowing the length of the pointer and the radius of the pulley. If the radius of the pulley is 4 inches and the length of pointer 20 inches the actual growth is measured as follows:

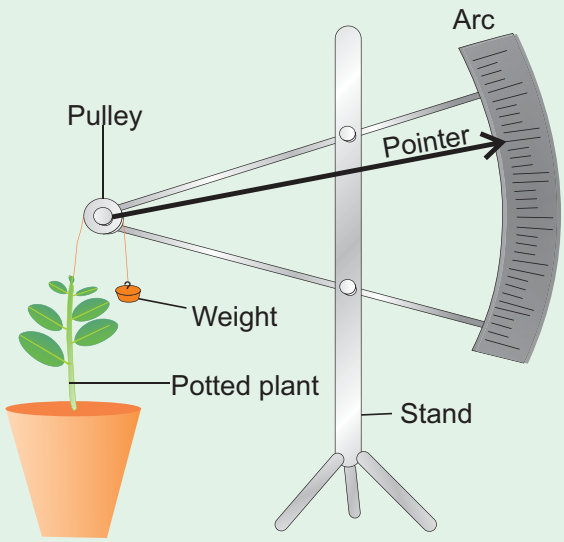


Figure 15.8: Arc auxanometer

$$\text{Actual growth in length} = \frac{\text{Distance travelled by the pointer} \times \text{radius of the pulley}}{\text{Length of the pointer}}$$

$$\text{For example, actual growth in length} = \frac{10 \times 4 \text{ inches}}{20 \text{ inches}}$$

$$= 2 \text{ inches}$$

1. Differentiation

The process of maturation of meristematic cells to specific types of cells performing specific functions is called **differentiation**.

2. Dedifferentiation

The living differentiated cells which had lost capacity to divide, regain the capacity to divide under certain conditions. Hence, dedifferentiation is the regaining of the ability of cell division by the differentiated cells. Example: Interfascicular cambium and Vascular cambium.

3. Redifferentiation

Differentiated cells, after multiplication again lose the ability to divide and mature to perform specific functions. This is called **redifferentiation** (Figure 15.9). Example: Secondary xylem and Secondary phloem.

4. Plasticity

Plants follow different pathways in response to environment or phases of life to form different kinds of structures.

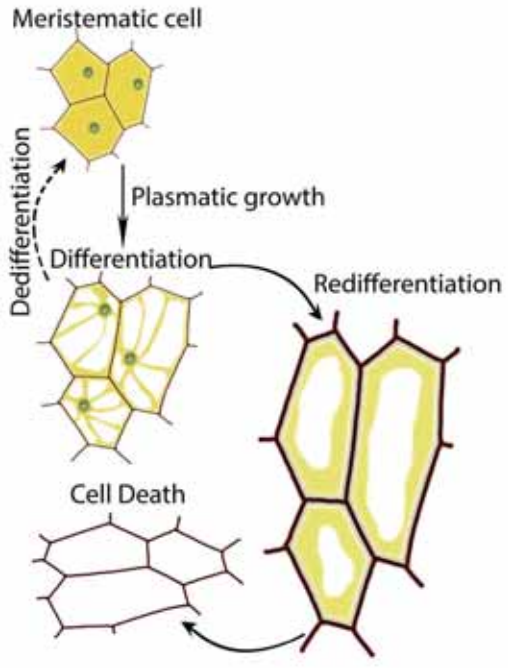


Figure 15.9: Sequences of developmental process in a plant cell

This ability is called **plasticity**. Example: Heterophylly in cotton and coriander. In such plants, the leaves of the juvenile plant are different in shape from those in mature plants. On the other hand, the difference in shapes of leaves produced in air and those produced in water in buttercup also represent the heterophyllous development due to the environment. This phenomenon of heterophylly is an example of plasticity.

15.2 Plant Growth Regulators

CRK9N8

Plant Growth Regulators (chemical messenger) are defined as organic substances which are synthesized in minute quantities in one part of the plant body and transported to another part where they influence specific physiological processes. Five major groups of hormones *viz.*, auxins, gibberellins, cytokinins, ethylene and abscisic acid are presently known to coordinate and regulate growth and development in plants. The term **phytohormones** is implied to those chemical substances which are synthesized by plants and thus, naturally occurring. On the other hand, there are several manufactured chemicals which often resemble the hormones in physiological action and even in molecular structure. Recently, another two groups, the brassinosteroids and polyamines were also known to behave like hormones.

1. Plant growth regulators – classification

Plant Growth Regulators are classified as natural and synthetic based on their

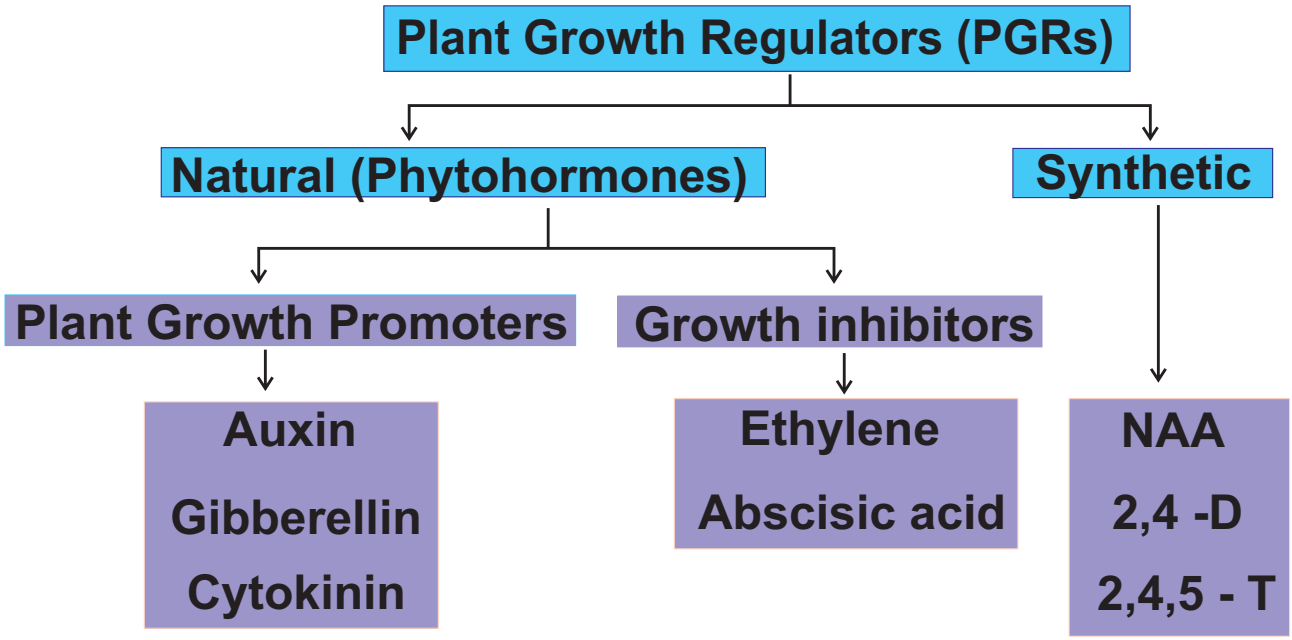


Figure 15.10: Classification of Plant Growth Regulators

source and a detailed flow diagram is given in Figure 15.10.

2. Characteristics of phytohormones

i. Usually produced in tips of roots, stems and leaves.
ii. Transfer of hormones from one place to another takes part through conductive systems.
iii. They are required in trace quantities.
iv. All hormones are organic in nature.
v. There are no specialized cells or organs for their secretion.
vi. They are capable of influencing physiological activities leading to promotion, inhibition and modification of growth.

3. Synergistic and Antagonistic effects

i. **Synergistic effects**: The effect of one or more substance in such a way that both promote each others activity. Example: Activity of auxin and gibberellins or cytokinins.
ii. **Antagonistic effects**: The effect of two substances in such a way that they have opposite effects on the same process. One accelerates and other inhibits. Example: ABA and gibberellins during seed or bud dormancy. ABA induces dormancy and gibberellins break it.

15.2.1 Auxins

1. Discovery

During 1880, **Charles Darwin** noted the unilateral growth and curvature of Canary grass (*Phalaris canariensis*) coleoptile to light. The term auxin (*Greek*: Auxin – to Grow) was first used by **F. W. Went** in 1926 using Oats (*Avena*) coleoptile and isolated the auxin. F. W. Went in 1928 collected auxin in agar jelly. **Kogl** and **Haugen Smith** (1931) isolated Auxin from human urine, and called it as **Auxin A**. Later on in 1934, similar active substances was isolated from corn grain oil and was named as **Auxin B**. Kogl *et al.*, (1934) found heteroauxin in the plant and chemically called it as **Indole Acetic Acid** (IAA)

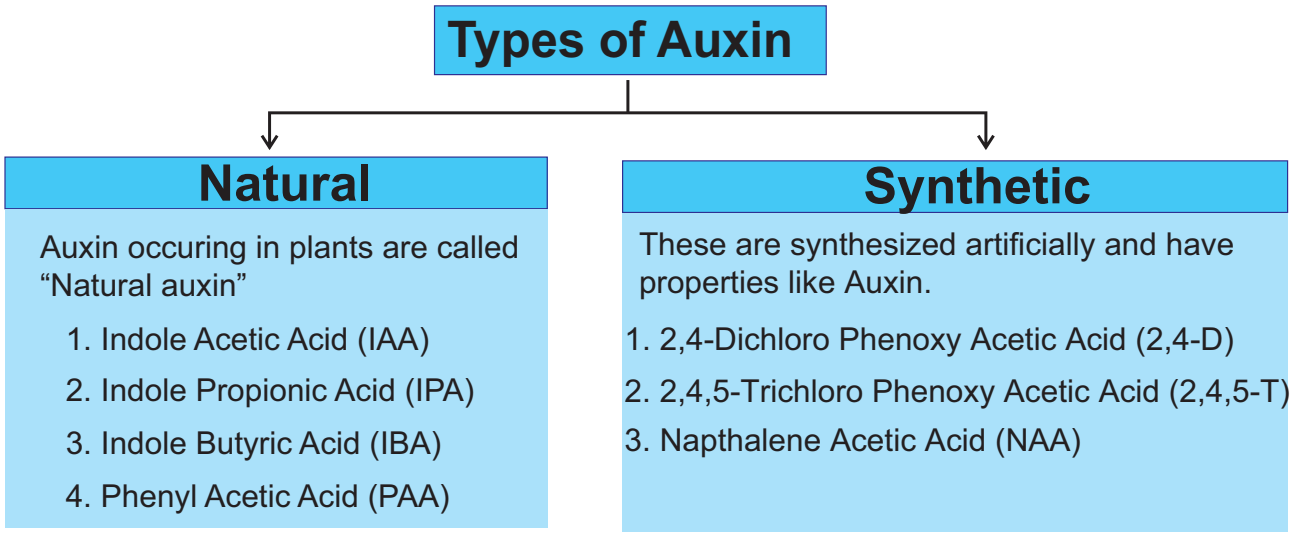


Figure 15.11: Classification of Auxins

2. Occurrence

Auxin is generally produced by the growing tips of the stem and root, from where they migrate to the region of the action.

3. Types of Auxin

Auxins are divided into two categories Natural auxins and Synthetic auxins (Figure 15.11).

Anti-auxins

Anti-auxin compounds when applied to the plant inhibit the effect of auxin. Example: 2, 4, 5-Tri Iodine Benzoic Acid (TIBA) and Napthylpthalamine.

4. Free auxin

They move out of tissues as they are easily diffusible. Example: IAA.

5. Bound Auxin

They are not diffusible. Example: IAA-Aspartic acid

6. Precursor

The amino acid Tryptophan is the precursor of IAA and zinc is required for its synthesis.

7. Chemical structure

Auxin has similar chemical structure of IAA.

8. Transport in Plants

Auxin is polar in transport. It includes basipetal and acropetal transport. Basipetal means transport through phloem from shoot to root and acropetal means transport through xylem from root to shoot.

9. Bioassay (Avena Curvature Test / Went Experiment)

Bioassay means testing of substances for their activity in causing a growth response in a living plant or its part.

The procedure involves the following steps:

When the *Avena* seedlings have attained a height of 15 to 30 mm, about 1mm of the coleoptile tip is removed. This apical part is the source of natural auxin. The tip is now placed on agar blocks for few hours. During this period, the auxin diffuses out of these tips into the agar. The auxin containing agar block is now

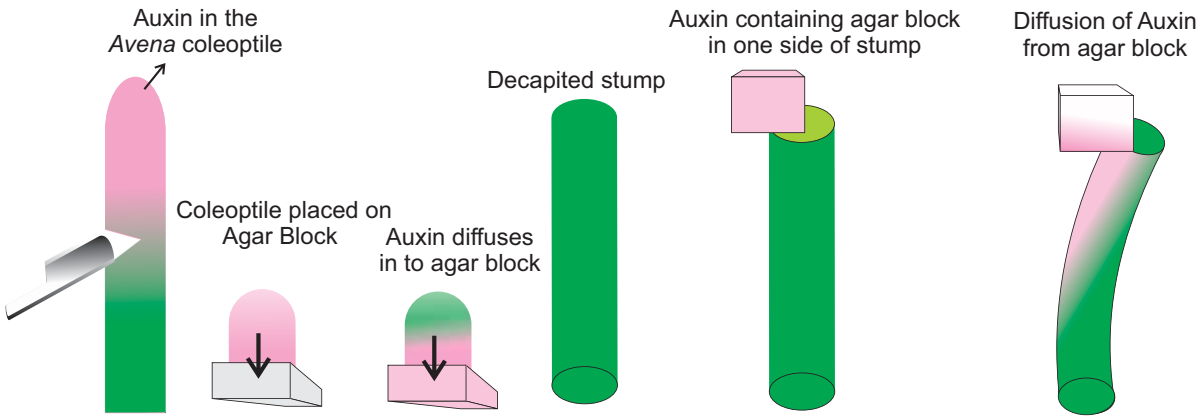


Figure 15.12: *Avena* Curvature Test

placed on one side of the decapitated stump of *Avena* coleoptile. The auxin from the agar blocks diffuses down through coleoptile along the side to which the auxin agar block is placed. An agar block without auxin is placed on another decapitated coleoptile. Within an hour, the coleoptiles with auxin agar block bends on the opposite side where the agar block is placed. This curvature can be measured (Figure 15.12).

10. Physiological Effects

- They promote cell elongation in stem and coleoptile.
- At higher concentrations auxins inhibit the elongation of roots but induce more lateral roots. Promotes growth of root only at extremely low concentrations.
- Suppression of growth in lateral bud by apical bud due to auxin produced by apical bud is termed as **apical dominance**.
- Auxin prevents abscission.
- It is responsible for initiation and promotion of cell division in cambium, which is responsible for the secondary growth and tumor. This property of induction of cell division has been exploited for tissue culture techniques and for the formation of callus.
- Auxin stimulates respiration.
- Auxin induces vascular differentiation.

Agent Orange

Mixture of two phenoxy herbicides 2,4-D and 2,4,5-T is given the name 'Agent orange' which was used by USA in Vietnam war for defoliation of forest (chemical warfare).

In botanical gardens and tea gardens, gardeners trim the plants regularly so that they remain bushy. Does this practice have any scientific explanation?

Yes, trimming of plants removes apical buds and hence apical dominance. The lateral buds sprout and make the plants bushy.

11. Agricultural role

- It is used to eradicate weeds. Example: 2,4-D and 2,4,5-T.
- Synthetic auxins are used in the formation of seedless fruits (Parthenocarpic fruit).
- It is used to break the dormancy in seeds.
- Induce flowering in Pineapple by NAA & 2,4-D.
- Increase the number of female flowers and fruits in cucurbits.

15.2.2 Gibberellins

1. Discovery

The effect of gibberellins had been known in Japan since early 1800 where certain rice plants were found to suffer from '**Bakanae**' or foolish seedling disease. This disease was found by **Kurosawa** (1926) to be caused by a fungus *Gibberella fujikuroi*. The active substance was separated from fungus and named as gibberellin by **Yabuta** (1935). These are more than 100 gibberellins reported from both fungi and higher plants. They are noted as GA_1, GA_2, GA_3 and so on. GA_3 is the first discovered gibberellin. In 1938, **Yabuta** and **Sumiki** isolated gibberellin in crystalline form. In1955, **Brain** *et al.,* gave the name **gibberellic acid**. In 1961, Cross *et al.,* established its structure.

2. Occurrence

The major site of gibberellin production in plants is parts like embryo, roots and young leaves near the tip. Immature seeds are rich in gibberellins.

3. Precursors

The gibberellins are chemically related to terpenoids (natural rubber, carotenoids and steroids) formed by 5-C precursor, an Isoprenoid unit called Iso Pentenyl Pyrophosphate (IPP) through a number of intermediates. The primary precursor is acetate.

4. Chemical structure

All gibberellins have gibbane ring structure.

5. Transport in plants

The transport of gibberellins in plants is non-polar. Gibberellins are translocated through phloem and also occur in xylem due to lateral movement between vascular bundles.

6. Bioassay (Dwarf Pea assay)

Seeds of dwarf pea are allowed to germinate till the formation of the coleoptile. GA solution is applied to some seedlings. Others are kept under control. Epicotyle length is measured and as such, GA stimulating epicotyle growth can be seen.

7. Physiological Effects

- It produces extraordinary elongation of stem caused by cell division and cell elongation.
- Rosette plants (genetic dwarfism) plants exhibit excessive internodal growth when they are treated with gibberellins. This sudden elongation of stem followed by flowering is called **bolting** (Figure 15.13).
- Gibberellin breaks dormancy in potato tubers.
- Many biennials usually flower during second year of their growth. For flowering to take place, these plants should be exposed to cold season. Such plants could be made to flower without

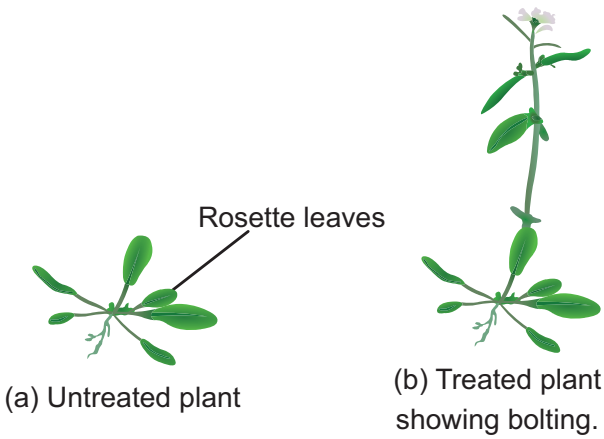


Figure 15.13: Bolting

exposure to cold season in the first year itself, when they are treated with gibberellins.

8. Agricultural role

- Formation of seedless fruits without fertilization is induced by gibberellins Example: Seedless tomato, apple and cucumber.
- It promotes the formation of male flowers in cucurbitaceae. It helps in crop improvement.
- Uniform bolting and increased uniform seed production.
- Improves number and size of fruits in grapes. It increase yield.
- Promotes elongation of inter-node in sugarcane without decreasing sugar content.
- Promotion of flowering in long day plants even under short day conditions.
- It stimulates the seed germination.

15.2.3 Cytokinins (*Cytos* – cell, *Kinesis* – division)

1. Discovery

The presence of cell division inducing substances in plants was first demonstrated by **Haberlandt** in 1913 in Coconut milk (liquid endosperm of coconut) which contains cell division inducing substances. In 1954, Skoog and Miller discovered that autoclaved DNA from herring sperm stimulated cell division in tobacco pith cells. They called this cell division inducing principle as kinetin (chemical structure: 6-Furfuryl Amino Acid). This does not occur in plants. In 1963, Lethan introduced the term cytokinin. In 1964, Lethan and Miller isolated and identified a new cytokinin called **Zeatin** from unripe grains of maize. The most widely occurring cytokinin in plants is Iso Pentenyl adenine (IPA).

2. Occurrence

Cytokinin is formed in root apex, shoot apex, buds and young fruits.

3. Precursor

Cytokinins are derivatives of the purine adenine.

4. Bioassay (Neem Cotyledon Assay)

Neem cotyledons are measured and placed in cytokinin solution as well as in ordinary water. Enlargement of cotyledons is an indication of cytokinin activity.

5. Transport in plants

The distribution of cytokinin in plants is not as wide as those of auxin and gibberellins but found mostly in roots. Cytokinins appear to be translocated through xylem.

6. Physiological effect

- Cytokinin promotes cell division in the presence of auxin (IAA).
- Induces cell enlargement associated with IAA and gibberellins

- Cytokinin can break the dormancy of certain light-sensitive seeds like tobacco and induces seed germination.
- Cytokinin promotes the growth of lateral bud in the presence of apical bud.
- Application of cytokinin delays the process of aging by nutrient mobilization. It is known as **Richmond Lang effect**.
- Cytokinin (i) increases rate protein synthesis (ii) induces the formation of inter-fascicular cambium (iii) overcomes apical dominance (iv) induces formation of new leaves, chloroplast and lateral shoots.
- Plants accumulate solutes very actively with the help of cytokinins.

15.2.4 Ethylene (Gaseous Phytohormone)

Almost all plant tissues produce ethylene gas in minute quantities.

1. Discovery

In 1924, **Denny** found that ethylene stimulates the ripening of lemons. In 1934, **R. Gane** found that ripe bananas contain abundant ethylene. In 1935, **Cocken** *et al.,* identified ethylene as a natural plant hormone.

2. Occurrence

Maximum synthesis occurs during climacteric ripening of fruits (*see* Box info) and tissues undergoing senescence. It is formed in almost all plant parts like roots, leaves, flowers, fruits and seeds.

3. Transport in plants

Ethylene can easily diffuse inside the plant through intercellular spaces.

4. Precursor

It is a derivative of amino acid methionine, linolenic acid and fumaric acid.

5. Bioassay (Gas Chromatography)

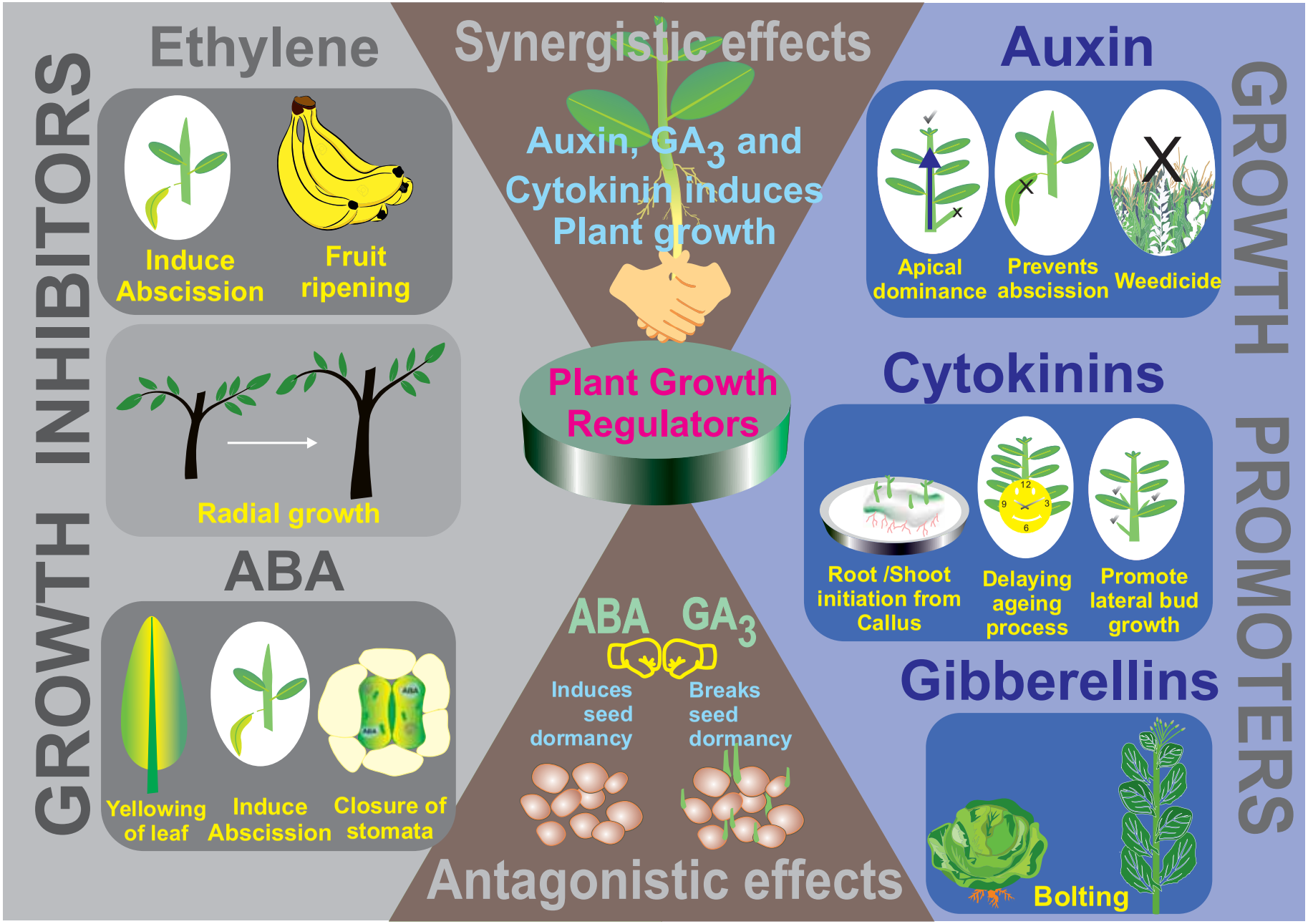
Ethylene can be measured by gas chromatography. This technique helps in the detection of exact amount of ethylene from different plant tissues like lemon and orange.

6. Physiological Effects

- Ethylene stimulates respiration and ripening in fruits.
- It stimulates radial growth in stem and root and inhibits linear growth.
- It breaks the dormancy of buds, seeds and storage organs.
- It stimulates formation of abscission zone in leaves, flowers and fruits. This makes the leaves to shed prematurely.
- Inhibition of stem elongation (shortening the internode).
- In low concentration, ethylene helps in root initiation.
- Growth of lateral roots and root hairs. This increases the absorption surface of the plant roots.
- The growth of fruits is stimulated by ethylene in some plants. It is more marked in climacteric fruits.
- Ethylene causes epinasty.

Agricultural role

- Ethylene normally reduces flowering in plants except in Pine apple and Mango.
- It increases the number of female flowers and decreases the number of male flowers.
- Ethylene spray in cucumber crop produces female flowers and increases the yield.


GROWTH INHIBITORS
Ethylene
Induce Abscission
Fruit ripening
Radial growth
ABA
Yellowing of leaf
Induce Abscission
Closure of stomata
Synergistic effects
Auxin, GA3 and Cytokinin induces Plant growth
Plant Growth Regulators
ABA GA3
Induces seed dormancy
Breaks seed dormancy
Antagonistic effects
GROWTH PROMOTERS
Auxin
Apical dominance
Prevents abscission
Weedicide
Cytokinins
Root /Shoot initiation from Callus
Delaying ageing process
Promote lateral bud growth
Gibberellins
Bolting

Climacteric fruits: In most of the plants, there is sharp rise in respiration rate near the end of the development of fruit, called climacteric rise. Such fruits are called climacteric fruits. The ripening on demand can be induced in these fruits by exposing them to normal air containing about 1 ppm of ethylene. A liquid called ethephon is being used in fruit ripening as it continuously releases ethylene.

Example: Tomato, Apples, Banana, Mango.

Non climacteric fruits: All fruits cannot be ripened by exposure to ethylene. Such fruits are called non-climacteric fruits and are insensitive to ethylene.

Example: Grapes, Watermelon, Orange.

15.2.5 Abscisic Acid (ABA) (Stress Phyto Hormone)

1. Discovery

In 1963, the hormone was first isolated by **Addicott *et al.*,** from young cotton bolls and named as **Abscission II**. Eagles and Wareing during 1963–64 isolated a dormancy inducing substance from leaves of *Betula* and called it as dormin. In 1965, it was found by Cornsforth *et al.*, that both dormin and abscission are chemically same compounds and called **Abscisic Acid (ABA)**.

2. Occurrence

This hormone is found abundantly inside the chloroplast of green cells.

3. Precursors

The hormone is formed from mevalonic acid pathway or xanthophylls.

4. Transport in plants

Abscisic acid is transported to all parts of the plant through diffusion as well as through phloem and xylem.

5. Chemical structure

It has carotenoid structure.

6. Bioassay (Rice Coleoptile)

The inhibition of IAA induces straight growth of rice seedling coleoptiles.

7. Physiological effects

- It helps in reducing transpiration rate by closing stomata. It inhibits K^+ uptake by guard cells and promotes the leakage of malic acid. It results in closure of stomata.
- It spoils chlorophylls, proteins and nucleic acids of leaves making them yellow.
- Inhibition of cell division and cell elongation.
- ABA is a powerful growth inhibitor. It causes 50% inhibition of growth in Oat coleoptile.
- It induces bud and seed dormancy.
- It promotes the abscission of leaves, flowers and fruits by forming abscission layers.
- ABA plays an important role in plants during water stress and during drought conditions. It results in loss of turgor and closure of stomata.
- It has anti-auxin and anti-gibberellin property.
- Abscisic acid promotes senescence in leaves by causing loss of chlorophyll pigment decreasing the rate of

photosynthesis and changing the rate of proteins and nucleic acid synthesis.

8. Agricultural Role

- In *Cannabis sativa*, induces male flower formation on female plants.
- Induction of flowers in short day plants.
- It promotes sprouting in storage organs like Potato.
- ABA plays an important role in plants during water stress drought conditions.
- It inhibits the shoot growth and promotes growth of root system. This character protect the plants from water stress. Hence, ABA is called as **stress hormone.**

15.3 Photoperiodism

Trees take several years for initiation of flowering whereas an annual herb flowers within few months. Each plant requires a specific time period to complete their vegetative phase which will be followed by reproductive phase as per their internal control points through Biological Clock. The physiological mechanisms in relation to flowering are controlled by (i) light period (Photoperiodism) and (ii) temperature (Vernalization). The physiological change on flowering due to relative length of light and darkness (photoperiod) is called **Photoperiodism**. The term photoperiodism was coined by **Garner** and **Allard** (1920) when they observed this in 'Biloxi' variety of soybean (*Glycine max*) and 'Maryland mammoth' variety of tobacco (*Nicotiana tabacum*). The photoperiod required to induce flowering is called **critical day length**. Maryland mammoth (tobacco variety) requires 12 hours of light and cocklebur (*Xanthium pensylvanicum*) requires 15.05 hours of light for flowering.

1. Classification of plants based on Photoperiodism

Depending upon the photoperiodic responses plants are classified as given in Figure 15.14.

i. **Long day plants**: The plants that require long critical day length for flowering are called long day plants or short night plants. Example: Pea, Barley and Oats.

ii. **Short long day plants**: These are long day plants but should be exposed to short day lengths during early period of growth for flowering. Example: Wheat and Rye.

iii. **Short day plants**: The plants that require a short critical day length for flowering are called short day plants or long night plants. Example: Tobacco, Cocklebur, Soybean, Rice and *Chrysanthemum*.

iv. **Long short day plants**: These are actually short-day plants but they have to be exposed to long days during their early periods of growth for flowering.

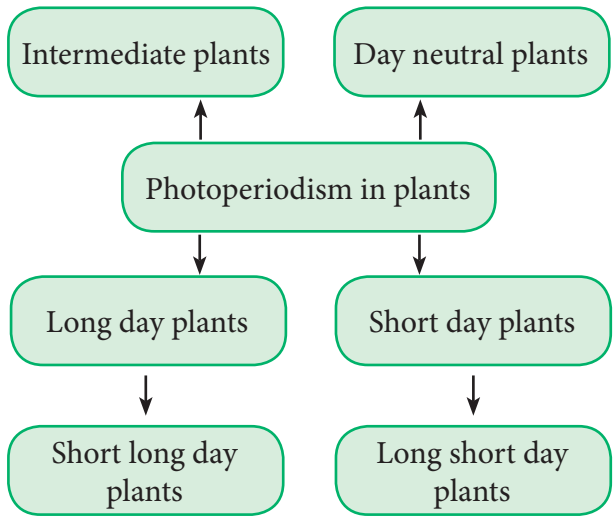


Figure: 15.14 Classification of Plants based on Photoperiodism

Example: Some species of *Bryophyllum* and Night jasmine.

v. **Intermediate day plants:** These require a photoperiod between long day and short day for flowering. Example: Sugarcane and *Coleus*.

vi. **Day neutral plants**: There are a number of plants which can flower in all possible photoperiods. They are also called **photo neutrals** or **indeterminate plants**. Example: Potato, *Rhododendron*, Tomato and Cotton.

2. Photoperiodic induction

An appropriate photoperiod in 24 hours' cycle constitutes one inductive cycle. Plants may require one or more inductive cycles for flowering. The phenomenon of conversion of leaf primordia into flower primordia under the influence of suitable inductive cycles is called **photoperiodic induction**. Example: *Xanthium* (SDP) – 1 inductive cycle and *Plantago* (LDP) – 25 inductive cycles.

3. Site of Photoinductive perception

Photoperiodic stimulus is perceived by the leaves. Floral hormone is synthesised in leaves and translocated to the apical tip to promote flowering. This can be explained by a simple experiment on Cocklebur (*Xanthium pensylvanicum*), a short day plant. Usually *Xanthium* will flower under short day conditions. If the plant is defoliated and kept under short day conditions it will not flower. Flowering will occur even when all the leaves are removed except one leaf. If a cocklebur plant is defoliated and kept under long day conditions, it will not flower. If one of its leaves is exposed to short day condition and rest are in long day condition, flowering will occur (Figure 15.15).

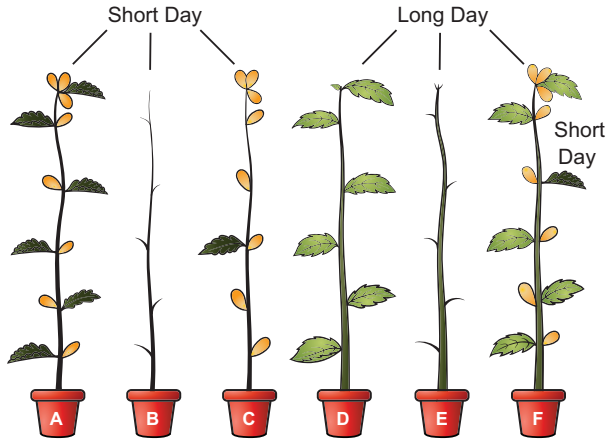


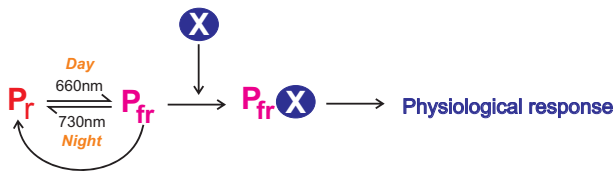
Figure 15.15: Experiment on Cocklebur plant showing photoperiodic stimulus

The nature of flower producing stimulus has been elusive so far. It is believed by many physiologists that it is a hormone called **florigen**. The term florigen was coined by **Chailakyan** (1936) but it is not possible to isolate.

4. Importance of photoperiodism

1. The knowledge of photoperiodism plays an important role in hybridisation experiments.
2. Photoperiodism is an excellent example of physiological pre-conditioning that is using an external factor to induce physiological changes in the plant.

5. Phytochrome



Phytochrome is a bluish biliprotein pigment responsible for the perception of light in photo physiological process. **Butler *et al.*,** (1959) named this pigment and it exists in two interconvertible forms:

Photoperiodism in plants

Pioneers of photoperiodism
Garner and Allard (1920)

Long day plants

The plants that require long critical day length for flowering

Short long day plants

These are long day plants but should be exposed to short day lengths during early period of growth for flowering.
Wheat and Rye

Plants which can flower in all possible photoperiods. They are also called **photo neutrals** or **indeterminate plants. Potato, *Rhododendron***

Day neutral plants

Intermediate plants

Plants require a photoperiod between long day and short day for flowering

A short-day plant but they have to be exposed to long days during their early periods of growth for flowering.
***Bryophyllum* and Night jasmine**

Long short day plants

The plants that require a short critical day length for flowering or long night plants

Short day plants

(i) red light absorbing pigment which is designated as P_r and (ii) far red light absorbing pigment which is designated as P_{fr}. The P_r form absorbs red light in 660nm and changes to $P_{fr.}$ The P_{fr} form absorbs far red light in 730nm and changes to P_r. The P_r form is biologically inactive and it is stable whereas P_{fr} form is biologically active and it is very unstable. In short day plants, P_r promotes flowering and P_{fr} inhibits the flowering whereas in long day plants flowering is promoted by P_{fr} and inhibited by P_r form. P_{fr} is always associated with hydrophobic area of membrane systems while P_r is found in diffused state in the cytoplasm. The interconversion of the two forms of phytochrome is mainly involved in flower induction and also additionally plays a role in seed germination and changes in membrane conformation.

15.4 Vernalization (*Vernal* – Spring Like)

Besides photoperiod certain plants require a low temperature exposure in their earlier stages for flowering. Many species of biennials and perennials are induced to flower by low temperature exposure (0°C to 5°C). This process is called **Vernalization.** The term Vernalization was first used by **T. D. Lysenko** (1938).

1. Mechanism of Vernalization:

Two main theories to explain the mechanism of vernalization are:

i. Hypothesis of phasic development
ii. Hypothesis of hormonal involvement

i. Hypothesis of phasic development

According to Lysenko, development of an annual seed plant consists of two phases. First phase is **thermostage**, which is vegetative phase requiring low temperature and suitable moisture. Next phase is **photo stage** which requires high temperature for synthesis of florigen (flowering hormone).

ii. Hypothesis of hormonal involvement

According to **Purvis** (1961), formation of a substance A from its precursor, is converted into B after chilling. The substance B is unstable. At suitable temperature B is converted into stable compound D called **Vernalin**. Vernalin is converted to F (Florigen). Florigen induces flower formation. At high temperature B is converted to C and devernalization occurs (Figure 15.16).

2. Technique of Vernalization:

The seeds are first soaked in water and allowed to germinate at 10°C to 12°C. Then seeds are transferred to low temperature (3°C to 5°C) from few days to 30 days. Germinated seeds after this treatment are allowed to dry and then sown. The plants will show quick flowering when compared to untreated control plants.

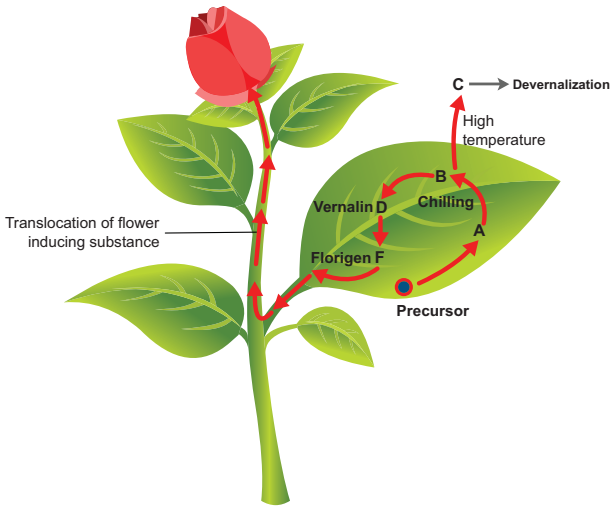


Figure 15.16: Vernalization and Flowering

3. Devernalization

Reversal of the effect of vernalization is called **devernalization**.

4. Practical applications

1. Vernalization shortens the vegetative period and induces the plant to flower earlier.
2. It increases the cold resistance of the plants.
3. It increases the resistance of plants to fungal disease.
4. Plant breeding can be accelerated.

15.5 Seed Germination and Dormancy

I. Seed Germination

The activation and growth of embryo from seed into seedling during favourable conditions is called **seed germination**.

1. Types of germination

There are two methods of seed germination. Epigeal and hypogeal.

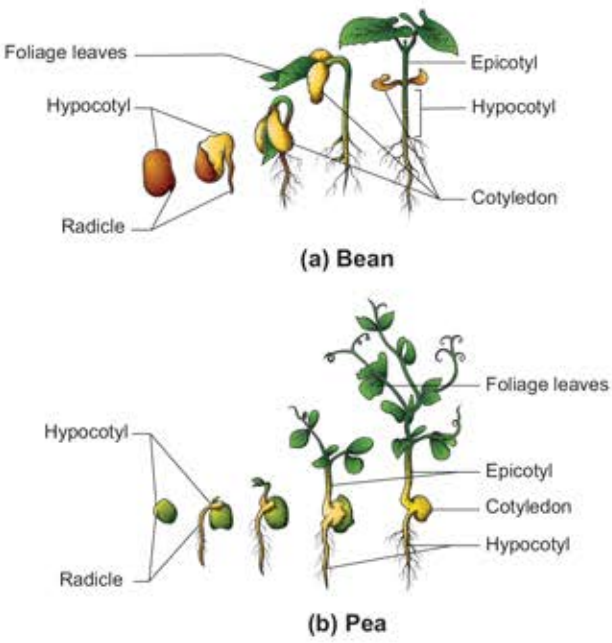


Figure 15.17: (a) Epigeal Germination
(b) Hypogeal Germination

i. Epigeal germination

During epigeal germination cotyledons are pushed out of the soil. This happens due to the elongation of the hypocotyl. Example: Castor and Bean.

ii. Hypogeal germination

During hypogeal germination cotyledons remain below the soil due to rapid elongation of epicotyls (Figure 15.17). Example: Maize

2. Factors affecting germination

Seed germination is directly affected by external and internal factors:

i. External factors

a. **Water**: It activates the enzymes which digest the complex reserve foods of the seed. If the water content of the seed goes below a critical level, seeds fail to germinate.

b. **Temperature**: Seeds fails to germinate at very low and high temperature. The optimum temperature is 25°C to 35°C for most tropic species.

c. **Oxygen**: It is necessary for germination. Since aerobic respiration is a physiological requirement for germination most will germinate well in air containing 20% oxygen.

d. **Light**: There are many seeds which respond to light for germination and these seeds said to be photoblastic.

e. **Soil conditions**: Germination of seed in its natural habit is influenced by soil conditions such as water holding capacity, mineral composition and aeration of the soil.

ii. Internal factors

a. **Maturity of embryo**: The seeds of some plants, when shed will contain

immature embryo. Such seeds germinate only after maturation of embryo.

b. **Viability**: Usually seeds remain viable or living only for a particular period. Viability of seeds range from a few days (Example: *Oxalis*) to more than hundred years. Maximum viability (1000 years) has been recorded in lotus seeds. Seeds germinate only within the period of viability.

c. **Dormancy**: Seeds of many plants are dormant at the time of shedding. A detailed treatment is given below.

II. Seed Dormancy

The seeds of most plants germinate under favourable environmental conditions but some seeds do not germinate when suitable conditions like water, oxygen and favourable temperature are not available. Germination of such seeds may be delayed for days, months or years. The condition of a seed when it fails to germinate even in suitable environmental condition is called **seed dormancy**. There are two main reasons for the development of dormancy: Imposed dormancy and innate dormancy. Imposed dormancy is due to low moisture and low temperature. Innate dormancy is related to the properties of seed itself.

1. Factors causing dormancy of seeds:

i. Hard, tough seed coat causes barrier effect as impermeability of water, gas and restriction of the expansion of embryo prevents seed germination.

ii. Many species of seeds produce imperfectly developed embryos called **rudimentary embryos** which promotes dormancy.

iii. Lack of specific light requirement leads to seed dormancy.

iv. A range of temperatures either higher or lower cause dormancy.

v. The presence of inhibitors like phenolic compounds which inhibits seed germination cause dormancy.

2. Methods of breaking dormancy:

The dormancy of seeds can be broken by different methods. These are:

i. **Scarification**: Mechanical and chemical treatments like cutting or chipping of hard tough seed coat and use of organic solvents to remove waxy or fatty compounds are called as **Scarification**.

ii. **Impaction**: In some seeds water and oxygen are unable to penetrate micropyle due to blockage by cork cells. These seeds are shaken vigorously to remove the plug which is called **Impaction**.

iii. **Stratification**: Seeds of rosaceous plants (Apple, Plum, Peach and Cherry) will not germinate until they have been exposed to well aerated, moist condition under low temperature (0°C to 10°C) for weeks to months. Such treatment is called **Stratification**.

iv. **Alternating temperatures**: Germination of some seeds is strongly promoted by alternating daily temperatures. An alternation of low and high temperature improves the germination of seeds.

v. **Light**: The dormancy of photoblastic seeds can be broken by exposing them to red light.

15.6 Senescence

Plant life comprises some sequential events, *viz*: germination, juvenile stage, maturation, old age and death. Old age is called **senescence** in plants. Senescence refers to all collective, progressive and deteriorative processes which ultimately lead to complete loss of organization and function. Unlike animals, plants continuously form new organs and older organs undergo a highly regulated senescence program to maximize nutrient export.

1. Types of Senescence

Leopold (1961) has recognised four types of senescence:

i. Overall senescence
ii. Top senescence
iii. Deciduous senescence
iv. Progressive senescence

> The branch of botany which deals with ageing, abscission and senescence is called **Phytogerontology**

i. **Overall senescence**: This kind of senescence occurs in annual plants when entire plant gets affected and dies. Example: Wheat and Soybean. It also occurs in few perennials also. Example: *Agave* and Bamboo.

ii. **Top senescence**: It occurs in aerial parts of plants. It is common in perennials, underground and root system remains viable. Example: Banana and *Gladiolus*.

iii. **Deciduous senescence**: It is common in deciduous plants and occurs only in leaves of plants, bulk of the stem and root system remains alive. Example: Elm and Maple.

iv. **Progressive senescence**: This kind of senescence is gradual. First it occurs in old leaves followed by new leaves then stem and finally root system. It is common in annuals (Figure 15.18).

2. Physiology of Senescence

- Cells undergo changes in structure.
- Vacuole of the cell acts as lysosome and secretes hydrolytic enzymes.
- The starch content is decreased in the cells.
- Photosynthesis is reduced due to loss of chlorophyll accompanied by synthesis and accumulation of anthocyanin pigments, therefore the leaf becomes red.

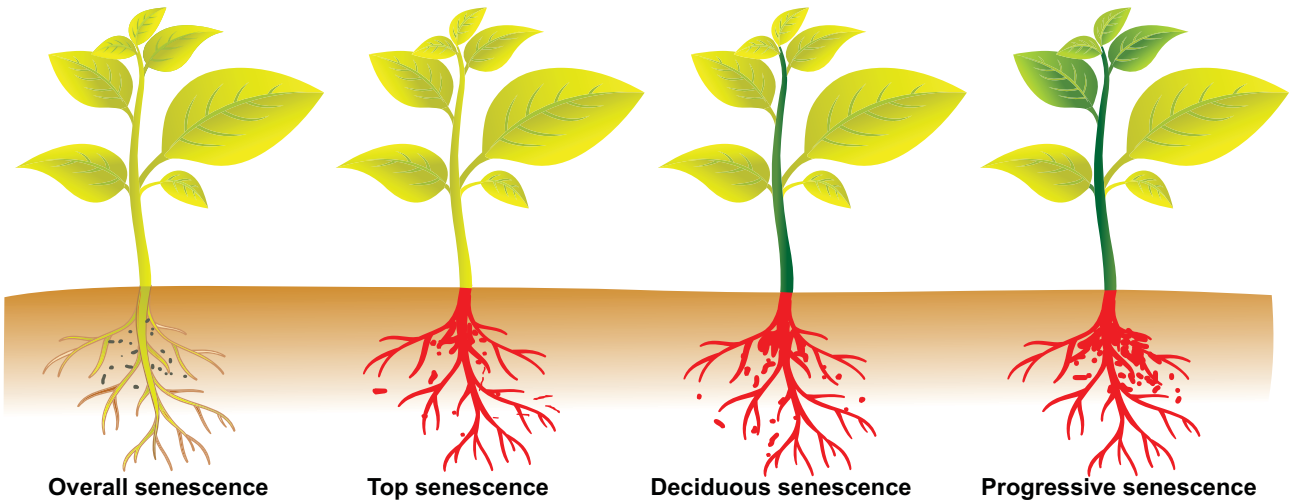


Figure 15.18: Different types of senescence in plants

- There is a marked decrease in protein content in the senescing organ.
- RNA content of the leaf particularly rRNA level is decreased in the cells due to increased activity of the enzyme RNAase.
- DNA molecules in senescencing leaves degenerate by the increased activity of enzyme DNAase.

3. Factors affecting Senescence:

- ABA and ethylene accelerate senescence while auxin and cytokinin retard senescence.
- Nitrogen deficiency increases senescence whereas nitrogen supply retards senescence.
- High temperature accelerates senescence but low temperature retards senescence.
- Senescence is rapid in dark than in light.
- Water stress leads to accumulation of ABA leading to senescence.

4. Programmed cell death (PCD)

Senescence is controlled by plants own genetic programme and death of the plant or plant part consequent to senescence is called **Programmed Cell Death**. In short senescence of an individual cell is called **PCD**. The proteolytic enzymes involving PCD in plants are **phytaspases** and in animals are **caspases**. The nutrients and other substrates from senescing cells and tissues are remobilized and reallocated to other parts of the plant that survives. The protoplasts of developing xylem vessels and tracheids die and disappear at maturity to make them functionally efficient to conduct water for transport. In aquatic plants, aerenchyma is normally formed in different parts of the plant such as roots and stems which encloses large air spaces that are created through PCD. In the development of unisexual flowers, male and female flowers are present in earlier stages, but only one of these two completes its development while other aborts through PCD (Figure 15.19).

5. Abscission

Abscission is a physiological process of shedding of organs like leaves, flowers, fruits and seeds from the parent plant body. When these parts are removed the plant seals off its vascular system to prevent loss of water and nutrients. Final stage of senescence is abscission. In temperate regions all the leaves of deciduous plants fall in autumn and give rise to naked appearance, then the new leaves are developed in the subsequent spring season. But in evergreen plants there is gradual abscission of leaves, the older leaves fall while new leaves are developed continuously throughout the year.

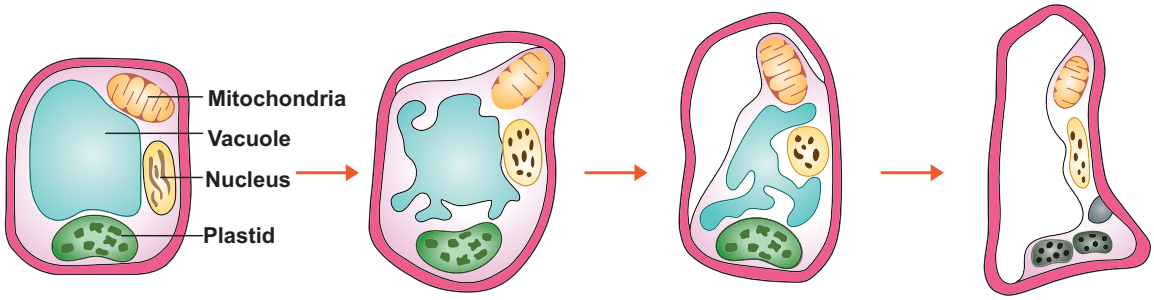


Figure 15.19: Programmed cell death

6. Morphological and Anatomical changes during abscission

Leaf abscission takes place at the base of petiole which is marked internally by a distinct zone of few layers of thin walled cells arranged transversely. This zone is called **abscission zone or abscission layer**. An abscission layer is greenish-grey in colour and is formed by rows of cells of 2 to 15 cells thick. The cells of abscission layer separate due to dissolution of middle lamella and primary wall of cells by the activity of enzymes **pectinase** and **cellulase** resulting in loosening of cells. Tyloses are also formed blocking the conducting vessels. Degrading of chlorophyll occur leading to the change in the colour of leaves, leaf detachment from the plant and leaf fall. After abscission, outer layer of cells becomes suberized by the development of periderm (Figure 15.20).

7. Hormones influencing abscission

All naturally occurring hormones influence the process of abscission. Auxins and cytokinins retard abscission, while abscisic acid (ABA) and ethylene induce it.

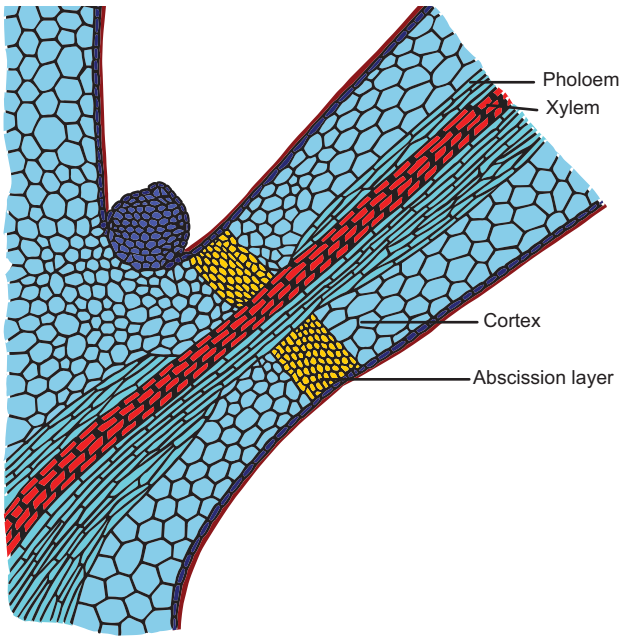


Figure 15.20: a) L.S of petiolar base showing abscission layer

8. Significance of abscission

1. Abscission separates dead parts of the plant, like old leaves and ripe fruits.
2. It helps in dispersal of fruits and continuing the life cycle of the plant.
3. Abscission of leaves in deciduous plants helps in water conservation during summer.
4. In lower plants, shedding of vegetative parts like gemmae or plantlets help in vegetative reproduction.

Summary

Growth occurs by cell division, cell elongation and cell maturation. The first phase is lag phase, the second is log phase and the final phase is steady state phase. The log phase is otherwise known as **exponential phase**. The three phases are collectively called Grand period of growth. Plant exhibits plasticity in development. Plant growth and development are controlled by both internal and external factors. The internal factors are chemical substances called Plant Growth Regulators (PGRs). The hormones are classified into five groups: Auxins, gibberellins, cytokinins, abscisic acid and ethylene. These PGRs are synthesized in various parts of the plant. PGRs may act synergistically or antagonistically. The external factors affecting growth includes water, nutrition, temperature, oxygen and light. Mechanism of flowering is controlled by light period (photoperiodism) and temperature (vernalization). The physiological changes on flowering with effect from relative length of light and darkness (photoperiodism) are called photoperiodism. A bluish biliprotein

responsible for the perception of light in photophysiological process (induction and inhibition of flowering) is called **Phytochrome**. Besides photoperiod certain plants require a low temperature in the earlier stages for flowering. Many biennial and perennial plants are induced to flower by low temperature (0°C to 5°C). This process is called **vernalization** and the reversal effect of vernalization is called **devernalization**. The condition of a seed when it fails to germinate even in suitable environmental condition is called **seed dormancy**. Thus, dormancy can be overcome by following methods such as scarification, impaction, stratification, alternating temperatures and light. Senescence refers to all collective, progressive and deteriorative processes which ultimately lead to complete loss of organization and function. Senescence is of four types and they are overall, top, deciduous and progressive. Senescence is controlled by plant's own genetic programme. Death of the plant or its parts consequent to senescence is called **Programmed Cell Death** (PCD). The final stage of senescence is abscission. Abscission is a physiological process of shedding of organs from the parent plant body.

Evaluation

CRU5PV

1. Select the wrong statement from the following:
   a. Formative phase of the cells retain the capability of cell division.
   b. In elongation phase development of central vacuole takes place.
   c. In maturation phase thickening and differentiation takes place.
   d. In maturation phase, the cells grow further.
2. If the diameter of the pulley is 6 inches, length of pointer is 10 inches and distance travelled by pointer is 5 inches. Calculate the actual growth in length of plant.
   a. 3inches b. 6 inches
   c. 12 inches d. 30 inches
3. In unisexual plants, sex can be changed by the application of
   a. Ethanol b. Cytokinins
   c. ABA d. Auxin
4. Select the correctly matched one

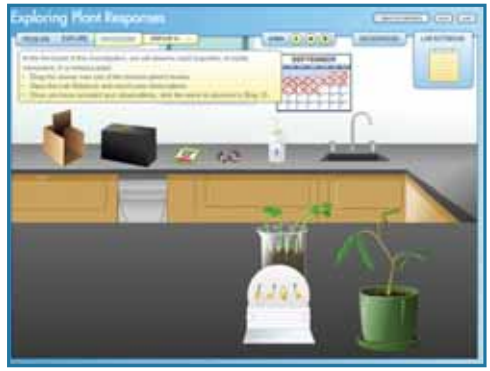
A) Human urine	i) Auxin –B
B) Corn gram oil	ii) GA_3
C) Fungus	iii) Abscisic acid II
D) Herring fish sperm	iv) Kinitin
E) Unripe maize grains	v) Auxin A
F) Young cotton bolls	vi) Zeatin

   a) A-iii, B-iv, C-v, D-vi, E-i, F-ii,
   b) A-v, B-i, C-ii, D-iv, E-vi, F-iii,
   c) A-iii, B-v, C-vi, D-i, E-ii, F-iv,
   d) A-ii, B-iii, C-v, D-vi, E-iv, F-i
5. Seed dormancy allows the plants to
   a. overcome unfavourable climatic conditions
   b. develop healthy seeds
   c. reduce viability
   d. prevent deterioration of seeds
6. What are the parameters used to measure growth of plants?
7. What is plasticity?
8. Write the physiological effects of Cytokinins.
9. Describe the mechanism of photoperiodic induction of flowering.
10. Give a brief account on Programmed Cell Death (PCD)

ICT Corner

How do Plants respond to different stimuli?

Let's Stimulate **the Plants.**

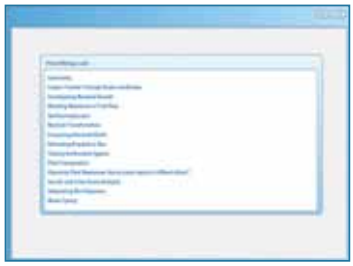


Steps

- Scan the QR code
- Click Exploring plant responses
- Select items and complete the check list
- Follow the procedure – 1 to 10 steps
- Record your prediction and not your observation in lab note – Right top

Activity

- Observe the movements of plant seedlings and plant parts.
- Conclude your observations.



Step 1

Step 2

Step 3

Step 4

Web URL:

https://www.classzone.com/books/hs/ca/sc/bio_07/virtual_labs/virtualLabs.html

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* Pictures are indicative only

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Glossary

Abscission zone	A region near the base of petiole of leaf which contains abscission layer.
Absorption Spectrum	A curve obtained by plotting the amount of absorption of different wavelengths of light by a pigment is called its absorption spectrum.
Action Spectrum	A graphic representation showing the rate of photosynthesis at different wavelengths of light is called action spectrum
Aeroponics	A technique of growing plants suspended over the nutrient solution in a mist chamber. Nutrient sprayed by motor driven rotor on the roots.
Agar	Jelly-like substance, derived from red algae
Allelopathy	The chemical substances released by one plant species which affect or benefit another plant
Amphicribal/ Hadrocentric	Xylem in the centre with phloem surrounding it. Example: Ferns (Polypodium)
Amphivasal /Leptocentric	Phloem in the centre with xylem surrounding it. Example: Dragon plant – Dracena and Yucca
Anabolic	It is an enzyme catalyzed reaction in a cell that involves synthesis of complex molecules from simple molecules which uses energy.
Apical cell theory	Single apical cell growing into whole plant
Axil Parenchyma	Parenchyma arranged longitudinally along the axis
Callose	Sieve pores are blocked by substances called callose
Carbonic acid	A weak acidic solution of carbon-di-oxide dissolved in water
Catabolic	It is an enzyme catalyzed reaction in a cell that involves degradation of molecules into simple subunits which release energy.
Chelating agents	A chelate is the soluble product formed when certain atoms in an organic ligand donate electrons to the cation.
Chlorosis	Breakdown of chlorophylls leads to yellowing of leaves
Closed vascular bundle	Cambium absent between xylem and phloem Example: Monocot stem
Coenzyme	A non-protein molecule involved in enzyme catalyzed reactions serves as transfer of protons or electrons between various molecules
Colloidal	An evenly distributed mixture of two different particles in a system without losing its own properties.
Deamination	The enzymatic removal of an amino group from an amino acid to form its corresponding keto acid.
Desiccation tolerance	Ability of plants which can tolerate extreme water stress without being killed.
Drought resistance	Capacity of a plant to limit and control consequences of water deficit.

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EDTA	Ethylene Diamine Tetra Acetic acid, chelating agent makes iron uptake possible by forming soluble complex in an alkaline soil.
Endergonic	A chemical reaction with a positive free energy charge or ATP utilizing reactions.
Exergonic	A chemical reaction with a negative free energy charge or ATP producing reactions.
Extra stellar ground tissue	Tissues outside the stele
Fibre-Tracheids	Transitional form between fibre and tracheids
Fluorescence	Emission of light by a substance that has absorbed light in the form luminescence.
Gelatin	An animal-based product used as a gelling agent.
Granum	A stack of thylakoid in a stroma of chloroplast
Hadrome	Xylem-by Haberlandt
Halophytes	Plants native to saline soils and complete their life cycle
Heliophytes	Plants which are adapted to light
Histogenesis	Differentiate tissues from undifferentiated cells of meristem
Indeterminate growth	Plants grow throughout their life
Intrastelar ground tissue	Tissues within the stele
Isomerisation	Rearrangement of atomic groups within the same molecule without any loss or gain of atoms.
Leptome	Phloem – by Haberlandt
Lumen	Space inside the tracheid/vessel/fibres
Malate Shuttle mechanism	It is a biochemical system for translocating electrons produced from glycolysis across inner membrane of mitochondrion for oxidative phosphorylation.
Mass meristem	Meristem which divides in all planes
Necrosis	Death of tissue
Non heme iron	An iron porphyrin prosthetic group of heme proteins from plant origin
Nutation	The growing stems of twiner and tendrils show automatic movement
Open vascular bundle	Cambium present between xylem and phloem Example: Dicot stem
Oxidation	Water is oxidised into Oxygen (loss of electrons)
PAR	The wavelength at which the rate of photosynthesis is more is called 'Photosynthetically Active Radiations' which falls between 400 to 700 nm.
Phosphorescence	Phosphorescence is the delayed emission of absorbed radiations.
Photolysis	Splitting of water molecules by light which generate protons, electrons and oxygen.
Photon	Light is electromagnetic radiant energy and travels as tiny particles called photons. A discrete Physical unit of light energy.

Photoperiodism	The response of plants to the photoperiod expressed in the form of flowering.
Phytochrome	A photo reversible proteinaceous plant pigment in very low concentration that absorbs red and far red light which controls flowering.
Pitted thickening	Uniformly thick except at their pits
Preparatory phase	First half of glycolysis comprising five enzymatic reactions in which one molecule of glucose splitting into two molecules of glyceraldehyde 3 phosphate with consumption of two ATP molecules.
Prickles	Stiff and sharp outgrowth
Quantasome	Morphological expression of physiological photosynthetic units, located on the inner membrane of thylakoid lamellae. Act as photosynthetic unit contains 200 to 300 chlorophyll molecules.
Quantum	The energy contained in a photon is represented as quantum
Quantum requirement	The number of photons or quanta required to release one molecule of oxygen during photosynthesis
Quantum yield	The number of oxygen molecules produced per quantum of light absorbed.
Quiescent centre concept	Inactive region of root meristem
Radial vascular bundles	Xylem and phloem present on different radii
Ray Parenchyma	Parenchyma cells arranged in radial rows
Redox reactions	Oxidation (loss of electrons) and Reduction (gain of electrons) reactions are called redox reactions.
Reduction	CO2 is reduced into Carbohydrates (gain of electrons)
Rib-meristem	Meristem which divides anticlinally in two planes
RUBISCO	Enzyme responsible for fixation of Carbon dioxide, the most abundant protein (Ribulose 1,5 bisphosphate Carboxylase Oxygenase)
Salt stress	Adverse effects of excess mineral salts on plants
Sap	It is a fluid consist of water and dissolved minerals
Slime body	A special protein (Phloem Protein) in sieve tubes
Stellate hairs	Star shaped hairs
Stratification	A process of breaking the dormancy of some plants resulting from chilling requirements
Subsidiary cells	Surrounding guard cells in the leaf epidermis
Sucrose	Non-reducing disaccharide composed of glucose and fructose
Trichoblasts	One type of epidermal cells that is also called short cell
Trichomes	Unicellular or multicellular appendages
Tunica-carpus theory	Two zones of apical meristem Tunica and Carpus
Xylos	Wood

English – Tamil Terminology

Abscission	உதிர்தல்
Abscission zone	உதிரும் அடுக்கு
Absorption spectrum	ஒளி ஈர்ப்பு நிறமாலை
Action spectrum	ஒளி செயல்திறன் நிறமாலை
Activated diffusion	மேம்படுத்தப்பட்ட பரவல்
Active transport	ஆற்றல்சார் கடத்தல்
Adhesion	ஒட்டிணைவு
Aeroponics	காற்றுடக வளர்ப்பு
Anabolic	சேர்க்கைச் செயல்
Annual rings	ஆண்டு வளையங்கள்
Antenna molecules	ஏற்பி மூலக்கூறுகள்
Apical cell theory	நுனி செல் கொள்கை
Arithmetic growth	எண் கணித வளர்ச்சி
Ascent of sap	சாறேற்றம்
Assimilatory power	தன்மயமாக்கும் ஆற்றல்
Autonomous movement	தன்னிச்சையான அசைவுகள்
Autumn wood or late wood	குளிர்க்காலக் கட்டை அல்லது பின்பருவக் கட்டை
Axial parenchyma	அச்சு பாரங்கைமா
Bicollateral vascular bundle	இருபக்க ஒருங்கமைந்த வாஸ்குலக் கற்றை
Biosynthetic phase	உயிர்மதோற்ற நிலை
Biosequestration	உயிர்வளி தனிமைப்படுத்துதல்
Brown heart disease	மைய கருக்கல் நோய்
Callus	திசுத்திரள்
Carbon fixation	கார்பன் நிலைநிறுத்தம்
Carbon di oxide compensation point	கார்பன்-டை-ஆக்ஸைட் ஈடு செய்யும் புள்ளி
Carrier protein	தாங்கிப் புரதம்/கொண்டு செல்லும் புரதம்
Catabolic	சிதைக்கும் செயல்
Catalytic amination	வினையூக்க அமைனோவாக்கம்
Cavitation	குமிழாதல்
Channel protein	கால்வாய் புரதம்
Chelating agents	பிணைக்கும் காரணி
Chemiosmotic theory	வேதி சவ்வூடு பரவல் கோட்பாடு
Chlorophyll	பச்சையம்
Chloroplast	பசுங்கணிகம்
Chlorosis	பச்சைய சோகை
Closed collateral vascular bundles	மூடிய ஒருங்கமைந்த வாஸ்குலக் கற்றைகள்
Cohesion	கூட்டிணைவு
Collateral vascular bundles	ஒருங்கமைந்த வாஸ்குலக் கற்றைகள்
Companion cells	துணைச் செல்கள்
Compensation point	ஈடுசெய்யும் புள்ளி

Concentration gradient	செறிவு சரிவு வாட்டம்
Concentric vascular bundles	சூழமைந்த வாஸ்குலக் கற்றைகள்
Core complex	மைய ஆதார கூட்டமைப்பு
Critical concentration	தீர்வுக் கட்ட செறிவு
Day neutral plants	நாள் நடுநிலை தாவரங்கள்
Deamination	அமினோ நீக்கம்
Dendrochronology	மர வயதியல்
Deplasmolysis	பிளாஸ்மா சிதைவு மீட்சி
Dicarboxylic acid pathway	டைகார்பாக்சிலிக் அமில சுழற்சி
Die back of shoot	தண்டின் நுனி அடி இறப்பு
Diffusion	பரவல்
Dimorphic chloroplast	இருவடிவ பசுங்கணிகம்
Drought resistance	வறட்சியை எதிர்ப்பவை
Efflux	அயனி வெளிப்புகல்
Electro magnetic spectrum	மின்காந்த நிறமாலை
Electron transport chain	எலக்ட்ரான் கடத்து சங்கிலி
Emerson's enhancement effect	எமர்சனுடைய மேம்படுத்தப்பட்ட விளைவு
Endergonic	ஆற்றல் ஏற்கும் வினை
Endosymbiotic hypothesis	அக கூட்டுயிர் கோட்பாடு
Eutrophication	மிகை ஊட்ட நிலை
Exarch Xylem	வெளிநோக்கு சைலம்
Exergonic	ஆற்றல் வெளியிடும் வினை
Extinction point	அழிவுப் புள்ளி
Fermentation	நொதித்தல்
Fibre Tracheids	நார் டிரக்கீடுகள்
Flourescence	உடன் ஒளிர்தல்
Flux	அயனிபுகல்
Geometric growth	ஜியோமித வளர்ச்சி
Grand period of growth	மொத்த வளர்ச்சிக் காலம்
Growth rate	பெரும வளர்ச்சி வீதம்
Halophiles	உவர்நாட்டவுயிரிகள்
Halophytes	உவர்நிலை தாவரங்கள்
Heart wood	வைரக்கட்டை
Heliophytes	ஒளியை விரும்பும் தாவரங்கள்
Histogen theory	ஹிஸ்டோஜன் கொள்கை
Histogenesis	ஹிஸ்டோஜெனிசிஸ்
HMP shunt	HMP மாற்றுவழிப் பாதை
Hydathode	நீர்கசிவுத் துளை
Hydroponics	நீர் ஊடக வளர்ப்பு
Imbibition	உள்ளீர்த்தல்
Influx	அயனி உட்புகல்

Interveinal chlorosis	நரம்பிடை பச்சைய சோகை
Isomerisation	மாற்றியமாதல்
Lag phase	உருவாக்க நிலை
Lenticel	பட்டைத்துளை
Light harvesting complex	ஒளி அறுவடை கூட்டமைப்பு
Link reaction	இணைப்பு வினை
Log phase	நீட்சியுறு நிலை
Macro nutrients	பெரும ஊட்ட மூலங்கள்
Malate Shuttle mechanism	மாலேட் திருப்பு செயல்
Mass meristem	பொருண்மை ஆக்குதிசு
Matric potential	ஊட க உட்திறன்
Micro nutrients	நுண் ஊட்ட மூலங்கள்
Mineral Nutrition	கனிம ஊட்டம்
Mitochondrial matrix	மைட்டோகாண்ட்ரிய உட்கூழ்மம்
Necrosis	நைவுப் புண்கள்
Nitrate Assimilation	நைட்ரேட் தன்மயமாதல்
Nitrogen metabolism	நைட்ரஜன் வளர்சிதை மாற்றம்
Non-porous wood	துளைகளற்ற கட்டை
Nutation	சுழலசைவு
Obligate parasite	கட்டாய ஒட்டுண்ணி
Open vascular bundle	திறந்த வாஸ்குலக் கற்றை
Oxygen evolving complex (OEC)	ஆக்ஸிஜன் உருவாக்கும் கூட்டமைப்பு
Paper chromatography	வண்ண பிரிகைதாள் வரைப்படம்
Paratonic movement	தூண்டப்படும் அசைவுகள்
Parthenocarpy	விதையிலாக் கனி
Passive transport	ஆற்றல்சாரா கடத்தல்
Pay off phase	விளை நிலை
Phosphorescence	நின்றொளிர்தல் / தாமத மறு ஒளிர்தல்
Photo chemical phase	ஒளி வேதிநிலை
Photo oxidation phase	ஒளி ஆக்ஸிஜனேற்ற நிலை
Photo respiration	ஒளி சுவாசம்
Photolysis	ஒளியின் நீராற் பகுப்பு
Photon	ஒளித்துகள்
Photoperiodic induction	ஒளிக் காலத்துவ தூண்டுதல்
Photoperiodism	ஒளிக்காலத்துவம்
Photophosphorylation	ஒளி பாஸ்பரிகரணம் / ஒளி பாஸ்பரஸ் சேர்க்கை
Photosynthetic carbon reduction cycle	ஒளிச்சேர்கையின் கார்பன் ஒடுக்க சுழற்சி
Photosynthetic unit (Quantasome)	ஒளிச்சேர்க்கை அலகு (குவாண்டோசோம்)
Photosystem	நிறமி அமைப்பு / ஒளி அமைப்பு
Plant antitranspirants	நீராவிப்போக்குத் தடுப்பான்கள்
Plasmolysis	பிளாஸ்மா சிதைவு

Plasticity	உருமாறும் தன்மை
Porous woods	துளைக்கட்டை
Preparatory phase	ஆயத்த நிலை
Pressure potential	அழுத்தயியல் திறன்
Primary growth	முதல்நிலை வளர்ச்சி
Programmed cell death	திட்டமிடப்பட்ட செல் இறப்பு
Proton gradient	புரோட்டான் சரிவு
Pumps	உந்திகள்
Quiescent centre concept	உறக்க மையக் கொள்கை
Radial vascular bundles	ஆரப்போக்கமைந்த வாஸ்குலக் கற்றைகள்
Ray parenchyma	கதிர் பாரங்கைமா
Reaction Centre	வினை மையம்
Red drop	சிவப்பு வீழ்ச்சி
Redox reaction	ஆக்ஸிஜனேற்ற ஒடுக்கவினை
Reducing power	ஒடுக்கும் ஆற்றல்
Respiratory quotient	சுவாச ஈவு
Reverse osmosis	பின்னோக்கிய சவ்வூடு பரவல்
Rib meristem	வரிசை ஆக்குத்திசு
Ring Bark	வளைய பட்டை
Sap wood	சாற்றுக்கட்டை
Scale Bark	செதில் பட்டை
Seed dormancy	விதை உறக்கம்
Semi autonomy	பாதி சுயசார்புதன்மை
Senescence	மூப்படைதல்
Sink	தேங்கிடம்
Slime bodies	ஸ்லைம் உடலங்கள்
Solute potential	கரைபொருள் திறன்
Source	தோற்றுவாய்
Spring wood or early wood	வசந்தக்காலக் கட்டை அல்லது முன்பருவக் கட்டை
Stress escapers	நெருக்கடியை தப்பித்துக் கொள்ளும் தாவரங்கள்
Stress physiology	நெருக்கடி சார் வாழ்வியல்
Substrate phosphorylation	தளப்பொருள் பாஸ்பரிகணம்
Sunken stomata	உட்குழிந்த இலைத்துளை
Terminal oxidation	இறுதி ஆக்ஸிஜனேற்றம்
Thermonastic	வெப்ப தூண்டல்
Thigmotactic	தொடு உணர்வு அசைவு
Transamination	அமைனோ மாற்றம்
Tunica corpus theory	டூனிகா கார்பஸ் கொள்கை
Vernalization	தட்பப்பதனம்
Water potential	நீரியல் திறன்
Xeric Succession	வறள் தாவர படிநிலை வளர்ச்சி

Competitive Exam Questions

Unit -4 – Plant Anatomy

1. The balloon – shaped structures called tyloses (NEET II – 2016)
   a. originate in the lumen of vessels
   b. characterise the sap wood
   c. are extensions of xylem parenchyma cells into vessels
   d. are linked to the ascent of sap through xylem vessels

2. Cortex is the region found between (NEET II – 2016)
   a. epidermis and stele
   b. pericycle and endodermis
   c. endodermis and pith
   d. endodermis and vascular bundle

3. Read I – IV and find the correct order of components from outer side to inner side in a woody dicot stem (CBSE -AIPMT – 2015)
   (I) secondary Cortex (II) wood
   (III) secondary phloem (IV) phellem
   a. III, IV, II and I b. I, II, IV and III
   c. IV, I, III and II d. IV, III, I and II

4. You are given a fairly old piece of a dicot stem and a dicot root. Which of the following anatomical structures will you use to distinguish between the two? (CBSE -AIPMT 2014)
   a. secondary xylem
   b. secondary phloem
   c. protoxylem
   d. cortical cells

5. Heart wood differs from sapwood in (CBSE -AIPMT 2010)
   a. the presence of rays and fibres
   b. the absence of vessels and parenchyma
   c. having dead and non-conducting elements
   d. being susceptible to hosts and pathogens

6. The annular and spirally thickened conducting elements generally develop in the protoxylem when the root or stem is (CBSE -AIPMT 2009)
   a. maturing b. elongating
   c. widening d. differentiating

7. Anatomically fairly old dicotyledonous root is distinguished from the dicotyledonous stem by the (CBSE- AIPMT 2009)
   a. absence of secondary xylem
   b. absence of secondary phloem
   c. presence of cortex
   d. position of protoxylem

8. In barley stem, vascular bundles are (CBSE -AIPMT 2009)
   a. open and scattered
   b. closed and scattered
   c. open and in a ring
   d. closed and radial

9. Palisade parenchyma is absent in the leaves of (CBSE- AIPMT 2009)
   a. sorghum b. mustard
   c. soyabean d. gram

10. Sugarcane plant has (AIIMS 2009)
    a. reticulate venation
    b. capsular fruits
    c. pentamerous flowers
    d. dump-bell shaped guard cells

11. Vascular tissues in flowering plants develop from (CBSE- AIPMT 2008 & JIPMER 2012)
    a. phellogen **b. plerome**
    c. periblem d. dermatogen

12. The length of different internodes in a culm of sugarcane is variable because of (CBSE -AIPMT 2008)
    a. short apical meristem
    b. position of axillary buds

c. size of leaf lamina at the node below each internode

d. intercalary meristems

13. Passage cells are thin-walled cells found in (CBSE -AIPMT 2007)
    a. endodermis of roots facilitating rapid transport of water from cortex to pericycle
    b. phloem elements that serve as entry points for substances for transport to other plant parts
    c. testa of seeds to enable emergence of growing embryonic axis during seed germination
    d. central region of style through which the pollen tube grows towards the ovary

14. Which one of the following is not a lateral meristem (CBSE -AIPMT 2010)
    a. interfascicular cambium
    b. phellogen
    c. intercalary meristem
    d. intrafascicular cambium

15. A common feature of vessel elements and sieve tube elements is (CBSE- AIPMT 2007)
    a. enucleate condition
    b. presence of P. Protein
    c. thick secondary wall
    d. pores on lateral walls

16. In a longitudinal section of a root, starting from the tip upward, the four zones occur in the following order (CBSE -AIPMT 2004)
    a. root cap, cell division, cell enlargement, cell maturation
    b. root cap, cell division, cell maturation, cell enlargement
    c. cell division, cell enlargement, cell maturation, root cap
    d. cell division, cell maturation, cell enlargement, root cap

17. The cells of the quiescent centre are characterized by (CBSE -AIPMT 2003)
    a. having dense cytoplasm and prominent nucleus
    b. having light cytoplasm and small nucleus
    c. dividing regularly to add to the corpus
    d. dividing regularly to add to tunica

18. P. Protein is found in (CBSE- AIPMT 2000)
    a. parenchyma b. collenchyma
    c. sieve tube d. xylem

19. Specialized epidermal cells surrounding the guard cells are called (NEET (I) 2016)
    a. bulliform cells
    b. lenticels
    c. complementary cells
    d. subsidiary cells

Directions:

The following questions 20 & 21 consist of two statements, one labelled **Assertion** and the another labelled **Reason**. Select the correct answer from the codes given below:

a) Both assertion and reason are true and reason is the correct explanation of assertion
b) Both assertion and reason are true, but reason is not the correct explanation of assertion
c) Assertion is true but reason is false
d) Assertion and reason are false

20. **Assertion:** Conducting tissues, especially xylem show greatest reduction in submerged hydrophytes.

    Reason: Hydrophytes live in water. So no need of tissues. (AIIMS – 2010)

    Ans: c.

21. **Assertion:** Long distance flow of photo assimilates in plants occurs through sieve tubes.

    Reason: Mature sieve tubes have partial cytoplasm and perforated sieve plates (AIIMS – 2012)

    Ans: a.

22. Duramen is present in (JIPMER 2016)
a. the inner region of secondary wood
b. a part of sap wood
c. the outer region of secondary wood
d. region of pericycle

23. The interxylary phloem is found in the stem of (JIPMER 2013)
a. Cucurbita b. Salvia
c. Calotropis d. none of these

24. Wound healing is due to (JIPMER 2013)
a. ventral meristem
b. secondary meristem
c. primary meristem
d. all of these

25. Which of the following tissues consists of living cells (JIPMER 2012)
a. vessels b. tracheids
c. companion cell d. sclerenchyma

26. The Quiescent centre in root meristem serves as a (JIPMER 2011)
a. site for storage of food, which is utilized during maturation
b. reservoir of growth hormones
c. reserve for replenishment of damaged cells of the meristem
d. region for absorption of water

27. In the sieve elements, which one of the following is the most likely function of P.Proteins? (JIPMER 2011)
a) Deposition of callose on sieve plates
b. Providing energy for active translocation
c. Autolytic enzymes
d. Sealing-off mechanism on wounding

28 .Which of the following is made up of dead cells? (NEET 2017)
a. Xylem parenchyma b. Collenchyma
c. Phellem d. Phloem

29. The vascular cambium normally gives rise to (NEET 2017)
a. phelloderm b.primary phloem
c. secondary xylem d. periderm

30. Which of the following plants shows multiple epidermis? (Manipal 2012)
a. Croton b. Allium
c. Nerium d. Cucurbita

UNIT -5 PLANT PHYSIOLOGY

1. The water potential of pure water is (NEET 2017)
a. Less than zero
b. More than zero but less than one
c. More than one
d. Zero

2. Transpiration and root pressure cause water to rise in plants by (NEET 2015)
a. pulling it upward
b. pulling and pushing it, respectively
c. pushing it upward
d. pushing and pulling it, respectively

3. Movement of ions or molecules in a direction opposite to that of prevailing electro-chemical gradient is known as (C.B.S.E. 2000)
a. Active transport
b. Pinocytosis
c. Brownian movement
d. Diffusion

4. Correct sequence of events in wilting? (P.M.T. Kerala 2001)
a. Exosmosis-deplasmolysis-temporary and permanent wilting
b. Exosmosis-plasmolysis-temporary and permanent wilting
c. Endosmosis-plasmolysis-temporary and permanent wilting
d. Endosmosis-deplasmolysis - temporary and permanent wilting
e. Exosmosis-deplasmolysis-plasmolysis - temporary and permanent wilting

5. What will be the direction of net osmotic movement of water if a solution 'A', enclosed in a semi permeable membrane, having an osmotic potential of '- 30' bars and turgor pressure of '5' bars is submerged in a solution 'B' with an osmotic potential of '- 10' bars and '0' turgor pressure ? (C.E.T. Karnataka 2002)
   a. Equal movement in both directions
   b. 'B' to 'A'
   c. No movement
   d. 'A' to 'B'

6. The pressure exerted by a swollen vacuole on the cell wall is (C.M.C. Vellore 2002)
   a. OP b. WP
   c. TP d. DPD

7. Who said that 'transpiration is a necessary evil'? (JIPMER-2006)
   a. Curtis b. Steward
   c. Anderson d. J.C.Bose

8. Which one gives the most valid and recent explanation for stomatal movements? (NEET 2015)
   a. Transpiration
   b. Potassium influx and efflux
   c. Starch hydrolysis
   d. Guard cell photosynthesis

9. Carrier proteins are involved in (P M T - UP-1998)
   a. Active transport of ions
   b. Passive transport of ions
   c. Water transport
   d. Water evaporation

10. Active transport of ions in the cell requires (PMT MP 2002)
   a. High temperature **b. ATP**
   c. Alkaline pH d. Salts

11. Guttated liquid is (AFMC 2002)
   a. Pure water
   b. Water plus minerals
   c. Water plus enzymes
   d. All of these

12. Stomata of a plant open due to (CBSE 2003)
   a. Influx of potassium ions
   b. Efflux of potassium ions
   c. Influx of hydrogen ions
   d. Influx of calcium ions

13. Potometer works on the principle of (CBSE 2000)
   a. Osmotic pressure
   b. Amount of water absorbed equals the amount transpired
   c. Potential difference between the tip of the tube and then of the plant
   d. Root pressure

14. Most suitable theory for ascent of sap is (CBSE 1991, CPMT-UP 1995)
   a. Transpirational pull and cohesion theory of Dixon and Jolly
   b. Pulsation theory of J.C. Bose
   c. Relay pump theory of Godlewski
   d. None of these

15. If a cell kept in a solution of unknown concentration gets deplasmolysed, the solution is, (CPMT-UP 1996)
   a. Detonic **b. Hypertonic**
   c. Isotonic d. Hypotonic

16. Which is essential for the growth of root tip ? (NEET PHASE II 2016)
   a. Zn b. Fe
   c. Ca d. Mn

17. On the basis of symptoms of chlorosis in leaves, a student inferred that this was due to deficiency of nitrogen. The inference could be correct only if we assume that yellowing of leaves appeared first in (AIIMS 2007)
   a. old leaves b. young leaves
   c. young leaves followed by mature leaves

d. mature leaves followed by young leaves.

18. Cytochrome oxidase contains (UP CPMT 2006)
    a. Iron b. Magnesium
    c. Zinc **d. Copper**

19. Which is correct to saprophytic angiosperms? (UP CPMT 2006)
    a. They secrete enzyme outside the body and absorb
    b. They have mycorrhizae fungi
    c. They take food and then digest it
    d. They are photosynthetic

20. The ability of the venus fly trap to capture insects is due to (JIPMER 2008)
    a. chemical stimulation by the prey
    b. a passive process requiring no special ability on the part of the plant.
    c. Specialized muscle like cells
    d. rapid turgor pressure changes

21. Boron in green plants assists in (RPMT 2007)
    a. photosynthesis
    b. Sugar transport
    c. activation of enzyme
    d. acting as enzyme cofactor

22. Which of the following elements is very essential for the uptake of Ca2+ and membrane function? (Kerala CEE 2007)
    a. phosphorus b. molybdenum
    c. manganese **d. boron**

23. Sulphur is not a constituent of (AMU 2011)
    a. cysteine b. methionine
    c. ferredoxin **d. pyridoxine**

24. Deficiency symptoms of nitrogen and potassium are visible first in _____ (AIPMT 2014)
    a. senescent leaves b. young leaves
    c. roots d. buds

25. The first stable product of fixation of atmospheric nitrogen in leguminous plants is _____ (AIPMT 2013)
    a. NO^{-3} b. glutamate
    c. NO^{-2} **d. ammonia**

26. C4 plants are more efficient in photosynthesis than C3 plants due to (AIPMT 2010)
    a. presence of thin cuticle
    b. lower rate of photorespiration
    c. higher leaf area
    d. presence of larger number of chloroplast in the leaf cells.

27. Chlorophyll b is (JIPMER 1980)
    a. $C_{54}H_{70}O_6N_4Mg$
    b. $C_{55}H_{70}O_6N_4Mg$
    c. $C_{55}H_{72}O_5N_4Mg$
    d. $C_{45}H_{72}O_5N_4Mg$

28. Synthesis of ADP + Pi $\rightarrow$ ATP in grana is (AIIMS 1993)
    a. phosphorylation
    b. photophosphorylation
    c. oxidative phosphorylation
    d. photolysis

29. In chloroplast, chlorophyll is present in the (AIPMT 2004)
    a. stroma
    b. outer membrane
    c. inner membrane
    d. thylakoids

30. Electrons from the excited chlorophyll molecule of photosystem II are accepted first by (AIPMT 2008)
    a. quinone b. ferredoxin
    c. cytochrome-b d. cytochrome-f

31. Read the following four statements A,B,C and D. Select the right option (AIPMT 2010)
    A. Z scheme of light reaction takes place in the presence of PS I only

B. only PS I is functional in cyclic photophosphorylation

C. cyclic photophosphorylation results into synthesis of ATP and NADPH2

D. stroma lamellae lack PS II as well as NADP

a. A and B b. B and C

c. C and D **d. B and D**

32. Photolysis of each water molecule in light reaction will yield ___ (Kerala CEE 2007)

a. 2 electrons and 4 protons

b. 4 electrons and 4 protons

c. 4 electrons and 3 protons

d. 2 electrons and 2 protons

33. Photosynthetic active radiation (PAR) has the following range of wavelength (AIPMT 2005)

a. 400-700 nm b. 450-920 nm

c. 340-450 nm d. 500-600 nm

34. Phosphoenol pyruvate (PEP) is the primary CO_2 acceptor in __ (NEET 2017)

a. C_3 plants **b. C_4 plants**

c. C_2 plants d. C_3 and C_4 plants

35. With reference to factors affecting the rate of photosynthesis, which of the following statements is not correct? (NEET 2017)

a light saturation for CO_2 fixation occurs at 10 % of full sunlight

b. increasing atmospheric CO_2 concentration up to 0.05% can enhance CO_2 fixation rate

c. C_3 plants respond to higher temperature with enhanced photosynthesis while C_4 plants have much lower temperature optimum.

d. tomato is a greenhouse crop which can be grown in CO_2 enriched atmosphere for higher yield

36. A plant in your garden avoids photorespiratory losses, has improved water use efficiency, shows high rates of photosynthesis at high temperatures and has improved efficiency of nitrogen utilization. In which of the following physiological groups would you assign this plant? (NEET PHASE I 2016)

a. C_4 b. CAM

c. Nitrogen fixer d. C_3

37. Emerson's enhancement effect and Red drop have been instrumental in the discovery of (NEET PHASE I 2016)

a. two photosystems operating simultaneously

b. photophosphorylation and cyclic electron transport

c. oxidative phosphorylation

d. photophosphorylation and non-cyclic electron transport

38. The process which makes major difference between C_3 and C_4 plants is (NEET PHASE II 2016)

a. glycolysis b. calvin cycle

c. photorespiration d. respiration

39. In a chloroplast the highest number of protons are found in (NEET PHASE I 2016)

a. lumen of thylakoids

b. inter membrane space

c. antennae complex

d. stroma

40. Oxidative phosphorylation is (NEET 2016)

a. formation of ATP by transfer of phosphate group from a substrate to ADP

b. oxidation of phosphate group in ATP

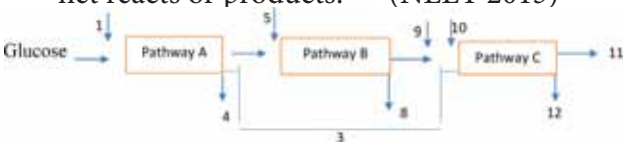
c. Aaddition of phosphate group to ATP

d. formation of ATP by energy released from electrons during substrate oxidation.

41. Which of the biomolecules is common to respiration-mediated breakdown of fats, carbohydrates and proteins? (NEET 2013, 2016)
a. glucose-6-phosphate
b. fructose1,6-bisphosphate
c. pyruvic acid
d. acetyl CoA

42 Which statement is wrong for Krebs cycle? (NEET 2017)
a. there is one point in the cycle where FAD is reduced to $FADH_2$
b. during conversion of succinyl CoA to succinic acid, a molecule of GTP is synthesised.
c. the cycle starts with condensation of acetyl group a.cetyl CoA. with pyruvic acid to yield citric acid
d. there are three points in the cycle where NAD^+ is reduced to $NADH+H^+$

43. The three boxes in this diagram represents the three major biosynthetic pathways in aerobic respiration and arrows represent net reacts or products. (NEET 2013)



Arrows numbered 4, 8 and 12 can be
a. ATP
b. H_2O
c. FAD or $FADH_2$
d. NADH

44. The energy released metabolic process in which substrate is oxidised without an external electron acceptor is called (AIPMT 2010)
a. glycolysis
b. fermentation
c. aerobic respiration
d. photorespiration

45. Krebs cycle starts with the formation of six carbon compound by a reaction between (CPMT 1980)
a. malic acid and acetyl coenzyme
b. oxaloacetic acid and acetyl coenzyme
c. succinic acid and pyruvic acid
d. fumaric acid and pyruvic acid

46. Respiration is a process in which (CPMT 1980)
a. energy is used up
b. energy is stored in the form of ADP
c. energy is released and stored in the form of ATP
d. energy is not released at all

47. The common phase between aerobic and anaerobic respiration is called (CPMT 1984)
a. glycolysis
b. krebs cycle
c. tricarboxylic acid cycle
d. oxidative phosphorylation

48. ATP synthesis occurs on/in the (AIIMS 1984)
a. matrix
b. outer membrane of mitochondrion
c. innermembrane of mitochondrion
d. none of the above

49. Which 5-carbon organic acid of the Krebs cycle is a key compound in the N2 metabolism of a cell (AIIMS 1989)
a. citric acid
b. fumaric acid
c. oxalosuccinic acid
d. α-Ketoglutaric acid

50. Which one of the following acts as a hormone involved in ripening of fruits (CBSE PMT 2000)
a. naphthalene acetic acid
b. ethylene

c. indole acetic acid
d. zeatin

51. Coconut milk factor is (PMT 2003)
a. auxin b. gibberellin
c. abscisic acid **d. cytokinin**

52. Banana is seedless because (JIPMER 2004)
a. it produces asexually
b. auxin is sprayed
c. both A and B
d. none of the above

53. Pruning of plants promotes branching due to sensation of axillary buds by (AIIMS 2004)
a. Ethylene b. Gibberellin
c. IAA d. Cytokinin

54 Avena curvature test is bioassay for activity of (AIIMS 2006) (NEET 2016)
a. Auxin b. Ethylene
c.Cytokinin d. Gibberellin

55. One of the synthetic auxin is (AIPMT 2009)
a. IBA **b. NAA**
c. IAA d. GA

56 Which one of the following acids is derivative of carotenoids (AIPMT 2009)
a. Abscisic acid
b. Indole butyric acid
c. Indole – 3 acetic
d. Gibberellic acid

57. Photoperiodism was first characterized in (AIPMT 2010)
a. Cotton **b. Tobacco**
c. Potato d. Tomato

58. One of the commonly used plant growth hormone in tea plantations is (AIPMT 2010)
a. Abscisic acid b. Zeatin
c. Indole – 3 – acetic acid
d. Ethylene

59. Root development is promoted by (AIPMT 2010)
a. Auxin b. Gibberellin
c. Ethylene d. Abscisic acid

60. Senscence as an active developmental cellular process in the growth and functioning of a flowering plant is indicated in (AIPMT 2008)
a. Annual plants
b. Floral plants
c. Vessels and Tracheid differentiation
d. Leaf abscission

61. You are given a tissue with its potential for differentiation in an artificial culture. Which of the following pairs of hormones would you add to the medium to secure shoots as well as roots?
(NEET 2016)
a. Gibberellin and abscissic acid
b. IAA and gibberellins
c. Auxin and cytokinin
d. Auxin and abscisic acid

62. Phytochrome is a (NEET 2016)
a. Chromo protein
b. Flavo protein
c. Glyco protein
d. Lipo protein

63. Typical growth curve in plants is
(NEET 2016)
a. Linear
b. Stair – steps shaped
c. Parabolic
d. Sigmoid

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