GOVERNMENT OF TAMIL NADU

HIGHER SECONDARY FIRST YEAR

BIOLOGY

BOTANY

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Department of School Education

Untouchability is Inhuman and a Crime

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Activity	Directions are provided to students to conduct activities in order to explore, enrich the concept.
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Evaluation	Assess students to pause, think and check their understanding
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ICT	To enhance digital Science skills among students
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Scope of Botany
Higher Studies and Career Opportunities

TNAU

- B.Sc. Agriculture,
- B.Sc. Horticulture
- B.Sc. Forestry,
- B.Sc Sericulture
- B.Tech Biotechnology
- B.Tech Agricultural Engineering
- B.Tech Horticulture
- B.Tech Food process Engineering
- B.Tech Energy and Environmental Engineering
- B.Tech Bioinformatics
- B.Sc Agribusiness Management
- B.Tech Agricultural IT
- M. Tech. Environmental Engineering
- M. Sc in Agriculture
- M. Sc in Agricultural Extension
- M. Sc in Agronomy
- M. Sc in Soil Science
- M. Sc in Agricultural Biotechnology
- M. Sc in Agricultural Marketing
- M. Sc in Agricultural Microbiology
- M. Tech in Agricultural Engineering
- M. E in Agricultural Engineering
- Master of Agriculture in Entomology
- Master of Agriculture in Horticulture
- Master of Agriculture in Animal Sciences
- Master of Agriculture in Entomology
- Master of Agriculture in Plant Pathology
- Master of Agriculture in Agricultural Economics and Rural Sociology
- Master In Agriculture And Rural Development

TNMGRMU

MEDICAL

- MBBS
- M.D/M.S/M.D.S
- M.Ch. (5 year course)
- B.D.S
- M.D.S

Indian Medicine and Homoeopathy Courses

- B.A.M.S. - Ayurvedic Medicine
- B.H.M.S. - Homoeopathic Medicine
- B.N.Y.S. - Naturopathy and Yogic
- B.S.M.S. - Siddha Medicine
- B.U.M.S. - Unani Medicine

Allied Health Sciences

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- B.P.T.- Bachelor of Physiotherapy
- M.P.T. - Master of Physiotherapy
- B.O.T. - Bachelor of Occupational Therapy
- M.O.T. - Master of Occupational Therapy
- B.Sc. - Accident & Emergency Care Technology
- B.Sc. - Audiology & speech Language Pathology
- B.Sc. - Cardiac Technology
- B.Sc. - Cardio Pulmonary Perfusion Care Technology
- B.Sc. - Critical Care Technology
- B.Sc. - Dialysis Technology
- B.Sc. - Neuro Electrophysiology
- B.Sc. - Medical Sociology
- B.Sc. - Nuclear Medicine Technology
- B.Sc. - Operation Theatre & Anaesthesia Technology
- B.Sc. - Physician Assistant
- B.Sc. - Radiology Imaging Technology
- B.Sc. - Radiotherapy Technology
- B.Sc. - Fitness and Lifestyle Modifications
- B.Sc. - Clinical Nutrition

Diploma Course

- Accident & Emergency Care Technology
- Critical Care Technology
- Health Care Aide (as per 245th GC)
- Operation Theatre & Anaesthesia Technology
- Ophthalmic Nursing Assistant
- Scope Support Technology
- Medical Record Science
- Optometry Technology
- Radiology & Imaging Technology
- Medical Lab Technology
- Cardiac Non Invasive Technology
- Dialysis Technology

AIIMS

Undergraduate Courses (UG)

- MBBS
- B.Sc Nursing (post Certificate)
- B.Sc. (Hons.) Nursing
- Paramedical Courses (PM)
- B.Sc. (Hons.) Opthalmic Techniques
- B.Sc. (Hons.) Medical Technology

Postgraduate Courses (PG)

- M.D/M.S/M.D.S
- M.Ch. (5 year course)
- M.Sc. / M. Biotechnology

Integrated courses

Mode of selection: Entrance conducted by concern institution or NEET

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
  Website: http://www.niser.ac.in

B.Sc.,B.Ed -5 year Integrated course

- Regional Institute of Education Ajmer, Bhopal, Bhubaneswar, Mysuru and Shilillong

Website: www.riemysore.ac.in

SCIENCE

Courses in Arts & Science Coleges and Universities

- B.Sc. Botany
- B.Sc. Plant Biology & Plant Biotechnology
- B.Sc Biochemisty
- B.Sc Bio-computing
- B.Sc. Plant Pathology
- M.Sc. Botany
- M.Sc Biotechnology
- M.Sc. Bio-chemistry
- M.Sc. Bioinformatics
- M.Sc Immunology and Microbiology
- M.Sc. Applied Medical Biotechnology & clinical Research
- M.Sc. Genetic Engineering & Plant Breeding
- M.Sc. Applied Plant Science
- M.Sc. Plant Biology & Plant Biotechnology
- M.Sc. Plant molecular Biology
- M.Sc. Mycology & Plant pathology
- M.Sc. Plant science

ANNA UNIVERSITY

- B.E. Bio Medical Engineering
- B.Tech. Industrial Bio technology
- B.Tech. Food technology
- B.Tech. Bio technology

Research Institutions in various areas of Botany

Name of the Institution	Research Areas	Website
Indian Agricultural Research Institute (IARI) New Delhi	Genetics & Plant Breeding; Microbiology; Post Harvest Technology	www.iari.res.in
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 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
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
Directorate of Cashewnut & Cocoa, Agri, Kerala	Cocoa production and processing	www.dccd.gov.in
National Research Center on Plant Biotechnology, New Delhi	Genetic engineering for biotic resistance.	www.nrcpb.org
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
Central Research Institute for Dryland Agriculture, Hyderabad	Dryland, Agrometerology and Crop sciences	crida.in
National Research Centre for Groundnut(NRCG) Junagarh, Gujarat	Productivity and quality of groundnut; repository of groundnut germplasm and information on groundnut researches	www.nrcg.res.in
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. Protein structure, Dynamic and Interactions Epigenetic	www.cdfd.org.in
Institute of Life Sciences, Bhubaneswar	Infectious disease;Iimmune biology; Cancer biology; Nanotechnology	www.ils.res.in
Centre for Cellular and Molecular Biology, Hyderabad.	Genetics & evolution, Genomics; Cell Biology & Development.	www.ccmb.res.in
Central Institute of medicinal and Aromatic Plants, Lucknow.	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
National Centre for Biological Sciecnes, Bangalore	Biochemistry, Biophysics, Bioinformatics, Genetics and development;Cellular organization & signelling neurobiology etc.	www.ncbs.res.in
Birbal Sahni Institute od Palaeobotany (BSIP) Lucknow.	Palynology in fossil fuel exploration; Dendrochronology; Ethnobotany; Micropaleontology; Carbon 14Dating	www.bsip.res.in
North East Institute of Science & Technology Jorhat, Assam.	Chemical science; Biological sciences;Material sciences; Agro-science and technology; Geosciences.	www.rrljorhat.res.in
Institute of Wood Science and Technology, Bangalore.	Tree improvement and Genetics; Chemistry of Forest Products.	iwst.icfre.gov.in
Centre for Ecological Sciences, Indian Institute of Science. Bangalore.	Behavior 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

Chapter 1

Unit I: Diversity of Living World

Living World

Learning Objectives

The learner will be able to,

- *Differentiate living and non-living things.*
- *Appreciate the attributes of living organisms.*
- *Compare the different classifications proposed by biologists.*
- *Recognize the general characters, structure and reproduction of Bacteria.*
- *Identify the characteristic features of Archaebacteria, Cyanobacteria, Mycoplasma and Actinomycetes.*
- *Describe the characteristic features of fungi.*
- *Discuss the structure and uses of Mycorrhizae and Lichens.*

Chapter Outline

Earth was formed some 4.6 billion years ago. It is the life supporting planet with land forms like mountains, plateaus, glaciers, etc. Life on earth exists within a complex structure called **biosphere**. There exist many mysteries and wonders in the living world some are not visible but the activity of some capture the attention of all. For example the response of sunflower to the sunlight, the twinkling firefly in the dark forest, the rolling water droplets on the surface of lotus leaf, the closure of the leaf of venus fly trap on insect touch and a squid squeezing ink to escape from its predator. From this it is clear that the wonder planet earth harbours both landforms and life forms. Have you thought of DNA molecule? It is essential for the regulation of life and is made up of carbon, hydrogen, oxygen, nitrogen and phosphorus. thus nonliving and living things exist together to make our planet unique.

According to a survey made by Mora *et al.*, 2011 the number of estimated species on earth is 8.7 million. The living world includes microbes, plants, animals and human beings which possess unique and distinct characteristic feature.

1.1 Attributes of living organisms

The attributes of living organisms are given below and is represented in Figure 1.1.

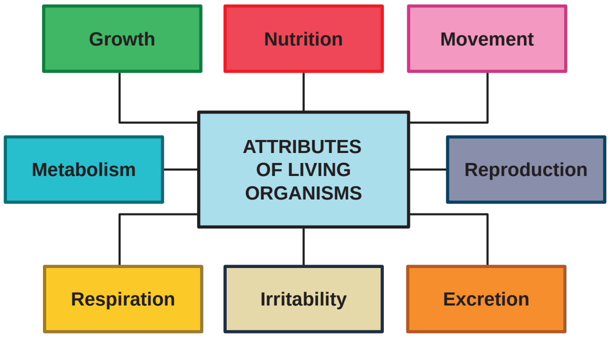


Figure 1.1: Attributes of living organisms

Growth

Growth is an intrinsic property of all living organisms through which they can increase cells both in number and mass. Unicellular and multicellular organisms grow by cell division. In plants, growth is indefinite and occurs throughout their life. In animals, growth is definite and occurs for some period. Growth in non-living objects is **extrinsic**. Mountains, boulders and sand mounds grow by simple aggregation of material on the surface. Living cells grow by the addition of new protoplasm within the cells. Therefore, growth in living thing is **intrinsic**. In unicellular organisms like Bacteria and Amoeba growth occurs by cell division and such cell division also leads to the growth of their population. Hence, growth and reproduction are mutually inclusive events.

Cellular structure

All living organisms are made up of cells which may be prokaryotic or eukaryotic. **Prokaryotes** are unicellular, lack membrane bound nuclei and organelles like mitochondria, endoplasmic reticulum, golgi bodies and so on (Example: Bacteria and Blue green algae). In **Eukaryotes** a definite nucleus and membrane bound organelles are present. Eukaryotes may be unicellular (*Amoeba*) or multicellular (*Oedogonium*).

Reproduction

Reproduction is one of the fundamental characteristic features of living organisms. It is the tendency of a living organism to perpetuate its own species. There are two types of reproduction namely asexual and sexual (Figure 1.2).

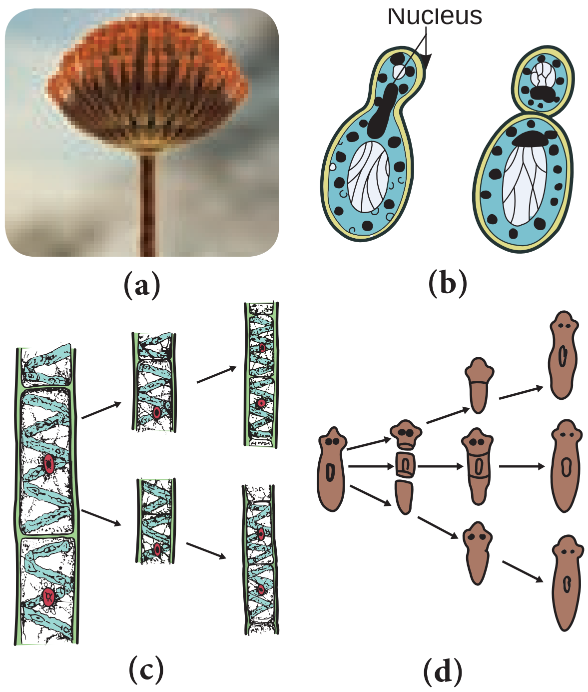


Figure 1.2: Types of Asexual Reproduction (a) Conidia formation-*Penicillium*, (b) Budding-Yeast, (c) Fragmentation-*Spirogyra*, (d) Regeneration-*Planaria*

Asexual reproduction refers to the production of the progeny possessing features more or less similar to those of parents. The sexual reproduction brings out variation through **recombination.** Asexual reproduction in living organisms occurs by the production of conidia (*Aspergillus*, *Penicillium*), budding (*Hydra* and Yeast), binary fission (Bacteria and *Amoeba*) fragmentation (*Spirogyra*), protonema (Mosses) and regeneration (*Planaria*). Exceptions are the sterile worker bees and mules.

Response to stimuli

All organisms are capable of sensing their environment and respond to various physical, chemical and biological stimuli. Animals sense their surroundings by sense organs. This is called **Consciousness**. Plants also respond to the stimuli. Bending of plants towards sunlight, the closure of leaves in touch-me-not plant to touch are some examples for response to stimuli in plants. This type of response is called **Irritability.**

Homeostasis

Property of self-regulation and tendency to maintain a steady state within an external environment which is liable to change is called **Homeostasis**. It is essential for the living organism to maintain internal condition to survive in the environment.

Metabolism

The sum of all the chemical reactions taking place in a cell of living organism is called **metabolism**. It is broadly divided into **anabolism** and **catabolism.** The difference between anabolism and catabolism is given in Table 1.1.

Table 1.1: Difference between anabolism and catabolism

Anabolism	Catabolism
Building up process	Breaking down process
Smaller molecules combine together to form larger molecule	Larger molecule break into smaller units
Chemical energy is formed and stored	The stored chemical energy is released and used
Example: Synthesis of proteins from amino acids	Example: Breaking down of glucose to CO_2 and water

Movement, Nutrition, Respiration and Excretion are also considered as the property of living things. The levels of organization in living organism begin with atoms and end in **Biosphere**. Each level cannot exist in isolation instead they form levels of integration as given in Figure 1.3.

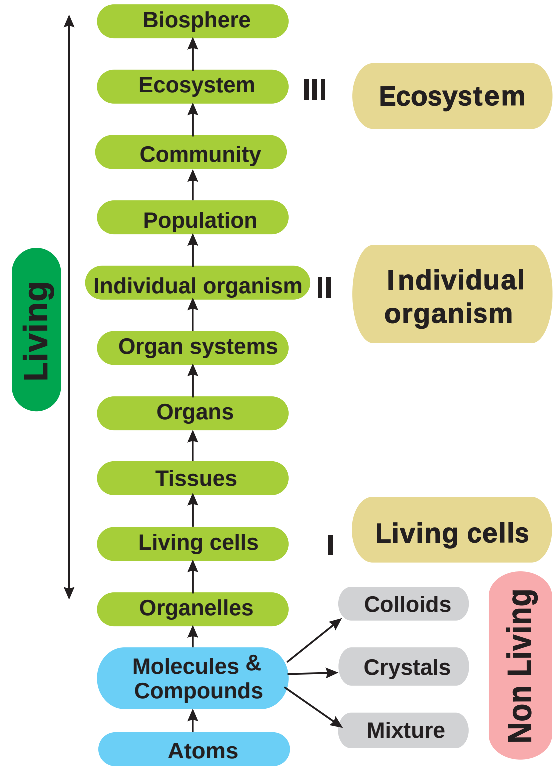


Figure 1.3: The levels of organization and integration in living organism

Activity 1.1

Collect *Vallisneria* leaves or *Chara* from nearby aquarium and observe a leaf or *Chara* thallus (internodal region)under the microscope. You could see cells clearly under the microscope. Could you notice the movement of cytoplasm? The movement of cytoplasm is called cytoplasmic streaming or **cyclosis**.

1.2 Viruses

Did you go through the headlines of newspapers in recent times? Have you heard of the terms EBOLA, ZIKA, AIDS, SARS, H1N1 etc.? There are serious entities which are considered as **"Biological Puzzle"** and cause disease in man. They are called viruses. We have learnt about the attributes of living world in the previous chapter. Now we shall discuss about viruses which connect the living and nonliving world.

The word virus is derived from Latin meaning 'Poison'. Viruses are sub-microscopic, obligate intracellular parasites. They have nucleic acid core surrounded by protein coat. Viruses in their native state contain only a single type of nucleic acid which may be either DNA or RNA. The study of viruses is called **Virology**.

An American Scientist obtained virus in crystallised form from infected tobacco juice in the year 1935. He was jointly awarded "Nobel Prize" with Dr. J.H. Northrop for Chemistry in 1946.

W.M. Stanley (1904-1971)

1.2.1 Milestones in Virology

1796 Edward Jenner used vaccination for small pox

1886 Adolf Mayer demonstrated the infectious nature of Tobacco mosaic virus using sap of mosaic leaves

1892 Dimitry Ivanowsky proved that viruses are smaller than bacteria

1898 M.W. Beijierink defined the infectious agent in tobacco leaves as '*Contagium vivum fluidum*'

1915 F.W.Twort identified Viral infection in Bacteria

1917 d'Herelle coined the term 'Bacteriophage'

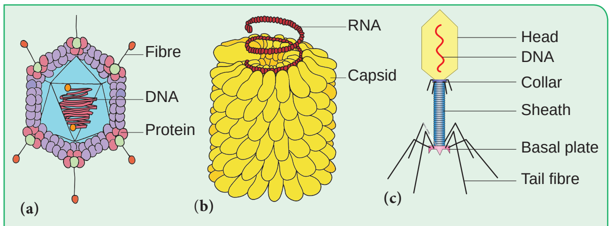
1984 Luc Montagnier and Robert Gallo discovered HIV (Human Immuno Deficiency Virus).

1.2.2 Size and Shape

Viruses are ultramicroscopic particles. They are smaller than bacteria and their diameter range from 20 to 300 nm. (1nm = 10^{-9}metres). Bacteriophage measures about 10-100 nm in size. The size of TMV is 300×20 nm.

Generally viruses are of three types based on shape and symmetry (Figure 1.4).

i. Cuboid symmetry – Example: Adenovirus, Herpes virus.
ii. Helical symmetry – Example: Influenza virus, TMV.
iii. Complex or Atypical – Example: Bacteriophage, Vaccinia virus.



(a) Adenovirus, (b) Tobacco Mosaic virus, (c) T_4 Bacteriophage

Figure 1.4: Shapes of Viruses

1.2.3 Characteristic Features of Viruses

Living Characters

- Presence of nucleic acid and protein.
- Capable of mutation
- Ability to multiply within living cells.
- Able to infect and cause diseases in living beings.
- Show irritability.
- Host –specific

Non-living Characters

- Can be crystallized.
- Absence of metabolism.
- Inactive outside the host.
- Do not show functional autonomy.
- Energy producing enzyme system is absent.

1.2.4 Classification of Viruses

Among various classifications proposed for viruses the classification given by David Baltimore in the year 1971 is given below. The classification is based on mechanism of RNA production, the nature of the genome (single stranded –ss or double stranded - ds), RNA or DNA, the use of reverse transcriptase (RT), ss RNA may be (+) sense or (–) antisense. Viruses are classified into seven classes (Table 1.2).

Viral genome

Each virus possesses only one type of nucleic acid either DNA or RNA. The nucleic acid may be in a linear or circular form. Generally nucleic acid is present as a single unit but in wound tumour virus and in influenza virus it is found in segments. The viruses possessing DNA are called **'Deoxyviruses'** whereas those possessing RNA are called **'Riboviruses'**. Majority of animal and bacterial viruses are DNA viruses (HIV is the animal virus which possess RNA). Plant viruses generally contain RNA (Cauliflower Mosaic virus possess DNA). The nucleic acids may be single stranded or double stranded. On the basis of nature of nucleic acid viruses are classified into four Categories. They are Viruses with ssDNA (Parvo viruses), dsDNA (Bacteriophages), ssRNA (TMV)and dsRNA(Wound Tumour Virus).

Table 1.2: Different Classes of viruses

Class	Example
Class 1 – Viruses with dsDNA	Adeno viruses
Class 2 –Viruses with (+) sense ssDNA	Parvo viruses
Class 3 – Viruses with dsRNA	Reo viruses
Class 4 – Viruses with (+)sense ssRNA	Toga viruses
Class 5 – Viruses with (−)sense ssRNA	Rhabdo viruses
Class 6 – Viruses with (+) sense ssRNA –RT: that replicate with DNA intermediate in life cycle	Retro viruses
Class 7 – Viruses with ds DNA –RT: that replicate with RNA intermediate in life cycle	Hepadna viruses

1.2.5 Tobacco Mosaic Virus (TMV)

Tobacco mosaic virus was discovered in 1892 by Dimitry Ivanowsky from the Tobacco plant. Viruses infect healthy plants through vectors like aphids, locusts etc. The first visible symptom of TMV is discoloration of leaf colour along the veins and show typical yellow and green mottling which is the mosaic symptom. The downward curling and distortion of young apical leaves occurs, plant becomes stunted and yield is affected.

Structure

Electron microscopic studies have revealed that TMV is a rod shaped (Figure 1.4b) helical virus measuring about 300x20nm with a molecular weight of $39x10^6$ Daltons. The virion is made up of two constituents, a protein coat called **capsid** and a core called **nucleic acid**. The protein coat is made up of approximately 2130 identical protein subunits called **capsomeres** which are present around a central single stranded RNA molecule. The genetic information necessary for the formation of a complete TMV particle is contained in its RNA. The RNA consists of 6,500 nucleotides.

1.2.6 Bacteriophage

Viruses infecting bacteria are called **Bacteriophages**. It literally means 'eaters of bacteria' (Gr: Phagein = to eat). Phages are abundant in soil, sewage water, fruits, vegetables, and milk.

Structure of T_4 bacteriophage

The T_4 phage is tadpole shaped and consists of head, collar, tail, base plate and fibres (Figure 1.4). The head is hexagonal which consists of about 2000 identical protein subunits. The long helical tail consists of an inner tubular core which is connected to the head by a collar. There is a base plate attached to the end of tail. The base plate contains six spikes and tail fibres. These fibres are used to attach the phage on the cell wall of bacterial host during replication. A dsDNA molecule of about 50 µm is tightly packed inside the head. The DNA is about 1000 times longer than the phage itself.

1.2.7 Multiplication or Life Cycle of Phages

Phages multiply through two different types of life cycle. a. Lytic or Virulent cycle b. Lysogenic or Avirulent life cycle.

a. Lytic Cycle

During lytic cycle of phage, disintegration of host bacterial cell occurs and the progeny virions are released (Figure 1.5a). The steps involved in the lytic cycle are as follows:

(i) Adsorption

Phage (T_4) particles interact with cell wall of host (*E. coli*). The phage tail makes contact between the two, and tail fibres recognize the specific receptor sites present on bacterial cell surface. The lipopolysaccharides of tail fibres act as receptor in phages. The process involving the recognition of phage to bacterium is called **landing**. Once the contact is established between tail fibres and bacterial cell, tail fibres bend to anchor the pins and base plate to the cell surface. This step is called **pinning.**

(ii) Penetration

The penetration process involves mechanical and enzymatic digestion of the cell wall of the host. At the recognition site phage digests certain cell wall structure by viral enzyme (lysozyme). After pinning the tail sheath contracts (using ATP) and appears shorter and thicker. After contraction of the base plate enlarges through which DNA is injected into the cell wall without using metabolic energy. The step involving injection of DNA particle alone into the bacterial cell is called **Transfection**. The empty protein coat leaving outside the cell is known as **'ghost'**.

(iii) Synthesis

This step involves the degradation of bacterial chromosome, protein synthesis and DNA replication. The phage nucleic acid takes over the host biosynthetic machinery. Host DNA gets inactivated and breaks down. Phage DNA suppresses the synthesis of bacterial protein and directs the metabolism of the cell to synthesis the proteins of the phage particles and simultaneously replication of Phage DNA also takes place.

(iv) Assembly and Maturation

The DNA of the phage and protein coat are synthesized separately and are assembled to form phage particles. The process of assembling the phage particles is known as **maturation**. After 20 minutes of infection, about 300 new phages are assembled.

(v) Release

The phage particle gets accumulated inside the host cell and are released by the lysis of host cell wall.

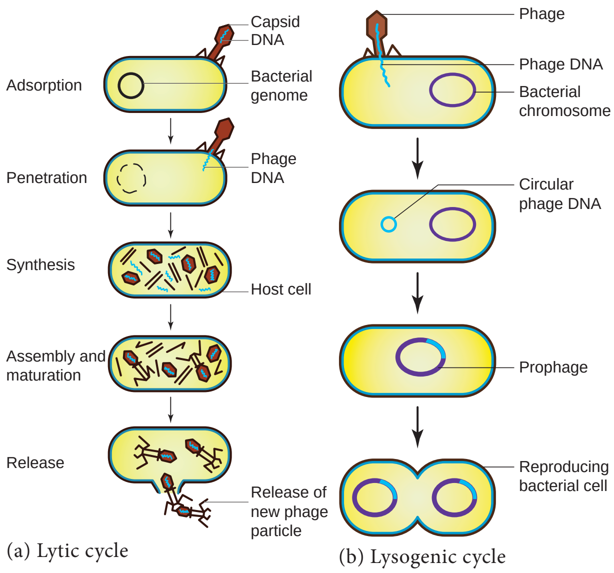


Figure 1.5: Multiplication cycle of phage

b. Lysogenic Cycle

In the lysogenic cycle the phage DNA gets integrated into host DNA and gets multiplied along with nucleic acid of the host. No independent viral particle is formed (Figure 1.5b).

As soon as the phage injects its linear DNA into the host cell, it becomes circular and integrates into the bacterial chromosome by recombination. The integrated phage DNA is now called **prophage.** The activity of the prophage gene is repressed by two repressor proteins which are synthesized by phage genes. This checks the synthesis of new phages within the host cell. However, each time the bacterial

Viruses infecting blue green algae are called **Cyanophages** and are first reported by Safferman and Morris in the year 1963(Example LPP1 - *Lyngbya, Plectonema* and *Phormidium*). Similarly, Hollings(1962) reported viruses infecting cultivated Mushrooms and causing die back disease. The viruses attacking fungi are called **Mycoviruses** or **Mycophages.**

cell divides, the prophage multiplies along with the bacterial chromosome. On exposure to UV radiation and chemicals the excision of phage DNA may occur and results in lytic cycle.

Virion is an intact infective virus particle which is non-replicating outside a host cell.

Viroid is a circular molecule of ssRNA without a capsid and was discovered by T.O.Diener in the year 1971. The RNA of viroid has low molecular weight. Viroids cause citrus exocortis and potato spindle tuber disease in plants.

Virusoids were discovered by J.W.Randles and Co-workers in 1981.They are the small circular RNAs which are similar to viroids but they are always linked with larger molecules of the viral RNA.

Prions were discovered by Stanley B. Prusiner in the year 1982 and are proteinaceous infectious particles. They are the causative agents for about a dozen fatal degenerative disorders of the central nervous system of humans and other animals. For example Creutzfeldt – Jakob Disease (CJD), Bovine Spongiform Encephalopathy (BSE) – commonly known as mad cow disease and scrapie disease of sheep.

1.2.8 Viral diseases

Viruses are known to cause disease in plants, animals and Human beings (Figure 1.6). A list of viral disease is given in Table 1.3.

(a)

(b)

Figure 1.6: Viral diseases (a) Mosaic disease of tomato, (b) Symptom of Chicken pox

DO YOU KNOW?

Streaks on Tulip flowers are due to Tulip Breaking Virus which belong to Potyviridae group.

Viruses of Baculoviridae group are commercially exploited as insecticides. Cytoplasmic Polyhedrosis Granulo viruses and Entomopox viruses were employed as potential insecticides.

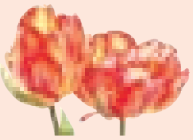


Table 1.3: Viral diseases

Plant diseases	Animal diseases	Human diseases
1.Tobacco mosaic 2. Cauliflower mosaic 3. Sugarcane mosaic 4. Potato leaf roll 5. Bunchy top of banana 6. Leaf curl of papaya 7. Vein clearing of Lady's finger 8. Rice Tungro disease 9. Cucumber mosaic 10. Tomato mosaic disease	1. Foot and mouth disease of cattle 2. Rabies of dog 3. Encephalomyelitis of horse	1. Common cold 2. Hepatitis B 3. Cancer 4. SARS(Severe Acute Respiratory Syndrome) 5. AIDS(Acquired Immuno Deficiency Syndrome) 6. Rabies 7. Mumps 8. Polio 9. Chikungunya 10. Small Pox 11. Chicken pox 12. Measles

1.3 Classification of Living World

From the previous chapter we know that the planet earth is endowed with living and non -living things. In our daily life we see several things in and around us. Imagine, you are on a trip to Hill station. You are enjoying the beauty of mountains, dazzling colour of the flowers, and melodious sound of the birds. You may be capturing most of the things you come across in the form of photography. Now, from this experience can you mention the objects you have come across? Can you record your observations and tabulate them?. How will you organize the things? Will you place mountain and flowers together or tall trees and trailing herbs in one category or place it in different category? If you place it in different category, what made you to place them in different category? So classification is essential and could be done only by understanding and comparing the things based on some characters. In this chapter we shall learn about classification of living world.

Many attempts have made in the past to classify the organisms on earth. **Theophrastus**, "Father of Botany" used the morphological characters to classify plants into trees, shrubs and herbs. Aristotle classified animals into two groups. i.e., *Enaima* (with red blood) and *Anaima* (without red blood).

Carl Linnaeus classified living world into two groups namely Plants and Animals based on morphological characters. His classification faced major setback because Prokaryotes and Eukaryotes were grouped together. Similarly fungi, heterotrophic organisms were placed along with the photosynthetic plants. In course of time, the development of tools compelled taxonomists to look for different areas like cytology, anatomy, embryology, molecular biology, phylogeny etc., for classifying organisms on earth. Thus, new dimensions to classifications were put forth from time to time.

1.3.1 Need of Classification

Classification is essential to achieve following needs.

- To relate things based on common characteristic features.
- To define organisms based on the salient features.
- Helps in knowing the relationship amongst different groups of organisms.
- It helps in understanding the evolutionary relationship between organisms.

1.3.2 Classification of Living World

A comparison of classification proposed for classification of living world is given in Table 1.4.

1.3.3 Five Kingdom Classification

R.H.Whittaker, an American taxonomist proposed five Kingdom classification in the year 1969. The Kingdoms include **Monera,**

Table 1.4: Systems of Classification

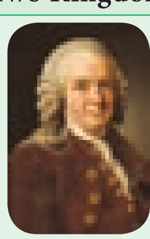
Two Kingdom	Three Kingdom	Four Kingdom	Five Kingdom
 Carl Linnaeus (1735)	 Ernst Haeckel (1866)	 Copeland (1956)	 R.H. Whittaker (1969)
1. Plantae 2. Animalia	1. Protista 2. Plantae 3. Animalia	1. Monera 2. Protista 3. Plantae 4. Animalia	1. Monera 2. Protista 3. Fungi 4. Plantae 5. Animalia

Table 1.5: Comparison of Five Kingdoms

Criteria	Kingdom				
	Monera	**Protista**	**Fungi**	**Plantae**	**Animalia**
Cell type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Level of organization	Mostly Unicellular, rarely multicellur	Unicellular	Multicellular and unicellular	Tissue/organ	Tissue/organ/organ system
Cell wall	Present (made up of Peptidoglycan and Mucopeptides)	Present in some (made up of cellulose), absent in others	Present (made up of chitin or cellulose)	Present (made up of cellulose)	absent
Nutrition	Autotrophic (Phototrophic, Chemoautotrophic) Heterotrophic (parasitic and saprophytic)	Autotrophic-Photosynthetic. Heterotrophic	Heterotrophic-parasitic or Saprophytic	Autotrophic (Photosynthetic)	Heterotrophic (Holozoic)
Motility	Motile or non-motile	Motile or non-motile	Non-motile	Mostly Non-motile	Mostly motile
Organisms	Archaebacteria, Eubacteria, Cyanobacteria, Actinomycetes and Mycoplasma	Chrysophytes, Dinoflagellates, Euglenoids, Slime molds, *Amoeba, Plasmodium, Trypanosoma, Paramecium*	Yeast, Mushrooms and Molds	Algae, Bryophytes, Pteridophytes, Gymnosperms and Angiosperms	Sponges, Invertebrates and Vertebrates

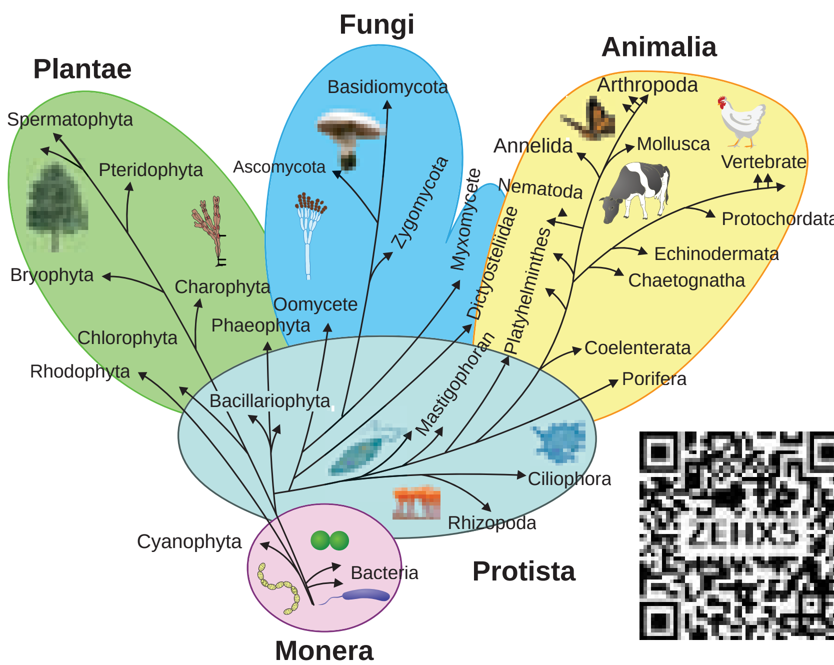


Figure 1.7: Five Kingdom Classification

Protista, Fungi, Plantae and Animalia (Figure 1.7). The criteria adopted for the classification include cell structure, thallus organization, mode of nutrition, reproduction and phylogenetic relationship**.** A comparative account of the salient features of each Kingdom is given in Table 1.5

Merits

- The classification is based on the complexity of cell structure and organization of thallus.
- It is based on the mode of nutrition
- Separation of fungi from plants
- It shows the phylogeny of the organisms

Demerits

- The Kingdom Monera and protista accommodate both autotrophic and heterotrophic organisms, cell wall lacking and cell wall bearing organisms thus making these two groups more heterogeneous.
- Viruses were not included in the system.

Carl Woese and co-workers in the year 1990 introduced three domains of life *viz.,* **Bacteria, Archaea** and **Eukarya** based on the difference in rRNA nucleotide sequence, lipid structure of the cell membrane. A revised six Kingdom classification for living world was proposed by Thomas Cavalier-Smith in the year 1998 and the Kingdom **Monera** is divided in to **Archaebacteria** and **Eubacteria.** Recently Ruggierio *et al.*, 2015 published a seven Kingdom classification which is a practical extension of Thomas Cavalier's six Kingdom scheme. According to this classification there are two Super Kingdoms. (**Prokaryota** and **Eukaryota**) **Prokaryota** includes two Kingdoms namely **Archaebacteria** and **Eubacteria.** Eukaryota includes the **Protozoa, Chromista, Fungi, Plantae** and **Animalia.** A new Kingdom, the **Chromista** was erected and it included all algae whose chloroplasts contain chlorophyll a and c, as well as various colourless forms that are closely related to them. Diatoms, Brown algae, Cryptomonads and Oomycetes were placed under this Kingdom.

Activity 1.2

Visit to a pond and record the names of the biotic components of it with the help of your teacher. Tabulate the data and segregate them according to Five Kingdom Classification.

DO YOU KNOW?

Red tide is caused by toxic bloom of Dinoflagellates like *Gymnodinium breve* and *Gonyaulax tamarensis.*

A major red tide incident in west coast of Florida in the year 1982 killed Hundreds and thousands of fishes.

1.4 Bacteria

Bacteria Friends or Foes?

Have you noticed the preparation of curd in our home? A little drop of curd turns the milk into curd after some time. What is responsible for this change? Why it Sours? The change is brought by *Lactobacillus lactis*, a bacterium present in the curd. The sourness is due to the formation of Lactic acid. Have you been a victim of Typhoid? It is a bacterial disease caused by *Salmonella typhi,* a bacterium. So we can consider this prokaryotic organism as friend and foe, due to their beneficial and harmful activities.

Robert Koch (1843–1910)

Robert Heinrich Hermann Koch was a German physician and microbiologist. He is considered as the founder of modern bacteriology.

He identified the causal organism for Anthrax, Cholera and Tuberculosis. The experimental evidence for the concept of infection was proved by him (Koch's postulates). He was awarded Nobel prize in Medicine/Physiology in the year 1905.

1.4.1 Milestones in Bacteriology

1829 C.G. Ehrenberg coined the term Bacterium

1884 Christian Gram introduced Gram staining method

1923 David H. Bergy published First edition of Bergey's Manual

1928 Fredrick Griffith discovered Bacterial transformation

1952 Joshua Lederberg discovered of Plasmid

Bacteria are prokaryotic, unicellular, ubiquitous, microscopic organisms. The study of Bacteria is called Bacteriology. Bacteria were first discovered by a Dutch scientist, Anton van Leeuwenhoek in 1676 and were called "animalcules".

1.4.2 General characteristic features of Bacteria

- They are Prokaryotic organisms and lack nuclear membrane and membrane bound organelles.
- The Genetic material is called **nucleoid** or **genophore** or **incipient nucleus**
- The cell wall is made up of Polysaccharides and proteins
- Most of them lack chlorophyll, hence they are heterotrophic (*Vibrio cholerae*) but some are autotrophic and possess Bacteriochlorophyll (*Chromatium*)
- They reproduce vegetatively by Binary fission and endospore formation.
- They exhibit variations which are due to genetic recombination and is achieved through conjugation, transformation and transduction.

The shape and flagellation of the bacteria varies and is given in Figure 1.8.

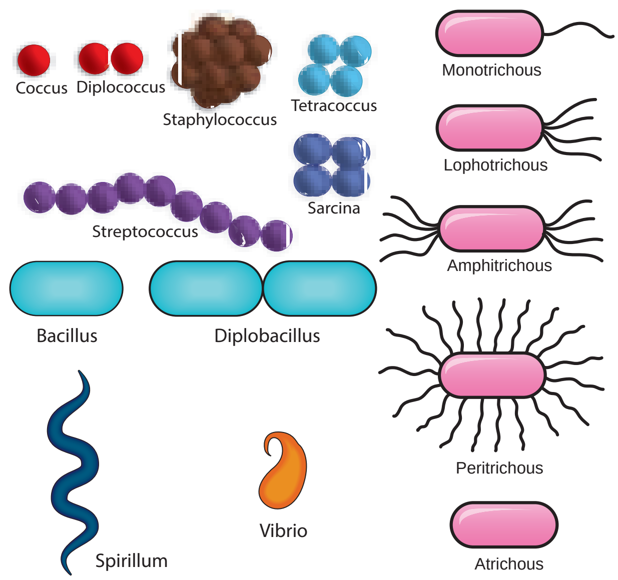


Figure 1.8: Shape and flagellation in bacteria

1.4.3 Ultrastructure of a Bacterial cell

The bacterial cell reveals three layers (i) Capsule/Glycocalyx (ii) Cell wall and (iii) Cytoplasm (Figure 1.9).

Capsule/Glycocalyx

Some bacteria are surrounded by a gelatinous substance which is composed of polysaccharides or polypeptide or both. A thick layer of **glycocalyx** bound tightly to the

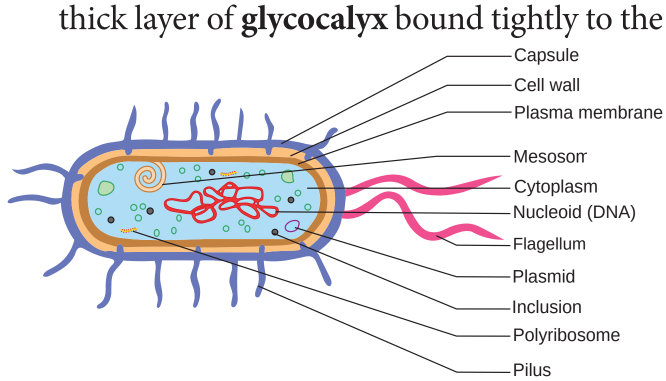


Figure 1.9: Ultrastructure of a bacterial cell

cell wall is called **capsule**. It protects cell from desiccation and antibiotics. The sticky nature helps them to attach to substrates like plant root surfaces, Human teeth and tissues. It helps to retain the nutrients in bacterial cell.

> **DO YOU KNOW?**
>
> - Duodenal and Gastric ulcers are caused by *Helicobacter pylori,* a Gram negative bacterium
> - Bt toxin from *Bacillus thuringiensis* finds application in raising insect resistant crops (Bt Crops).

Cell wall

The bacterial cell wall is granular and is rigid. It provides protection and gives shape to the cell. The chemical composition of cell wall is rather complex and is made up of peptidoglycan or mucopeptide (N-acetyl glucosamine, N-acetyl muramic acid and peptide chain of 4 or 5 aminoacids). One of the most abundant polypeptide called porin is present and it helps in the diffusion of solutes.

Plasma membrane

The plasma membrane is made up of lipoprotein. It controls the entry and exit of small molecules and ions. The enzymes involved in the oxidation of metabolites (i.e., the respiratory chain) as well as the photosystems used in photosynthesis are present in the plasma membrane.

Cytoplasm

Cytoplasm is thick and semitransparent. It contains ribosomes and other cell inclusions. Cytoplasmic inclusions like glycogen, poly-β-hydroxybutyrate granules, sulphur granules and gas vesicles are present.

Bacterial chromosome

The bacterial chromosome is a single circular DNA molecule, tightly coiled and is not enclosed in a membrane as in Eukaryotes. This genetic material is called **Nucleoid or Genophore.** It is amazing to note that the DNA of *E.coli* which measures about 1mm long when uncoiled, contains all the genetic information of the organism. The DNA is not bound to **histone** proteins. The single chromosome or the DNA molecule is circular and at one point it is attached to the plasma membrane and it is believed that this attachment may help in the separation of two chromosomes after DNA replication.

Plasmid

Plasmids are extra chromosomal double stranded, circular, self-replicating, autonomous elements. The size of a plasmid varies from 1 to 500 kb usually plasmids contribute to about 0.5 to 5.0% of the total DNA of bacteria. They contain genes for fertility, antibiotic resistant and heavy metals. It also help in the production of bacteriocins and toxins which are not found in bacterial chromosome. The number of plasmids per cell varies. Plasmids are classified into different types based on the function. Some of them are F (Fertility) factor, R (Resistance) plasmids, Col (Colicin) plasmids, Ri (Root inducing) plasmids and Ti (Tumour inducing) plasmids.

Mesosomes

These are localized infoldings of plasma membrane produced into the cell in the form of vesicles, tubules and lamellae. They are clumped and folded together to maximize their surface area and helps in respiration and in binary fission.

Polysomes / Polyribosomes

The ribosomes are the site of protein synthesis. The number of ribosome per cell varies from 10,000 to 15,000. The ribosomes are 70S type and consists of two subunits (50S and 30S). The ribosomes are held together by mRNA and form polyribosomes or polysomes.

Flagella

Certain motile bacteria have numerous thin hair like projections of variable length emerge from the cell wall called flagella. It is 20–30 µm in diameter and 15 µm in length. The flagella of Eukaryotic cells contain 9+2 microtubles but each flagellum in bacteria is made up of a single fibril. Flagella are used for locomotion. Based on the number and position of flagella there are different types of bacteria (Figure 1.8)

Fimbriae or Pili

Pili or fimbriae are hair like appendages found on surface of cell wall of gram-negative bacteria (Example: *Enterobacterium*). The pili are 0.2 to 20 µm long with a diameter of about 0.025µm. In addition to normal pili there are special type of pili which help in conjugation called sex pili are also found.

1.4.4 Gram staining procedure

The Gram staining method to differentiate bacteria was developed by Danish Physician Christian Gram in the year1884. It is a differential staining procedure and it classifies bacteria into two classes - Gram positive and Gram negative. The steps involved in Gram staining procedure is given in Figure 1.10. The Gram positive bacteria retain crystal violet and appear dark violet whereas Gram negative type loose the crystal violet and when counterstained by safranin appear red under a microscope.

Most of the gram positive cell wall contain considerable amount of teichoic acid and teichuronic acid. In addition, they may contain

Prepare a smear of bacterial culture
↓
Stain with Crystal violet for 30 seconds
↓
Rinse in distilled water for 2 seconds
↓
Grams Iodine for 1 minute
↓
Rinse in distilled water
↓
Wash in 95% ethanol or acetone for 10 to 30 seconds
↓
Rinse in distilled water
↓
Safranin for 30–60 seconds
↓
Rinse in distilled water and blot
↓
Observe under microscope

Figure 1.10: Steps involved in Gram Staining

polysaccharide molecules. The gram negative cell wall contains three components that lie outside the peptidoglycan layer. 1. Lipoprotein 2. Outer membrane 3.Lipopolysaccharide. Thus the different results in the gram stain

Table 1.6: Difference between Gram Positive and Gram Negative Bacteria

S. No.	Characteristics	Gram positive Bacteria	Gram negative Bacteria
1.	Cell wall	Thick layered with (0.015 µm-0.02µm)	Thin layered with (0.0075µm–0.012µm)
2.	Rigidity of cell wall	Rigid due to presence of Peptidoglycans	Elastic due to presence of lipoprotein-polysaccharide mixture
3.	Chemical composition	Peptidoglycans-80% Polysaccharide-20% Teichoic acid present	Peptidoglycans-3 to 12% rest is polysaccharides and lipoproteins. Teichoic acid absent
4.	Outer membrane	Absent	Present
5.	Periplasmic space	Absent	Present
6.	Susceptibility to penicillin	Highly susceptible	Low susceptible
7.	Nutritional requirements	Relatively complex	Relatively simple
8.	Flagella	Contain 2 basal body rings	Contain 4 basal body rings
9.	Lipid and lipoproteins	Low	High
10.	Lipopolysaccharides	Absent	Present

are due to differences in the structure and composition of the cell wall. The difference between Gram Positive and Gram negative bacteria is given in Table 1.6.

What are Magnetosomes ?

Intracellular chains of 40-50 magnetite (Fe_3O_4) particles are found in bacterium *Aquaspirillum magnetotacticum*. and it help the bacterium to locate nutrient rich sediments.

1.4.5 Life processes in Bacteria

Respiration

Two types of respiration are found in Bacteria. They are 1. Aerobic respiration 2. Anaerobic respiration.

1. Aerobic respiration

These bacteria require oxygen as terminal acceptor and will not grow under anaerobic conditions. (i.e. in the absence of O_2) **Example:** *Streptococcus.*

Obligate aerobes

Some *Micrococcus* **species** are obligate aerobes (i.e. they must have oxygen to survive).

2. Anaerobic respiration

These bacteria do not use oxygen for growth and metabolism but obtain their energy from fermentation reactions.**Example:** *Clostridium.*

Facultative anaerobes

There are bacteria that can grow either using oxygen as a terminal electron acceptor or anaerobically using fermentation reaction to obtain energy. When a facultative anaerobe such as *E. coli* is present at a site of infection like an abdominal abscess, it can rapidly consume all available O_2 and change to anaerobic metabolism producing an anaerobic environment and thus allow the anaerobic bacteria that are present to grow and cause disease. **Example:** *Escherichia coli* and *Salmonella.*

Capnophilic Bacteria

Bacteria which require CO_2 for their growth are called as capnophilic bacteria. **Example:** *Campylobacter.*

Nutrition

On the basis of their mode of nutrition bacteria are classified into two types namely autotrophs and heterotrophs.

I Autotrophic Bacteria

Bacteria which can synthesise their own food are called autotrophic bacteria. They may be further subdivided as

A. Photoautotrophic bacteria

Bacteria use sunlight as their source of energy to synthesize food. They may be

1. Photolithotrophs

In photolithotrophs the hydrogen donor is an inorganic substance.

a. Green sulphur bacteria: In this type of bacteria the hydrogen donor is H_2S and possess pigment called **Bacterioviridin.** Example: *Chlorobium.*

b. Purple sulphur bacteria: For bacteria belong to this group the hydrogen donor is thiosulphate, **Bacteriochlorophyll** is present**.** Chlorophyll containing chlorosomes are present Example: *Chromatium.*

2. Photoorganotrophs

They utilize organic acid or alcohol as hydrogen donor. Example: Purple non sulphur bacteria – *Rhodospirillum.*

B. Chemoautotrophic bacteria

They do not have photosynthetic pigment hence they cannot use sunlight energy. This type of bacteria obtain energy from organic or inorganic substance.

1. Chemolithotrophs

This type of bacteria oxidize inorganic compound to release energy.

Examples:

1. Sulphur bacteria - *Thiobacillus thiooxidans*
2. Iron bacteria - *Ferrobacillus ferrooxidans*
3. Hydrogen bacteria - *Hydrogenomonas*
4. Nitrifying bacteria - *Nitrosomonas* and *Nitrobacter*

2. Chemoorganotrophs

This type of bacteria oxidize organic compounds to release energy.

Examples:

1. Methane bacteria – *Methanococcus*
2. Acetic acid bacteria – *Acetobacter*
3. Lactic acid bacteria – *Lactobacillus*

II. Heterotrophic Bacteria

They are Parasites (*Mycobacterium*) Saprophytes (*Bacillus mycoides*) or Symbiotic (*Rhizobium* in root nodules of leguminous crops).

1.4.6 Reproduction in Bacteria

Bacteria reproduces asexually by binary fission, conidia and endospore formation (Figure 1.11). Among these, binary fission is the most common one.

Binary fission

Under favourable conditions the cell divides into two daughter cells. The nuclear material divides first and it is followed by the formation of a simple median constriction which finally results in the separation of two cells.

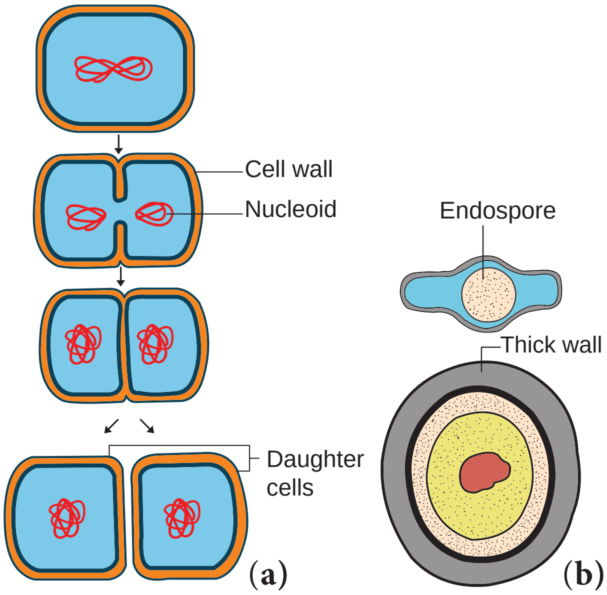


Figure 1.11: Asexual Reproduction in Bacteria (a) Binary fission, (b) Endospore

Endospores

During unfavourable condition bacteria produce endospores. Endospores are produced in *Bacillus megaterium*, *Bacillus sphaericus* and *Clostridium tetani*. Endospores are thick walled resting spores. During favourable condition, they germinate and form bacteria.

Sexual Reproduction

Typical sexual reproduction involving the formation and fusion of gametes is absent in bacteria. However gene recombination can occur in bacteria by three different methods they are

1. Conjugation
2. Transformation
3. Transduction

1. Conjugation

J. Lederberg and Edward L. Tatum demonstrated conjugation in *E. coli.* in the year 1946. In this method of gene transfer the donor cell gets attached to the recipient cell with the help of pili. The pilus grows in size and forms the conjugation tube. The plasmid of donor cell which has the F^+ (fertility factor) undergoes replication. Only one strand of DNA is transferred to the recipient cell through conjugation tube. The recipient completes the structure of double stranded DNA by synthesizing the strand that complements the strand acquired from the donor (Figure 1.12).

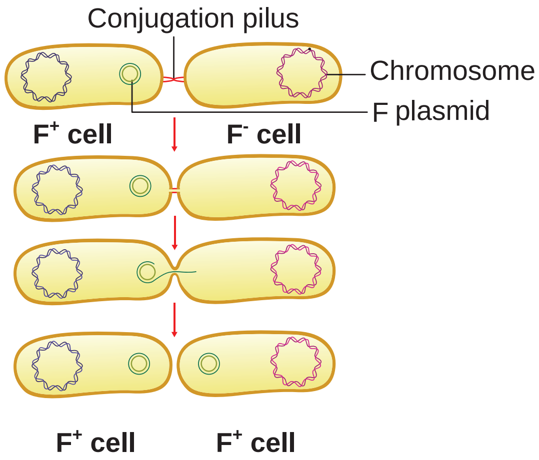


Figure 1.12: Conjugation

2. Transformation

Transfer of DNA from one bacterium to another is called transformation (Figure 1.13). In 1928 the bacteriologist Frederick Griffith demonstrated transformation in Mice using *Diplococcus pneumoniae*. Two strains of this bacterium are present. One strain produces smooth colonies and are virulent in nature (S-type). In addition another strain produce rough colonies and are avirulent (R-type). When S-type of cells were injected into the mouse, the mouse died. When R-type of cells were injected, the mouse survived. He injected heat killed S-type cells into the mouse. The mouse did not die. When the mixture of heat killed S-type cells and R-type cells were injected into the mouse, the mouse died. The avirulent rough strain of *Diplococcus* had been transformed into S-type cells. The hereditary material of heat killed S-type cells had transformed R-type cell into virulent smooth strains. Thus the phenomenon of changing the character of one strain by transferring the DNA of another strain into the former is called Transformation.

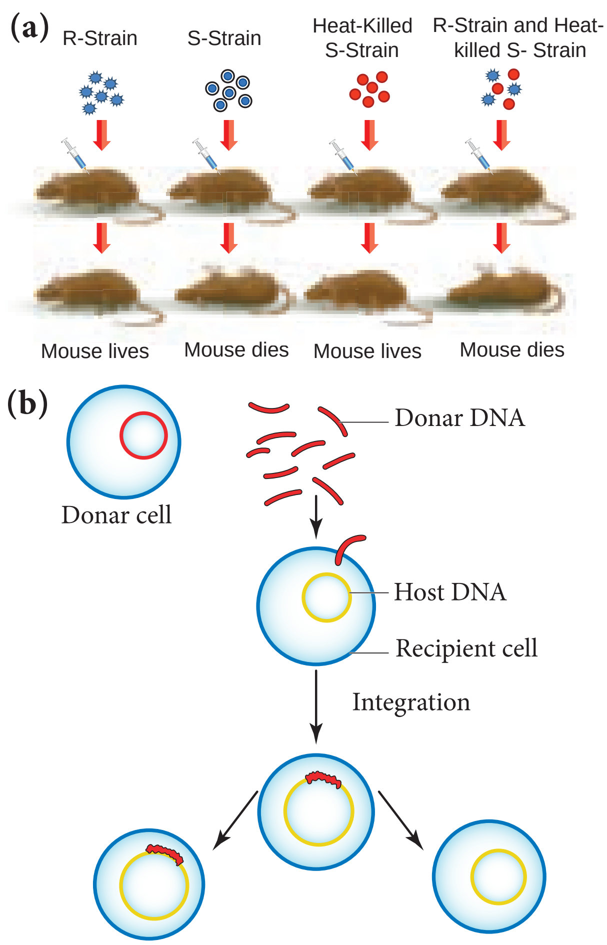


Figure 1.13: Transformation in Bacteria (a) Griffith's experiment on Transformation (b) Mechanism of Transformation

3. Transduction

Zinder and Lederberg (1952) discovered Transduction in *Salmonella typhimurum*. Phage mediated DNA transfer is called Transduction (Figure 1.14).

Transduction is of two types

(i) Generalized transduction (ii) Specialized or Restricted transduction

(i) Generalized Transduction

The ability of a bacteriophage to carry genetic material of any region of bacterial DNA is called generalised transduction.

(ii) **Specialized or Restricted Transduction**

The ability of the bacteriophage to carry only a specific region of the bacterial DNA is called specialized or restricted transduction.

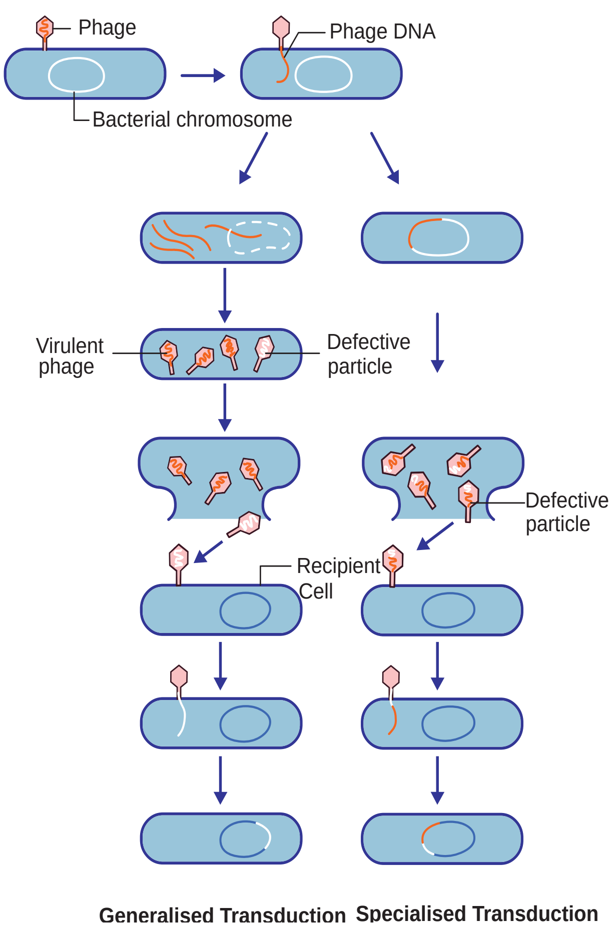


Figure 1.14: Transduction in Bacteria

1.4.7 Economic importance of Bacteria

Bacteria are both beneficial and harmful. The beneficial activities of bacteria are given in table 1.7.

Table 1.7: Economic importance of Bacteria

Beneficial aspects	Bacteria	Role
1. Soil fertility		
Ammonification	1. *Bacillus ramosus* 2. *Bacillus mycoides*	Convert complex proteins in the dead bodies of plants and animals into ammonia which is later converted into ammonium salt
Nitrification	1. *Nitrobacter* 2. *Nitrosomonas*	Convert ammonium salts into nitrites and nitrates
Nitrogen fixation	1. *Azotobacter* 2. *Clostridium* 3. *Rhizobium*	(i) Converting atmospheric nitrogen into organic nitrogen (ii) The nitrogenous compounds are also oxidized to nitrogen (iii) All these activities of bacteria increase soil fertility
2. Antibiotics		
1. Streptomycin	*Streptomyces griseus*	It cures urinary infections, tuberculosis, meningitis and pneumonia
2. Aureomycin	*Streptomyces aureofaciens*	It is used as a medicine to treat whooping cough and eye infections
3. Chloromycetin	*Streptomyces venezuelae*	It cure typhoid fever
4. Bacitracin	*Bacillus licheniformis*	It is used to treat syphilis
5. Polymyxin	*Bacillus polymyxa*	It cure some bacterial diseases
3. Industrial Uses		
1. Lactic acid	*Lactobacillus lactis* and *Lactobacillus bulgaricus*	Convert milk sugar lactose into lactic acid
2. Butter	*Lactococcus lactis, Leuconostoc citrovorum*	Convert milk into butter, cheese, curd and yoghurt
3. cheese	*Lactobacillus acidophilus, Lactobacillus lactis*	
4. Curd	*Lactobacillus lactis*	
5. Yoghurt	*Lactobacillus bulgaricus*	
6. Vinegar (Acetic acid)	*Acetobacter aceti*	This bacteria oxidizes ethyl alcohol obtained from molasses by fermentation to vinegar(acetic acid)
7. Alcohol and Acetone (i) Butyl alcohol (ii) Methyl alcohol	*Clostridium acetobutylicum*	Alcohols and acetones are prepared from molasses by fermentation activity of the anaerobic bacterium.
8. Retting of fibres	*Clostridium tertium*	The fibres from the fibre yielding plants are separated by the action of *Clostridium* is called retting of fibres.
9. Vitamins	*Escherichia coli*	Living in the intestine of human beings produce large quantities of vitamin K and vitamin B complex.
	Clostridium acetobutylicum	Vitamins B_2 is prepared by the fermentation of sugar.
10. Curing of Tea and Tobacco	*Micrococcus candicans, Bacillus megatherium*	The special flavor and aroma of the tea and tobacco are due to fermentation.

Bacteria are known to cause disease in plants, animals and Human beings. The List is given in Table 1.8, 1.9, 1.10 and Figure 1.15.

Table 1.8: Plant diseases caused by Bacteria

S.No.	Name of the Host	Name of the disease	Name of the pathogen
1	Rice	Bacterial blight	*Xanthomonas oryzae*
2	Apple	Fire blight	*Erwinia amylovora*
3	Carrot	Soft rot	*Erwinia caratovora*
4	Citrus	Citrus canker	*Xanthomonas citri*
5	Cotton	Angular leaf spot	*Xanthomonas malvacearum*
6	Potato	Ring rot	*Clavibacter michiganensis* subsp. *sepedonicus*
7	Potato	Scab	*Streptomyces scabies*

Table 1.9: Animal diseases caused by Bacteria

S. No	Name of the Animal	Name of the disease	Name of the pathogen
1.	Sheep	Anthrax	*Bacillus anthracis*
2.	Cattle	Brucellosis	*Brucella abortus*
3.	Cattle	Bovine tuberculosis	*Mycobacterium bovis*
4.	Cattle	Black leg	*Clostridium chauvoei*

Table 1.10: Human diseases caused by Bacteria

Serial No.	Name of the disease	Name of the pathogen
1.	Cholera	*Vibrio cholerae*
2.	Typhoid	*Salmonella typhi*
3.	Tuberculosis	*Mycobacterium tuberculosis*
4.	Leprosy	*Mycobacterium leprae*
5.	Pneumonia	*Diplococcus pneumoniae*
6.	Plague	*Yersinia pestis*
7.	Diphtheria	*Corynebacterium diptheriae*
8.	Tetanus	*Clostridium tetani*
9.	Food poisoning	*Clostridium botulinum*
10.	Syphilis	*Treponema pallidum*

(a) (b)

Figure 1.15: Plant diseases caused by bacteria (a) Citrus canker (b) Potato scab

Have you heard about the word "Probiotics"

Probiotic milk products and tooth paste are available in the market. *Lactobacillus and Bifidobacterium* are used to prepare probiotic yoghurt and tooth paste

Activity 1.3

Collect some root nodules of leguminous crops. Draw diagram. Wash it in tap water and prepare a smear by squeezing the content into a clean slide. Follow Gram staining method and identify the bacteria.

DO YOU KNOW?

Bacteria forms Biofilms and leads to dental caries and Urinary tract infection (UTI)

Ralstonia synthesize PHB (Poly-β-hydroxyl butyrate) a microbial plastic which is biodegradable.

1.4.8 Archaebacteria

Archaebacteria are primitive prokaryotes and are adapted to thrive in extreme environments like hot springs, high salinity, low pH and so on. They are mostly chemoautotrophs. The unique feature of this group is the presence of lipids like glycerol & isopropyl ethers in their cell membrane. Due to the unique chemical composition the cell membrane show resistance against cell wall antibiotics and lytic agents. Example: *Methanobacterium, Halobacterium, Thermoplasma*.

1.4.9 Cyanobacteria (Blue Green Algae)

How old are Cyanobacteria ?
Stromatolites reveals the truth.

Stromatolites are deposits formed when colonies of cyanobacteria bind with calcium carbonate. They have a geological age of 2.7 billion years. Their abundance in the fossil record indicates that cyanobacteria helped in raising the level of free oxygen in the atmosphere.

> **DO YOU KNOW?**
>
> - *Pseudomonas putida* is a superbug genetically engineered which breakdown hydrocarbons.
> - "Pruteen" is a single cell protein derived from *Methylophilus methylotrophus*.
> - *Agrobacterium tumefaciens* cause crown gall disease in plants but its inherent tumour inducing principle helps to carry the desired gene into the plant through Genetic engineering.
> - *Thermus aquaticus* is a thermophilic gram negative bacteria which produces Taq Polymerase a key enzyme for Polymerase Chain Reaction (PCR).
> - *Methanobacterium* is employed in biogas production. *Halobacterium*, an extremophilic bacterium grows in high salinity. It is exploited for the production β carotene.

Cyanobacteria are popularly called as 'Blue green algae' or 'Cyanophyceae'. They are photosynthetic, prokaryotic organisms. According to evolutionary record Cyanobacteria are primitive forms and are found in different habitats. Most of them are fresh water and few are marine (*Trichodesmium* and *Dermacarpa*) *Trichodesmium erythraeum* a cyanobacterium imparts red colour to Red sea. Species of *Nostoc*, *Anabaena* lead an endophytic life in the coralloid root of *Cycas*, leaves of aquatic fern *Azolla* by establishing a symbiotic association and fix atmospheric nitrogen. Members like *Gloeocapsa, Nostoc, Scytonema* are found as phycobionts in lichen thalli.

Salient features

- The members of this group are prokaryotes and lack motile reproductive structures.
- The thallus is unicellular in *Chroococcus*, Colonial in *Gloeocapsa* and filamentous trichome in *Nostoc*.
- Gliding movement is noticed in some species (*Oscillatoria*).
- The protoplasm is differentiated into central region called centroplasm and peripheral region bearing chromatophore called chromoplasm.
- The photosynthetic pigments include c-phycocyanin and c-phycoerythrin along with myxoxanthin and myxoxanthophyll.
- The reserve food material is Cyanophycean starch.
- In some forms a large colourless cell is found in the terminal or intercalary position called Heterocysts. They are involved in nitrogen fixation.
- They reproduce only through vegetative methods and produce Akinetes (thick wall dormant cell formed from vegetative cell), Hormogonia (a portion of filament get detached and reproduce by cell division), fission and endospores.
- The presence of mucilage around the thallus is characteristic feature of this group. Therefore, this group is also called Myxophyceae.
- Sexual reproduction is absent.
- *Microcystis aeruginosa*, *Anabaena flos-aquae* cause water blooms and release toxins and affect the aquatic organism.

Most of them fix atmospheric nitrogen and are used as biofertilizers (Example: *Nostoc, Anabaena*). *Spirulina* is rich in protein hence it is used as single cell protein. The thallus organisation and methods of reproduction is given in Figure 1.16.

DO YOU KNOW?

A prokaryote takes a joy ride on polar bear (*Aphanocapsa montana* - a cynobacterium grow on the fur of polar bear).

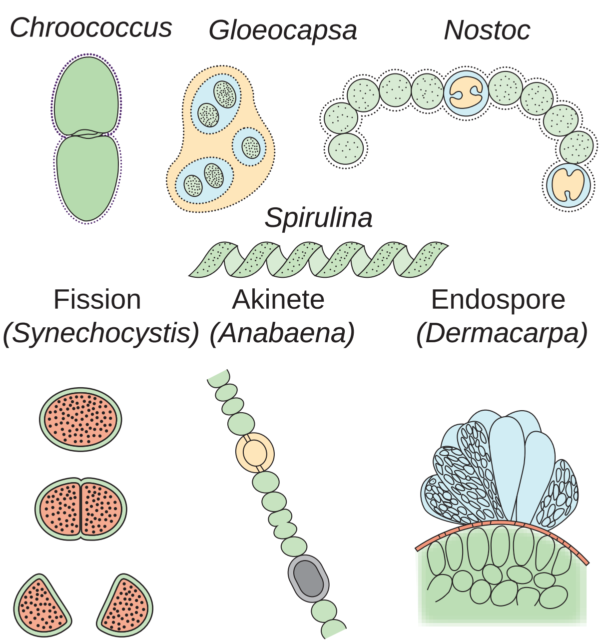


Figure 1.16: Structure and reproduction in cyanophyceae

1.4.10 Mycoplasma or Mollicutes

The Mycoplasma are very small (0.1–0.5µm), pleomorphic gram negative microorganisms. They are first isolated by Nocard and co-workers in the year 1898 from pleural fluid of cattle affected with bovine pleuropneumonia. They lack cell wall and appear like "Fried Egg" in culture. The DNA contains low Guanine and Cytosine content than true bacteria. They cause disease in animals and plants. Little leaf of brinjal, witches broom of legumes phyllody of cloves, sandal spike are some plant diseases caused by mycoplasma. Pleuropneumonia is caused by *Mycoplasma mycoides.* The structure of Mycoplasma is given in Figure 1.17.

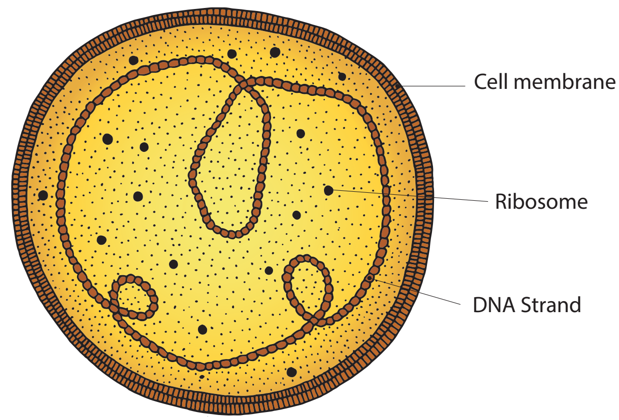


Figure 1.17: Structure of *Mycoplasma*

1.4.11 Actinomycetes (Actinobacteria)

Actinomycetes are also called 'Ray fungi' due to their mycelia like growth. They are anaerobic or facultative anaerobic microorganisms and are Gram positive. They do not produce an aerial mycelium. Their DNA contains high guanine and cytosine content (Example: *Streptomyces*).

Frankia is a symbiotic actinobacterium which produces root nodules and fixes nitrogen in non – leguminous plants such as *Alnus* and *Casuarina*. They produce multicellular sporangium. *Actinomyces bovis* grows in oral cavities and cause lumpy jaw.

Streptomyces is a mycelial forming Actinobacteria which lives in soil, they impart "earthy odour" to soil after rain which is due to the presence of Geosmin (volatile organic compound). Some important antibiotics namely, Streptomycin, Chloramphenicol, and Tetracycline are produced from this genus.

1.5 Fungi

World War II and Penicillin

History speaks on fungi

Sir Alexander Fleming

Discovery of Penicillin in the year 1928 is a serendipity in the world of medicine. The History of World War II recorded the use of Penicillin in the form of yellow powder to save lives of soldiers. For this discovery - The wonderful antibiotic he shared Nobel Prize in Medicine in the year 1945 along with Ernest Boris chain and Sir Howard Walter Florey.

1.5.1 Milestones in Mycology

1729 P.A.Micheli conducted spore culture experiments

1767 Fontana proved that Fungi could cause disease in plants

1873 C.H. Blackley proved fungi could cause allergy in Human beings

1904 A.F.Blakeslee reported heterothallism in fungi

1952 Pontecorvo and Roper reported Parasexual cycle

The word 'fungus' is derived from Latin meaning 'mushroom'. Fungi are ubiquitous, eukaryotic, achlorophyllous heterotrophic organisms. They exist in unicellular or multicellular forms. The study of fungi is called mycology. (Gr. mykes – mushroom: logos – study). P.A. Micheli is considered as founder of Mycology. Few renowned mycologists include Arthur H.R. Buller, John Webster, D.L.Hawksworth, G.C.Ainsworth, B.B.Mundkur, K.C.Mehta, C.V. Subramanian and T.S. Sadasivan.

E.J. Butler is the Father of Indian Mycology. He established Imperial Agricultural Research Institute at Pusa, Bihar. It was later shifted to New Delhi and at present known as Indian Agricultural Research Insitute (IARI).

E.J. Butler (1874-1943)

He published a book, 'Fungi and Disease in Plants' on Indian plant diseases in the year 1918.

1.5.2 General characteristic features

- Majority of fungi are made up of thin, filamentous branched structures called hyphae. A number of hyphae get interwoven to form mycelium. The cell wall of fungi is made up of a polysaccharide called **chitin** (polymer of N-acetyl glucosamine) and fungal cellulose.
- The fungal mycelium is categorised into two types based on the presence or absence of septa (Figure 1.18). In lower fungi the hypha is aseptate, multinucleate and is known as coenocytic mycelium (Example: *Albugo*). In higher fungi a septum is present between the cells of the hyphae. Example: *Fusarium*.

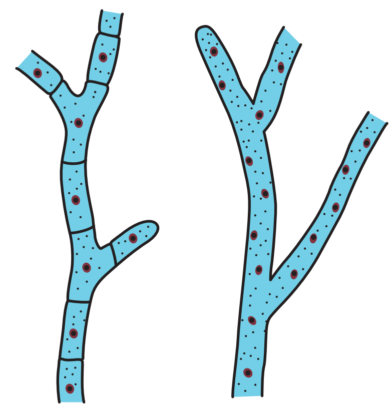


Figure 1.18: Types of mycelium

- The mycelium is organised into loosely or compactly interwoven fungal tissues called **plectenchyma**. It is further divided into two types **prosenchyma** and **pseudoparenchyma**. In the former type the hyphae are arranged loosely but parallel to one another. In the latter hyphae are compactly arranged and loose their identity.
- In holocarpic forms the entire thallus is converted into reproductive structure whereas in Eucarpic some regions of the thallus are involved in the reproduction other regions remain vegetative. Fungi reproduce both by asexual and sexual methods. The asexual phase is called **Anamorph** and the sexual phase is called **Teleomorph**. Fungi having both phases are called **Holomorph**.

General sexual reproduction in fungi includes three steps 1. Fusion of two protoplasts (plasmogamy) 2. Fusion of nuclei (karyogamy) and 3. Production of haploid spores through meiosis. Methods of reproduction in fungi is given in Figure 1.19.

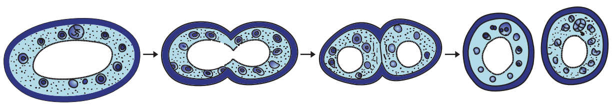
1.5.3 Methods of Reproduction in Fungi

Asexual Reproduction

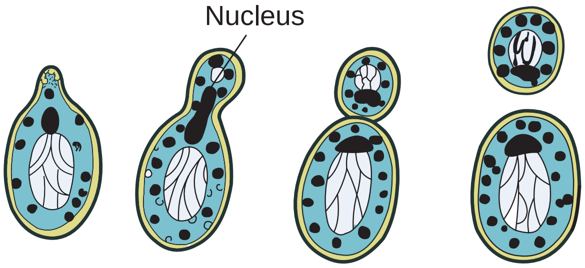
1. Zoospores: They are flagellate structures produced in zoosporangia (Example: Chytrids).
2. Conidia: The spores produced on condiophores (Example: *Aspergillus, Penicillium*).
3. Oidia/Thallospores/Arthrospores: The hypha divided and developed in to spores called oidia (Example: *Erysiphe*).
4. Fission: The vegetative cell divides into 2 daughter cells. (Example: *Schizosaccharomyces*-yeast).
5. Budding: A small outgrowth is developed on parent cell, which gets detached and becomes independent. (Example: *Saccharomyces*-yeast*)*
6. Chlamydospore: Thick walled resting spores are called chlamydospores (Example: *Fusarium*).

Sexual Reproduction

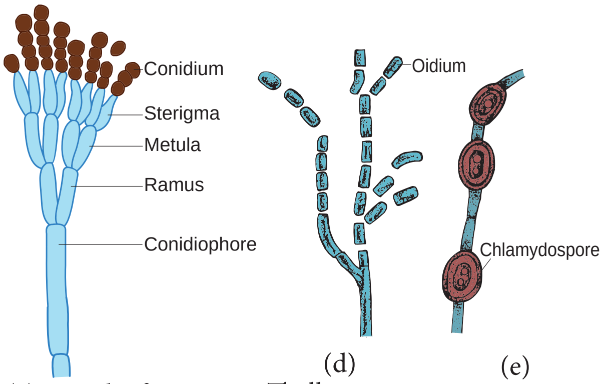
1. Planogametic copulation: Fusion of motile gamete is called planogametic copulation. a. Isogamy – Fusion of morphologically and physiologicall similar gametes. (Example: *Synchytrium*). b. Anisogamy – Fusion of morphologically or physiologically dissimilar gametes (Example: *Allomyces*). c. Oogamy – Fusion of both morphologically and physiologically dissimilar gametes. (Example: *Monoblepharis*).
2. Gametangial contact: During sexual reproduction a contact is established between antheridium and Oogonium (Example: *Albugo*).
3. Gametangial copulation: Fusion of gametangia to form zygospore (Example: *Mucor, Rhizopus*).
4. Spermatization: In this method a uninucleate pycniospore/microconidium is transferred to receptive hyphal cell (Example: *Puccinia, Neurospora*)
5. Somatogamy: Fusion of two somatic cells of the hyphae (Example: *Agaricus*)



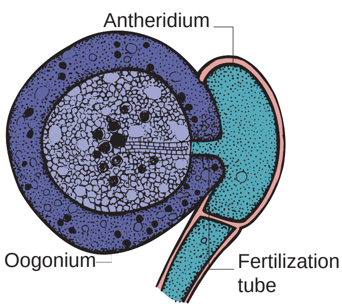
(a) Fission - Yeast



(b) Budding - Yeast



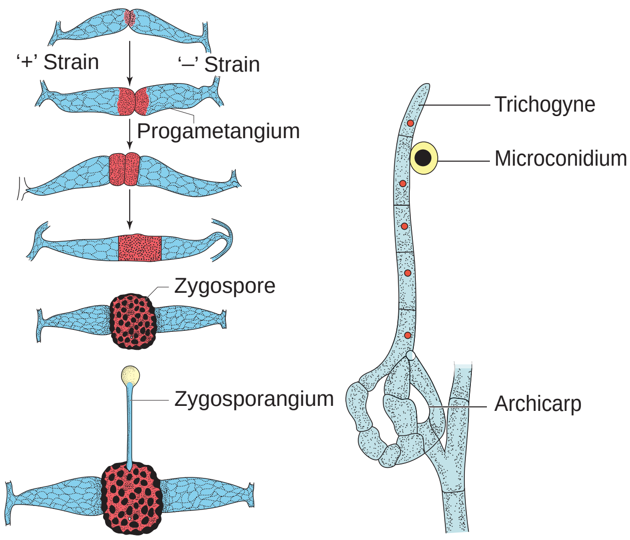
(c) Conidia formation - *Penicillium*   (d) Thallospore - Erysiphe   (e) Chlamydospore - Fusarium



(f) Gametangial contact - *Albugo*

(g) Sporangia - *Mucor*

Figure 1.19: Reproduction in Fungi



(h) Gametangial copulation - *Rhizopus*

(i) Spermatisation - *Neurospora*

Figure 1.19: Reproduction in Fungi

1.5.4 Classification of Fungi

Many mycologists have attempted to classify fungi based on vegetative and reproductive characters. Traditional classifications categorise fungi into 4 classes – Phycomycetes, Ascomycetes, Basidiomycetes and Deuteromycetes. Among these 'Phycomycetes' include fungal species of Oomycetes, Chytridiomycetes and Zygomycetes which are considered as lower fungi indicating algal origin of fungi. Constantine J. Alexopoulos and Charles W. Mims in the year 1979 proposed the classification of fungi in the book entitled 'Introductory Mycology'. They classified fungi into three divisions namely Gymnomycota, Mastigomycota and Amastigomycota. There are 8 subdivisions, 11 classes, 1 form class and 3 form subclasses in the classification proposed by them.

The salient features of some of the classes – Oomycetes, Zygomycetes, Ascomycetes, Basidiomycetes and Form class Deuteromycetes are discussed below.

Oomycetes

Coenocytic mycelium is present. The cell wall is made up of Glucan and Cellulose. Zoospore with one whiplash and one tinsel flagellum is present. Sexual reproduction is oogamous. Example: *Albugo.*

Zygomycetes

- Most of the species are saprophytic and live on decaying plant and animal matter in the soil. Some lead parasitic life (Example: *Entomophthora* on housefly).
- Bread mold fungi (Example: *Mucor, Rhizopus*) and coprophilous fungi (Fungi growing on dung Example: *Pilobolus*) belong to this group (Figure 1.20).

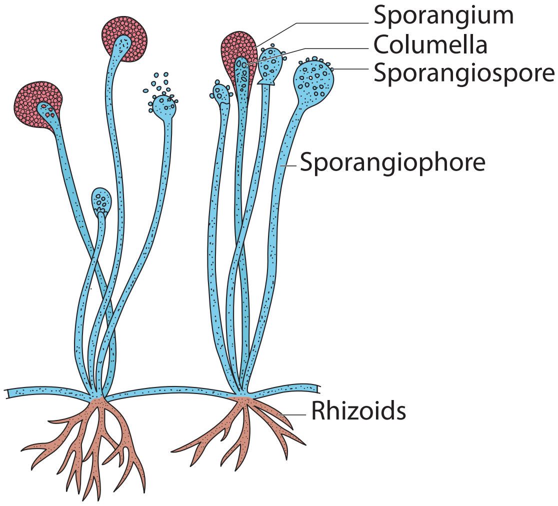


Figure 1.20: Zygomycetes – *Rhizopus*

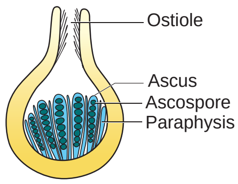
- The mycelium is branched and coenocytic.
- Asexual reproduction by means of spores produced in sporangia.
- Sexual reproduction is by the fusion of the gametangia which results in thick walled zygospore. It remains dormant for long periods. The zygospore undergoes meiosis and produce spores.

Ascomycetes

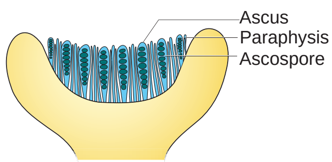
- Ascomycetes include a wide range of fungi such as yeasts, powdery mildews, cup fungi, morels and so on (Figure 1.21).
- Although majority of the species live in terrestrial environment, some live in aquatic environments both fresh water and marine.
- The mycelium is well developed, branched with simple septum.
- Majority of them are saprophytes but few parasites are also known (Powdery mildew – *Erysiphe*).

(a) *Peziza*

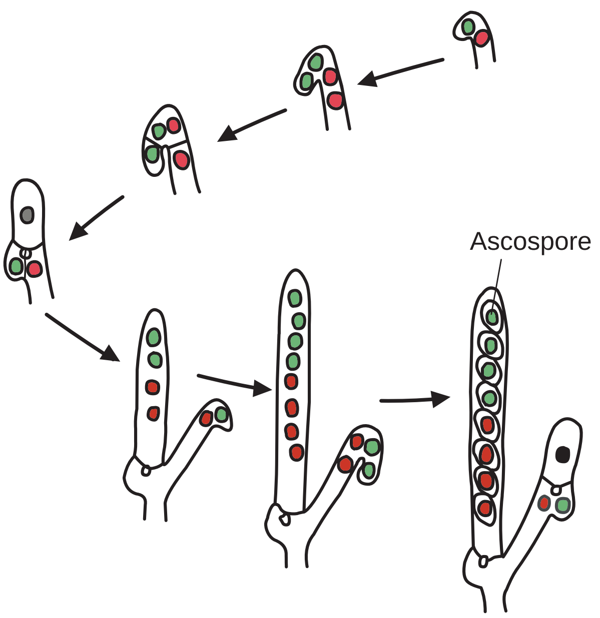
(b) Cleistothecium



(c) V.S. of Perithecium



(d) V.S. of Apothecium



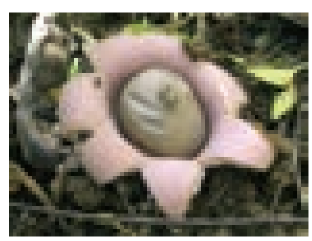
(e) Steps involved in the development of Ascus

Figure 1.21: Structure and reproduction in Ascomycetes

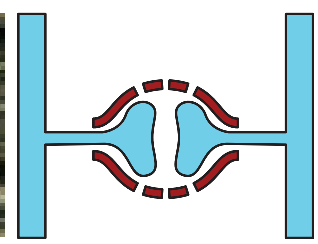
- Asexual reproduction takes place by fission, budding, oidia, conidia, and chlamydospore.
- Sexual reproduction takes place by the fusion of two compatible nuclei.
- Plasmogamy is not immediately followed by karyogamy, instead a dikaryotic condition is prolonged for several generations.
- A special hyphae called ascogenous hyphae is formed.
- A crozier is formed when the tip of the ascogenous hyphae recurves forming a hooked cell. The two nuclei in the penultimate cell of the hypha fuse to form a diploid nucleus. This cell forms young ascus.
- The diploid nucleus undergo meiotic division to produce four haploid nuclei, which further divide mitotically to form eight nuclei. The nucleus gets organised into 8 ascospores.
- The ascospores are found inside a bag like structure called ascus. Due to the presence of ascus, this group is popularly called "Sac fungi".
- Asci gets surrounded by sterile hyphae forming fruit body called ascocarp.
- There are 4 types of ascocarps namely **Cleistothecium** (Completely closed), **Perithecium** (Flask shaped with ostiole), **Apothecium** (Cup shaped, open type) and **Pseudothecium**.

Basidiomycetes

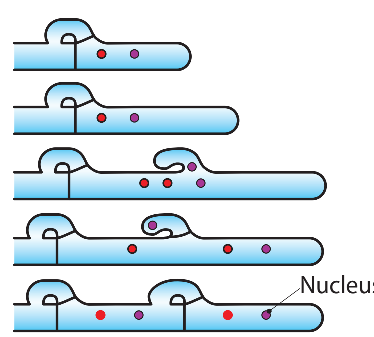
- Basidiomycetes include puff balls, toad stools, Bird's nest fungi, Bracket fungi, stink horns, rusts and smuts (Figure 1.22).



(a) *Geaster*



(b) Dolipore septum



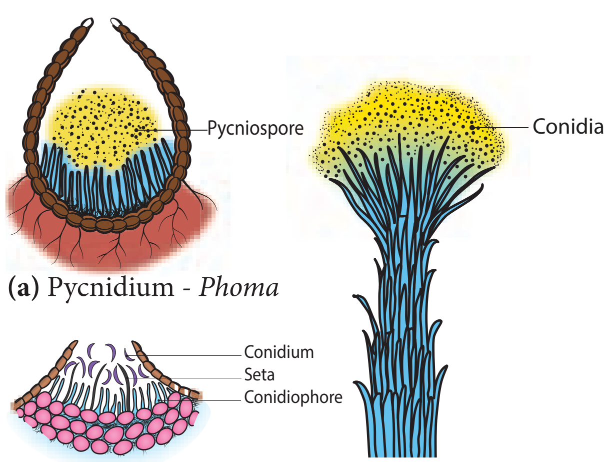
(c) Clamp connection

Figure 1.22: Structure and Reproduction in Basidiomycetes

- The members are terrestrial and lead a saprophytic and parasitic mode of life.

- The mycelium is well developed, septate with dolipore septum(bracket like). Three types of mycelium namely primary (Monokaryotic), secondary (Dikaryotic) and tertiary are found.
- Clamp connections are formed to maintain dikaryotic condition.
- Asexual reproduction is by means of conidia, oidia or budding.
- Sexual reproduction is present but sex organs are absent. Somatogamy or spermatisation results in plasmogamy. Karyogamy is delayed and dikaryotic phase is prolonged. Karyogamy takes place in basidium and it is immediately followed by meiotic division.
- The four nuclei thus formed are transformed into basidiospores which are borne on sterigmata outside the basidium (Exogenous). The basidium is club shaped with four basidiospores, thus this group of fungi is popularly called "Club fungi". The fruit body formed is called Basidiocarp.

Deuteromycetes or Fungi Imperfecti



(a) Pycnidium - *Phoma*

(b) Acervulus - Colletotrichum

(c) Synnema - Graphium

Figure 1.23: Reproduction in Deuteromycetes

The fungi belonging to this group lack sexual reproduction and are called imperfect fungi. A large number of species live as saprophytes in soil and many are plant and animal parasites. Asexual reproduction takes place by the production of conidia, chlamydospores, budding, oidia etc., Conidia are also produced in special structures called **pycnidium**, **acervulus**, **sporodochium** and **synnemata** (Figure 1.23). Parasexual cycle operates in this group of fungi. This brings genetic variation among the species.

1.5.5 Economic importance

Fungi provide delicious and nutritious food called mushrooms. They recycle the minerals by decomposing the litter thus adding fertility to the soil. Dairy industry is based on a single celled fungus called yeast. They deteriorate the timber. Fungi cause food poisoning due the production of toxins. The Beneficial and harmful activities of fungi are discussed below:

Beneficial activities

Food

Mushrooms like *Lentinus edodes, Agaricus bisporus, Volvariella volvaceae* are consumed for their high nutritive value. Yeasts provide vitamin B and *Eremothecium ashbyii* is a rich source of Vitamin $B_{12.}$

Medicine

Fungi produce antibiotics which arrest the growth or destroy the bacteria. Some of the antibiotics produced by fungi include Penicillin (*Penicillium notatum*) Cephalosporins (*Acremonium chrysogenum*) Griseofulvin (*Penicillium griseofulvum*). Ergot alkaloids (Ergotamine) produced by *Claviceps purpurea* is used as vasoconstrictors.

Industries

Production of Organic acid: For the commercial production of organic acids fungi are employed in the Industries. Some of the organic acids and fungi which help in the production of organic acids are: citric acid and gluconic acid – *Aspergillus niger*, Itaconic acid – *Aspergillus terreus*, Kojic acid – *Aspergillus oryzae.*

Bakery and Brewery

Yeast(*Saccharomyces cerevisiae*) is used for fermentation of sugars to yield alcohol.Bakeries utilize yeast for the production of Bakery products like Bread, buns, rolls etc., *Penicillium roquefortii* and *Penicillium camemberti* were employed in cheese production.

Production of enzymes

Aspergillus oryzae, *Aspergillus niger* were employed in the production of enzymes like amylase, protease, lactase etc. **Rennet** which helps in the coagulation of milk in cheese manufacturing is derived from *Mucor* spp.

Agriculture

Mycorrhiza forming fungi like *Rhizoctonia*, *Phallus*, *Scleroderma* helps in absorption of water and minerals.

Fungi like *Beauveria bassiana*, *Metarhizium anisopliae* are used as Biopesticides to eradicate the pests of crops. Gibberellin, produced by a fungus *Gibberella fujikuroi* induce the plant growth and is used as growth promoter.

Harmful activities

Fungi like *Amanita phalloides*, *Amanita verna*, *Boletus satanus* are highly poisonous due to the production of Toxins. These fungi are commonly referred as **"Toad stools"**.

Aspergillus, *Rhizopus*, *Mucor* and *Penicilium* are involved in spoilage of food materials. *Aspergillus flavus* infest dried foods and produce carcinogenic toxin called aflatoxin.

Patulin, ochratoxin A are some of the toxins produced by fungi.Fungi cause diseases in Human beings and plants (Table 1.11).

Activity 1.4

Get a button mushroom. Draw diagram of the fruit body. Take a thin longitudinal section passing through the gill and observe the section under a microscope. Record your observations.

DO YOU KNOW?

Dermatophytes are fungi which cause infection in skin. Example: *Trichophyton*, *Tinea*, *Microsporum* and *Epidermophyton*

The late blight disease of Potato by *Phytophthora infestans* caused a million deaths, and drove more to emigrate from Ireland (1843-1845). In India *Helminthosporium oryzae*, Blight of Paddy is also a factor for Bengal famine in 1942-1943.

Table 1.11: Diseases caused by fungi

Name of the disease	*Causal organism*
Plant diseases	
Blast of Paddy	*Magnaporthe grisea*
Red rot of sugarcane	*Colletotrichum falcatum*
Anthracnose of Beans	*Colletotrichum lindemuthianum*
White rust of crucifers	*Albugo candida*
Peach leaf curl	*Taphrina deformans*
Rust of wheat	*Puccinia graminis tritici*
Human diseases	
Athlete's foot	*Epidermophyton floccosum*
Candidiasis	*Candida albicans*
Coccidioidomycosis	*Coccidioides immitis*
Aspergillosis	*Aspergillus fumigatus*

Activity 1.5

Keep a slice of bread in a clean plastic tray or plate. Wet the surface with little water. Leave the setup for 3 or 4 days. Observe the mouldy growth on the surface of the bread. Using a needle remove some mycelium and place it on a slide and stain the mycelium using lactophenol cotton blue. Observe the mycelium and sporangium under the microscope and record your observation and identify the fungi and its group based on characteristic features.

1.5.6 Mycorrhizae

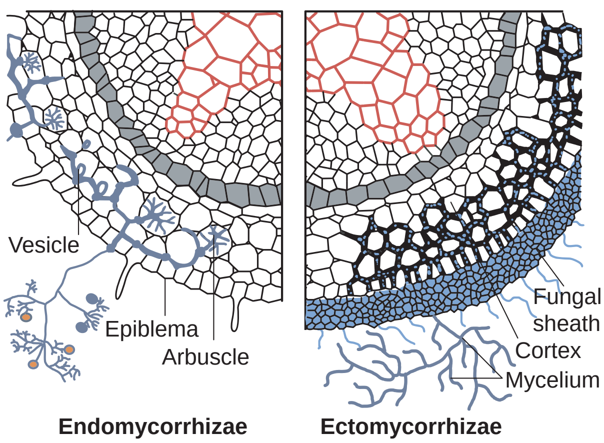


Figure 1.24: T.S. of root showing mycorrhizae

The symbiotic association between fungal mycelium and roots of plants is called as mycorrhizae. In this relationship fungi absorb nutrition from the root and in turn the hyphal network of mycorrhizae forming fungi helps the plant to absorb water and mineral nutrients from the soil (Figure 1.24). Mycorrhizae is classified into three types (Table 1.12)

Importance of Mycorrhizae

- Helps to derive nutrition in *Monotropa*, a saprophytic angiosperm,
- Improves the availability of minerals and water to the plants.
- Provides drought resistance to the plants
- Protects roots of higher plants from the attack of plant pathogens

1.5.7 Lichens

The symbiotic association between algae and fungi is called lichens. The algal partner is called Phycobiont or Photobiont., and the fungal partner is called Mycobiont. Algae provide nutrition for fungal partner in turn fungi provide protection and also help to fix the thallus to the substratum through rhizinae. Asexual reproduction takes place through fragmentation, Soredia and Isidia. Phycobionts reproduce by akinetes, hormogonia, aplanospore etc., Mycobionts undergo sexual reproduction and produce ascocarps.

Classification

- Based on the habitat lichens are classified into following types: **Corticolous(**

Table 1.12: Types of Mycorrhizae

Ectomycorrhizae	Endomycorrhizae	Ectendomycorrhizae
The fungal mycelium forms a dense sheath around the root called mantle. The hyphal network penetrate the intercellular spaces of the epidermis and cortex to form Hartig net. Example: *Pisolithus tinctorius*	The hyphae grows mainly inside the roots, penetrate the outer cortical cells of the plant root. A small portion of the mycelium is found outside the root. This form is also called Vesicular Arbuscular Mycorrhizal fungi (VAM Fungi) due to the presence of Vesicle or arbuscle like haustoria 1. Arbuscular mycorrhizae(AM) Example: *Gigaspora* 2. Ericoid mycorrhizae -Example: *Oidiodendron* 3. Orchid mycorrhizae -Example: *Rhizoctonia*	The fungi form both mantle and also penetrates the cortical cells.

on Bark) **Lignicolous**(on Wood) **Saxicolous**(on rocks) **Terricolous**(on ground) Marine(on siliceous rocks of sea) Fresh water(on siliceous rock of fresh water).

- On the basis of morphology of the thallus they are divided into **Leprose** (a distinct fungal layer is absent) **Crustose**-crust like; Foliose-leaf like; **Fruticose**- branched pendulous shrub like (Figure 1.25).

(a) Crustose lichen

(b) Foliose Lichen **(c)** Fruticose Lichen

Figure 1.25: Types of Lichens

- The distribution of algal cells distinguishes lichens into two forms namely **Homoiomerous** (Algal cells evenly distributed in the thallus) and **Heteromerous** (a distinct layer of algae and fungi present).
- If the fungal partner of lichen belongs to ascomycetes, it is called **Ascolichen** and if it is basidiomycetes it is called **Basidiolichen**.

Lichens secrete organic acids like Oxalic acids which corrodes the rock surface and helps in weathering of rocks, thus acting as pioneers in Xerosere. Usnic acid produced from lichens show antibiotic properties. Lichens are sensitive to air pollutants especially to sulphur-di-oxide. Therefore, they are considered as pollution indicators. The dye present in litmus paper used as acid base indicator in the laboratories is obtained from *Roccella montagnei. Cladonia rangiferina* (Reindeer mose) is used as food for animals living in Tundra regions.

Summary

Earth is endowed with living and nonliving things. The attributes of living things include growth, metabolism, reproduction, irritability and so on. Viruses are considered as Biological puzzle and exhibit both living and non living characteristic features. They are ultramicroscopic, obligate parasites and cause disease in plants and animals. They multiply by lytic and lysogenic cycle.

Five Kingdom classification was proposed by Whittaker, which include Monera, Protista, Fungi, Plantae and Animalia. Carl woese divided the living world into 3 domains- Bacteria, Archaeae and Eukarya. The domain Eukarya include Plantae, Animalia and Fungi. A new Kingdom called Chromista was erected to include Diatoms, Cryptomonads and Oomycetes. Bacteria are microscopic, prokaryotic organisms and possess peptidoglycan in their cell wall. Based on Gram Staining method they are classified into Gram positive and Gram negative type. They reproduce asexually by binary fission. Sexual reproduction occurs through conjugation, transformation and transduction. Archaebacteria are prokaryotic and are adapted to thrive in extreme environments.

Cyanobacteria are prokaryotic organisms and are also called Blue Green Algae. The members of this group are ensheathed by mucilage cover. They reproduce by vegetative and asexual methods.

Fungi are eukaryotic, heterotrophic, unicellular or multicellular organisms. The cell wall is made up of chitin. They reproduce asexually by producing sporangiospores, conidia, thallospores, chlamydospores etc., The sexual reproduction is isogamous, ansiogamous and oogamous. In addition, gametic copulation, gametic fusion, spermatisation are also found. They are beneficial to mankind. Some are known to cause disease in plants and human beings.

The symbiotic association between the roots of higher plants and fungal mycelium is called mycorrhizae. Lichen thallus includes both phycobiont and mycobiont. It is an example for symbiotic association.

Evaluation

1. Which one of the following statement about virus is correct?
   a. Possess their own metabolic system
   b. They are facultative parasites
   c. They contain DNA or RNA
   d. Enzymes are present

2. Identify the incorrect statement about the Gram positive bacteria
   a. Teichoic acid absent
   b. High percentage of peptidoglycan is found in cell wall
   c. Cell wall is single layered
   d. Lipopolysaccharide is present in cell wall

3. Identify the Archaebacterium
   a. *Acetobacter* b. *Erwinia*
   c. *Treponema* d. *Methanobacterium*

4. The correct statement regarding Blue green algae is ____________
   a. lack of motile structures
   b. presence of cellulose in cell wall
   c. absence of mucilage around the thallus
   d. presence of floridean starch

5. Identify the correctly matched pair
   a. Actinomycete – a) Late blight
   b. Mycoplasma – b) lumpy jaw
   c. Bacteria – c) Crown gall
   d. Fungi – d) sandal spike

6. Differentiate homoiomerous and heteromerous lichens.
7. Write the distinguishing features of monera.
8. Why do farmers plant leguminous crops in crop rotations/mixed cropping?
9. Briefly discuss on five Kingdom classification. Add a note on merits and demerits.
10. Give a general account on lichens.

ICT Corner

Bacteria

Let's explore the structure and shapes of **Bacteria.**

Steps

- Scan the QR code or go to google play store and type bacteria interactive educational VR 3D
- Download the app and install it
- Follow the above steps and explore the interactives of each part and its functions.

Activity

- Select structure tap and note the internal structure of bacteria
- Click cell wall and note the difference between different shapes

Step 1 Step 2 Step 3 Step 4 Step 5

URL:

https://play.google.com/store/apps/details?id=com.rendernet.bacteria&hl=en

* Pictures are indicative only

Unit I: Diversity of Living World

Chapter 2

Plant Kingdom

Learning Objectives

The learner will be able to,

- *Outline the classification of plants*
- *Illustrate the life cycles in plants*
- *Recognize the general characteristic features and reproduction of Algae*
- *Recognize the general characteristic features of Bryophytes*
- *Recognize the general characteristic features of Pteridophytes*
- *Describe the general characteristic features of Gymnosperms*
- *Recognize the salient features of Angiosperms*

Chapter Outline

Traditionally organisms existing on the earth were classified into plants and animals based on nutrition, locomotion and presence or absence of cell wall. Bacteria, Fungi, Algae, Bryophytes, Pteridophytes, Gymnosperms and Angiosperms were included under plant group. Recently, with the aid of molecular characteristics. Bacteria and Fungi were segregated and placed under separate kingdoms. Botany is one of the oldest science in the world because its origin was from time immemorial as early men explored and identified plants for the needs of food, clothing, medicine, shelter etc., Plants are unique living entities as they are endowed with the power to harvest the light energy from the sun and to convert it to chemical energy in the form of food through the astounding reaction, **photosynthesis**. They not only supply nutrients to all living things on earth but sequester carbon-di-oxide during photosynthesis, thus minimizing the effect of one of the major green house gases that increase the global temperature. Plants are diverse in nature, ranging from microscopic algae to macroscopic highly developed angiosperms. There are mysteries and wonders in the plant world in terms of size, shape, habit, habitat, reproduction etc., Although plants are all made up of cells there exists high diversity in form and structure (Table 2.1).

2.1 Classification of Plants

Classification widely accepted for plants now include Embryophyta which is divided into Bryophyta and Tracheophyta. The latter is further divided into Pteridophyta and Spermatophyta (Gymnospermae and Angiospermae). An outline Classification of Plant Kingdom is given in Figure 2.1

2.2 Life Cycle Patterns in Plants

Alternation of Generation

Alternation of generation is common in all plants. Alternation of the haploid

Table 2.1: Total Number of Plant groups in the World and India		
Plant group	**Number of known species**	
	World#	**India***
Algae	40,000	7,357
Bryophytes	16,236	2,748
Pteridophytes	12,000	1,289
Gymnosperms	1,012	79
Angiosperms	2,68,600	18,386

* *Singh, P. and Dash, S.S. 2017-Plants discoveries 2016-New Genera, species and new records, BSI, India.*
\# *Chapman, A.D. 2009. Number of living species in Australia and the world 2nd edition. Australian government, Department of environment, water Heritage and Arts.*

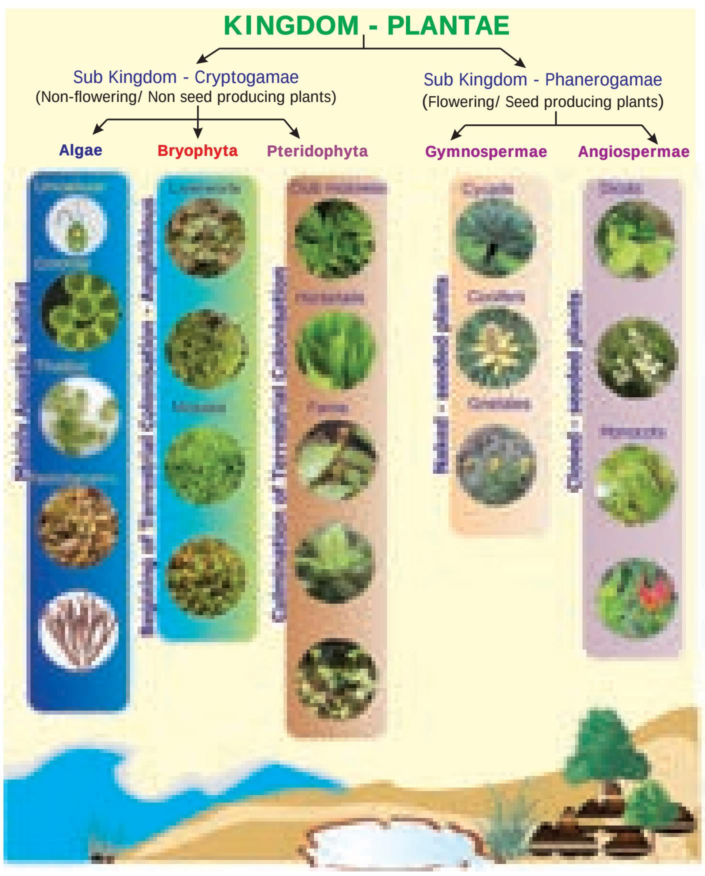


Figure 2.1: Classification of Plant Kingdom

gametophytic phase (n) with diploid sporophytic phase (2n) during the life cycle is called alternation of generation. Following type of life cycles are found in plants (Figure 2.2).

Haplontic Life Cycle

Gametophytic phase is dominant, photosynthetic and independent, whereas sporophytic phase is represented by the zygote. Zygote undergoes meiosis to restore haploid condition. Example: *Volvox*, *Spirogyra*.

Diplontic Life Cycle

Sporophytic phase (2n) is dominant, photosynthetic and independent. The gametophytic phase is represented by the single to few celled gametophyte. The gametes fuse to form zygote which develops into sporophyte. Example: *Fucus*, gymnosperms and angiosperms

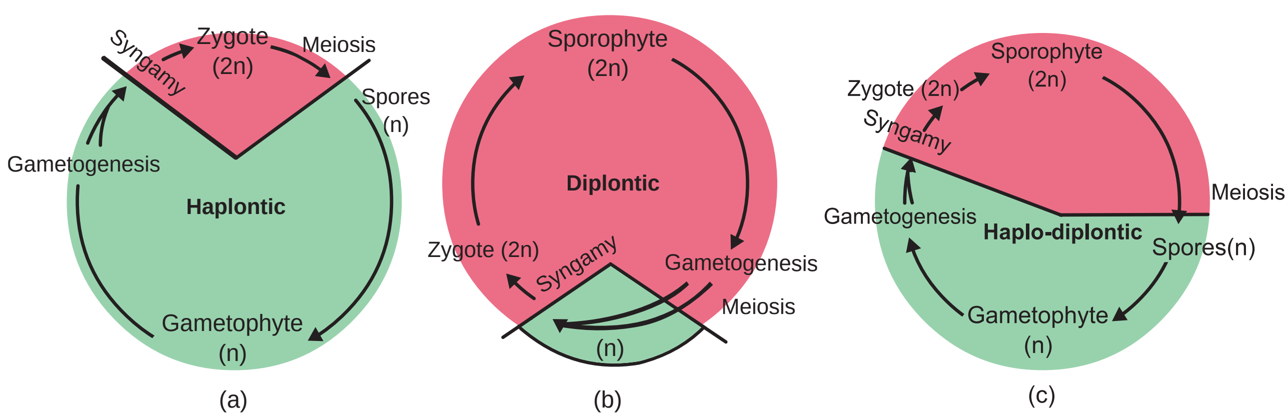


Figure 2.2: Life cycle patterns in plants a) Haplontic, b) Diplontic, c) Haplo-diplontic

Haplodiplontic Life Cycle

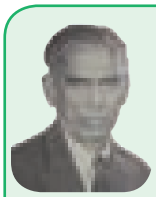
This type of life cycle is found in bryophytes and pteridophytes which is intermediate between haplontic and diplontic type. Both the phases are multicellular. but they differ in their dominant phase.

In bryophytes dominant independent phase is gametophyte and it alternates with short-lived multicellular sporophyte totally or partially dependent on the gametophyte.

In pteridophytes sporophyte is the independent phase. It alternates with multicellular saprophytic or autotrophic, independent, short lived gametophyte(n).

2.3 Algae

Rain brings joy and life to various organisms on earth. Have you noticed some changes in and around you after the rain? Could you identify the reason for the slippery nature of the terrace and green patches on the wall of our home, green colour of puddles and ponds? Why should we clean our water tanks very often? The reason is algae. Algae are simple plants that lack true roots, true stems and true leaves. Two-third of our earth's surface is covered by oceans and seas. The photosynthetic plants called algae are present here. More than half of the total primary productivity of the world depends on this plant group. Further, other aquatic organisms also depend upon them for their existence.



M.O.Parthasarathy (1886-1963) 'Father of Indian Phycology'.

He conducted research on structure, cytology, reproduction and taxonomy of Algae. He published a Monograph on Volvocales. New algal forms like *Fritschiella, Ecballocystopsis, Charasiphon* and *Cylindrocapsopsis*. were reported by him.

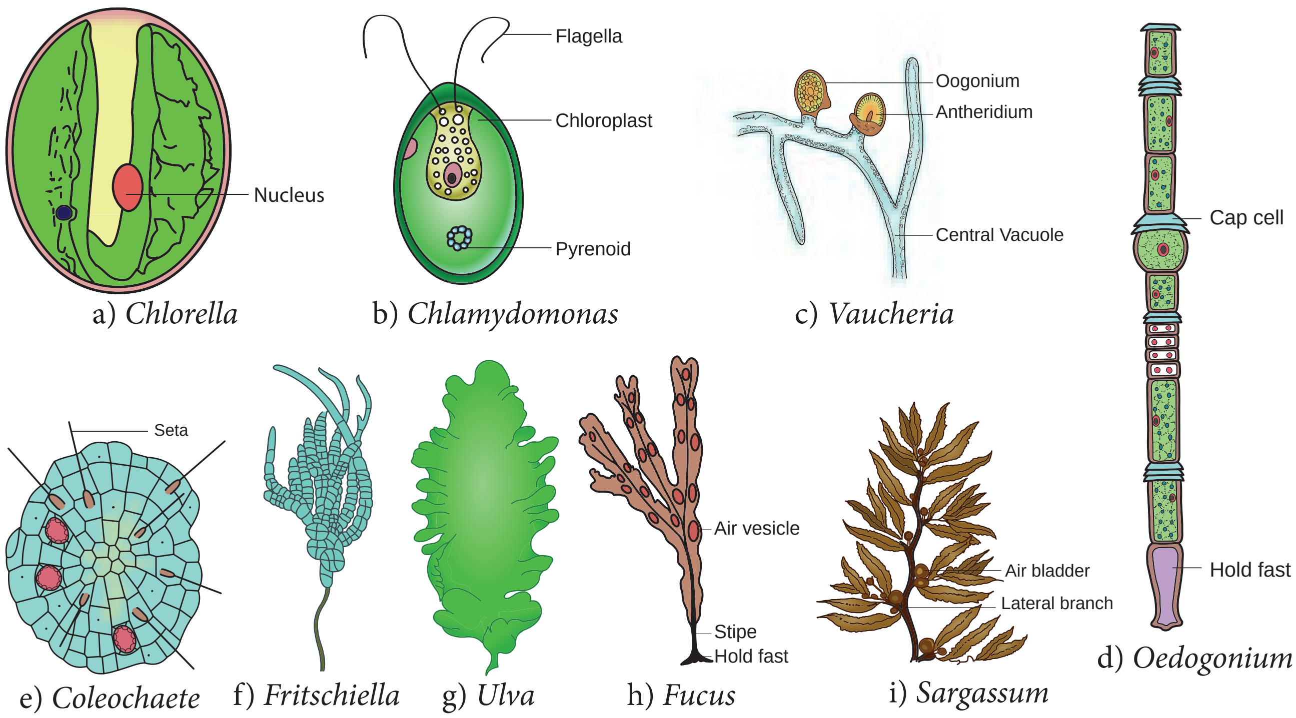
Algae are autotrophs, and grow in a wide range of habitats. Majority of them are aquatic, marine (*Gracilaria,* and *Sargassum*) and freshwater (*Oedogonium,* and *Ulothrix*) and also found in soils (*Fritschiella,* and *Vaucheria*). *Chlorella* lead an endozoic life in hydra and sponges whereas *Cladophora crispata* grow on the shells of molluscs. Algae are adapted to thrive in harsh environment too. *Dunaliella salina* grows in salt pans (**Halophytic alga**). Algae growing in snow are called **Cryophytic algae**. *Chlamydomonas nivalis* grow in snow covered mountains and impart red colour to the snow (**Red snow**). A few algae grow on the surface of aquatic plants and are called **epiphytic algae** (*Coleochaete,* and *Rhodymenia*). The study of algae is called **algology** or **phycology**. Some of the eminent algologists include F.E. Fritsch, F.E. Round, R.E. Lee, M.O.Parthasarathy Iyengar, M.S. Randhawa, Y. Bharadwaja, V.S. Sundaralingam and T.V.Desikachary.

2.3.1 General Characteristic features

The algae show a great diversity in size, shape and structure. A wide range of thallus organisation is found in algae. Unicellular motile (*Chlamydomonas*), unicellular non-motile (*Chlorella*), Colonial motile (*Volvox*), Colonial non motile (*Hydrodictyon*), siphonous (*Vaucheria*), unbranched filamentous (*Spirogyra*), branched filamentous (*Cladophora*), discoid (*Coleochaete*) heterotrichous (*Fritschiella*), Foliaceous (*Ulva*) to giant kelps (*Laminaria* and *Macrocystis*). The thallus organization in algae is given in Figure 2.3.

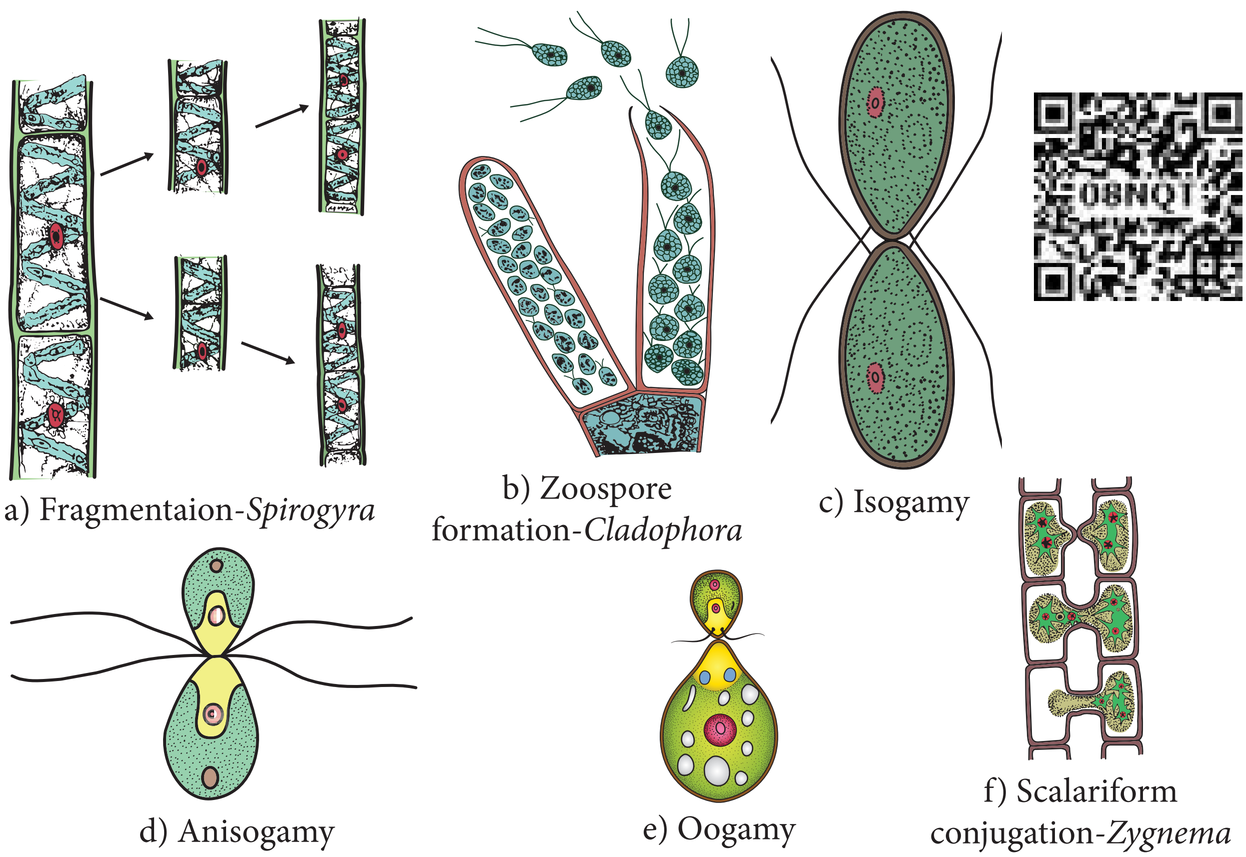
Algae are eukaryotes except blue green algae. The plant body does not show differentiation into tissue systems. The cell wall of algae is made up of cellulose and hemicellulose. Siliceous walls are present in diatoms. In *Chara* the thallus is encrusted with calcium carbonate. Some algae possess algin, polysulphate esters of polysaccharides which are the sources for the alginate, agar agar and carrageenan. The cell has a membrane bound nucleus and cell organelles like chloroplast, mitochondria, endoplasmic reticulum, golgi bodies etc., Pyrenoids are present. They are proteinaceous bodies found in chromatophores and assist in the synthesis and storage of starch. The pigmentation, reserve food material and flagellation differ among the algal groups.

Algae reproduces by vegetative, asexual and sexual methods (Figure 2.4). Vegetative reproduction includes fission (In unicellular forms the cell divides mitotically to produce



a) *Chlorella* b) *Chlamydomonas* c) *Vaucheria* d) *Oedogonium* e) *Coleochaete* f) *Fritschiella* g) *Ulva* h) *Fucus* i) *Sargassum*

Figure 2.3: Thallus organization in Algae



a) Fragmentaion-*Spirogyra* b) Zoospore formation-*Cladophora* c) Isogamy d) Anisogamy e) Oogamy f) Scalariform conjugation-*Zygnema*

Figure 2.4: Reproduction in Algae

two daughter cells Example: *Chlamydomonas)*; Fragmentation (fragments of parent thallus grow into new individual Example: *Ulothrix*) budding (A lateral bud is formed in some members like *Protosiphon* and helps in reproduction) bulbils, (a wedge shaped modified branch develop in *Sphacelaria*) akinetes (Thick walled spores meant for perennation and germinates with the advent of favourable condition Example: *Pithophora*) and Tubers (Structures found on the rhizoids and the lower nodes of *Chara* which store food materials).

Asexual reproduction takes place by the production of zoospores motile spores (*Ulothrix, Oedogonium*) aplanospore (thin walled non motile spores Example: *Vaucheria*); autospores (spores which look similar to parent cell Example: *Chlorella*); hypnospore (thick walled aplanospore – Example: *Chlamydomonas nivalis*) and Tetraspores (Diploid thallus of *Polysiphonia* produce haploid spores after meiosis).

Sexual reproduction in algae is of three types 1. Isogamy (Fusion of morphologically and Physiologically similar gametes Example: *Ulothrix*) 2. Anisogamy (Fusion of either morphologically or physiologically dissimilar gametes Example: *Pandorina*) 3. Oogamy (Fusion of both morphologically and physiologically dissimilar gametes. Example: *Sargassum*). The life cycle shows distinct alternation of generation.

DO YOU KNOW?

The Oldest recorded alga is Grypania, which was discovered in the banded iron formations of northern Michigan and dated to approximately 2100Ma

2.3.2. Classification

F.E. Fritsch proposed a classification for algae based on pigmentation, types of flagella, reserve food materials, thallus structure and reproduction. He published his classification in the book "The structure and reproduction of the Algae"(1935). He classified algae into 11 classes namely Chlorophyceae, Xanthophyceae, Chrysophyceae, Bacillariophyceae, Cryptophyceae, Dinophyceae, Chloromonadineae, Euglenophyceae, Phaeophyceae, Rhodophyceae, Cyanophyceae.

The salient features of Chlorophyceae, Phaeophyceae and Rhodophyceae are given below.

Chlorophyceae

The members are commonly called **'Green algae'**. Most of the species are aquatic(Fresh water-*Spirogyra*, Marine -*Ulva*). A few are terrestrial(*Trentipohlia*). Variation among the shape of the chloroplast is found in members of algae. It is cup shaped (*Chlamydomonas*), discoid (*Chara*), girdle shaped, (*Ulothrix*), reticulate (*Oedogonium*), spiral (*Spirogyra*), stellate (*Zygnema*) and plate like (*Mougeoutia*).

Chlorophyll 'a' and Chlorophyll 'b' are the major photosynthetic pigments. Storage bodies called pyrenoids are present in the chloroplast and store starch. They also contain proteins. The cell wall is made up of inner layer of cellulose and outer layer of pectin. Vegetative reproduction takes place by means of fragmentation and asexual reproduction is by the production of zoospores, aplanospores and akinetes. Sexual reproduction is present and may be isogamous, anisogamous or oogamous. Examples for this group of algae includes *Chlorella, Chlamydomonas, Volvox, Spirogyra, Ulothrix, Chara* and *Ulva.*

Phaeophyceae

The members of this class are called **'Brown algae'**. Majority of the forms are found in marine habitats. *Pleurocladia* is a fresh water form. The thallus is filamentous (*Ectocarpus*) frond like (*Dictyota*)or may be giant kelps (*Laminaria* and *Macrocystis*). The thallus is differentiated into leaf like photosynthetic part called fronds, a stalk like structure called stipe and a holdfast which attach thallus to the substratum.

The Pigments include Chlorophyll a, c, Carotenoids and Xanthophylls. A golden brown pigment called fucoxanthin is present and it gives shades of colour from olive green to brown to the algal members of this group. Mannitol and Laminarin are the reserve food materials. Motile reproductive structures are present. Two laterally inserted unequal flagella are present. Among these one is whiplash and another is tinsel. Although sexual reproduction ranges from isogamy to oogamy, Most of the forms show oogamous type. Alternation of generation is present (isomorphic, heteromorphic or diplontic). Examples for this group include *Sargassum, Laminaria, Fucus* and *Dictyota.*

Rhodophyceae

Members of this group include '**Red algae**' and are mostly marine. The thallus is multicellular, macroscopic and diverse in form. *Porphyridium* is the unicellular form. Filamentous (*Goniotrichum*) ribbon like (*Porphyra*) are also present. *Corallina* and *Lithothamnion* are heavily impregnated with lime and form coral reefs. Apart from chlorophyll a, r-phycoerythrin and r-phycocyanin are the photosynthetic pigments. Asexual reproduction takes place by means of monospores, neutral spores and tetraspores.

The storage product is floridean starch. Sexual reproduction is oogamous. Male sex organ is spermatangium which produces spermatium. Female sex organ is called carpogonium. The spermatium is carried by the water currents and fuse with egg nucleus to form zygote. The zygote develops into carpospores. Meiosis occurs during carpospore formation. Alternation of generation is present. Examples for this group of algae include *Ceramium, Polysiphonia, Gelidium, Cryptonemia* and *Gigartina.*

2.3.3 Economic Importance

The Economic importance of Algae is given in Table 2.2

Table 2.2: Economic importance of Algae

Name of the Algae	Economic importance
Beneficial activities	
Chlorella, Laminaria, Sargassum, Ulva, Enteromorpha	Food
Gracilaria, Gelidiella, Gigartina	Agar Agar – Cell wall material used for media preparation in the microbiology lab. Packing canned food, cosmetic, textile paper industry
Chondrus crispus	Carrageenan – Preparation of tooth paste, paint, blood coagulant
Laminaria, Ascophyllum	Alginate – ice cream, paints, flame proof fabrics
Laminaria, Sargassum, Ascophyllum, Fucus	Fodder
Diatom (Siliceous frustules)	Diatomaceous earth– water filters, insulation material, reinforcing agent in concrete and rubber.
Lithophyllum, Chara, Fucus	Fertilizer
Chlorella	Chlorellin -Antibiotic
Chlorella, Scenedesmus, Chlamydomonas	Sewage treatment, Pollution indicators
Harmful activity	
Cephaleuros virescens	Red rust of coffee

DO YOU KNOW?

A green alga *Botryococcus braunii* is employed in Bio-fuel production.

Algae in Health care

Kelps are the rich source of Iodine *Chlorella* is used as single cell Protein (SCP).

Dunaliella salina an alga, growing in salt pan is complement to our health and provide β carotene.

DO YOU KNOW?

A Productive Cultivation in Sea

Algae like *Kappaphycus alvarezii, Gracilaria edulis* and *Gelidiella acerosa* are commercially grown in the sea for harvesting the phycocolloids.

Sea Palm It is *Postelia palmaeformis* a brown alga.

2.4 Bryophytes

Amphibians of Plant Kingdom

In the previous chapter, we noticed a wide range of thallus organization in Algae. Majority of them are aquatic. The development of heterotrichous habit, development of parenchyma tissue and dichotomous branching in some algae supports the view that colonization of plants in land occurred in the past. Bryophytes are simplest and most primitive plant groups descended from alga – like ancestors. They are simple embryophytes. Let us learn about the structure and reproduction of these primitive land plants called Bryophytes in detail.

Bryophytes are simplest land inhabiting cryptogams and are restricted to moist, shady habitats. They lack vascular tissue and hence called **'Non- vascular cryptogams'**. They are also called as '**amphibians of plant kingdom**' because they need water for completing their life cycle.

Shiv Ram Kashyap (1882-1934)

Father of Indian Bryology. He published a book- 'Liverworts of Western Himalayas and Punjab Plains' He identified new genera like *Atchinsoniella, Sauchia, Sewardiella* and *Stephansoniella.*

2.4.1 General characteristic features

- The plant body of bryophyte is gametophyte and is not differentiated into root, stem and leaf like structure.
- Most of them are primitive land dwellers. Some of them are aquatic (*Riella, Ricciocarpus*).
- The gametophyte is conspicuous, long lived phase of the life cycle. Thalloid forms are present in liverworts and Hornworts. In Mosses leaf like, stem like structures are present. In Liverworts thallus grows prostrate on the ground and is attached to the substratum by means of rhizoids. Two types of rhizoids are present namely smooth walled and pegged or tuberculate. Multicellular scales are also present. In Moss the plant body is erect with central axis bearing leaf like expansions. Multicellular rhizoids are present. The structure and reproduction in Bryophytes is given in Figure 2.5.
- Vascular tissue like xylem and phloem are completely absent, hence called 'Non vascular cryptogams'.
- Vegetative reproduction takes place by the formation of adventitious buds (*Riccia fluitans*) tubers develop in *Anthoceros.* In some forms small detachable branches

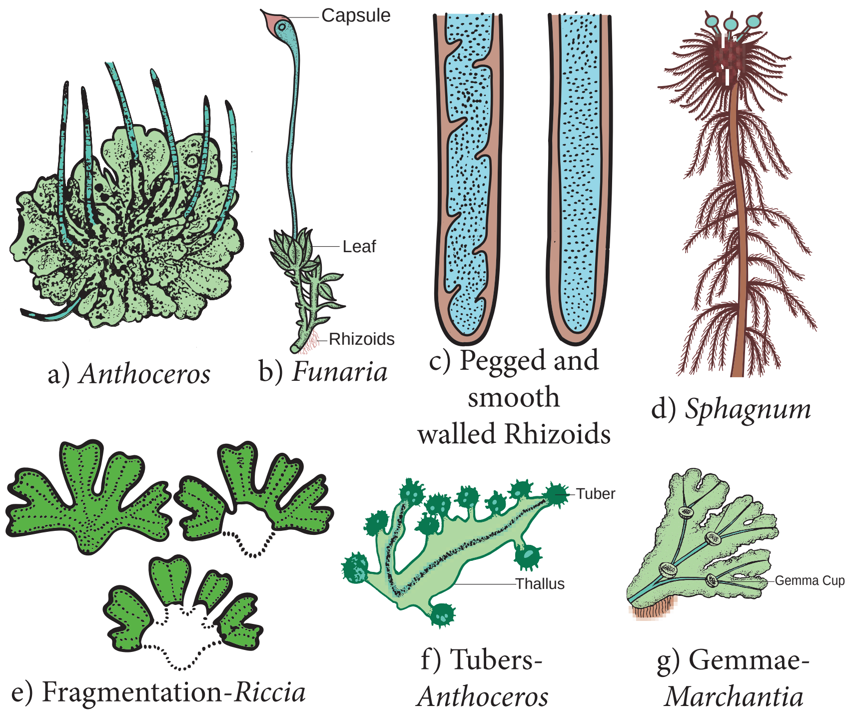


Figure 2.5: Structure and reproduction in Bryophytes

or brood bodies are formed, they help in vegetative reproduction as in *Bryopteris fruticulosa*. In *Marchantia* propagative organs called gemmae are formed and help in reproduction.

- Sexual reproduction is oogamous. Antheridia and Archegonia are produced in a protective covering and are multicellular.
- The antheridia produces biflagellate antherozoids which swims in thin film of water and reach the archegonium and fuse with the egg to form diploid zygote.
- Water is essential for fertilization.
- The zygote is the first cell of the sporophyte generation. It undergoes mitotic division to form multicellular undifferentiated embryo. The embryogeny is exoscopic (the first division of the zygote is transverse and the apex of the embryo develops from the outer cell). The embryo divides and give rise to sporophyte.
- The sporophyte is dependent on gametophyte.
- It is differentiated into three recognizable parts namely foot, seta and capsule.
- Foot is the basal portion and is embedded in the gametophyte through which water and nutrients are supplied for the sporophyte. The diploid spore mother cells found in the capsule region undergoes meiotic division and give rise to haploid spores. Bryophytes are homosporous. In some sporophytes elaters are present and help in dispersal of spores (Example: *Marchantia*). The spores germinate to produce gametophyte.
- The zygote, embryo and the sporogonium constitute sporophytic phase. The green long living haploid phase is called gametophytic phase. The haploid gametophytic phase alternates with diploid sporophyte and shows heterologous alternation of generation.

Proskauer in the year 1957 classified Bryophytes into 3 Classes namely

i. **Hepaticopsida** (*Riccia, Marchantia, Porella* and *Riella*)

ii. **Anthocerotopsida** (*Anthoceros* and *Dendroceros*)

iii. **Bryopsida** (*Funaria, Polytrichum* and *Sphagnum*).

2.4.2 Economic importance

Dead thalli of *Sphagnum* gets accumulated and compressed, hardened to form peat. In northern Europe (Netherlands)peat is used as fuel in commercial scale. Apart from this nitrates, brown dye and tanning materials are derived from peat. *Sphagnum* and peat are also used in horticulture as packing material because of their water holding capacity. *Marchantia polymorpha* is used to cure pulmonary tuberculosis. *Sphagnum*, *Bryum* and *Polytrichum* are used as food. Bryophytes play a major role in soil formation through succession and help in soil conservation.

> DO YOU KNOW?
> *Buxbaumia aphylla* and *Cryptothallus mirabilis* are saprophytic bryophytes

2.5 Pteridophytes

Seedless Vascular Cryptogams

From the previous section, we are aware of the salient features of amphibious plants called bryophytes. But there is a plant group called pteridophytes which are considered as first true land plants. Further, they were the first plants to acquire vascular tissue namely xylem and phloem, hence called vascular cryptogams. Club moss, horsetails, quill worts, water ferns and tree ferns belong to this group. This chapter deals with the characteristic features of Pteridophytes.

Pteridophytes are the vascular cryptogams and were abundant in the Devonian period of Palaeozoic era (400 million years ago). These plants are mostly small, herbaceous and grow well in moist, cool and shady places where water is available. The photographs for some pteridophytes are given in Figure 2.6.

a) *Lycopodium* (club moss) b) *Equisetum* (Horse tail) c) *Azolla* (Water fern)

Figure 2.6: Pteridophytes

2.5.1 General characteristic features of Pteridophytes:

- Plant body is sporophyte (2n) and it is the dominant phase. It is differentiated into root, stem and leaves.
- Roots are adventitious.
- Stem shows monopodial or dichotomous branching.
- Leaves may be microphyllous or megaphyllous.
- Stele is protostele but in some forms siphonostele is present (*Marsilea*)
- Tracheids are the major water conducting elements but in *Selaginella* vessels are found.
- Sporangia, spore bearing bag like structures are borne on special leaves called sporophyll. The Sporophylls get organized to form cone or strobilus. Example: *Selaginella*, *Equisetum* .
- They may be **homosporous** (produce one type of spores-*Lycopodium*) or **Heterosporous** (produce two types of spores-*Selaginella)*. Heterospory is the origin for seed habit.
- Development of sporangia may be **eusporangiate** (development of sporangium from group of initials) or **leptosporangiate** (development of sporangium from single initial).
- Spore mother cells undergo meiosis and produce spores (n).
- Spore germinates to produce haploid, multicellular green, cordate shaped independent gametophytes called prothallus.
- Fragmentation, resting buds, root tubers and adventitious buds help in vegetative reproduction.
- Sexual reproduction is oogamous. Sex organs, namely antheridium and archegonium are produced on the prothallus.
- Antheridium produces spirally coiled and multiflagellate antherozoids.
- Archegonium is flask shaped with broad venter and elongated narrow neck. The

venter possesses egg or ovum and neck contain neck canal cells.

- Water is essential for fertilization. After fertilization a diploid zygote is formed and undergoes mitotic division to form embryo.
- Pteridophytes show **apogamy** and **apospory.**

Reimer (1954) proposed a classification for pteridophytes. In this classification, the pteridophytes are divided into five subdivisions. 1. Psilophytopsida 2. Psilotopsida 3. Lycopsida 4. Sphenopsida 5. Pteropsida. There are 19 orders and 48 families in the classification.

DO YOU KNOW?

The success and dominance of vascular plants is due to the development of

- Extensive root system.
- Efficient conducting tissues.
- Cuticle to prevent desiccation.
- Stomata for effective gaseous exchange.

2.5.2 Economic Importance

The Economic importance of Pteridophyte is given in Table 2.3.

Table 2.3: Economic importance of Pteridophyte

Pteridophyte	Uses
Rumohra adiantiformis (leather leaf fern)	Cut flower arrangements.
Marsilea	Food
Azolla	Biofertilizer.
Dryopteris filix–mas	Treatment for tapeworm.
Pteris vittata	Removal of heavy metals from soils - Bioremediation
Pteridium sp.	Leaves yield green dye.
Equisetum sp.	Stems for scouring.
Psilotum, Lycopodium, Selaginella, Angiopteris, Marattia	Ornamental plants

2.5.3 Types of Stele

The term stele refers to the central cylinder of vascular tissues consisting of xylem, phloem, pericycle and sometimes medullary rays with pith (Figure 2.7).

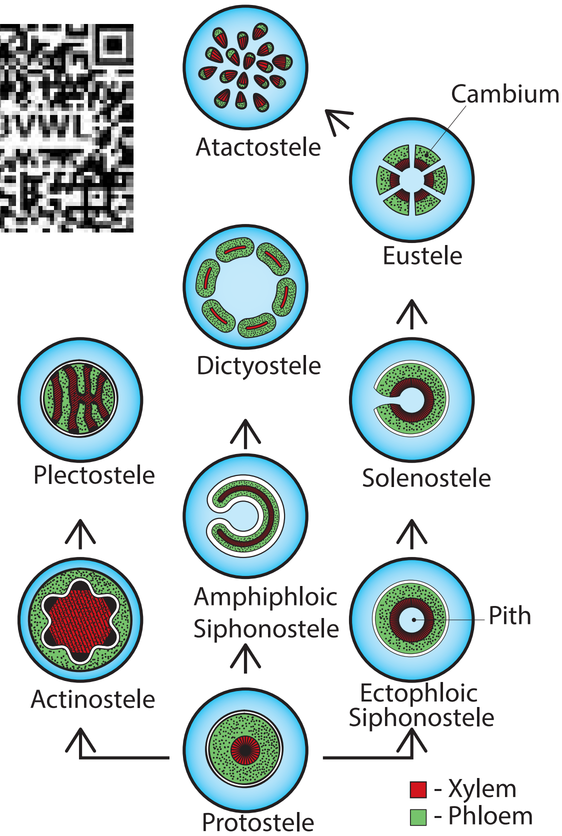


Figure 2.7: Types of Stele

There are two types of steles

1. Protostele 2. Siphonostele

1. Protostele:

In protostele phloem surrounds xylem. The type includes Haplostele, Actinostele, Plectostele, and Mixed protostele.

(i) **Haplostele**: Xylem surrounded by phloem is known as haplostele. Example: *Selaginella.*

(ii) **Actinostele**: Star shaped xylem core is surrounded by phloem is known as actinostele. Example: *Lycopodium serratum.*

(iii) **Plectostele**: Xylem plates alternates with phloem plates. Example: *Lycopodium clavatum.*

(iv) **Mixed prototostele**: Xylem groups uniformly scattered in the phloem. Example: *Lycopodium cernuum*.

2. Siphonostele:

In siphonostele xylem is surrounded by phloem with pith at the centre. It includes Ectophloic siphonostele, Amphiphloic siphonostele, Solenostele, Eustele, Atactostele and Polycylic stele.

(i) Ectophloic siphonostele: The phloem is restricted only on the external side of the xylem. Pith is in centre. Example: *Osmunda.*

(ii) Amphiphloic siphonostele: The phloem is present on both the sides of xylem. The pith is in the centre. Example: *Marsilea.*

(iii) Solenostele: The stele is perforated at a place or places corresponding the origin of the leaf trace.

(**a**) **Ectophloic solenostele** – Pith is in the centre and the xylem is surrounded by phloem Example *Osmunda*.

(b) Amphiphloic solenostele – Pith is in the centre and the phloem is present on both sides of the xylem. Example: *Adiantum pedatum*.

(c) Dictyostele – The stele is separated into several vascular strands and each one is called meristele. Example: *Adiantum capillus-veneris*.

(iv) Eustele: The stele is split into distinct collateral vascular bundles around the pith. Example: Dicot stem.

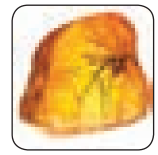
(**v**) **Atactostele**: The stele is split into distinct collateral vascular bundles and are scattered in the ground tissue. Example: Monocot stem.

(vi) Polycyclicstele: The vascular tissues are present in the form of two or more concentric cylinders. Example: *Pteridium*.

2.6 Gymnosperms

Naked seed producing Plants

Michael Crichton's Science Fiction is a book transformed into a Film of Steven Spielberg (1993) called **Jurassic Park**. In this film you might have noticed insects embedded in a transparent substance called amber which preserves the extinct forms. What is amber? Which group of plants produces Amber?


Amber is a plant secretion which is an efficient preservative that doesn't get degraded and hence can preserve remains of extinct life forms. The amber is produced by ***Pinites succinifera***, a Gymnosperm.

In this chapter we shall discuss in detail about one group of seed producing plants called **Gymnosperms**.

Gymnosperms (Gr. Gymnos = naked; sperma= seed) are naked seed producing plants. They were dominant in the Jurassic and Cretaceous periods of Mesozoic era. The members are distributed throughout the temperate and tropical region of the world

2.6.1 General characteristic features

- Most of the gymnosperms are evergreen, woody trees or shrubs. Some are lianas (*Gnetum*)
- The plant body is sporophyte and is differentiated into root, stem and leaves.
- A well developed tap root system is present. Coralloid roots of *Cycas* have symbiotic association with blue green algae. In *Pinus* the roots have mycorrhizae.
- The stem is aerial, erect and branched or unbranched (*Cycas*) with leaf scars.
- In conifers two types of branches namely branches of limited growth (Dwarf shoot) and Branches of unlimited growth (Long shoot) is present.
- Leaves are dimorphic, foliage and scale leaves are present. Foliage leaves are green, photosynthetic and borne on

branches of limited growth. They show xerophytic features.

- The xylem consists of tracheids but in *Gnetum* and *Ephedra* vessels are present.
- Secondary growth is present. The wood may be **Manoxylic** (Porous, soft, more parenchyma with wide medullary ray -*Cycas*) or **Pycnoxylic** (compact with narrow medullary ray-*Pinus*).
- They are heterosporous. The plant may be monoecious (*Pinus*) or dioecious (*Cycas*).
- Microsporangia and megasporangia are produced on microsporophyll and megasporophyll respectively.
- Male and female cones are produced.
- Anemophilous pollination is present.
- Fertilization is siphonogamous and pollen tube helps in the transfer of male nuclei.
- Polyembryony (presence of many embryo) is present. The naked ovule develops into seed. The **endosperm** is haploid and develop before fertilization.
- The life cycle shows alternation of generation. The sporophytic phase is dominant and gametophytic phase is highly reduced. The photograph of some of the gymnosperms is given in Figure 2.8

Sporne (1965) classified gymnosperms into 3 classes, 9 orders and 31 families. The classes include i) Cycadospsida ii) Coniferopsida iii) Gnetopsida.

a) *Taxus* b) *Ginkgo*

Figure 2.8: Gymnosperms

2.6.2 Comparison of Gymnosperm with Angiosperms

Gymnosperms resemble with angiosperms in the following features

- Presence of well organised plant body which is differentiated into roots, stem and leaves.
- Presence of cambium in gymnosperms as in dicotyledons.
- Flowers in *Gnetum* resemble the male flower of the angiosperm. The zygote represent the first cell of sporophyte.
- Presence of integument around the ovule.
- Both plant groups produce seeds.
- Pollen tube helps in the transfer of male nucleus in both.
- Presence of eustele.

The difference between Gymnosperms and Angiosperms were given in Table 2.4.

Table 2.4: Difference between Gymnosperms and Angiosperms

S.No	Gymnosperms	Angiosperms
1.	Vessels are absent [except Gnetales]	Vessels are present
2.	Phloem lacks companion cells	Companion cells are present
3.	Ovules are naked	Ovules are enclosed within the ovary
4.	Wind pollination only	Insects, wind, water, animals etc., act as pollinating agents
5.	Double fertilization is absent	Double fertilization is present
6.	Endosperm is haploid	Endosperm is triploid
7.	Fruit formation is absent	Fruit formation is present
8.	Flowers absent	Flowers present

2.6.3 Economic importance of Gymnosperms

Table 2.5: Economic importance of Gymnosperms

S.No	Plants	Products	uses
1.	*Cycas circinalis, Cycas revoluta*	Sago	Starch used as food
2.	*Pinus gerardiana*	Roasted seed	Used as a food
3.	*Abies balsamea*	Resin (Canada balsam)	Used as mounting medium in permanent slide preparation
4.	*Pinus insularis, Pinus roxburghii*	Rosin and Turpentine	Paper sizing and varnishes
5.	*Araucaria* (Monkey's puzzle), *Picea* and *Phyllocladus*	Tannins	Bark yield tannins and is used in Leather industries
6.	*Taxus brevifolia*	Taxol	Drug used for cancer treatment
7.	*Ephedra gerardiana*	Ephedrine	For the treatment of asthma, bronchititis
8.	*Pinus roxburghii*	Oleoresin	Used to make soap, varnishes and printing ink
9.	*Pinus roxburghii, Picea smithiana*	Wood pulp	Used to make papers
10.	*Cedrus deodara*	wood	Used to make doors, boats and railway sleepers
11.	*Cedrus atlantica*	oil	Used in perfumery
12	*Thuja, Cupressus, Araucaria, and Cryptomeria*	whole plant	Ornamental plants/Floral Decoration

Palaeobotany in India

The National wood fossil park is situated in Tiruvakkarai, a Village of Villupuram district of Tamil Nadu. The park contains petrified wood fossils approximately 20 million years old. The term 'form genera' is used to name the fossil plants because the whole plant is not recovered as fossils instead organs or parts of the extinct plants are obtained in fragments. Shiwalik fossil park-Himachal Pradesh, Mandla Fossil park-Madhya Pradesh, Rajmahal Hills–Jharkhand, Ariyalur – Tamilnadu are some of the fossil rich sites of India.

Some of the fossil representatives of different plant groups are given below

Fossil Algae - *Palaeoporella, Dimorphosiphon*

Fossil Bryophytes – *Naiadita, Hepaticites, Muscites*

Fossil Pteridophytes – *Cooksonia, Rhynia,, Baragwanthia, Calamites*

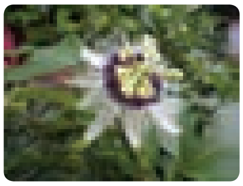
Fossil Gymnosperms – *Medullosa, Lepido-carpon, Williamsonia, Lepidodendron*

Fossil Angiosperms – *Archaeanthus, Furcula*

Prof. Birbal Sahni (1891-1949)

Father of Indian Palaeobotany. He described Fossil plants from Rajmahal Hills of Eastern Bihar. *Pentoxylon sahnii, Nipanioxylon* are some of the form genera described by him. Birbal Sahni Institute of Palaeobotany is located in Lucknow.

2.7 Angiosperms



In the previous section, the characteristic features of one of the spermatophyte called Gymnosperms were discussed. Spermatophytes also include plants bearing ovules enclosed in a protective cover called ovary, such plants are called Angiosperms. They constitute major plant group of our earth and are adapted to the terrestrial mode of life. This group of plants appeared during the early cretaceous period (140 million years ago) and dominates the vegetation on a global scale. The sporophyte is the dominant phase and gametophyte is highly reduced.

2.7.1 Salient features of Angiosperms

- Vascular tissue (Xylem and Phloem) is well developed.
- Flowers are produced instead of cone
- The Ovule remains enclosed in the ovary.
- Pollen tube helps in fertilization, so water is not essential for fertilization.
- Double fertilization is present. The endosperm is triploid.
- Angiosperms are broadly classified into two classes namely Dicotyledons and Monocotyledons.

2.7.2 Characteristic features of Dicotyledons and Monocotyledons

Dicotyledons

Morphological features

Reticulate venation is present in the leaves. Presence of two cotyledons in the seed. Primary root radicle persists as tap root.

Flowers tetramerous or pentamerous.

Tricolpate (3 furrow) pollen is present.

Anatomical features

- Vascular bundles are arranged in the form of a ring in stem.
- Vascular bundles are open (Cambium present).
- Secondary growth is present.

Monocotyledons

Morphological features

Parallel venation is present in the leaves. Presence of single cotyledon in the seed. Radicle doesn't persist and fibrous root is present.

Flowers trimerous.

Monocolpate (1 furrow) Pollen is present.

Anatomical features

- Vascular bundles are scattered in the stem
- Vascular bundles are closed (Cambium absent).
- Secondary growth is absent.

Current Angiosperm Phylogeny Group (APG) System of classification doesn't recognize dicots as a monophyletic group. Plants that are traditionally classified under dicots are dispersed in several clades such as early Magnolids and Eudicots.

Summary

Plant Kingdom includes Algae, Bryophytes, Pteridophytes, Gymnosperms and Angiosperms

The life cycle in plants fall under three types 1. Haplontic,2. Diplontic and 3. Haplodiplontic

Algae are autotrophic, chlorophyll bearing organisms. The Plant body is not differentiated into root like, stem like or leaf like structures. A wide range of thallus organization is found in algae. They reproduce vegetatively through fragmentation, tuber and akinete formation. Zoospores, autospores and hypnospores are produced during asexual reproduction and sexual reproduction occurs through isogamy, anisogamy and oogamy.

Bryophytes are the simplest land plants. They are called amphibians of plant kingdom or nonvascular cryptogams. The plant body is gametophyte. The sporophyte depends upon gametophyte. Conducting tissues like xylem and phloem is absent. Vegetative reproduction takes place through fragmentation, formation of adventitious bud and gemmae. Sexual reproduction is oogamous. Water is essential for fertilization.

Pteridophytes are also called vascular cryptogams. The plant body is sporophyte and is long lived, which is differentiated into root, stem and leaves. They may be homosporous or heterosporous. The sporangia with spores are found in sporophylls. The sporophylls organise to form cones or strobilus. The spores germinates to produce haploid, multicellular heart shaped independent gametophyte called prothallus. Sexual reproduction is oogamous. The life cycle shows alternation of generation.

The term stele includes central cylinder of vascular tissues comprising xylem, phloem, pericycle, endodermis and pith . There are two major types of stele namely protostele and siphonostele.

Gymnosperms are naked seed producing plants. The plant body is sporophyte and it is the dominant phase. Coralloid roots are found in *Cycas*. The roots of *Pinus* possess mycorrhizal association. Two types of branches called long shoot and dwarf shoot are present. Stem shows secondary growth. Spores are produced in cones. Pollen tube helps in fertilization. The endosperm is haploid. Alternation of generation is present

Angiosperms are highly evolved plant group and their ovules remain enclosed in an ovary. A wide range of habit is present. These include trees, shrubs, herbs, climbers, lianas. Double fertilization is present. The endosperm is triploid. They are classified into dicotyledons and monocotyledons.

Evaluation

1. Which of the plant group has gametophyte as a dominant phase?
   a. Pteridophytes
   b. Bryophytes
   c. Gymnosperm
   d. Angiosperm
2. Which of following represents gametophytic generation in pteridophytes?
   a. Prothallus
   b. Thallus
   c. Cone
   d. Rhizophore
3. The haploid number of chromosome for an angiosperm is 14, the number of chromosome in its endosperm would be
   a. 7 b. 14 c. 42 d. 28
4. Endosperm in gymnosperm is formed
   a. At the time of fertilization
   b. Before fertilization
   c. After fertilization
   d. Along with the development of embryo
5. Differentiate halpontic and diplontic life cycle.
6. What is plectostele? give example.
7. What do you infer from the term pycnoxylic?
8. Mention two characters shared by gymnosperms and angiosperms.
9. Do you think shape of chloroplast is unique for algae. Justify your answer?
10. Do you agree with the statement 'Bryophytes need water for fertilization'? Justify your answer.

ICT Corner

Different forms of plants

Is all the **plants** are same? →

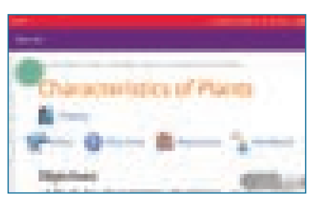
Steps

- Scan the QR code or go to google play store
- Type online labs and install it.
- Select biology and select Characteristics of plants
- Click theory to know the basic about Characteristics of plants
- Register yourself with mail-id and create password to access online lab simulations

Activity

- Select video and record your observations of different forms of plant group.

Step 1



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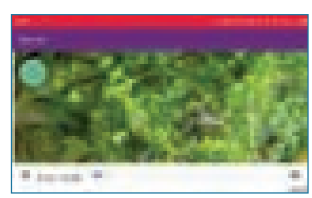

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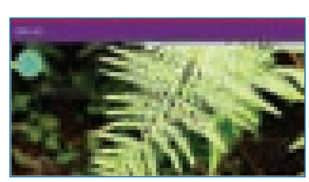

Step 4

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

Alternate web:

http://www.phschool.com/atschool/phbio/active_art/plant_life_cycle/plantlifecycle.swf

* Pictures are indicative only

Unit II: Plant Morphology and Taxonomy of Angiosperm

Chapter 3

Vegetative Morphology

Learning Objectives

The learner will be able to,

- *Explore the parts of the flowering plants*
- *Differentiate vegetative morphology and reproductive morphology*
- *Compare various Root systems and their modifications*
- *Understand the stem modifications and functions*
- *Interpret the structure and functions of leaf*

Chapter Outline

The study of various external features of the organism is known as **Morphology. Plant Morphology** is also known as **external morphology that** deals with the study of shape, size and structure of plants and their parts (roots, stems, leaves, flowers, fruits and seeds). Study of Morphology is important in Taxonomy. Morphological features are important in determining productivity of crops. Morphological characters indicate the specific habitats of living as well as the fossil plants and help to correlate the distribution in space and time of fossil plants. Morphological features are also significant for phylogeny.

Plant Morphology can be studied under two broad categories:

A. **Vegetative Morphology** – It includes shoot system and root system
B. **Reproductive Morphology** – It includes Flower/Inflorescence, Fruit and Seed

A. Vegetative morphology

Vegetative morphology deals with the study of shape, size and structure of plants and their parts like roots, stems and leaves. To understand the vegetative morphology the following important components are to be studied. They are, 1) Habit, 2) Habitat and 3) Lifespan.

3.1 Habit

The general form of a plant is referred as habit. Based on habit, plants are classified into herbs, shrubs, climbers (vines) and trees.

I. Herbs

Herbs are soft stemmed plants with less wood or no wood. Example: *Phyllanthus amarus, Cleome viscosa.* According to the duration of their life they may be classified as **annuals, biennials** and **perennials**. Perennial herbs having a bulb, corm, rhizome or tuber as the underground stem are termed as **geophytes.** Example: *Allium cepa*

II. Shrubs

A shrub is a perennial, woody plant with several main stems arising from the ground level. Example: *Hibiscus rosa sinensis* (shoe flower)

III. Climbers (Vine)

An elongated weak stem generally supported by means of climbing devices are called **Climbers** (vines) which may be annual or perennial, herbaceous or woody.

Liana is a vine that is perennial and woody. Liana's are major components in the tree canopy layer of some tropical forests. Example: *Ventilago, Entada, Bougainvillea.*

IV. Trees

A tree is a stout, tall, perennial, woody plant having one main stem called **trunk** with many lateral branches. Example: Mango, Sapota, Jack, Fig, Teak. If the trunk remains unbranched it is said to be **caudex.** Example: Palmyra, Coconut.

3.2 Plant habitat

Depending upon where plants grow habitats may be classified into two major categories: I. Terrestrial and II.Aquatic.

I. Terrestrial

Plants growing on land are called **terrestrial plants.**

II. Aquatic

Plants that are living in water are called **aquatic plants** or hydrophytes.

3.3 Life Span

Based on life span plants are classified into 3 types. They are annuals, biennials and perennials

I. Annuals

A plant that completes its life cycle in one growing season. Example: Maize, Water melon, Groundnut, Rice.

II. Biennials

A plant that lives for two seasons, growing vegetatively during the first season and flowering and fruiting during the second season. Example: Carrot, Radish, Cabbage.

III. Perennials

A plant that grows for many years that flowers and set fruits for several seasons during the life span. When they bear fruits every year, they are called **polycarpic perennials.** Example: Mango, Sapota. Some plants produce flowers and fruits only once and die after a vegetative growth of several years. These plants are called **monocarpic perennials**. Example: *Bambusa, Agave, Musa.*

3.4 Parts of a flowering plant

Flowering plants are called **"Angiosperms"** or **Magnoliophytes**. They are sporophytes consisting of an axis with an underground **"Root system"** and an aerial **"Shoot System".** The shoot system has a stem, branches and leaves. The root system consists of root and its lateral branches.

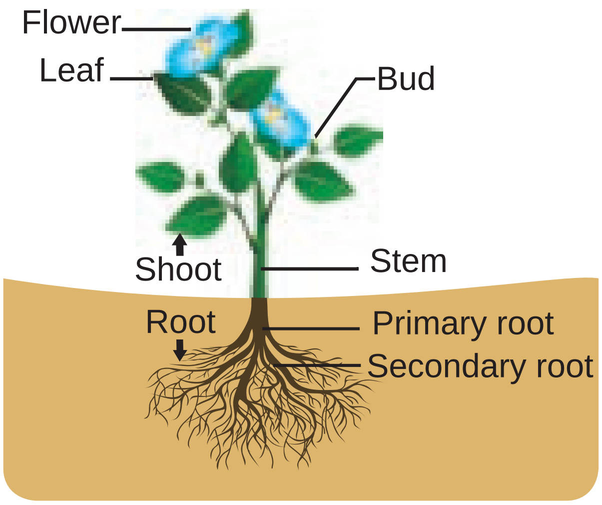


Figure: 3.1: Parts of a flowering plant

3.5 Root System

The root is non-green, cylindrical descending axis of the plant that usually grows into the soil (positively geotropic). It develops from the radicle which is the first structure that comes out when a seed is placed in the soil. Root is responsible for absorption of water and nutrients and anchoring the plant.

I. Characteristic features

- Root is the descending portion of the plant axis.
- Generally non-green in colour as it lacks chlorophyll.
- Does not possess nodes, internodes and buds (Exception in sweet potato and members of Rutaceae, roots bear buds which help in vegetative propagation)

- It bears root hairs (To absorb water and minerals from the soil)
- It is positively geotropic and negatively phototropic in nature.

II. Regions of root

Root tip is covered by a dome shaped structure made of parenchymatous cells called **root cap.**

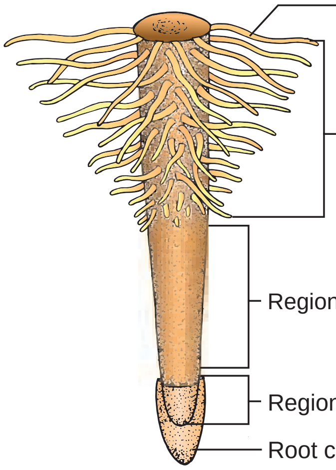
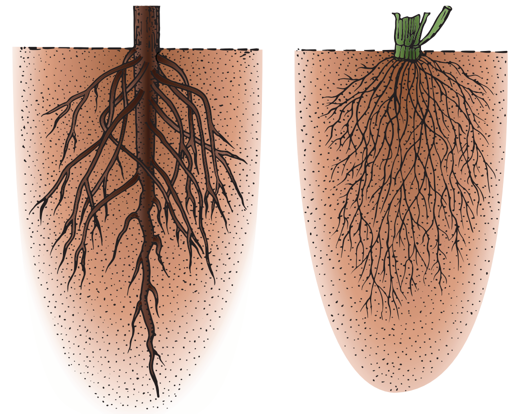


Figure 3.2: Regions of root

It protects the meristematic cells in the apex. In *Pandanus* multiple root cap is present. In *Pistia* instead of root cap, root pocket is present. A few millimeters above the root cap the following three distinct zones have been classified based on their meristematic activity.

1. Meristematic Zone
2. Zone of Elongation
3. Zone of Maturation

3.5.1 Types of root system



Tap root system   Fibrous root system

Figure 3.3: Types of root system

I. Tap root system

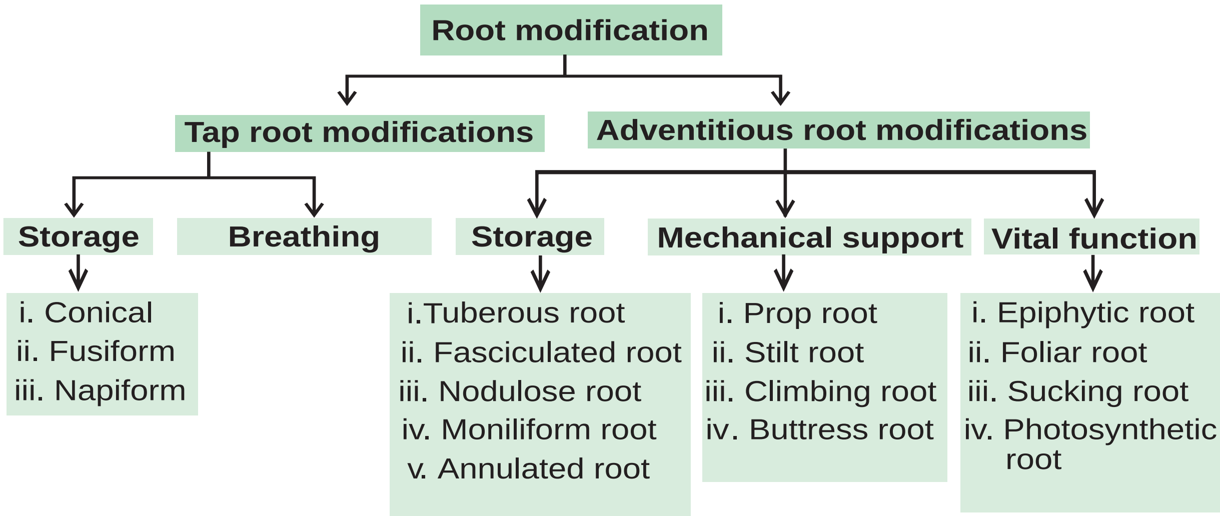
Primary root is the direct prolongation of the radicle. When the primary root persists and continues to grow as in dicotyledons, it forms the main root of the plant and is called the **Tap root.** Tap root produces lateral roots that further branches into finer roots. Lateral roots along with the branches together called as **secondary roots**.

II. Adventitious root system

Root developing from any part of the plant other than radicle is called **adventitious** root. It may develop from the base of the stem or nodes or internodes. Example: *Monstera deliciosa, Piper nigrum*. In most of the monocots the primary root of the seedling is short lived and lateral

Table 3.1: Root zones

Feature	1. Meristematic Zone (Region of cell division)	2. Zone of Elongation	3. Zone of Maturation
Position	It lies just above the root cap	It lies just above the meristematic zone	It lies above the zone of elongation.
Types of cells	Meristematic cells, actively divide and continuously increase in number	Elongated cells	Mature differentiated cells
Functions	This is the main growing tip of the root	The cells increase the length and cause enlargement of the root.	The cells differentiate into various tissues like epidermis, cortex and vascular bundles. It also produces root hairs which absorb water and minerals from the soil



roots arise from various regions of the plant body. These are bunch of thread-like roots nearly equal in size which are collectively called **fibrous** root system generally found in grasses. Example: *Oryza sativa, Eleusine coracana*.

3.5.2 Functions of root

Root performs two kinds of functions namely primary and secondary functions.

Primary function

1. Absorb water and minerals from soil.
2. Help to anchor the plant firmly in the soil.

Secondary function

In some plants roots perform additional functions. These are called **secondary functions.** To perform additional functions, structure of roots are modified.

3.5.3 Modifications of root

I. Tap root modification

a. Storage roots

1. Conical Root

These are cone like, broad at the base and gradually tapering towards the apex. Example: *Daucus carota*.

2. Fusiform Root

These roots are swollen in the middle and tapering towards both ends. Example: *Raphanus sativus*

3. Napiform Root

It is very broad at the apex and suddenly tapers like a tail at the base. Example: *Beta vulgaris*

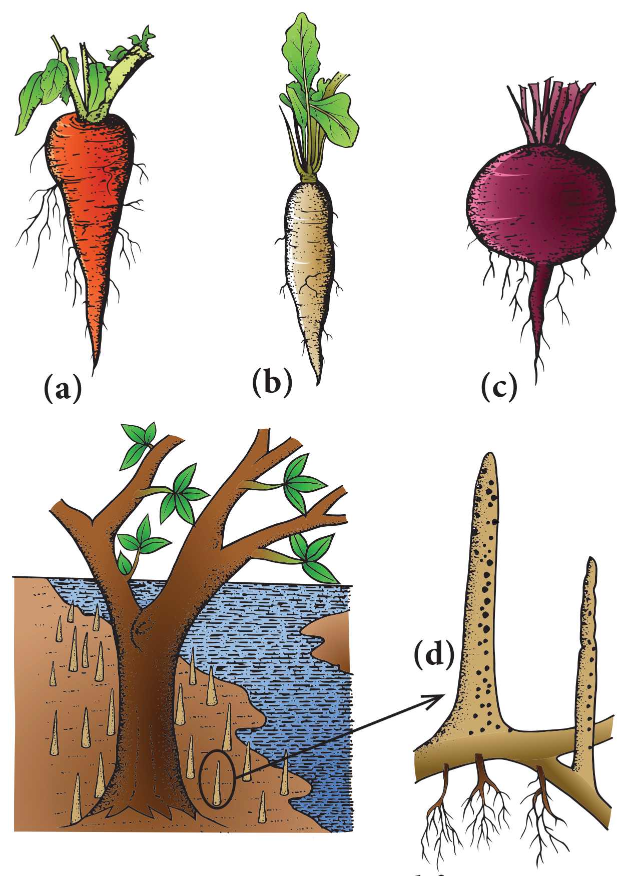


Figure 3.4: Tap root modifications
(a) *Daucus carota* **(b)** *Raphanus sativus*
(c) *Beta vulgaris* **(d)** *Avicennia* - pneumatophores

b. Breathing root

Some mangrove plants like ***Avicennia, Rhizophora, Bruguiera*** develop special kinds of roots (Negatively geotropic) for respiration because the soil becomes saturated with water and aeration is very poor. They have a number of breathing pores on pneumatophores for exchange of gases.

II. Adventitious root modification

a. Storage roots

1. Tuberous root

These roots are swollen without any definite shape. Tuberous roots are produced singly and not in clusters. Example: *Ipomoea batatas.*

2. Fasciculated root

These roots are in cluster from the base of the stem Example: *Dahlia, Asparagus.*

3. Nodulose root

In this type of roots, swelling occurs only near the tips. Example: *Maranta* (Arrow root) *Curcuma amada* (Mango ginger), *Curcuma longa* (Turmeric)

4. Moniliform or Beaded root

These roots swell at frequent intervals giving them a beaded appearance. Example: *Vitis, Portulaca, Momordica.*

5. Annulated root

These roots have a series of ring- like swelling on their surface at regular intervals. Example: *Psychotria* (Ipecac)

b. Mechanical support

1. Prop (Pillar) root

These roots grow vertically downward from the lateral branches into the soil. Example: *Ficus benghalensis* (banyan tree), Indian rubber.

2. Stilt (Brace) root

These are thick roots growing obliquely from the basal nodes of the main stem. These provide mechanical support. Example: *Saccharum officinarum, Zea mays, Pandanus and Rhizophora.*

3. Climbing (clinging) roots

These roots are produced from the nodes of the stem which attach themselves to the support and help in climbing. To ensure a foothold on the support they secrete a sticky juice which dries up in air, attaching the roots to the support. Example: *Piper betel.*

4. Buttress root

In certain trees broad plank like outgrowths develop towards the base all around the trunk. They grow obliquely downwards and give support to huge trunks of trees. This is an adaptation for tall rain forest trees. Example: *Bombax ceiba* (Red silk cotton tree), *Ceiba pentandra* (white silk cotton tree), *Delonix regia, Bombax.*

Ipomoea batatas

Dahlia

Maranta

Psychotria

Figure 3.5: Adventitious Root Modification for Storage

Ficus benghalensis

Saccharum officinarum

Epipremnum pinnatum

Bombax

Figure 3.6: Adventitious root modifications for mechanical support

c. Vital functions

1. Epiphytic or velamen root

Some epiphytic orchids develop a special kind of aerial roots which hang freely in the air. These roots develop a spongy tissue called **velamen** which helps in absorption of moisture from the surrounding air. Example: *Vanda, Dendrobium*.

2. Foliar root

Roots are produced from the veins or lamina of the leaf for the formation of new plant. Example: *Bryophyllum, Begonia*.

3. Sucking or Haustorial roots

These roots are found in parasitic plants. Parasites develop adventitious roots from stem which penetrate into the tissue of host plant and suck nutrients.

Example: *Cuscuta* (dodder), *Cassytha*, *Orobanche* (broomrape), *Viscum* (mistletoe), *Dendrophthoe*.

4. Photosynthetic or assimilatory roots

Roots of some climbing or epiphytic plants develop chlorophyll and turn green which help in photosynthesis. Example: *Tinospora*, *Trapa natans* (water chestnut), *Taeniophyllum*.

3.6 Shoot system

The plumule of the embryo of a germinating seed grows into stem. The epicotyl elongates after embryo growth into the axis (the stem) that bears leaves from its tip, which contain the actively dividing cells of the shoot called **apical meristem.** Further cell divisions and growth result in the formation of mass of tissue called **a leaf primordium.** The point from which the leaf arises is called **node**. The region between two adjacent nodes is called **internode.**

I. Characteristic features of the stem

1. The stem is aerial, green, photosynthetic and has nodes and internodes.
2. It is positively phototropic and negatively geotropic.
3. It has nodes and internodes.
4. Stem bears vegetative bud for vegetative growth of the plant, and floral buds for reproduction, and ends in a terminal bud.
5. The young stem is green and thus carries out photosynthesis
6. During reproductive growth stem bears flowers and fruits.
7. Branches arise exogenously
8. Some stems bears multicellular hairs of different kinds.

II. Functions of the stem

Primary functions

1. It provides support and bears leaves, flowers and fruits.
2. It transports water and mineral nutrients to other parts from the root.
3. It transports food prepared by leaves to other parts of the plant body.

Secondary functions

1. **Food storage**- Example: *Solanum tuberosum, Colocasia* and *Zingiber officinale*
2. **Perennation / reproduction** – Example: *Zingiber officinale, Curcuma longa*
3. **Water storage** – Example: *Opuntia*
4. **Bouyancy** – Example: *Neptunia*

Vanda *Bryophyllum* *Cuscuta* *Tinospora*

Figure 3.7: Adventitious Root Modification for Vital Functions

5. **Photosynthesis** – Example: *Opuntia, Ruscus, Euphorbia.*
6. **Protection** – Example: *Citrus, Bougainvillea, Acacia.*
7. **Support** - Example: *Passiflora, Vitis, Cissus quadrangularis.*

3.6.1 Buds

Buds are the growing points surrounded by protective scale leaves. The bud primordium matures into bud. They have compressed axis in which the internodes are not elongated and the young leaves are closed and crowded. When these buds develop, the internodes elongate and the leaves spread out. Buds have architecture identical to the original shoot and develop into lateral branches or may terminate by developing into a flower or inflorescence. Based on origin, buds are classified into (a) Terminal or Apical bud (b) Lateral or Axillary or Axil bud. Based on function buds are classified into (a) Vegetative bud (b) Floral or Reproductive bud.

1. **Terminal bud or apical bud:** These buds are present at the apex of the main stem and at the tips of the branches.
2. **Lateral bud or Axillary bud:** These buds occur in the axil of the leaves and develop into a branch or flower.
3. **Extra axillary bud :** These buds are formed at nodes but outside the axil of the leaf as in *Solanum americanum.*
4. **Accessory Bud:** An extra bud on either side (collateral bud) or above (superposed bud or serial bud) the axillary bud. Example: *Citrus* and *Duranta.*
5. **Adventitious buds:** Buds arising at any part other than stem are known as **adventitious buds. Radical buds** are those that arises from the lateral roots which grow into plantlets. Example: *Millingtonia, Bergera koenigii (Murraya koenigii), Coffea arabica* and *Aegle marmelos.* **Foliar buds** are those that grow on leaves from veins or from margins of the leaves. Example: *Begonia* (Elephant ear plant) and *Bryophyllum* (Sprout leaf plant). **Cauline buds** arise directly from the stem either from cut, pruned ends or from branches. Adventitious buds function as propagules which are produced on the stem as tuberous structures. Example: *Dioscorea, Agave.*
6. **Bulbils (or specialized buds) :** Bulbils are modified and enlarged bud, meant for propagation. When bulbils detach from parent plant and fall on the ground, they germinate into new plants and serve as a means of vegetative propagation. *Example Agave* and *Allium proliferum.*

3.6.2 Types of Stem

Majority of angiosperm possess upright, vertically growing erect stem. They may be many types they are (i) Excurrent, (ii) Decurrent, (iii) Caudex and (iv) Culm.

i. Excurrent

The main axis shows continuous growth and the lateral branches gradually becoming shorter towards the apex which gives a conical appearance to the trees. Example: *Monoon longifolium(Polyalthia longifolia), Casuarina.*

ii. Decurrent

The growth of lateral branch is more vigorous than that of main axis. The tree has a rounded or spreading appearance. Example: *Mangifera indica.*

iii. Caudex

It is an unbranched, stout, cylindrical stem, marked with scars of fallen leaves. Example: *Cocos nucifera.*

iv. Culm

Erect stems with distinct nodes and usually hollow internodes clasped by leaf sheaths. Example: Majority of grasses including Bamboo.

3.6.3 Modification of Stem

I. Aerial modification of stem

1. Creepers

These are plants growing closer (horizontally) to the ground and produce roots at each node. Example: *Cynodon dactylon, Centella.*

2. Trailers (Stragglers)

It is a weak stem that spreads over the surface of the ground without rooting at nodes. They are divided into 3 types,

i. **Prostrate (Procumbent):** A stem that grows flat on the ground. Example: *Indigofera prostrata.*

ii. **Decumbent:** A stem that grows flat but becomes erect during reproductive stage. Example: *Tridax.*

iii. **Diffuse:** A trailing stem with spreading branches. Example: *Boerhavia diffusa.*

3. Climbers

These plants have long weak stem and produce special organs for attachment for climbing over a support. Climbing helps to display the leaves towards sunlight and to position the flower for effective pollination.

i. Root climbers

Plants climbing with the help of adventitious roots (arising from nodes) as in species of *Piper betel, Piper nigrum, Pothos.*

ii. Stem climbers (Twiners)

These climbers lack specialised structure for climbing and the stem itself coils around the support. Example: *Ipomoea, Clitoria, Quisqualis.*

Stem climbers may coil around the support either clockwise or anti-clockwise. Clockwise coiling climbers are called **dextrose.** Example: *Dioscorea alata.* Anti-clockwise coiling climbers are called **sinistrose.** Example: *Dioscorea bulbifera.*

iii. Hook climbers

These plants produce specialized hook like structures which are the modification of various organs of the plant. In *Artabotrys* inflorescence axis is modified into hook. In *Calamus* (curved hook) leaf tip is modified into hook. In *Bignonia unguis-cati* the leaflets are modified into curved hook (figure: 3.17). In *Hugonia* the axillary buds modified into hook.

iv. Thorn climbers

Climbing or reclining on the support with the help of thorns as in *Bougainvillea* and *Carissa.*

v. Lianas (woody stem climber)

Woody perennial climbers found in tropical forests are lianas. They twine themselves around tall trees to get light. Example: *Hiptage benghalensis, Bauhinia vahlii.*

vi. Tendril climbers

Tendrils are thread-like coiling structures which help the plants in climbing. Tendrils may be modifications of Stem – as in *Vitis* and *Cissus quadrangularis;* Inflorescence axis – *Antigonon;* Leaf – *Lathyrus;* Leaflets - *Pisum sativum;* Petiole – *Clematis;* Leaftip – *Gloriosa;* Stipules – *Smilax.* In pitcher plant (*Nepenthes*) the midrib of the leaf often coils around a support like a tendril and holds the pitcher in a vertical position.

4. Phylloclade

This is a green, flattened cylindrical or angled stem or branch of unlimited growth, consisting of a series of nodes and internodes at long or short intervals. Phylloclade is characteristic adaptation of xerophytes where the leaves often fall off early and modified into spines or scales to reduce transpiration. The phylloclade takes over all the functions of leaves, particularly photosynthesis. The phylloclade is also called as **cladophyll.** Example: *Opuntia, Phyllocactus, Muehlenbeckia* (flattened phylloclade) *Casuarina, Euphorbia tirucalli, Euphorbia antiquorum* (cylindrical phylloclade).

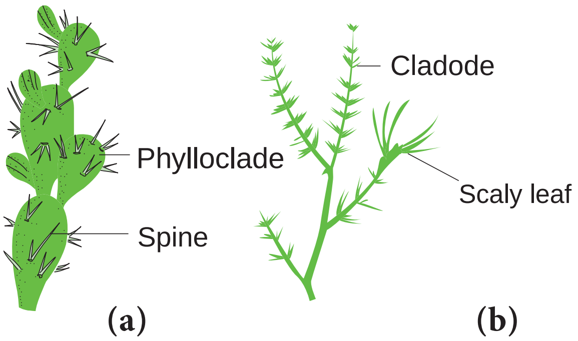
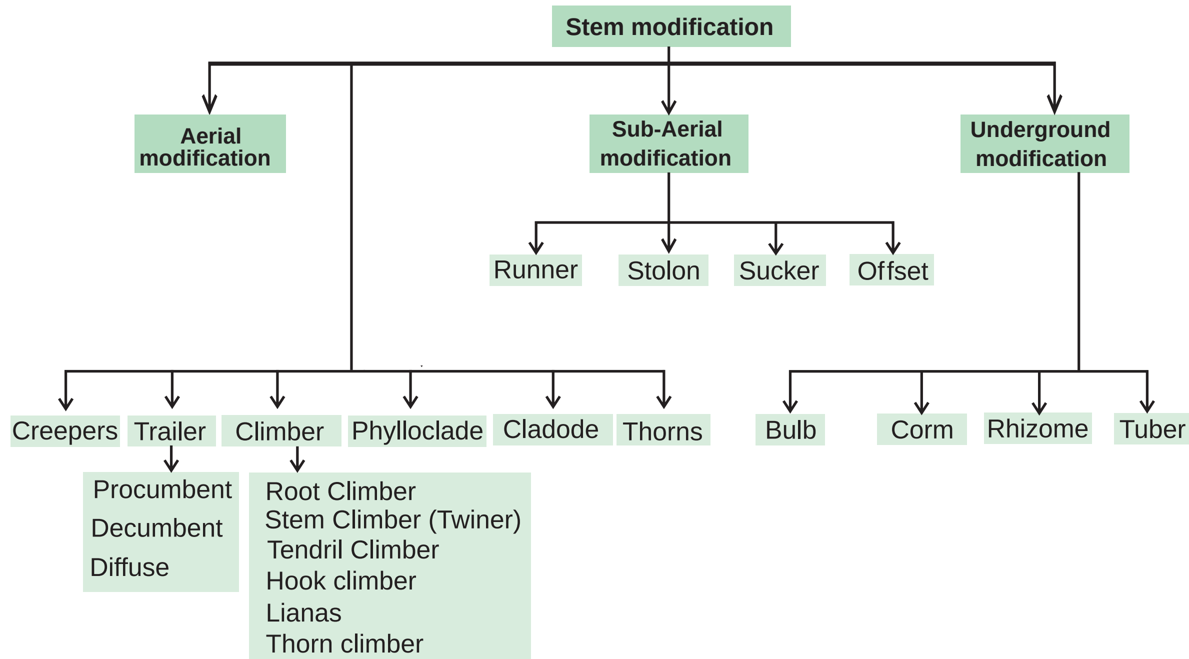


Figure 3.8: (a) Phylloclade-*Opuntia*
(b) Cladode-*Asparagus*

5. Cladode

Cladode is a flattened or cylindrical stem similar to Phylloclade but with one or two



internodes only. Their stem nature is evident by the fact that they bear buds, scales and flowers. Example: *Asparagus* (cylindrical cladode), *Ruscus* (flattened cladode).

6. Thorns

Thorn is a woody and sharp pointed modified stem. Either the axillary bud or the terminal bud gets modified into thorns. In *Citrus* and *Atalantia* axillary bud is modified into thorns.

II. Sub aerial stem modifications

Sub aerial stem found in plants with weak stem in which branches lie horizontally on the ground. These are meant for vegetative propagation. They may be sub aerial or partially sub terranean.

1. Runner

This is a slender, prostrate branch creeping on the ground and rooting at the nodes. Example: *Oxalis* (Wood sorrel), lawn grass (*Cynodon dactylon*).

2. Stolon

This is also a slender, lateral branch originating from the base of the stem. But it first grows obliquely above the ground, produces a loop and bends down towards the ground. When touches the ground it produces roots and becomes an independent plantlet. Example: *Mentha piperita* (peppermint), *Fragaria indica* (wild strawberry).

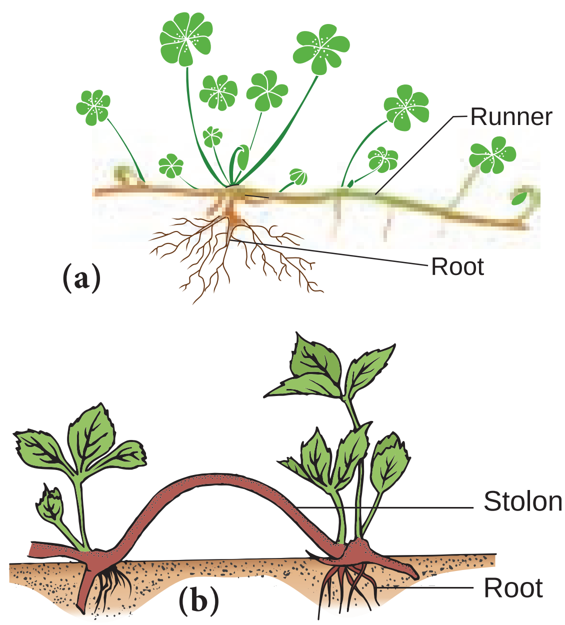


Figure 3.9: (a) Runner-*Oxalis*
(b) Stolon-*Fragaria*

3. Sucker

Sucker develops from an underground stem and grows obliquely upwards and gives rise to a separate plantlet or new plant. Example: *Chrysanthemum, Bambusa.*

4. Offset

Offset is similar to runner but found in aquatic plants especially in rosette leaved forms. A short thick lateral branch arises from the lower axil and grows horizontally leafless for a short distance, then it produces a bunch of rosette leaves and root at nodes. Example: *Eichhornia* (water hyacinth), *Pistia* (water lettuce).

(c)

(d)

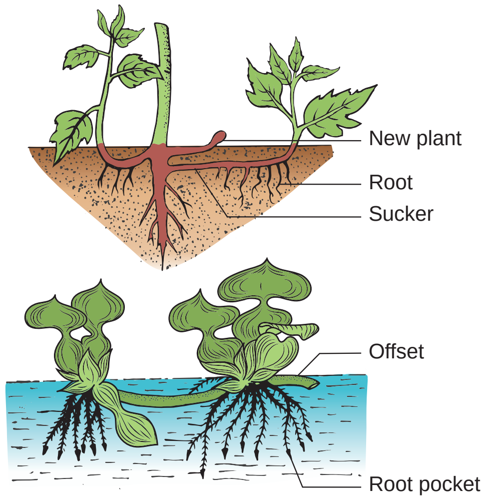


Figure 3.9: (c) Sucker-*Chrysanthemum*
(d) Offset-*Eichhornia*

III. Underground stem modifications

Perennial and some biennial herbs have underground stems, which are generally known as **root stocks**. Rootstock functions as a storage and protective organ. It remains alive below the ground during unfavourable conditions and resumes growth during the favourable conditions.

Underground stems are not roots because they possess nodes, internodes, scale-leaves and buds. Rootstock also lack root cap and root hairs but they possess terminal bud which is a characteristics of stem.

1. Bulb

It is a condensed conical or convex stem surrounded by fleshy scale leaves. They are of two types 1. Tunicated (coated) bulb: In which the stem is much condensed and surrounded by several concentric layers of scale leaves. The inner scales commonly fleshy, the outer ones dry. They can be classified into two types (a) Simple Tunicated bulb Example: *Allium cepa* (b) Compound Tunicated bulb. Example: *Allium sativum*.

2. Corm

This is a succulent underground stem with an erect growing tip. The corm is surrounded by scale leaves and exhibit nodes and internodes. Example: *Amorphophallus, Colocasia, Colchicum*

Bulb-
Allium cepa

Rhizome
Zingiber officinale

Corm-
Colocasia esculenta

Tuber
Solanum tuberosum

Figure 3.10: Underground Stem Modification

3. Rhizome

This is an underground stem growing horizontally with several lateral growing tips. Rhizome posses conspicuous nodes and internodes covered by scale leaves. Example: *Zingiber officinale, Canna, Curcuma longa, Musa.*

4. Tuber

This is a succulent underground spherical or globose stem with many embedded axillary buds called **"eyes".** Example: *Solanum tuberosum, Helianthus tuberosus.*

IV. Stem Branching

Branching pattern is determined by the relative activity of apical meristems. The mode of arrangement of branches on a stem is known as **branching.** There are two main types of branching, 1. Lateral branching and 2. Dichotomous branching. Based on growth pattern stems may show indeterminate or determinate growth.

1. **Indeterminate:** The terminal bud grows uninterrupted and produce several lateral branches. This type of growth is also known as **monopodial branching.** Example: *Polyalthia, Swietenia*.
2. **Determinate:** The terminal bud caese to grow after a period of growth and the further growth is taken care by successive or several lateral meristem or buds. This type of growth is also known as **sympodial branching.** Example: *Cycas*.

3.7 Leaf

Leaves are green, thin flattened lateral outgrowths of the stem. Leaves are the primary photosynthetic organs and the main site of transpiration. All the leaves of a plant together are referred to as **phyllome**.

I. Characteristics of leaf

1. Leaf is a lateral appendage of the stem.
2. It is borne at the node of the stem.
3. It is exogenous in origin.
4. It has limited growth.
5. It does not posses apical bud.
6. It has three main parts namely, leaf base, petiole and lamina.
7. Lamina of the leaf is traversed by vascular strands, called **veins.**

II. Functions of the leaf

Primary functions

1. Photosynthesis
2. Transpiration
3. Gaseous exchange
4. Protection of buds
5. Conduction of water and dissolved solutes.

Secondary functions

1. Storage – Example: *Aloe, Agave*.
2. Protection – Example: *Opuntia, Argemone mexicana*.
3. Support – Example: *Gloriosa, Nepenthes.*
4. Reproduction - Example: *Bryophyllum, Begonia, Zamia.*

3.7.1 Parts of the leaf

Three main parts of a typical leaf are:

i. Leaf base (Hypopodium)
ii. Petiole (Mesopodium)
iii. Lamina (Epipodium)

I. Leaf base (hypopodium)

The part of the leaf attached to the node of the stem is called **leaf base.** Usually it protects the growing buds at its axil.

Pulvinus: In legumes leaf base become broad and swollen which is known as **pulvinus.** Example: *Clitoria, Lablab, Cassia, Butea*.

Sheathing leafbase: In many monocot families such as Arecaceae, Musaceae, Zingiberaceae and Poaceae the leafbase extends into a sheath and clasps part or whole of the internode. Such leafbase also leave permanent scars on the stem when they fall.

II. Petiole (stipe or mesopodium)

It is the bridge between lamina and stem. Petiole or leaf stalk is a cylindrical or sub cylindrical or flattened structure of a leaf which joins the lamina with the stem. A leaf with petiole are said to be **petiolate.** Example: *Ficus, Hibiscus.* Leaves that do not possess petiole is said to be **sessile**. Example*: Calotropis.*

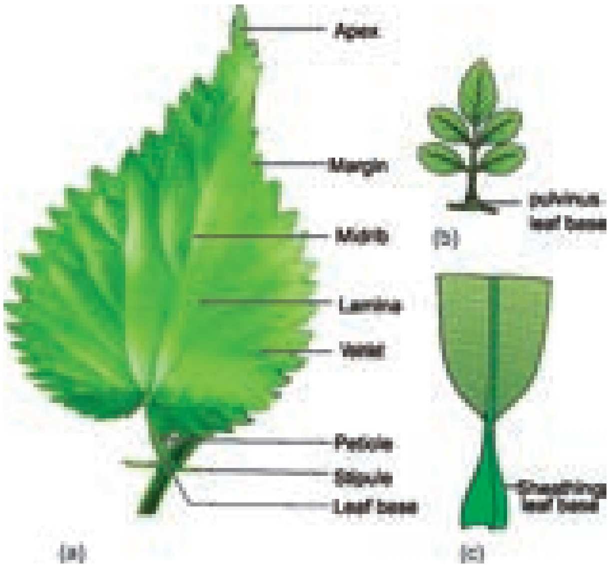


Figure 3.11: (a) Parts of the leaf **(b)** Pulvinus leaf base **(c)** Sheathing leaf base

III. Lamina (Leaf blade)

The expanded flat green portion of the leaf is the blade or lamina. It is the seat of photosynthesis, gaseous exchange, transpiration and most of the metabolic reactions of the plant. The lamina is traversed by the midrib from which arise numerous lateral veins and thin veinlets. The lamina shows great variations in its shape, margin, surface, texture, colour, venation and incision.

Stipules

In most of the dicotyledonous plants, the leaf base bears one or two lateral appendages called the **stipules**. Leaves with stipules are called **stipulate**. The leaves without stipules are called **exstipulate or estipulate**. The stipules are commonly found in dicotyledons. In some grasses (Monocots) an additional out growth is present between leaf base and lamina. It is called **Ligule.** Sometimes, small stipule like outgrowths are found at the base of leaflets of a compound leaf. They are called **stipels.** The main function of the stipule is to protect the leaf in the bud condition.

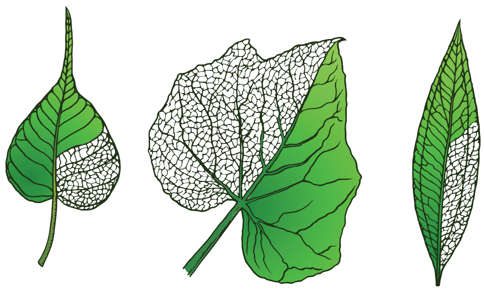
3.7.2 Venation

The arrangement of veins and veinlets on the leaf blade or lamina is called **venation.** Internally, the vein contains vascular tissues. Conventionally venation is classified into two types namely, Reticulate venation and Parallel venation.

I. Reticulate venation

In this type of venation leaf contain a prominent midrib from which several secondary veins arise that branch and anastomose like a network. This type of venation is common in all dicot leaves. It is of two types.

1. **Pinnately reticulate venation (unicostate):** In this type of venation there is only one midrib in the centre which forms many lateral branches to form a network. Example: *Mangifera indica.*
2. **Palmately reticulate venation (multicostate):** In this type of venation there are two or more principal veins arising from a single point and they proceed outwards or upwards. The two types of palmate reticulate venation are



(a) *Ficus* **(b)** *Cucurbita* **(c)** *Cinnamomum*

Figure 3.12: Types of reticulate venation
(a) Pinnately reticulate
(b) Palmately reticulate (Divergent)
(c) Palmately reticulate (Convergent)

   i. **Divergent type:** When all principal veins originate from the base and diverge from one another towards the margin of the leaf as in *Carica papaya*.
   ii. **Convergent:** When the veins converge to the apex of the leaf, as in Indian plum (*Zizyphus*), bay leaf (*Cinnamomum*).

II. Parallel venation

Veins run parallel and do not form a prominent reticulum. It is a characteristic feature of monocot leaves. It is classified into two sub types.

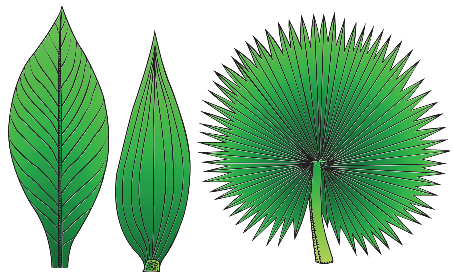
1. Pinnately Parallel Venation (Unicostate)

When there is a prominent midrib in the center, from which arise many veins perpendicularly and run parallel to each other. Example: *Musa*, Zinger.

2. Palmate Parallel Venation (Multicostate)

In this type several veins arise from the tip of the petiole and they all run parallel to each other and unite at the apex. It is of two sub types.

i. **Divergent type:** All principal veins originate from the base and diverge towards the margin, the margin of the leaf as in fan palm (*Borassus flabelliformis*)
ii. **Convergent type:** All principal veins run parallel to each other from the base of the lamina and join at the apex as in Bamboos, rice, water hyacinth.



(a) *Canna* **(b)** Bamboo **(c)** Borassus

Figure 3.13: Types of Parallel venation

(a) Pinnately parallel venation **(b)** Palmately parallel(Convergent) **(c)** Palmately parallel (Divergent)

3.7.3 Phyllotaxy

The mode of arrangement of leaves on the stem is known as **phyllotaxy (Gk. Phyllon = leaf ; taxis = arrangement)**. Phyllotaxy is to avoid over crowding of leaves and expose the leaves maximum to the sunlight for photosynthesis. The four main types of phyllotaxy are (1) Alternate (2) Opposite (3) Ternate (4) Whorled.

1. Alternate phyllotaxy

In this type there is only one leaf per node and the leaves on the successive nodes are arranged alternate to each other. Spiral arrangement of leaves show vertical rows are called **orthostichies**. They are of two types.

a) **Alternate spiral:** In which the leaves are arranged alternatively in a spiral manner. Example: *Hibiscus, Ficus.*

b) **Alternate distichous** or **Bifarious**: In which the leaves are organized alternatively in two rows on either side of the stem. Example: *Monoon longifolium* (*Polyalthia longifolia*).

2. Opposite phyllotaxy

In this type each node possess two leaves opposite to each other. They are organized in two different types.

i. **Opposite superposed:** The pair of leaves arranged in succession are in the same direction, that is two opposite leaves at a node lie exactly above those at the lower node. Example: *Psidium* (Guava), *Quisqualis* (Rangoon creeper).

ii. **Opposite decussate:** In this type of phyllotaxy one pair of leaves is placed at right angles to the next upper or lower pair of leaves. Example: *Calotropis*, *Ocimum*

3. Ternate phyllotaxy

In this type there are three leaves attached at each node. Example: *Nerium*

4. Whorled (verticillate) type of phyllotaxy

In this type more than three leaves are present in a whorl at each node forming a circle or whorl. Example: *Allamanda.*

3.7.4 Leaf mosaic

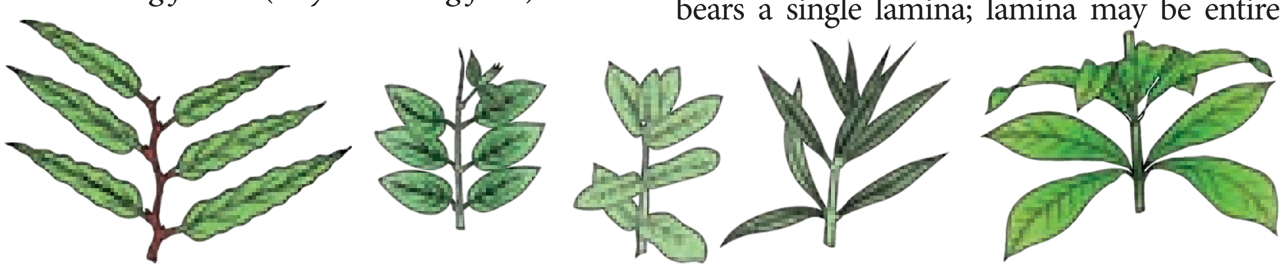
In leaf mosaic leaves tend to fit in with one another and adjust themselves in such a way that they may secure the maximum amount of sunlight with minimum amount of overlapping. The lower leaves have longer petioles and successive upper leaves possess shorter petioles. Example: *Acalypha.*

3.7.5 Leaf type

The pattern of division of a leaf into discrete components or segments is termed leaf type. Based on the number of segments

I. Simple leaf

A leaf is said to be simple when the petiole bears a single lamina; lamina may be entire



Alternate *Polyalthia* | Opposite Superposed *Guava* | Opposite Decussate *Calotropis* | Ternate *Nerium* | Whorled *Allamanda*

Figure 3.14: Phyllotaxy

(undivided) Example: Mango or incised to any depth but not upto the midrib or petiole. Example: *Cucurbita*.

II. Compound leaf

Compound leaf is one in which the main rachis bears more than one lamina surface, called **leaflets.** Compound leaves have evolved to increase total lamina surface. There is one axillary bud in the axil of the whole compound leaf. The leaflets however, do not possess axillary buds.

1. Pinnately compound leaf

A pinnately compound leaf is defined as one in which the rachis, bears laterally a number of leaflets, arranged alternately or in an opposite manner, as in Tamarindus, *Cassia*.

i. **Unipinnate:** The rachis is simple and unbranched which bears leaflets directly on its sides in alternate or opposite manner. Example: *Rose*, *Neem*. Unipinnate leaves are of two types.
   a. when the leaflets are even in number, the leaf is said to be **paripinnate**. Example: *Tamarindus*.
   b. when the leaflets are odd in number, the leaf is said to be **imparipinnate.** Example: *Azadirachta* (Neem).

ii. **Bipinnate:** The primary rachis produces secondary rachii which bear the leaflets. The secondary rachii are known as **pinnae.** Number of pinnae varies depending on the species. Example: *Delonix*.

iii. **Tripinnate:** When the rachis branches thrice the leaf is called **tripinnate.** (i.e) the secondary rachii produce the tertiary rachii which bear the leaflets. Example: *Moringa*.

iv. **Decompound:** When the rachis of leaf is branched several times it is called **decompound.** Example: *Daucus carota, Coriandrum sativum.*

2. Palmately compound leaf

A palmately compound leaf is defined as one in which the petiole bears terminally, one or more leaflets which seem to be radiating from a common point like fingers from the palm.

i. **Unifoliolate:** When a single leaflet is articulated to the petiole is said to be unifoliolate. Example: *Citrus*.

(a) (b) (c) (d) (e)

Figure 3.15: Types of pinnately compound leaves

(a) Unipinnate (Paripinnate)-*Tamarindus* **(b)** Unipinnate (Imparipinnate)-*Azadirachta* **(c)** Bipinnate-*Caesalpinia* **(d)** Tripinnate-*Moringa* **(e)** Decompound-*Coriandrum*

(a) (b) (c) (d) (e)

Figure 3.16: Types of palmately compound leaves

(a) Unifoliolate - *Citrus* (b) Bifoliolate – *Zornia* **(c)** Trifoliolate – *Aegle marmelos* (d) Quadrifoliolate – *Paris quadrifolia* (e) Multifoliolate – *Bombax*

ii. **Bifoliolate:** When there are two leaflets articulated to the petiole it is said to be bifoliolate. Example: *Zornia diphylla*
iii. **Trifoliolate:** There are three leaflets articulated to the petiole it is said to be trifoliolate. Example: wood apple (*Aegle marmelos*), Clover (*Trifolium*).
iv. **Quadrifoliolate:** There are four leaflets articulated to the petiole it is said to be quadrifoliolate. Example: *Paris quadrifolia, Marsilia*
v. **Multifoliolate or digitate:** Five or more leaflets are joined and spread like fingers from the palm, as in *Cleome pentaphylla, Bombax ceiba*

3.7.6 Modification of Leaf

The main function of the leaf is food preparation by photosynthesis. Leaves modified to perform some specialized functions. They are described below.

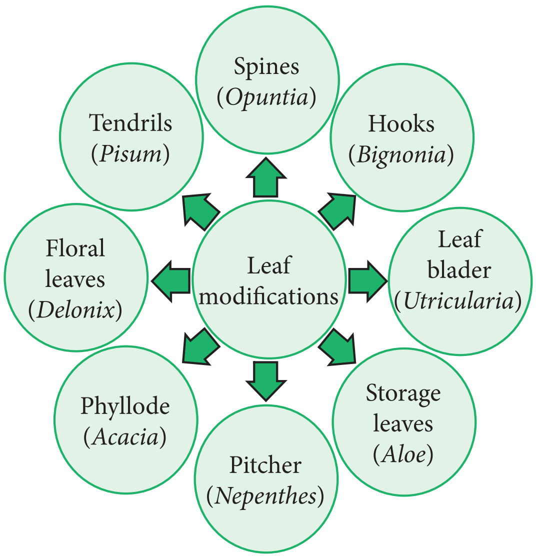
I. Leaf tendrils

In some plants stem is very weak and hence they have some special organs for attachment to the support. So some leaves are partially or wholly modified into tendril. Tendril is a slender wiry coiled structure which helps in climbing the support. Some of the modification of leaf tendrils are given below:

Entire leaf—*Lathyrus,* stipules—*Smilax,* terminal leaflet—*Naravelia,* Leaf tip— *Gloriosa,* Apical leaflet—*Pisum,* petiole— *Clematis.*

II. Leaf hooks

In some plants, leaves are modified into hook-like structures and help the plant to climb. In cat's nail (*Bignonia unguis-cati)* an elegant climber, the terminal leaflets become modified into three, very sharp, stiff and curved hooks, very much like the nails of a cat. These hooks cling to the bark of a tree and act as organs of support for climbing. The leaf spines of *Asparagus* also act as hooks.



III. Leaf Spines and Prickles

Leaves of certain plants develop spinesent structures. Either on the surface or on the margins as an adaptation to herbivory and xeric conditions. Example: *Zyzypus Argemone mexicana* (Prickly poppy), *Solanum trilobatum*. In xerophytes such as *Opuntia* (Prickly pear) and *Euphorbia* leaves and stipules are modified into spines.

Prickles are small, sharp structure which are the outgrowths from epidermal cells of stem or leaf. It helps the plant in scrambling over other plants. It is also protective against herbivory. Example: *Rosa spp.*

IV. Storage Leaves

Some plants of saline and xerophytic habitats and members of the family Crassulaceae commonly have fleshy or swollen leaves. These succulent leaves store water, mucilage or food material. Such storage leaves resist desiccation. Example: *Aloe, Agave, Bryophyllum*.

V. Phyllode

Phyllodes are flat, green-coloured leaf-like modifications of petioles or rachis. The leaflets or lamina of the leaf are highly reduced or caducous. The phyllodes perform photosynthesis and other functions of leaf. Example: *Acacia auriculiformis* (Australian *Acacia*), *Parkinsonia.*

Leaf hooks-*Bignonia* Leaf spines- *Opuntia* Phyllode-*Acacia* Pitcher-*Nepenthes*

Figure 3.17: Leaf Modification

VI. Pitcher

The leaf becomes modified into a pitcher in *Nepenthes* and *Sarracenia*. In *Nepenthes* the basal part of the leaf is laminar and the midrib continues as a coiled tendrillar structure. The apical part of the leaf is modified into a pitcher the mouth of the pitcher is closed by a lid which is the modification of leaf apex.

VII. Bladder

In bladderwort (*Utricularia*), a rootless free-floating or slightly submerged plant common in many water bodies, the leaf is very much segmented. Some of these segments are modified to form bladder-like structures, with a trap-door entrance that traps aquatic animalcules.

VIII Floral leaves

Floral parts such as sepals, petals, stamens and carpels are modified leaves. Sepals and petals are leafy. They are protective in function and considered non-essential reproductive parts. Petals are usually coloured which attract the insects for pollination. Stamens are considered pollen bearing microsporophylls and carpels are ovule bearing megasporophylls.

3.7.7 Leaf duration

Leaves may stay and function for few days to many years, largely determined by the adaptations to climatic conditions.

Caducuous (Fagacious)

Falling off soon after formation. Example: *Opuntia, Cissus quadrangularis.*

Deciduous

Falling at the end of growing season so that the plant (tree or shrub) is leafless in winter/ summer season. Example: *Maple*, *Plumeria, Launea, Erythrina.*

Evergreen

Leaves persist throughout the year, falling regularly so that tree is never leafless. Example: *Mimusops, Calophyllum.*

Marcescent

Leaves not falling but withering on the plant as in several members of Fagaceae.

Summary

Flowering plants consist of two major organ systems: Underground root system and aerial shoot system. Roots perform the functions of anchoring and absorbing nutrients from the soil. However some roots perform additional functions for which they undergo various modifications in shape, form and structure. Tap root continue the growth from the radicle which further branches into secondary roots. Adventitious roots arise from different parts of the plant other than radicle. Stem helps to display the leaves to get maximum sunlight and positioning flowers and fruits to attract pollination and dispersal agents. Apart from the normal functions the stems are modified to perform various functions such as food storage, perennation and protection. Leaves are exogenous in origin and function as food synthesizing and gaseous exchange sites. Some leaves also perform additional functions for which they are modified in their morphology.

Leaves possess vascular tissues in the form of veins which render support to the lamina and help in transport of water, nutrients and food in and out of leaves. Phyllotaxy is the arrangement or distribution of leaves on the stem or its branches in such a way that they receive maximum sunlight to perform photosynthesis.

Activity

1. Collection of medicines prepared from root, stem, leaf of organic plants.
2. Prepare a report of traditional medicines.
3. Classroom level exhibition on Siddha and Ayurvedic medicine prepared from root, leaf, stem.
4. Growing micro greens in class room – project work. (Green seed sprouts)

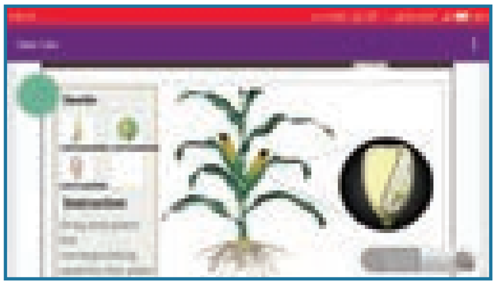
Evaluation

1. Which of the following is polycarpic plant?
   a. *Mangifera*
   b. *Bambusa*
   c. *Musa*
   d. *Agave*
2. Roots are
   a. Descending, negatively geotropic, positively phototropic
   b. Descending, positively geotropic, negatively phototropic
   c. Ascending, positively geotropic, negatively phototropic
   d. Ascending, negatively geotropic, positively phototropic
3. *Bryophyllum* and *Dioscorea* are example for
   a. Foliar bud, apical bud
   b. Foliar bud, cauline bud
   c. Cauline bud, apical bud
   d. Cauline bud, foliar bud
4. Which of the following is the correct statement?
   a. In *Pisum sativum* leaflets modified into tendrils
   b. In *Atalantia* terminal bud is modified into thorns
   c. In *Nepenthes* midrib is modified into lid
   d. In *Smilax* inflorescence axis is modified into tendrils
5. Select the mismatch pair
   a. *Musa* - Unicostate
   b. *Lablab* - Trifoliolate
   c. *Acalypha* - Leaf mosaic
   d. *Allamanda* - Ternate phyllotaxy
6. Draw and label the parts of regions of root.
7. Write the similarities and differences between
   1. *Avicennia* and *Trapa*
   2. Radical buds and foliar buds
   3. Phylloclade and cladode
8. How root climbers differ from stem climbers?
9. Compare sympodial branching with monopodial branching.
10. Differentiate pinnate unicostate with palmate multicostate venation

ICT Corner

Monocot and Dicot plants

Is plants differ **morphologically**?

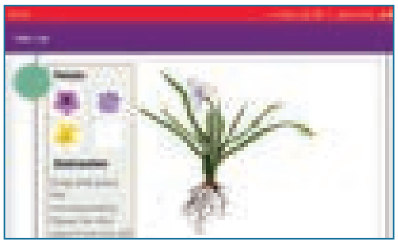


Steps

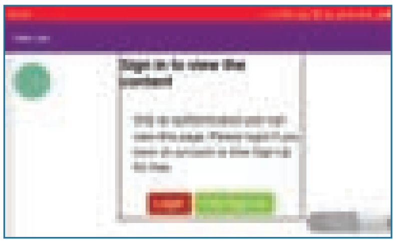
- Scan the QR code or go to google play store
- Type online labs and install it.
- Select biology and select Characteristics of plants
- Click theory to know the basic about Characteristics of plants
- Register yourself with mail-id and create password to access online lab simulations

Activity

- Select video and record your observations of different forms of plant group.



Step 1



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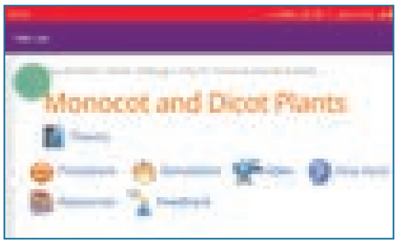

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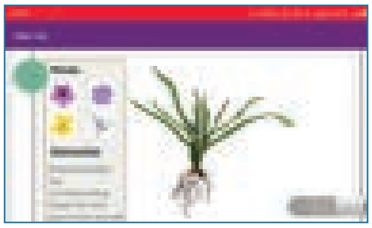

Step 4

URL:

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* Pictures are indicative only

Chapter 4

Unit II: Plant Morphology and Taxonomy of Angiosperm

Reproductive Morphology

Learning Objectives

The learner will be able to,

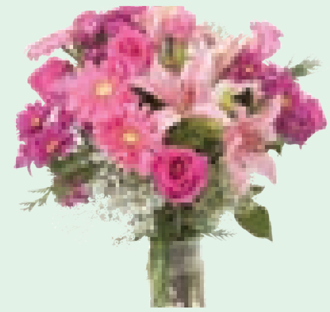
- *List the types of Inflorescence.*
- *Distinguish Racemose and Cymose inflorescence*
- *Dissect a flower and explore the parts of a flower.*
- *Compare various types of Aestivation.*
- *Explore various types of Placentation.*
- *Understands the types of Fruits and seeds*
- *To differentiate Monocot and Dicot seeds*

Chapter Outline

Flowers have been a universal cultural object for millennia. They are an important aesthetic element in everyday life, and have played a highly symbolic role in our culture throughout the ages. Exchange of flowers marks respect, affection, happiness, and love. However, the biological purpose of the flower is very different from the way we use and perceive. Flower helps a plant to reproduce its own kind. This chapter discusses flowers, their arrangement, fruits and seeds which are the reproductive units of a plant.

Floriculture

Floriculture is a branch of Horticulture. It deals with the cultivation of flowers and ornamental crops. The Government of India has identified floriculture as a sunrise industry and accorded the status of 100% export oriented. Agriculture and Processed Food Product Export Development Authority (APEDA) is responsible for export promotion of agricultural and horticultural products from India.



4.1 Inflorescence

Have you seen a bouquet being used during functions? Group of flowers arranged together on our preference is a bouquet. But an inflorescence is a group of flowers arising from a branched or unbranched axis with a definite pattern. Function of inflorescence is to display the flowers for effective pollination and facilitate seed dispersal. The grouping of flowers in one place gives a better attraction to the visiting pollinators and maximize the energy of the plant.

4.1.1 Types of Inflorescence

Based On Position

Have you ever noticed the inflorescence arising from different positions? Where is the inflorescence present in a plant? Apex or axil?

Based on position of inflorescences, it may be classified into three major types. They are,

Terminal: Inflorescence grows as a part of the terminal shoot. Example: Raceme of *Nerium oleander*

Axillary: Inflorescence presents in the axile of the nearest vegetative leaf. Example: *Hibiscus rosa-sinensis*

Cauliflorous: Inflorescence developed directly from a woody trunk. Example: *Theobroma cocoa, Couraupita guinensis*

Observe the inflorescence of Jackfruit and Canon ball tree. Where does it arise?

4.1.2 Based on branching pattern and other characters

Inflorescence may also be classified based on branching, number and arrangement of flowers, and some specialized structures.

I. **Indeterminate (Racemose)**

II. **Determinate (Cymose)**

III. **Mixed inflorescence**: Inflorescence of some plants show a combination of indeterminate and determinate pattern

IV. **Special inflorescence**: Inflorescence which do not confine to these patterns

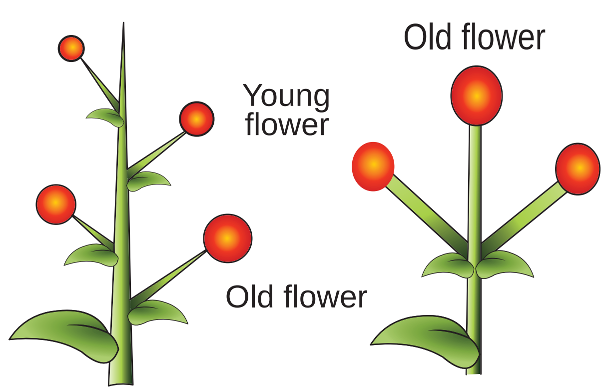


Figure 4.1: (a) Racemose

Figure 4.1: (b) Cymose inflorescence

Racemose	Cymose
Main axis of unlimited growth	Main axis of limited growth.
Flowers arranged in an acropetal succession	Flowers arranged in a basipetal succession
Opening of flowers is centripetal	Opening of flowers is centrifugal
Usually the oldest flower at the base of the inflorescence axis.	Usually the oldest flower at the top of the inflorescence axis.

I. Racemose

The central axis of the inflorescence (peduncle) possesses terminal bud which is capable of growing continuously and produce lateral flowers is called **Racemose inflorescence**. Old flowers are at the base and younger flowers and buds are towards the apex. It is further divided into 3 types based on growth pattern of main axis.

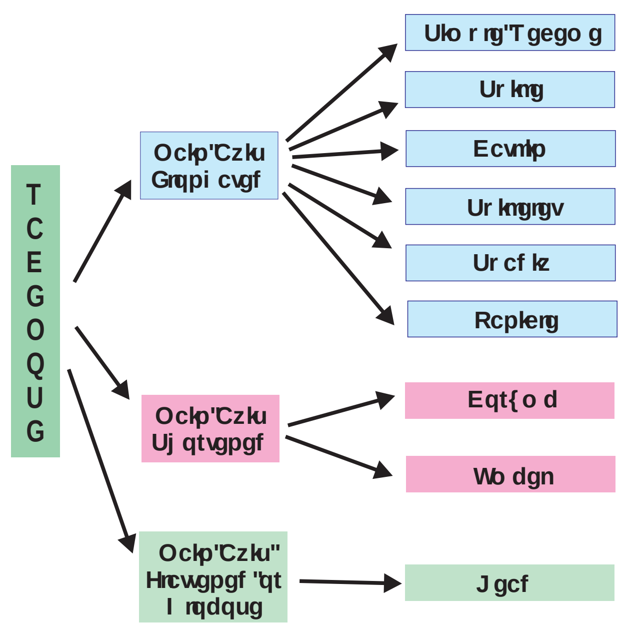


Figure 4.2: Racemose

1. Main axis elongated

The axis of inflorescence is elongated and contains pedicellate or sessile flowers on it. The following types are discussed under main axis elongated type.

a. Simple raceme: The inflorescence with an unbranched main axis bears **pedicellate**

flowers in acropetal succession. Example: *Crotalaria retusa,* Mustard.

b. Spike: Spike is an unbranched indeterminate inflorescence with **sessile flowers**. Example: *Achyranthes.*

c. Spikelet: Literally it is a small spike. The Inflorescence is with branched central axis. Each branch is a **spikelet**. Sessile flowers are formed in acropetal succession on the axis. A pair of inflorescence bracts called **glumes** is present at the base. Each sessile flower has a **lemma** (bract) and a **palea** (bracteole). Tepals reduced to colourless scaly leaves (lodicule). Each flower has stamen and pistil only. Example: Paddy, Wheat.

d. Catkin: **Pendulous spikes** with a long and drooping axis bearing small unisexual or bisexual flowers. It is also called **ament**. Example: *Acalypha hispida*, *Prosopis juliflora.*

e. Spadix: An inflorescence with a fleshy or thickened central axis that possesses many unisexual sessile flowers in acropetal succession. Usually female flowers are found towards the base and male flowers are found at the apex. Entire inflorescence is covered by a brightly coloured or hard bract called a **spathe**. Example: *Amorphophallus*, *Colocasia.*

f. Panicle: A branched raceme is called **panicle**. Example: *Mangifera,* neem. It is also called **Compound raceme** or **Raceme of Racemes**.

2. Main axis shortened:

Inflorescence with reduced growth of central axis. There are two types, namely corymb and umbel.

a. Corymb: An inflorescence with shorter pedicellate flowers at the top and longer

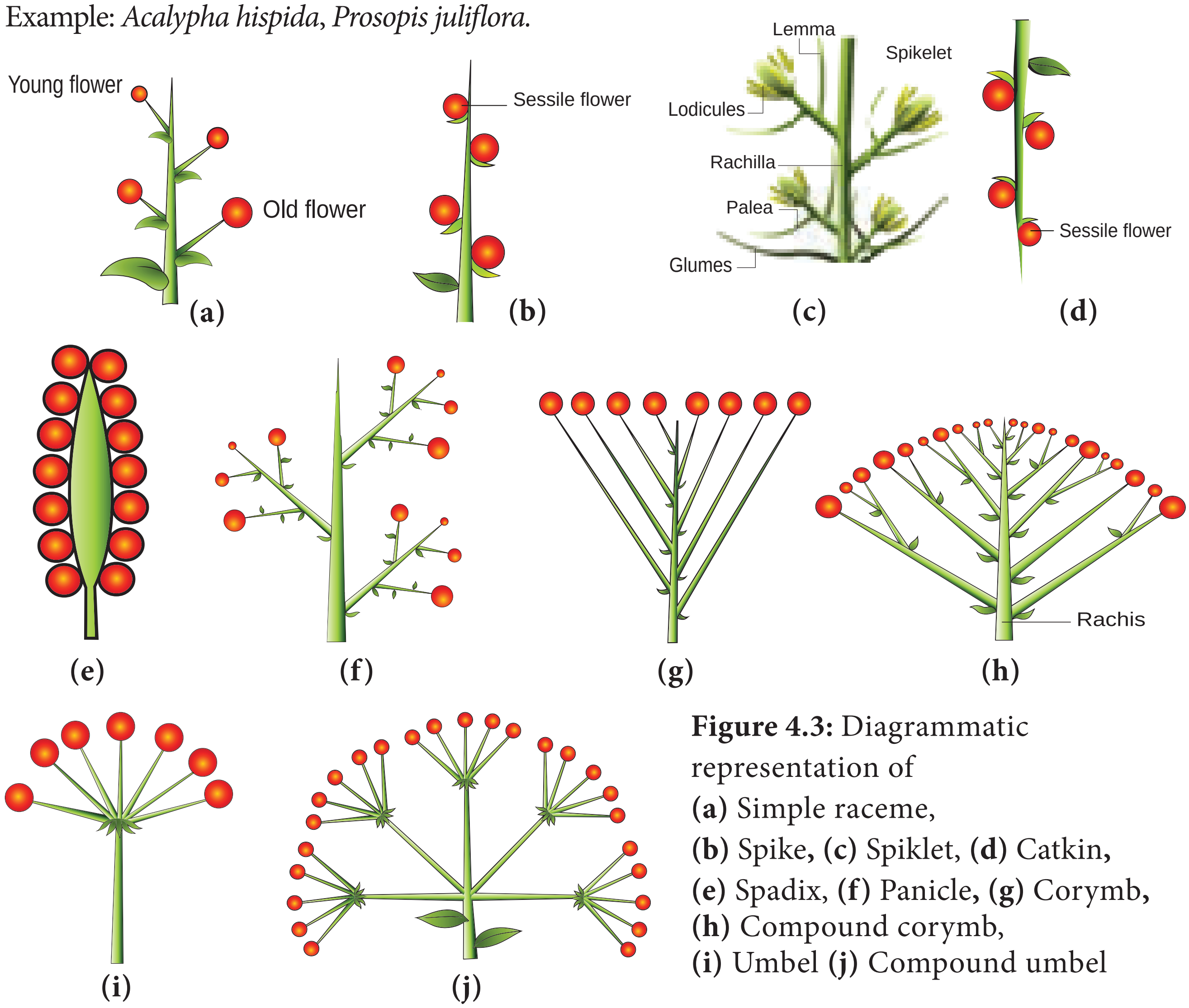


Figure 4.3: Diagrammatic representation of
(a) Simple raceme,
(b) Spike, **(c)** Spiklet, **(d)** Catkin,
(e) Spadix, **(f)** Panicle, **(g)** Corymb,
(h) Compound corymb,
(i) Umbel **(j)** Compound umbel

pedicellate flowers at the bottom. All flowers appear at the same level to form convex or flat topped racemose inflorescence. Example: *Caesalpinia*. **Compound corymb:** A branched corymb is called **Compound corymb**. Example: Cauliflower.

b. Umbel: An inflorescence with indeterminate central axis and pedicellate flowers arise from a common point of peduncle at the apex. Example: *Allium cepa*. **Compound umbel**: It is a branched umbel. Each smaller unit is called **umbellule**.Example: *Daucas carota*, *Coriandrum sativum*.

3. Main axis flattened:

The main axis of inflorescence is mostly flattened (convex or concav) or globose. A **head** or **capitulum** is determinate or indeterminate, group of sessile or sub sessile flowers arising on a receptacle, often subtended by an involucre.

a. Head: A head is a characteristic inflorescence of Asteraceae and is also found in some members of Rubiaceae and Mimosaceae.

Torus contains two types of florets: 1. Disc floret or tubular floret. 2. Ray floret or ligulate floret. Based on the type of florets present, the heads are classified into two types.

i. Homogamous head: This type of inflorescence exhibits single kind of florets. Inflorescence has disc florets alone. Example: *Vernonia*, Ray florets alone. Example: *Launaea*.

ii. Heterogamous head: The inflorescence possesses both types of florets. Example: *Helianthus, Tridax*.

Disc florets at the centre of the head are tubular and bisexual, whereas the **ray florets** found at the margin of the head which are ligulate and pistilate (unisexual).

The flower and inflorescence are subtended by a lateral appendage called bract. In sunflower, you may notice that the whorl of bracts forms a cup like structure beneath mimicking the calyx. Such whorl of bracts is called involucre. A group of bracts present beneath the sub unit of inflorescence is known as Involucre.

II. Cymose inflorescence.

Central axis stops growing and ends in a flower, further growth is by means of axillary buds. Old flowers present at apex and young flowers at base

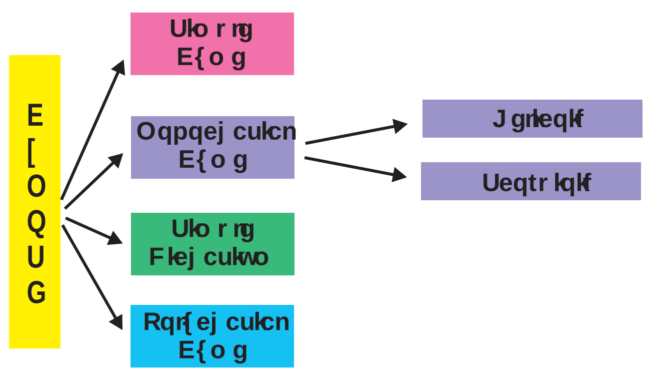


Figure 4.4: Cyme

1. Simple cyme (solitary): Determinate inflorescence consists of a single flower. It may be terminal or axillary. Example: terminal in *Trillium grandiflorum* and axillary in *Hibiscus*.

2. Monochasial Cyme (uniparous): The main axis ends with a flower. From two lateral bracts, only one branch grows further. It may be **Helicoid** or **Scorpioid.**

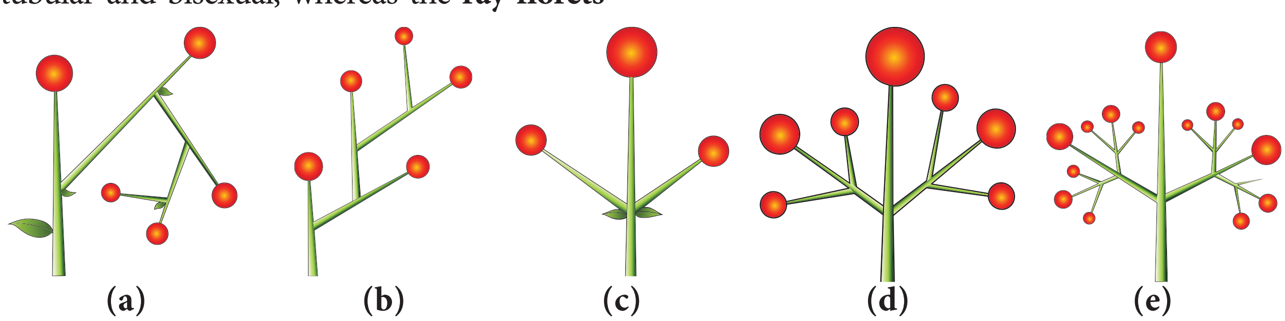


Figure 4.5: Diagrammatic representation of **(a)** Helicoid, **(b)** Scorpioid**, (c)** Simple dichasium, **(d)** Compound dichasium**, (e)** Polychasial Cyme

a. Helicoid: Axis develops on only one side and forms a coil structure atleast at the earlier development stage. Example: *Hamelia*, potato.

b. Scorpioid: Axis develops on alternate sides and often becomes a coiled structure. Example: *Heliotropium*.

3. Simple dichasium (Biparous): A central axis ends in a terminal flower; further growth is produced by two lateral buds. Each cymose unit consists of three flowers of which central one is old one. This is **true cyme**. Example: *Jasminum*.

4. **Compound dichasium**: It has many flowers. A terminal old flower develops lateral simple dichasial cymes on both sides. Each compound dichasium consists of seven flowers. Example: *Clerodendron*.

A small,simple dichasium is called **cymule**

5. Polychasial Cyme (multiparous): The central axis ends with a flower. The lateral axis branches repeatedly. Example: *Nerium*

Sympodial Cyme: In monochasial cyme, successive axis at first develop in a zigzag manner and later it develops into a straight pseudo axis. Example: *Solanum americanum*.

III. Mixed Inflorescence

Inflorescences in which both racemose and cymose patterns of development occur in a mixed manner. It is of the following two types.

1. Thyrsus: It is a '**Raceme of cymes**'. Indefinite central axis bears lateral pedicellate cymes, (simple or compound dichasia). Example: *Ocimum*.

2. Verticillaster: Main axis bears two opposite lateral sessile cymes at the axil of the node,each of it produces monochasial scorpioid lateral branches so that flowers are crowded around the node. Example: *Leucas*.

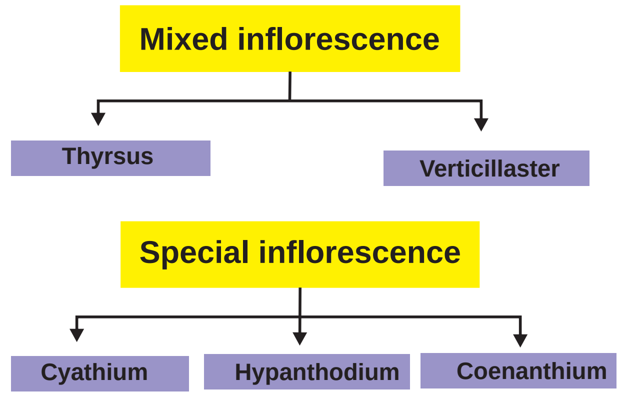


Figure 4.6: Mixed and special inflorescence

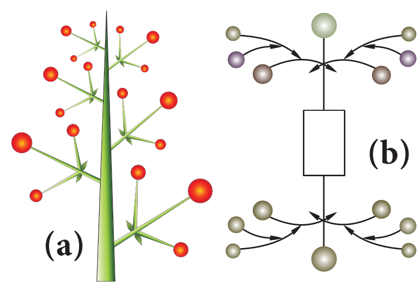


Figure 4.7: Diagrammatic representation of, **(a)** Thyrsus, **(b)** Verticillaster

IV. Special Inflorescence

The inflorescence that do not show any of the development pattern types are classified under special type of inflorescence.

1. Cyathium: Cyathium inflorescence consists of small unisexual flowers enclosed by a common involucre which mimics a single flower. Male flowers are organised in a scorpioid manner. Female flower is solitary and centrally located on a long pedicel. Male flower is represented only by stamens and female flower is represented only by a pistil. Cyathium may be actinomorphic (Example: *Euphorbia*) or zygomorphic (Example: *Pedilanthus*). Nectar is present in involucre.

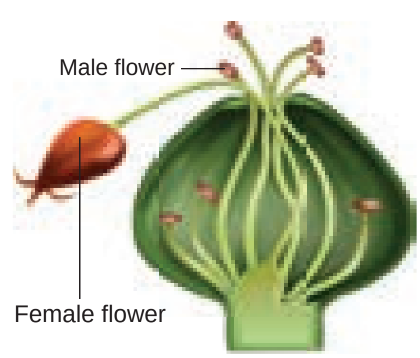


Figure 4.8: Cyathium

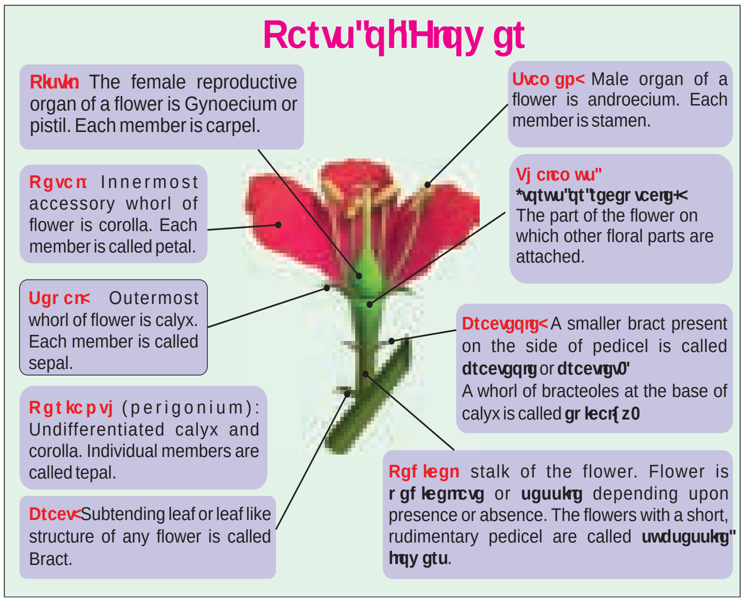


Figure 4.9: Parts of flower

2. Hypanthodium: Receptacle is a hollow, globose structure consisting of unisexual flowers present on the inner wall of the receptacle. Receptacle is closed leaving a small opening called **ostiole** which is covered by a series of bracts. Male flowers are present nearer to the ostiole, female and neutral flowers are found in a mixed manner from middle below. Example: *Ficus sp*. (Banyan, Fig and Pipal).

3. Coenanthium: Circular disc like fleshy open receptacle that bears pistillate flowers at the center and staminate flowers at the periphery. Example: *Dorstenia*

4.2 Flower

In a plant, which part would you like the most? Of course, it is a flower, because of its colour and fragrance. The flower is a significant diagnostic feature of angiosperms. It is a modified condensed reproductive shoot. The growth of the flower shoot is determinate.

4.2.1 Whorls of flower

There are two whorls, accessory and essential. Accessory whorl consists of calyx and corolla and essential whorl comprises of androecium and gynoecium.

Flower is said to be **Complete** when it contains all four whorls. An **Incomplete** flower is devoid of one or more whorls.

4.2.2 Flower sex

Flower sex refers to the presence or absence of androecium and gynoecium within a flower.

1. Perfect or bisexual: If a flower contains both androecium and gynoecium it is called as a **perfect flower**.

2. Imperfect or unisexual: When the flower contains only one of the essential whorls is called **Imperfect flower**. It is of two types:

i) **Staminate flowers**: Flowers with androecium alone.

ii) Pistillate flowers: Flowers with gynoecium alone.

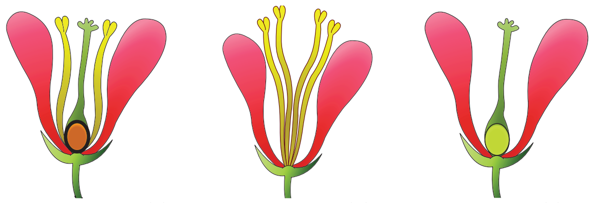


Figure 4.10: (a) Bisexual flower **Figure 4.10: (b)** Male flower **Figure 4.10: (c)** Female flower

Figure 4.11: (a) Monoecious **Figure 4.11: (b)** Dioecious **Figure 4.11: (c)** Polygamous

4.2.3 Plant sex

Plant sex refers to the presence and distribution of flowers with different sexes in an individual plant.

1. **Hermaphroditic**: All the flowers of the plant are bisexual.
2. **Monoecious**: Both male and female flowers are present in the same plant Example: Coconut.
3. **Dioecious**: Male and Female flowers are present on separate plants. Example: Papaya, Palmyra.
4. **Polygamous**: The condition in which bisexual and unisexual (staminate/pistillate) flowers occur in a same plant is called **polygamous**. Example: *Musa*, *Mangifera*.

4.2.4 Flower symmetry

What is the radius of a circle? Cut a paper into round shape, fold it so as to get two equal halves. In how many planes will you get equal halves? In how many planes you can divide a cucumber in two equal halves? A flower is symmetrical when it is divided into equal halves in any plane running through the center. Flower symmetry is an important structural adaptation related to pollination systems.

1. **Actinomorphic (or) radial or polysymmetric**: The flower shows two mirror images when cut in any plane or radius through the centre.Normally there are more than two planes of symmetry. Example: *Hibiscus, Datura*.

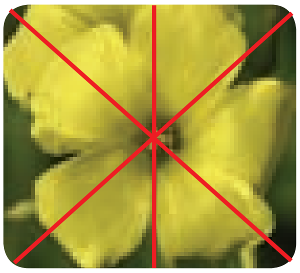


Figure 4.12: (a) Actinomorphic

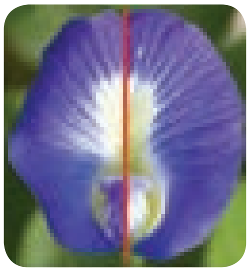


Figure 4.12: (b) Zygomorphic

Figure 4.12: (c) Asymmetric

2. **Zygomorphic (bilateral symmetry)** or **monosymmetric**: The flower can be divided into 2 equal halves in only one plane. Zygomorphic flower can efficiently transfer pollen grains to visiting pollinators. Example: *Pisum*, Bean.

3. **Asymmetric (amorphic)**: Flower lacks any plane of symmetry and cannot be divided into equal halves in any plane. Parts of such flowers are twisted. Example: *Canna indica*.

4.3 Accessory organs

4.3.1 Arrangement of whorls

The position of perianth (sepals, petals, tepals) parts relative to one another is called **perianth arrangement**.

1. **Cyclic or whorled:** All the floral parts are arranged in definite whorls. Example: *Brassica*.

2. **Acyclic or spiral:** The floral parts are arranged in spirals on the elongated fleshy torus. Example: *Magnolia*.

3. **Spirocyclic or hemicyclic**: Some parts are in whorls and others parts are in spirals. Example:*Annona, Polyalthia*

4.3.2 Calyx

Calyx protects the flower in bud stage. Outermost whorl of flower is calyx. Unit of calyx is sepal. Normally green in colour.

1. Fusion: **a. Aposepalous** (polysepalous): The flower with distinct sepals. Example: *Brassica, Annona.*

b. Synsepalous: The flower with united or fused sepals. Example: *Hibiscus*.

2. Duration of floral parts:

What is the green part of brinjal fruit? Have you seen similar to this in any other fruits?

a. Caducous or fugacious calyx: Calyx that withers or falls off during the early development stage of flower. Example: *Papaver*.

Figure 4.13: (a) Caducous bud with sepal

Figure 4.13: (b) Caducous flower without sepal

b. Deciduous: Calyx that falls soon after the opening of flower (anthesis) Example: *Nelumbo*.

Figure 4.13: (c) Deciduous

c. Persistant: Calyx that persists and continues to be along with the fruit and forms a cup at the base of the fruit. Example: Brinjal.

d. Accrescent: Calyx that is persistent, grows along with the fruit and encloses the fruit either completely or partially. Example: *Physalis*.

Figure 4.13: (d) Persistant calyx

Figure 4.13: (e) Accrescent

3. Shapes of calyx

Have you noticed the shoe flower's calyx? It is bell shaped called **Campanulate**. The fruiting calyx is urn shaped in *Withania* and it is called **urceolate**. In *Datura* calyx is tube like and it is known as **tubular**. Two lipped calyx is present *in Ocimum*. Sometimes calyx is coloured and called **petaloid.** Example: *Saraca* and *Mussanda*. In Tridax, calyx is modified into hair like structures are called pappus.

Figure 4.14: (a) Companulate

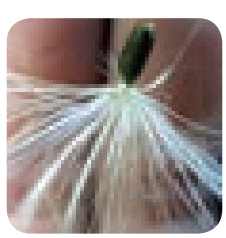


Figure 4.14: (b) Pappus

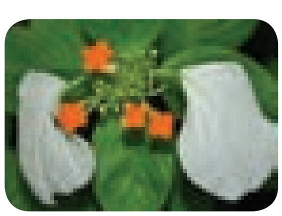


Figure 4.14: (c) Mussaenda

4.3.3 Corolla

Corolla is the most attractive part in majority of the flowers and is usually brightly coloured. Corolla helps to display the flower and attracts the pollinators.

1. Fusion:

a. **Apopetalous (polypetalous)**: Petals are distinct. Example: *Hibiscus*.

b. **Sympetalous (gamopetalous)**: Petals are fused. Example: *Datura*.

4.3.4 Perianth

Can you recall the term homochlamydeous? Undifferentiated calyx and corolla in a flower is called **perianth**. Each member is called **tepal**. If the tepals are distinct they are called **Apotepalous** (Polyphyllous). Example: *Allium sativum*. Fused tepals are called **Syntepalous**. (Gamophyllous). Example: *Allium cepa*.

> **Lodicule**: Reduced scale like perianth in the members of Poaceae is called lodicule.

4.3.5 Aestivation: Arrangement of sepals and petals in the flower bud is said to be aestivation.

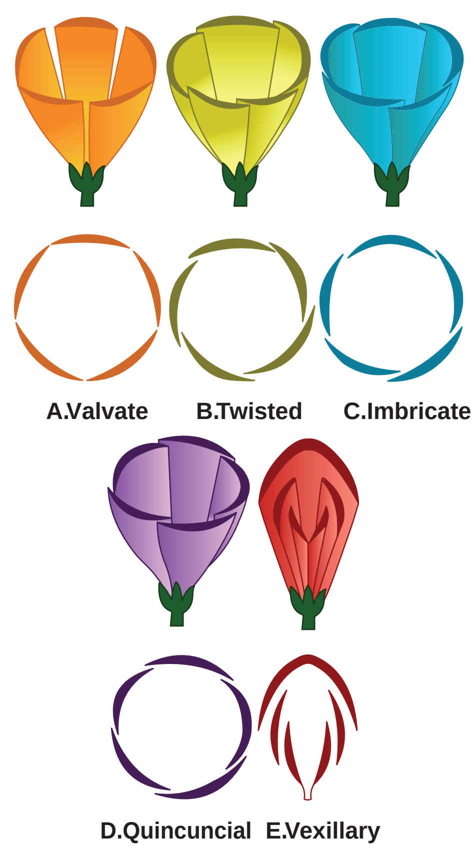


Figure 4.15: Aestivation

A. Valvate: Margins of sepals or petals do not overlap but just touch each other.
Example: Calyx in members of *Malvaceae, Calotropis, Annona.*

B. Twisted or Convolute or Contorted: One margin of each petal or sepal overlapping on the other petal.
Example: *Petals of Chinarose.*

Aestivation: Arrangement of Sepals and Petals in the flower bud

C. Imbricate: Sepals and petals irregularly overlap on each other; one member of the whorl is exterior, one interior and rest of the three having one margin exterior and other interior.
Example: *Cassia, Delonix*
There are 3 types: 1. Ascendingly imbricate; 2. Quincuncial;
3. Vexillary.

D. Quincuncial: It is a type of imbricate aestivation in which two petals are external and two internal and one petal with one margin internal and the other margin external.
Example: *Guava, Calyx of Ipomoea, Catharanthus.*

E. Vexillary: Large posterior petals both margins overlap lateral petals. Lateral petals other margin overlaps anterior petals.
Example: *Pea, Bean.*

Essential Parts of Flower

4.4 Androecium

Androecium: Third whorl of flower is the male reproductive part of the flower. It is composed of stamens(microsporophylls). Each Stamen consist of 3 parts,
a. Filament b. Anther c. Connective

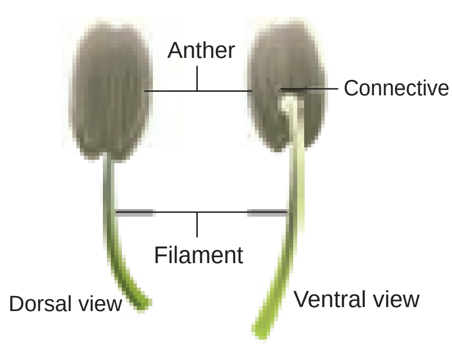


Figure 4.16: Stamen

Anther: Upper swollen part with microsporangia.

Filament: Stalk of stamen

Connective: Tissue connecting anther lobes with filament

Anther typically contains two compartments called **thecae** (singular theca).Each theca consists of two microsporangia.Two microsporangia fused to form a **locule.**

Sterile stamens are called **Staminodes**. Example: *Cassia*. **Distinct:** stamens which do not fuse to one another. **Free:** stamens which do not fuse with other parts of flower. **Apostemonous:** flowers with stamens that are free and distinct.

4.4.1 Fusion of stamens: The fusion of stamens fusing among themselves or with other parts of flower. They are of two types.

1. Connation and 2. Adnation

1. Connation: Refers to the fusion of stamens among themselves. It is of 3 types. **a.** Adelphy. **b.** Syngenecious. **c.** Synandrous.

a. Adelphy: Filaments connate into one or more bundles but anthers are free. It may be the following types.

1. Monadelphous: Filaments of stamens connate into a single bundle.Example: Malvaceae (Chinarose, Cotton).

2. Diadelphous: Filaments of stamens connate into two bundles. Example: *Fabaceae (pea)* and *Clitoria*.

3. Polyadelphous: Filaments connate into many bundles. Example: *Citrus*, *Bombax*

b. Syngenesious: Anthers connate, filaments free. Example: Asteraceae.

c. Synandrous: Filaments and anthers are completely fused. Example: *Coccinea*.

2. Adnation: Refers to the fusion of stamens with other floral parts. **Epipetalous** : Stamens are adnate to petals .Example: brinjal, *Datura*.

a. Episepalous: stamens are adnate to sepals. Example: *Grevillea* (Silver oak)

b. Epitepalous (**epiphyllous**): stamens are adnate to tepals. Example: *Asparagus*.

c. Gynostegium:Connation product of stamens and stigma is called **gynostegium**. Example: *Calotropis* and Orchidaceae.

d. Pollinium: Pollen grains are fused together as a single mass Example: *Calotropis*

4.4.2 Arrangement of stamens relate to length of stamens:

1. **Didynamous:** Four stamens of which two with long filaments and two with short filaments. Example: *Ocimum*

2. **Tetradynamous**: Six stamens of which four with long filaments and two with short filaments. Example: *Brassica*.

3. **Heterostemonous**: stamens are of different lengths in the same flower. Example: *Cassia*.

4.4.3 Anther types

1. Monothecal: One lobe with two microsporangia. They are kidney shaped in a cross section. Example: Malvaceae

Figure 4.19: (a) Monothecal

Figure 4.19: (b) Dithecal

2. Dithecal: It is a typical type,having two lobes with four microsporangia.They are butterfly shaped in cross section. Example: Solanaceae.

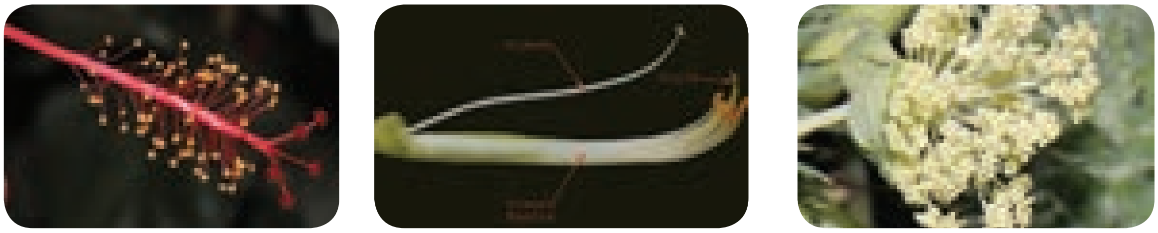
4.4.4 Anther attachment

1. Basifixed:(Innate) Base of anther is attached to the tip of filament. Example: *Datura*.

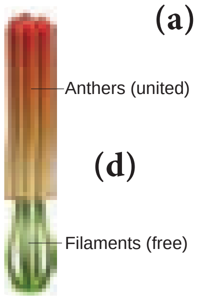
2. Dorsifixed: Apex of filament is attached to the dorsal side of the anther. Example: *Hibiscus*.

3. Versatile: Filament is attached to the anther at midpoint. Example: Grasses.

4. Adnate: Filament is continued from the base to the apex of anther. Example: *Nelumbo*



(a) (b) (c)



(d)

Figure 4.17:
(a) Monadelphous,
(b) Diadelphous,
(c) Polyadelphous
(d) Syngenesious

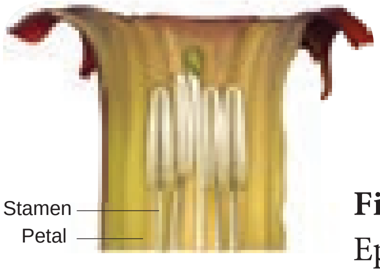


Figure 4.18: Epipetalous

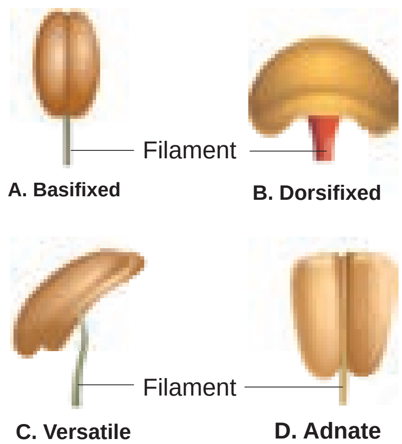


Figure 4.20: Anther attachment

4.5 Gynoecium

Gynoecium or pistil is the female reproductive part of the flower.

A pistil consists of an expanded basal portion called the ovary, an elongated section called a **style** and an apical structure that receives pollen called a **stigma**. Ovary with stipe is called **stipitate ovary.**

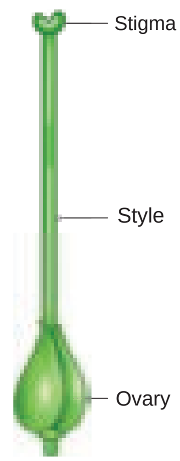


Figure 4.21: Pistil

Carpel: They are components of a gynoecium. Gynoecium is made of one or more carpels. Carpels may be distinct or connate.

4.5.1 Number of carpel

Unicarpellary (monocarpellary) Single carpel Example: Fabaceae	**Bicarpellary** Two carpels Example: Rubiaceae
Tricarpellary Three carpels Example: Cucurbitaceae	**Tetracarpellary** Four carpels Example: Lamiaceae.
Multicarpellary Many carpels Example: Nymphaeceae.	

4.5.2 Fusion of carpels

It is an important systematic character. Apocarpous gynoecium is generally thought to be ancestral condition in Angiosperms.

Apocarpous A pistil contains two or more distinct carpels. Example: *Annona*.	**Syncarpous** A pistil contains two or more carpels which are connate. Example: *Citrus*, tomato.

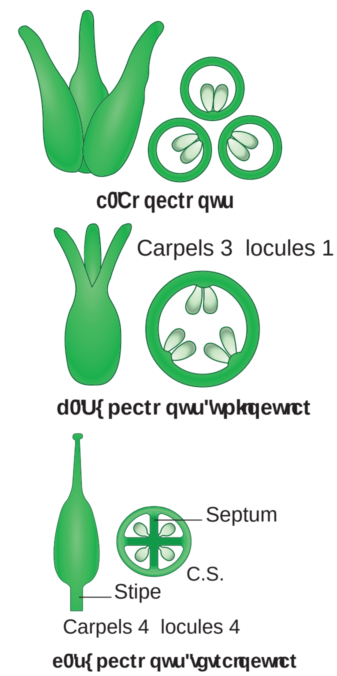


Figure 4.22: Fusion of carpels

4.5.3 Number of locules

Ovary bears ovules on a specialized tissue called **placenta**. A **septum** is a crosswall or partition of ovary. The walls of ovary and septa form a cavity called **locule**. Like that tetralocular and pentalocular ovaries are present according to the locule numbers four or five. More than one locule ovaries are called **plurilocular**.

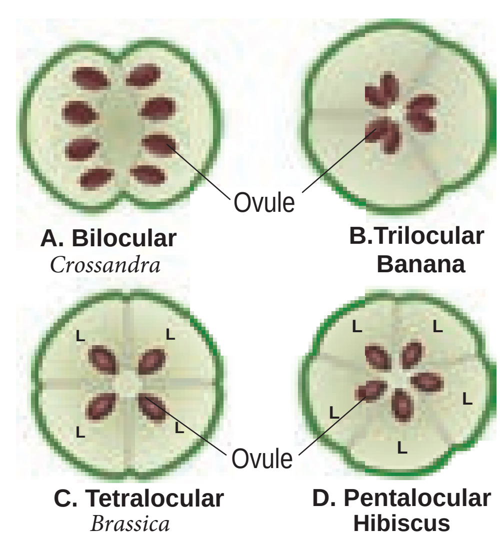


Figure 4.23: Locules

4.5.4 Extension of the condensed internode of the receptacle

1. Anthophore:The internodal elongation between calyx and corolla. Example: caryophyllaceae (*Silene conoidea*)

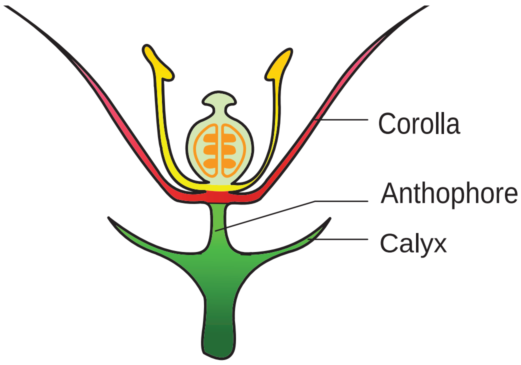


Figure 4.24: (a) Anthophore

2. Androphore: The internodal elongation between the corolla and androecium. Example: *Grewia*.

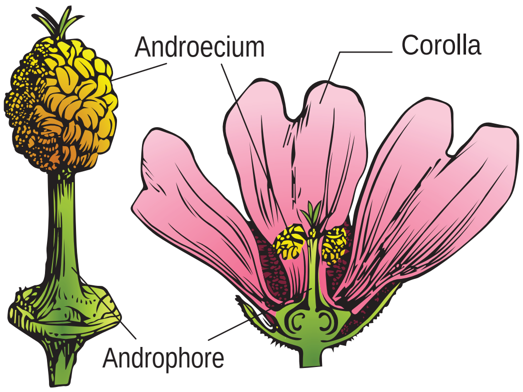


Figure 4.24: (b) Androphore

3. Gynophore: The internodal elongation between androecium and gynoecium. Example: *Capparis*.

Figure 4.24: (c) Gynophore

4. Gynandrophore or **Androgynophore**: The unified internodal elongation between corolla and androecium and androecium and gynoecium. Example: *Gynandropsis*.

Figure 4.24: (d) Androgynophore

4.5.5 Ovary position

The position or attachment of ovary relative to the other floral parts. It may be classified into

1. **Superior ovary:** It is the ovary with the sepals, petals and stamens attached at the base of the ovary.

2. **Inferior ovary:** It is the ovary with the sepals, petals and stamens attached at the apex of the ovary.

3. **Half-inferior ovary:** It is the ovary with the sepals, petals and stamens or hypanthium attached near the middle of the ovary.

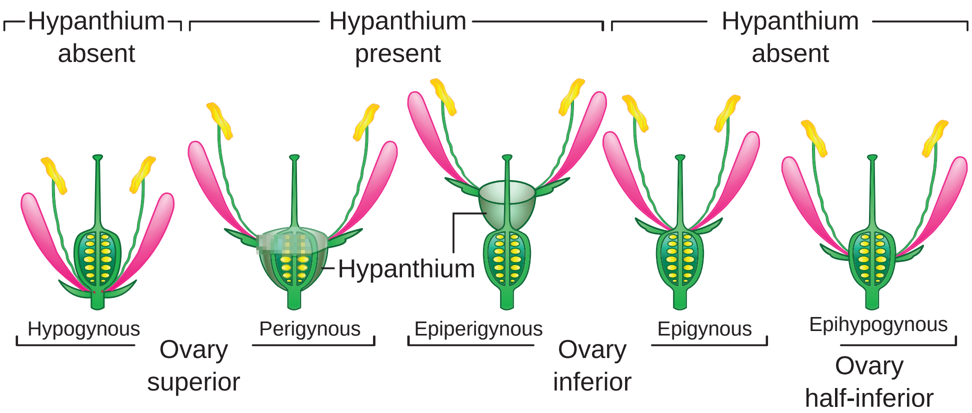


Figure 4.25: Perianth / Androecial position on thalamus

Hypogynous: The term is used for sepals, petals and stamens attached at the base of a superior ovary. Example: Malvaceae	**Epihypogynous:** The term is used for sepals, petals and stamens attached at the middle of the ovary (half-inferior). Example: Fabaceae, Rosaceae.	**Epigynous**: The term is used for sepals, petals and stamens attached at the tip of an inferior ovary. Example: Cucumber, Apple, Asteraceae.

Perigynous: The term is used for a hypanthium attached at the base of a superior ovary.	**Epiperigynous:** The term is used for hypanthodium attached at the apex of an inferior ovary.

Placentation

The mode of distribution of placenta inside the ovary

Marginal
It is with the placentae along the margin of a unicarpellate ovary.
Example: *Fabaceae.*

Superficial
Ovules arise from the surface of the septa.
Example:
Nymphaeaceae.

Free-central
It is with the placentae along the column in a compound ovary without septa.
Example:
Caryophyllaceae, Dianthus, Primerose.

Axile
The placentae arises from the column in a compound ovary with septa.
Example:
Hibiscus, Tomato Lemon.

Parietal
It is the placentae on the ovary walls or upon intruding partitions of a unilocular, compound Ovary.
Example:
Mustard, Argemone, Cucumber.

Basal
It is the placenta at the base of the ovary.
Example: *Sunflower (Asteraceae) Marigold*

4.5.6 Perianth / Androecial position on thalamus:

It describes placement of the perianth and androecium relative to the ovary and to a hypanthium, if present (Figure 4.25).

Hypanthium (Staminal disk) : a fleshy elevated often nectariferous cup like thalamus

4.6 Construction of floral diagram and floral formula

A floral formula is a simple way to explain the salient features of a flower. The floral diagram is a representation of the cross section of the flower. It represents floral whorls arranged as viewed from above. Floral diagram shows the number and arrangement of bract, bracteoles and floral parts, fusion, overlapping and placentation.

The branch that bears the flower is called **mother axis**.

The side of the flower facing the mother axis is called **posterior side**. The side facing the bract is the anterior side.

The members of different floral whorls are shown arranged in concentric rings.

Br : Bracteate.

Ebr : Ebracteate

Brl : Bracteolate

Ebrl : Ebracteolate

⊕ : Actinomorphic

% : Zygomorphic

♂ : Staminate

♀ : Pistillate

⚥ : Bisexual flower

K : Calyx, **K_5** five sepals, **aposepalous**, **$K_{(5)}$** five sepals **synsepalous**.

C : Corolla, C_5 five petals, **apopetalous**, $C_{(5)}$ five petals **sympetalous** **$C_{(2+3)}$** corolla bilabiate with upper lib two lobes.

A : Androecium **A_3** three stamens free, A_2+_2, Stamens 4, two whorls (**didynamous**) each whorl two stamens (free)

$A_{(9)+1}$ – stamens ten, two bundles **(diadelphous)** 9 stamens unite to form one bundle,1 stamen form another bundle.

$\overset{\frown}{C_5A_5}$—Epipetalous represented by an arc.

A^0 :**Staminode**(sterile stamen)

G. Gynoecium or pistil – **G_2** – Carpels two, free **(apocarpous)**

$G_{(3)}$ – Carpels three, united **(syncarpous)**

G_0 – pistillode (sterile carpel)

$\underline{G}$ – superior ovary

G inferior ovary

G– – semi-inferior ovary

∞ – Indefinite number of units

4.7 Fruits

We know about several kinds of fruits, but by botanical study we will be surprised to know the types of fruits and how they are produced by plants. Fruits are the products of pollination and fertilization, usually containing seeds inside. In common person's perspective a fruit may be defined as an edible product of the entire gynoecium and any floral part which is sweet, juicy or fleshy, coloured, aromatic and enclosing seeds. However the fruit is a fertilized and ripened ovary. The branch of horticulture that deals with the study of fruits and their cultivation is called **pomology**.

4.7.1 Structure of Fruit

Fruit has a fruit wall. It is otherwise called **pericarp**. It is differentiated into outer **epicarp**, middle **mesocarp** and inner **endocarp**. The inner part of the fruit is occupied by the seed.

4.7.2 Types of Fruit

Fruits are classified into three types:

Simple Fruits

The fruits are derived from a single ovary of a flower Example: Mango, Tomato. Simple fruits are classified based on the nature of pericarp as follows.

A. Fleshy Fruit

The fruits are derived from single pistil where the pericarp is fleshy, succulent and differentiated into

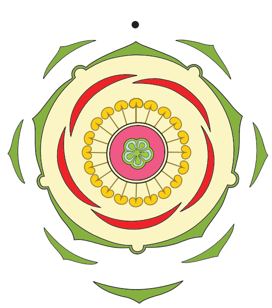


Figure 4.26: (a) *Hibiscus rosa-sinensis*

Br Brl ⊕ ⚥ $K_{(5)}$ C_5 $A_{(\infty)}$ $\underline{G}_{(5)}$

Figure 4.26: (b) *Ixora coccinea*

Br Ebrl ⊕ ⚥ $K_{(4)}$ $\overset{\frown}{C_{(4)}A_4}$ $\overline{G}_{(2)}$

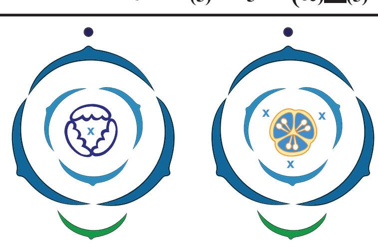


Figure 4.26: (c) *Phyllanthus amarus*

Br Ebrl ⊕ ♂ P_{3+3} $A_{(3)}$ G_0

Br Ebrl ⊕ ♀ P_{3+3} A_0 $\underline{G}_{(3)}$

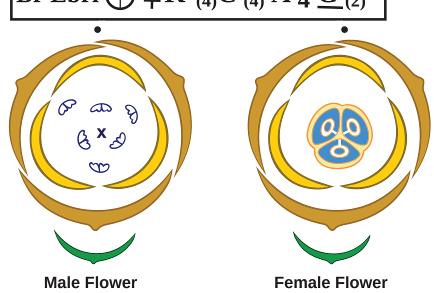


Figure 4.26: (d) *Cocos nucifera*

Br Ebrl ⊕ ♂ P_{3+3} A_{3+3} G_0

Br Ebrl ⊕ ♀ P_{3+3} A_0 $\underline{G}_{(3)}$

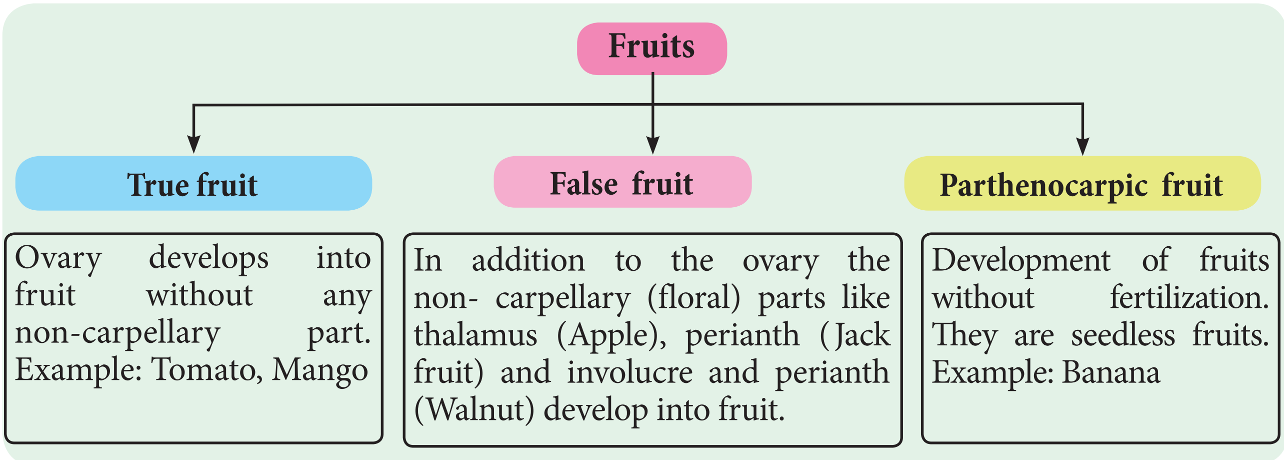


Figure 4.27: Classification of fruits based on formation

epicarp, mesocarp and endocarp. It is subdivided into the following.

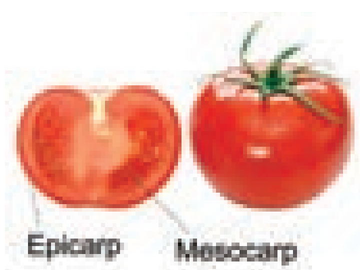
a) Berry: Fruit develops from bicarpellary or multicarpellary, syncarpous ovary. Here the epicarp is thin, the mesocarp and endocarp remain undifferentiated. They form a pulp in which the seeds are embedded. Example: Tomato, Grapes, Brinjal.

b) Drupe: Fruit develops from monocarpellary, superior ovary. It is usually one seeded. Pericarp is differentiated into outer skinny epicarp, fleshy and pulpy mesocarp and hard and stony endocarp around the seed. Example: Mango, Coconut.

c) Pepo: Fruit develops from tricarpellary inferior ovary. Pericarp turns leathery or woody which encloses, fleshy mesocarp and smooth endocarp. Example: Cucumber, Watermelon, Bottle gourd, Pumpkin.

d) Hesperidium: Fruit develops from multicarpellary, multilocular, syncarpous, superior ovary. The fruit wall is differentiated into leathery epicarp with oil glands, a middle fibrous mesocarp. The endocarp forms distinct chambers, containing juicy hairs. Example: Orange, Lemon.

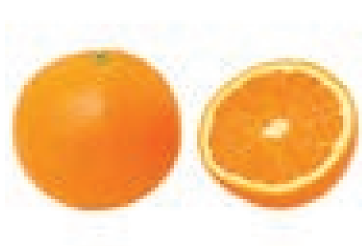
e) Pome: It develops from multicarpellary, syncarpous, inferior ovary. The receptacle



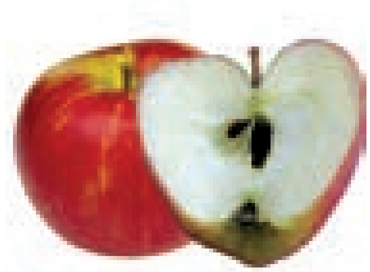
Berry (Tomato)

Drupe (Mango)

Pepo (Cucumber)



Hesperidium (Orange)



Pome (Apple)

Balausta (Pomegranate)

Figure 4.28: Simple fleshy fruits

also develops along with the ovary and becomes fleshy, enclosing the true fruit. In pome the epicarp is thin skin like and endocarp is cartilagenous. Example: Apple, Pear.

f) Balausta: A fleshy indehiscent fruit developing from multicarpellary, multilocular inferior ovary whose pericarp is tough and leathery. Seeds are attached irregularly with testa being the edible portion. Example: Pomegranate.

B. Dry Fruit

They develop from single ovary where the pericarp is dry and not differentiated into epicarp, mesocarp and endocarp. It is further subdivided into three types.

1) Dry dehiscent fruit

Pericarp is dry and splits open along the sutures to liberate seeds. They can be classified into following types.

a) Follicle: Fruit develops from mono-carpellary, superior ovary and dehisces along one suture. Example: *Calotropis.*

b) Legume or pod: Fruit develops from monocarpellary, superior ovary and dehisces through both dorsal and ventral sutures. Example: *Pisum.*

c) Siliqua: Fruit develops from bicarpellary, syncarpous, superior ovary initially one chambered but subsequently becomes two chambered due to the formation of false septum (**replum**). The fruit dehisces along two suture. Example: *Brassica.*

d) Silicula: Fruit similar to siliqua but shorter and broader. Example: *Capsella.*

e) Capsule: Fruit develops from multicarpellary, syncarpous, superior ovary. Based on the dehiscence pattern they are divided into.

i) Septicidal: Capsule splitting along septa and valves remaining attached to septa. Example: *Aristolochia.*

Follicle (*Calotropis*) **Legume** (*Pisum*)
Siliqua (*Brassica*) **Silicula** (*Capsella*)
Loculicidal (*Abelmoschus*) **Septifragal** (*Datura*)

Figure 4.29: Dry dehiscent fruit

ii) Loculicidal: Capsule splitting along locules and valves remaining attached to septa. Example: *Abelmoschus.*

iii) Poricidal: Dehiscence through terminal pores. Example: *Papaver.*

2) Dry indehiscent fruit

Dry fruit which does not split open at maturity. It is subdivided into.

a) Achene: Single seeded dry fruit developing from single carpel with superior ovary. Achenes commonly develop from apocarpous pistil, Fruit wall is free from seed coat. Example: *Clematis, Delphinium.*

b) Cypsela: Single seeded dry fruit, develops from bicarpellary, syncarpous, inferior ovary with reduced scales, hairy or feathery calyx lobes. Example: *Tridax.*

c) Caryopsis: It is a one seeded fruit which develops from a monocarpellary,

Achene (*Clematis*)

Cypsela (*Tridax*)

Caryopsis (*Oryza*)

Nut (*Anacardium*)

Samara (*Acer*)

Utricle (*Chenopodium*)

Figure 4.30: Dry indehiscent fruit

Cremocarp (*Coriandrum*)

Carcerulus (*Leucas*)

Lomentum (*Mimosa*)

Regma (*Ricinus*)

Figure 4.31: Schizocarpic Fruit

superior ovary. Pericarp is inseparably fused with seed. Example: *Oryza.*

d) Nut: They develop from mulicarpellary, syncarpous, superior ovary with hard, woody or bony pericap. It is a one seeded fruit. Example: *Anacardium.*

e) Samara: A dry indehiscent, one seeded fruit in which the pericarp devlops into thin winged structure around the fruit. Example: *Acer.*

f) Utricle: They develop from bicarpellary, unilocular, syncarpus, superior ovary with pericarp loosely enclosing the seeds. Example: *Chenopodium.*

3) Schizocarpic Fruit

This fruit type is intermediate between dehiscent and indehiscent fruit. The fruit instead of dehiscing, splits into number of segments, each containing one or more seeds. They are of following types.

a) Cremocarp: Fruit develops from bicarpellary, syncarpous, inferior ovary and splitting into two one seeded segments known as **mericarps**. Example: Coriander.

b) Carcerulus: Fruit develops from bicarpellary, syncarpous, superior ovary and splitting into four one seeded segments known as **nutlets**. Example: *Leucas.*

c) Lomentum: The fruit is derived from monocarpellary, unilocular ovary. A leguminous fruit, constricted between the seeds to form a number of one seeded compartments that separate at maturity. Example: *Mimosa.* `

d) Regma: They develop from tricarpellary, syncarpous, superior, trilocular ovary and splits into one-seeded cocci which remain attached to carpophore. Example: *Ricinus.*

Aggregate Fruits

Aggregate fruits develop from a single flower having an apocarpous pistil. each of the free carpel develops into a simple fruitlet. A collection of simple fruitlets makes an **Aggregate fruit**. An individual ovary develops into a drupe, achene, follicle or berry. An aggregate of these fruits borne by a single flower is known as an **etaerio**. Example: *Annona, Polyalthia.*

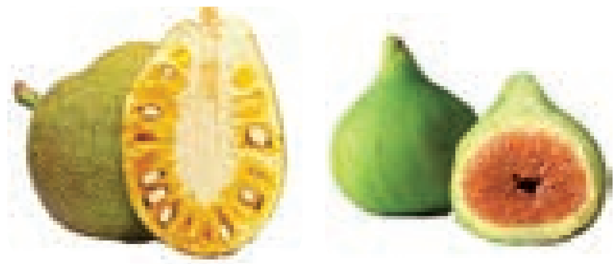
Annona *Polyalthia*

Figure 4.32: Aggregate Fruits

Multiple or Composite Fruit

A Multiple or composite fruit develops from the whole inflorescence along with its peduncle on which they are borne.

a) Sorosis: A fleshy multiple fruit which develops from a spike or spadix. The flowers fused together by their succulent perianth and at the same time the axis bearing them become fleshy or juicy and the whole inflorescence forms a compact mass. Example: Pine apple, Jack fruit.



Sorosis (Jack fruit) **Syconus** (*Ficus*)

Figure 4.33: Multiple or Composite fruit

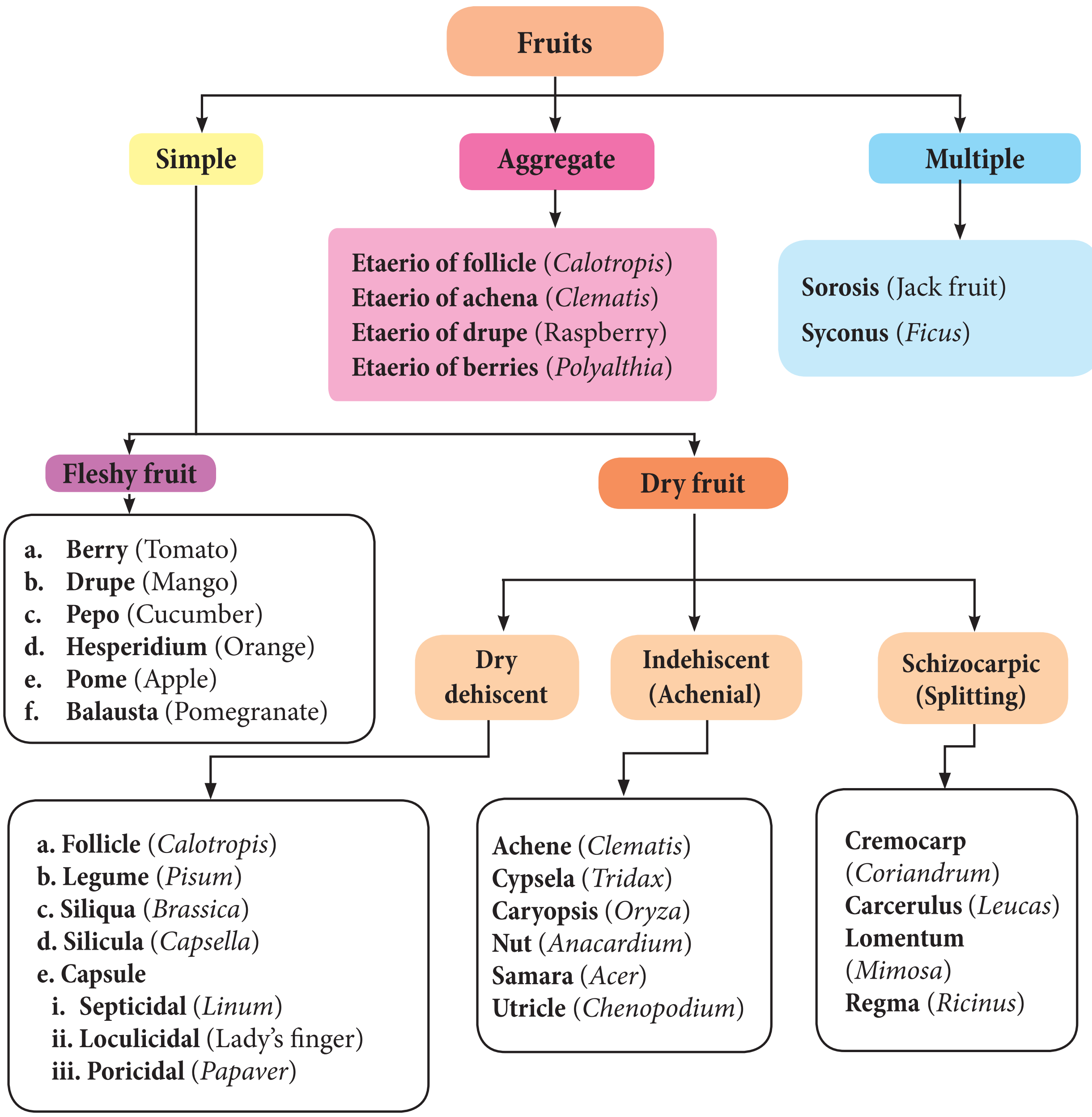


Figure 4.34: Types of fruits

Edible Parts of Fruit			
Type of Fruit	**Common Name**	**Botanical Name**	**Edible Part**
Berry	Tomato	*Lycopersicon esculentum*	Whole fruit
	Brinjal	*Solanum melongena*	Tender fruit
	Guava	*Psidium guajava*	Whole fruit
Drupe	Mango	*Mangifera indica*	Mesocarp
	Coconut	*Cocos nucifera*	Endosperm (both cellular and liquid)
	Date	*Phoenix dactylifera*	Pericarp
Pepo	Cucumber	*Cucumis sativus*	Whole fruit
Hesperidium	Citrus (Orange, Lemon)	*Citrus sinensis*	Juicy hairs on the endocarp
Pome	Apple	*Pyrus malus*	Thalamus (false fruit) and a part of pericarp
Balausta	Pomegranate	*Punica granatum*	Succulent testa of the seeds
Legume	Pea	*Pisum sativum*	Seed
Siliqua	Mustard	*Brassica campestris*	Seed
Poricidal capsule	Poppy	*Papaver somniferum*	Seeds
Loculicidal capsule	Lady's finger	*Abelmoschus esculentus*	Tender fruit
Cypsela	Sunflower	*Helianthus annuus*	Seed (for oil)
Caryopsis	Maize	*Zea maize*	Seed
	Paddy	*Oryza sativa*	Seed
Nut	Cashew nut	*Anacardium occidentale*	Pedicel (false fruit) and cotyledons (true fruit)
Cremocarp	Coriander	*Coriandrum sativum*	Mericarps
Lomentum	Touch-me-not	*Mimosa pudica*	Seed
Aggregate fruit	Custard apple	*Annona squamosa*	Pericarps
Composite fruits			
Sorosis	Jack fruit	*Artocarpus heterophyllus*	Perianth, seeds
	Pine apple	*Ananas comosus*	Perianth, rachis
	Mulberry	*Morus alba*	Whole fruit
Syconus	Fig	*Ficus carica*	Whole inflorescence

DO YOU KNOW?

- *Lodoicea maldivica* is the world's largest fruit. The size of mature fruit is 40–50 cm in diameter and weights 15–30 kg.
- Progesterone which supports pregnancy is obtained naturally from a fruit of *Balanites aegyptiaca* and *Trigonella foenum - graecum*.

b) Syconus: A multiple fruit which develops from hypanthodium inflorescence. The receptacle develops further and converts into fleshy fruit which encloses a number of true fruit or achenes which develops from female flower of hypanthodium inflorescence. Example: *Ficus*

4.7.3 Functions of Fruit

1. Edible part of the fruit is a source of food and gives energy for animals.
2. They are source of many chemicals like sugar, pectin, organic acids, vitamins and minerals.
3. The fruit protects the seeds from unfavourable climatic conditions and animals.

4. Both fleshy and dry fruits help in the dispersal of seeds to distant places.
5. In certain cases, fruit may provide nutrition to the developing seedling.
6. Fruits provide source of medicine to human.

> **DO YOU KNOW?**
>
> - *Lupinus arcticus* (legume family) of Artic Tundra is the oldest viable seed remained dormant for 10,000 years.
> - *Pheonix dactylifera* (date palm) of king Herod's palace near dead sea has viable seed for 20,000 years.
> - Powdered seeds of *Moringa oleifera* is used to purify water.

4.8 Seed

Do all fruits contain seeds? No, triploid fruits do not. The seed is a fertilized mature ovule which possess an embryonic plant, usually stores food material and has a protective coat. After fertilization, changes occur in various parts of the ovule and transforms into a seed.

4.8.1 Types of Seed

I. Based on the number of cotyledons two types of seeds are recognized.

i. Dicotyledonous seed: Seed with two cotyledons.

ii. Monocotyledonous seed: Seed with one cotyledon.

II. Based on the presence or absence of the endosperm the seed is of two types.

i. Albuminous or Endospermous seed: The cotyledons are thin, membranous and mature seeds have endosperm persistent and nourishes the seedling during its early development. Example: Castor, sunflower, maize.

ii. Ex-albuminous or non-endospermous seed: Food is utilized by the developing embryo and so the mature seeds are without endosperm. In such seeds, colyledons store food and become thick and fleshy. Example: Pea, groundnut.

4.8.2 Significance of Seeds:

- The seed encloses and protects the embryo for next generation.
- It contains food for the development of embryo.
- It is a means for the dispersal of new individuals of the species.
- A seed is a means for perpetuation of the species. It may lie dormant during unfavorable conditions but germinates on getting suitable conditions.
- Seeds of various plants are used as food, both for animals and men.
- They are the basis of agriculture.
- Seeds are the products of sexual reproduction so they provide genetic variation and recombination in a plant.

> **Activity**
>
> Prepare a diet chart to provide balanced diet to an adolescent (a school going child) which includes food items (fruits, vegetable and seeds) which are non - expensive and are commonly available.

Summary

Inflorescence is a group of flowers present on a common stalk. Inflorescence may be classified into 3 types based on position. Inflorescence classified into racemose, cymose, mixed and special type based on the flower arrangement and branching of axis. Flower is a modified shoot and meant for sexual reproduction. Flower has various parts to enhance reproduction. Flower can be explained by its sex and symmetry. Calyx is outermost whorl of flower and many types. Corolla is second whorl of flower and used for pollination. Corolla may be united or free and has various forms in different flowers. Aestivation is arrangement of sepals, petals in bud condition and is of many types. Androecium is the male part of flower and made up of stamens. Stamens contain filament,anther and connective.

Gynoecium is the female part of flower. Ovary, style and stigma are parts of pistil.According to number of carpels it is divided into monocarpellary, bicarpellary etc. It may be apocarpous or syncarpous. Locule number may be one to many.

The ovary is superior or inferior or semi inferior. Mode of distribution of placenta inside the ovary is placentation. Construction of floral diagram and floral formula for given flower with some examples.

Fruits are the products of pollination and fertilization. Fruit developed from single ovary of flower is called **simple fruit**. Simple fruits are two types based on the fruit wall as simple fleshy and simple dry. An intermediate between dehiscent and indehiscent fruit is called schizocarpic fruit. The simple fruits could be fleshy or dry which could again be dehiscent or indehiscent. Fruits that are developed from multicarpellary, apocarpus pistil is called aggregate. Multiple or composite fruit develops from the flowers of the complete inflorescence. Seed is a ripened ovule which contains the embryo or the miniature of plant body. Seeds with one cotyledon are monocotyledonous and with two cotyledons are dicotyledonous.

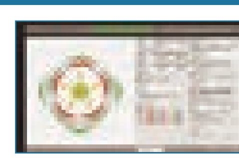
Evalution

1. Vexillary aestivation is characteristic of the family
   a. Fabaceae b. Asteraceae
   c. Solanaceae d. Brassicaceae
2. Gynoecium with united carples is termed as
   a. Apocarpous b. Multicarpellary
   c. Syncarpous d. None of the above
3. Aggregate fruit develops from
   a. Multicarpellary, apocarpous ovary
   b. Multicarpellary, syncarpous ovary
   c. Multicarpellary ovary
   d. Whole inflorescence
4. In an inflorescence where flowers are borne laterally in an acropetal succession the position of the youngest floral bud shall be
   a. Proximal b. Distal
   c. Intercalary d. Anywhere
5. A true fruit is the one where
   a. Only ovary of the flower develops into fruit
   b. Ovary and calyx of the flower develops into fruit
   c. Ovary, calyx and thalamus of the flower develops into fruit
   d. All floral whorls of the flower develops into fruit
6. Find out the floral formula for a bisexual flower with bract, regular, pentamerous, distinct calyx and corolla, superior ovary without bracteole.
7. Give the technical terms for the following: -
   a. A sterile stamen
   b. Stamens are united in one bunch
   c. Stamens are attached to the petals
8. Explain the different types of placentation with example.
9. Differentiate between aggregate fruit with multiple fruit.
10. Explain the different types of fleshy fruit with suitable example.

ICT Corner

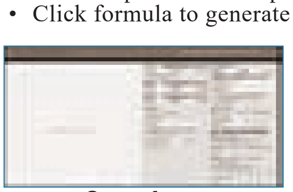
Floral Diagram and Floral Formula

Let's generate **Floral diagram and Floral formula**. →

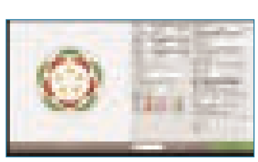


Steps
- Scan the QR code
- Enter sepal, petal, androecium & Gynoecium
- Select enable colour
- Select shape of sepal & petal, fused (if so)
- Enter carpel number & position submit the from
- Click formula to generate floral formula

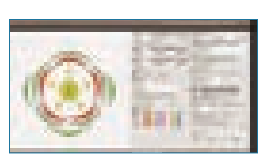
Activity
- Make floral diagram and formula of various flower by changing numbers and positions of floral parts.
- You can edit the floral diagram using **Inkscape**, which is denoted in help tap.



Step 1



Step 2



Step 3

URL: http://kvetnidiagram.8u.cz/index_en.php

* Pictures are indicative only

Unit II: Plant Morphology and Taxonomy of Angiosperm

Chapter 5

Taxonomy and Systematic Botany

Learning Objectives

The learner will be able to,

- *Differentiate systematic botany from taxonomy.*
- *Explain the ICN principles and to discuss the codes of nomenclature.*
- *Compare the national and international herbaria.*
- *Appreciate the role of morphology, anatomy, cytology, DNA sequencing in relation to Taxonomy,*
- *Describe diagnostic features of families Fabaceae, Solanaceae and Liliaceae.*

Chapter Outline

5.1 Taxonomy and Systematics
5.2 Taxonomic Hierarchy
5.3 Concept of species – Morphological, Biological and Phylogenetic
5.4 International Code of Botanical Nomenclature
5.5 Taxonomic Aids
5.6 Botanical Gardens
5.7 Herbarium – Preparation and uses
5.8 Classification of Plants
5.9 Need for classification
5.10 Types of classification
5.11 Modern trends in taxonomy
5.12 Cladistics
5.13 Selected Families of Angiosperms

Plants are the prime companions of human beings in this universe. Plants are the source of food, energy, shelter, clothing, drugs, beverages, oxygen and the aesthetic environment. Taxonomic activity of human is not restricted to living organisms alone. Human beings learn to identify, describe, name and classify food, clothes, books, games, vehicles and other objects that they come across in their life. Every human being thus is a taxonomist from the cradle to the grave.

Taxonomy has witnessed various phases in its early history to the present day modernization. The need for knowledge on plants had been realized since human existence, a man started utilizing plants for food, shelter and as curative agent for ailments.

Theophrastus (372 – 287 BC), the Greek Philosopher known as "**Father of Botany**". He named and described some 500 plants in his *"De Historia Plantarum"*. Later Dioscorides (62 – 127 AD), Greek physician, described and illustrated in his famous **"Materia medica"** and described about 600 medicinal plants. From 16^{th} century onwards Europe has witnessed a major developments in the field of Taxonomy. Some of the key contributors include Andrea Caesalpino, John Ray, Tournefort, Jean Bauhin and Gaspard Bauhin. Linnaeus ***'Species Plantarum'*** (1753) laid strong foundation for the binomial nomenclature.

Taxonomy is no more classical morphology based discipline but become a dynamic and transdisciplinary subject, making use of many branches of botany such as Cell Biology, Physiology, Biochemistry, Ecology, Pharmacology and also Modern Biotechnology, Molecular Biology and Bioinformatics. It helps to understand biodiversity, wildlife, forest management of natural resources for sustainable use of plants and eco restoration.

5.1 Taxonomy and Systematics

The word taxonomy is derived from Greek words ***"taxis"*** (arrangement) and ***"nomos"*** (rules or laws). Taxonomy is defined as as "the science dealing with the study of classification including the bases, principles, rules and procedures".

Simpson (1961) defined Systematics as, "Scientific study of the kinds and diversity of organisms and all relationships among them". Though there are two terms are used in an interchangeable way, they differ from each other.

5.2 Taxonomic Hierarchy

Taxonomic hierarchy was introduced by Carolus Linnaeus. It is the arrangement of various taxonomic levels in descending order starting from kingdom up to species.

Differences between Taxonomy and Systematics

Taxonomy	Systematics
• Discipline of classifying organisms into taxa. • Governs the practices of naming, describing, identifying and specimen preservation. • Classification + Nomenclature = Taxonomy	• Broad field of biology that studies the diversification of species. • Governs the evolutionary history and phylogenetic relationship in addition to taxonomy. • Taxonomy + Phylogeny = Systematics

Species is the lowest of classification and shows the high level of similarities among the organisms. For example, *Helianthus annuus* and *Helianthus tuberosus*. These two species differ in their morphology. Both of them are herbs but *Helianthus tuberosus* is a perennial herb.

Genus consists of multiple species which have similar characters but differ from the species of another genus. Example: *Helianthus*, *Tridax.*

Family comprises a number of genera which share some similarities among them. Example: Asteraceae.

Order includes group of families which show less similarities among them.

Class consists of group of orders which share few similarities.

Division is the next level of classification that consists of number of classes.

Example: Magnoliophyta.

Kingdom is the highest level or rank of the classification. Example: Plantae

Rank	Ending	Example
Kingdom	-	Plantae
Phylum = Division	-phyta	Magnoliophyta
Subphylum = Sub division	-phytina	Magnoliophytina
Class	-opsida	Asteropsida
Sub class	-idea	Asteridea
Order	-ales	Asterales
Suborder	-ineae	Asterineae
Family	-aceae	Asteraceae
Sub family	-oideae	Asteroideae
Tribe	-eae	Heliantheae
Genus	-	Helianthus
Sub genus	-	*Helianthus* subg. *Helianthus*
Series	-	*Helianthus* ser. *Helianthus*
Species	-	*Helianthus annuus*

5.3 Concept of species-Morphological, Biological and Phylogenetic

Species is the fundamental unit of taxonomic classification. Species is a group of individual organisms which have the following characters.

1. A population of organisms which closely resemble each other more than the other population.
2. They descend from a common ancestor.
3. In sexually reproducing organisms, they interbreed freely in nature, producing fertile offspring.

Species concepts can be classified into two general groups. Concept emphasizing process of evolution that maintains the species as a unit and that can result in evolutionary divergence and speciation. Another concept emphasises the product of evolution in defining a species.

Types of Species

There are different types of species and they are as follows:

1. Process of evolution - Biological Species
2. Product of evolution - Morphological Species and Phylogenetic Species

Morphological Species (Taxonomic species)

When the individuals are similar to one another in one or more features and different from other such groups, they are called **morphological species.**

Biological Species (Isolation Species)

According to **Ernest Mayr** 1963,“ these are groups of populations that interbreed and are reproductively isolated from other such groups in nature”.

Phylogenetic Species

This concept was developed by **Meglitsch** (1954), **Simpson** (1961) and **Wiley** (1978). Wiley defined phylogenetic species as “an evolutionary species is a single lineage of ancestor descendent populations which maintains its identity from other such lineages which has its own evolutionary tendencies and historical fate”.

5.4 International Code of Botanical Nomenclature (ICBN)

Assigning name for a plant is known as **Nomenclature.** This is based on the rules and recommendations of the International Code of Botanical Nomenclature. ICBN deals with the names of existing (living) and extinct (fossil) organisms. The elementary rule of naming of plants was first proposed by **Linnaeus** in 1751 in his *Philosophia Botanica*. In 1813 a detailed set of rules regarding plant nomenclature was given by **A.P. de Candolle** in his famous work “*Theorie elementaire de la botanique*”. Then the present ICBN was evolved by following the same rules of **Linnaeus, A.P. de Candolle** and his son **Alphonse de Candolle.**

ICBN due to specific reasons and in order to separate plant kingdom from other organisms, is redesignated as ICN. The International Botanical Congress held in Melbourne in July 2011 brought this change. The ICN stands for International Code of Nomenclature for Algae, Fungi and Plants.

ICN Principles

International Code of Nomenclature is based on the following six principles.

1. Botanical nomenclature is independent of zoological and bacteriological nomenclature.
2. Application of names of taxonomic group is determined by means of nomenclatural types.
3. Nomenclature of a taxonomic group is based on priority of publication.
4. Each taxonomic group with a particular circumscription, position and rank can bear only one correct name.
5. Scientific names of taxonomic groups are treated as Latin regardless of their derivation.
6. The rules of nomenclature are retroactive unless expressly limited.

Codes of Nomenclature

ICN has formulated a set of rules and recommendations dealing with the botanical name of plants. International Botanical Congress is held at different places every six years. Proposals for nomenclatural changes and changes in rules are discussed and implemented. Changes are published in their website.

18th International Botanical Congress held in 2011at Melbourne, Australia made the following major changes.

1. The code now permits electronic publication of names of new taxa.
2. Latin diagnosis or description is not mandatory and permits the use of English or Latin for the publication of a new name (Art-39).
3. "One fungus, one name" and "one fossil one name" are important changes, the concept of anamorph and teleomorph (for fungi) and morphotaxa (for fossils) have been eliminated. (Previously, sexual and asexual stages of the fungus/ fossils were provided with different names).

> **Anamorph** – Asexual reproductive stage of fungus.
>
> **Teleomorph** – Sexual reproductive stage of fungus.

4. As an experiment with "registration of names" new fungal descriptions require the use of an identifier from a "recognized repository". There are two recognized repositories **Index fungorum** and **Myco Bank**.

19th International Botanical Congress was held in Shenzhen in China in 2017. Changes accepted by International Botanical Congress are yet to be published.

Vernacular names (Common names)

Vernacular names are known as **common names.** They are very often descriptive and poetic references to plants. Common name refer to more than one plant or many plants may have same common name. These names are regional or local and are not universal. Example: *Albizia amara* . L belongs to *Mimosaceae* is called as *Usilai* in South Tamilnadu and *Thurinji* in North Tamilnadu.

> **Activity**
>
> Write common name and scientific name of 10 different plants around your home.

Scientific Names / Botanical Names

Each and every taxon as per the ICN (species, genus, family etc) can have only one correct scientific name. Scientific name of a species is always a binomial. These names are universally applied. Example: *Oryza sativa L.* is the scientific name of paddy.

Polynomial

Polynomial is a descriptive phrase of a plant. Example: *Ranunculus calycibus retroflexis pedunculis falcatis caule erecto folius compositis*. It means butter cup with reflexed sepals, curved flower stalks, erect stem and compound leaves. Polynomial system of naming a plant is replaced by a binomial system by Linnaeus.

Binomial

Binomial nomenclature was first introduced by **Gaspard Bauhin** and it was implemented by **Carolus Linnaeus**. Scientific name of a species consists of two words and according to binomial nomenclature, the first one is called **genus name** and second one is **specific epithet.** Example: *Mangifera indica*. *Mangifera* is a genus name and *indica* is specific epithet. This system is in vogue even now.

Author citation

This refers to valid name of the taxa accompanied by the author's name who published the name validly. Example: *Solanum nigrum* L. There are two types of author citation.

Single author: When a single author proposed a valid name, the name of the author alone is accompanied by his abbreviated name. Example: *Pithecellobium cinereum* Benth.

Multiple authors: When two or more authors are associated with a valid publication of name, their names should be noted with the help of Latin word *et* or &.

Example: *Delphinium viscosum* Hook. f. *et* Thomson.

Standard form of author's abbreviations has to be followed.

Author	Standard form of Abbreviation
Linnaeus	L.
G.Bentham	Benth.
William Hooker	Hook.
Robert Brown	R.Br.
J.P.Lamarck	Lamk.
A.P.de Candolle	DC.
Wallich	Wall.
Alphonse de Candolle	A. DC.

5.5 Taxonomic Aids

Taxonomic aids are the tools for the taxonomic study. Some techniques, procedures and stored information that are useful in identification and classification of organisms are called **taxonomical aids.** They are required in almost all branches of biological studies for their proper identification and for finding their relationship with others. Some of the taxonomical aids are keys, flora, revisions, monograph, catalogues, herbarium, botanical gardens etc.

Keys

Taxonomic keys are the tools for the identification of unfamiliar plants. These keys are based on characters which are stable and reliable. The most common type of key is a dichotomous key. It consists of a sequence of two contrasting statements. A pair of contrasting statements is known as **couplet.** Each statement is known as **lead.** The plant is correctly identified with keys by narrowing down the characters found in plant.

Example:

1. a) Flowers cream-coloured; fruiting calyx enclosing the berry ......*Physalis*

   b) Flowers white or violet; fruiting calyx not enclosing the berry *2*

2. a) Corolla rotate; fruit a berry .....*Solanum*

   b) Corolla funnel-form or salver-form; fruit a capsule: *3*

3. a) Radical leaves present; flowers in racemes; fruits without prickles ...*Nicotiana*

   b) Radical leaves absent; flowers solitary; fruits with prickles .....*Datura*

Another type of key for identification is the **Polyclave** or **Multi-entry key**. It consists of a list of numerous character states. The user selects all states that match the specimen. Polyclave keys are implemented by a computer algorithm.

5.6 Botanical Gardens

In true sense all gardens are not botanical gardens. Botanical gardens are centres for collection of plants in their various stages of living. Gardens existed for growing ornamental plants for aesthetic value, religious and status reasons. The famous "hanging gardens" of Babylon in Mesopotamia is an example. For the purpose of science and education the first garden was maintained by **Theophrastus** in his public lecture hall at Athens.

First modern botanical garden was established by **Luca Ghini** (1490-1556) a professor of Botany at Pisa, Italy in 1544.

Botanical garden contains special plant collections such as cacti, succulent, green house, shade house, tropical, alpine and exotic plants. Worldwide there are about 1800 botanical gardens and arboreta.

Role of Botanical Garden: Botanical Gardens play the following important roles.

1. Gardens with aesthetic value which attract

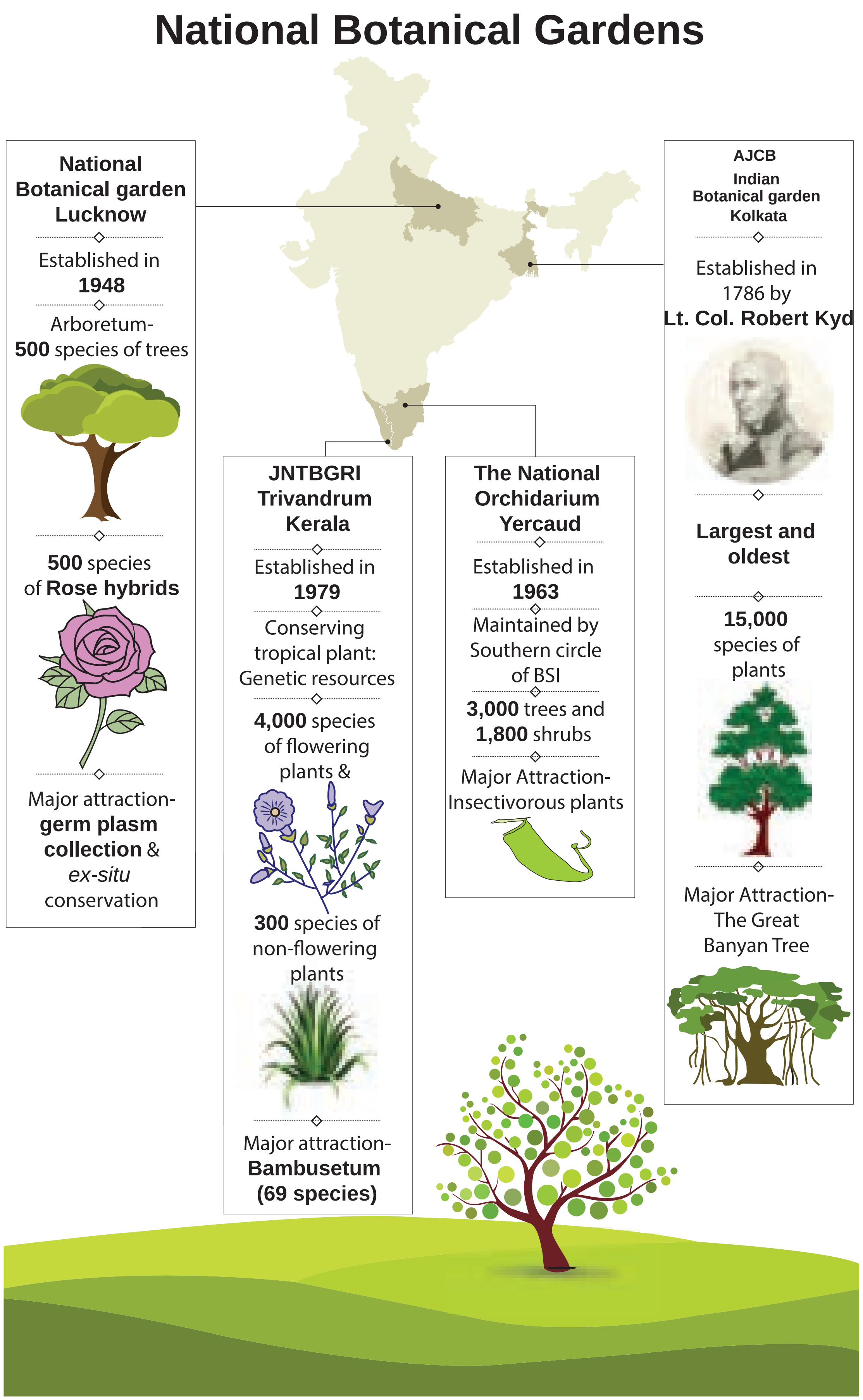


Figure 5.1: National Botanical Garden

a large number of visitors. For example, the Great Banyan Tree *(Ficus benghalensis)* in the Indian Botanical Garden at Kolkata.

2. Gardens have a wide range of species and supply taxonomic material for botanical research.
3. Garden is used for self-instruction or demonstration purposes.
4. It can integrate information of diverse fields like Anatomy, Embryology, Phyto-chemistry, Cytology, Physiology and Ecology.
5. Act as a conservation centre for diversity, rare and endangered species.
6. It offers annual list of available species and a free exchange of seeds.
7. Botanical garden gives information about method of propagation, sale of plant material to the general public.

Royal Botanic garden, Kew- England

Figure 5.2: Royal Botanic garden, Kew - England

Royal Botanic garden Kew- England is a non- departmental public body in the United Kingdom. It is the largest botanical garden in the world, established in 1760, but officially opened in the year 1841.

Plant collections include Aquatic garden, Arboretum with 14,000 trees, Bonsai collection, Cacti collection and Carnivorous plant collection.

5.7 Herbarium – Preparation and uses

Herbaria are store houses of preserved plant collections. Plants are preserved in the form of pressed and dried specimens mounted on a sheet of paper. Herbaria act as a centre for research and function as sources of material for systematic work.

Preparation of herbarium Specimen

Herbarium Specimen is defined as a pressed and dried plant sample that is permanently glued or strapped to a sheet of paper along with a documentation label.

Preparation of herbarium specimen includes the following steps.

1. **Plant collection:** Field collection, Liquid preserved collection, Living collection, Collection for molecular studies.
2. **Documentation of field site data**
3. **Preparation of plant specimen**
4. **Mounting herbarium specimen**
5. **Herbarium labels.**
6. **Protection of herbarium sheets against mold and insects**

Uses of Herbarium

1. Herbarium provides resource material for systematic research and studies.
2. It is a place for orderly arrangement of voucher specimens.
3. Voucher specimen serves as a reference for comparing doubtful newly collected fresh specimens.
4. Voucher specimens play a role in studies like floristic diversity, environmental assessment, ecological mechanisms and survey of unexplored areas.
5. Herbarium provides opportunity for documenting biodiversity and studies related to the field of ecology and conservation biology.

Kew Herbarium

Kew Garden is situated in South West London that houses the "largest and most diverse botanical and mycological collections in the world" founded in the year 1840. Living collection includes more than 30,000 different kinds of plants. While herbarium which is one of the largest in the world has over seven million preserved plant specimens. The library contains more than 7,50,000 volumes and the

Preparation of herbarium Specimen

Plant Collection
Plant specimen with flower or fruit is collected

↓

Documentation of field site data
Certain data are to be recorded at the time of plant collection. It includes date, time, country, state, city, specific locality information, latitude, longitude, elevation and land mark information. These data will be typed onto a herbarium label.

↓

Preparation of plant specimen
Plant specimen collected from the field is pressed immediately with the help of portable field plant press. plant specimen is transferred to a standard plant press (12” x 18”) which between two outer 12” x 18” frames and secured by two straps.

↓

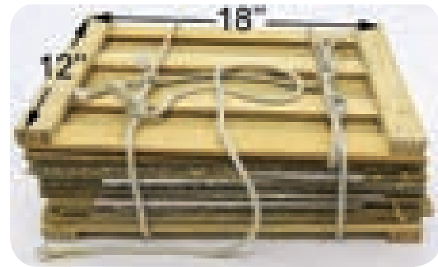
Mounting herbarium specimen
The standard size of herbarium sheet is used for mounting the specimen (29cm x 41cm). specimens are affixed to herbarium sheet with standard white glue or solution of Methyl cellulose.

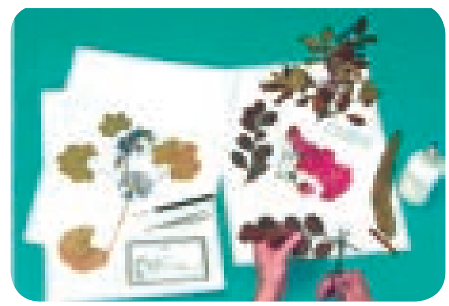
↓

Herbarium label
Herbarium label size is generally 4-5” wide and 2-3” tall. A typical label contains all information like habit, habitat, vegetation type, land mark information, latitude, longitude, image document, collection number, date of collection and name of the collector.

↓

Protection of herbarium sheets against mold and insects
Apply cation of 2% Mercuric chloride, Naphthalene, DDT, carbon disulphide. Fumigation using formaldehyde. Presently deep freezing(**-20ºC**) method is followed throughout the world.





DO YOU KNOW?

World’s smallest water – lily *Nymphaea thermarum* was saved from extinction when it was grown from seed at Kew in 2009.

International Herbarium

S.No	Herbarium	Year Established	Acronym	Number of specimens
1.	*Museum National d'Histoire Naturelle*, Paris, France	1635	P ,PC	10,000,000
2.	New York Botanical Garden, Bronx, New York, U.S.A	1891	NY	72,00,000
3.	Komarov Botanical Institute, St.Petersburg (Leningrad), Russia	1823	LE	71,60,000
4.	Royal Botanic Gardens, Kew, England, U.K	1841	K	70,00,000

National Herbarium

S.No	Herbarium	Year Established	Acronym	Number of specimens
1.	Madras Herbarium BSI campus, Coimbatore	1955	MH	4,08,776
2.	Central National Herbarium West Bengal	1795	CAL	2,00,000
3.	Jawaharlal Nehru Tropical Botanical Garden and Research Institute Thiruvananthapuram, Kerala	1979	TBGRI	30,500
4.	Presidency College Herbarium, Chennai.	1844	PCM	15,000

illustrations and also a collection of more than 1,75,000 prints, books, photographs, letters, manuscripts, periodicals, maps and botanical illustrations.

5.8 Classification of Plants

Imagine walking into a library and looking for a Harry Potter story book. As you walk into the library you notice that it is under renovation and all the books are scattered. Will it not be hard to find the exact book you are looking for? It might take hours. So you decide to come the next day when all the books are arranged according to the genres. One rack for adventure, another for Detective, Fantasy, Horror, Encyclopaedia and so on. You automatically know Harry Potter is in the fantasy section and it takes less than ten minutes for you to find it. That is because the books have been classified and arranged according to a system.

Similarly there is a vast assemblage of group of plants in the world. Is it possible to study and understand all of these? No. Since it is difficult to study all these plants together, it is necessary to device some means to make this possible.

Classification is essential to biology because there is a vast diversity of organisms to sort out and compare. Unless they are organized into manageable categories it will be difficult for identification. Biological classifications are the inventions of biologists based upon the best evidence available. The scientific basis for cataloguing and retrieving information about the tremendous diversity of flora is known as **classification**.

Classification paves way for the arrangement of organisms into groups on the basis of their similarities, dissimilarities and relationships. The purpose of classification is to provide a systematic arrangement

Botanical Survey of India

On 13 February 1890, a survey was formally constituted and designated as the Botanical Survey of India. After independence, the need was felt for a more comprehensive documentation of the country's plant resources to boost the economy. Padmashree **Dr.E.K.Janaki Ammal** was appointed as officer on special Duty on 14th Oct 1952. Then reorganization plan was finally approved by the Govt. of India on 29 March 1954, with Calcutta as the headquarters of BSI. Jammu Tavi Botanical Garden has been named after Dr. E. K. Janaki Ammal.

Figure 5.3: Dr. E.K. Janaki Ammal

expressing the relationship between the organisms.

Taxonomists have assigned a method of classifying organisms which are called **ranks.** These taxonomical ranks are hierarchical. The scheme of classification has to be flexible, allowing newly discovered living organisms to be added where they fit best.

5.9 Need for Classification

- Understanding the classification of organisms can give an insight into other fields and has significant practical value.
- Classification helps us to know about different taxa, their phylogenetic relationship and exact position.
- It helps to train the students of plant sciences with regard to the diversity of organisms and their relationship with other biological branches.

5.10 Types of classification

Taxonomic entities are classified in three ways. They are artificial classification, natural classification and phylogenetic classification.

5.10.1 Artificial system of classification

24 classes recognized by Linnaeus in his *Species Plantarum* (1753) on the basis of stamens.

No.	Classes	Characters
1	Monandria	stamen one
2	Diandria	stamens two
3	Triandria	stamens three
4	Tetrandria	stamens four
5	Pentandria	stamens five
	up to 24th class Cryptogamia	flowerless plants

Carolus Linnaeus (1707 -1778) was a great Swedish Botanist and said to be the "**Father of Taxonomy**." He outlined an artificial system of classification in "***Species Plantarum***" in 1753, wherein he listed and described 7,300 species and arranged in 24 classes mostly on the basis of number, union (adhesion and cohesion), length, and distribution of stamens. The classes were further subdivided on the basis of carpel characteristics into orders. Hence the system of classification is also known as **sexual system of classification**.

Figure 5.4: Carolus Linnaeus

This system of classification though artificial, was continued for more than 100 years after the death of Linnaeus, due to its simplicity and easy way of identification of plants.

However the system could not hold good due to the following reasons.

1. Totally unrelated plants were kept in a single group, whereas closely related plants were placed in widely separated groups. Example:
   a. Zingiberaceae of monocotyledons and Anacardiaceae of dicotyledonous were placed under the class **Monandria** since these possess single stamens.
   b. *Prunus* was classified along with *Cactus* because of the same number of stamens.

No attempts were made to classify plants based on either natural or phylogenetic relationships which exist among plant groups.

5.10.2 Natural system

Botanists who came after Linnaeus realised that no single character is more important than the other characters. Accordingly an approach to a natural system of classification sprouted in France. The first scheme of classification based on overall similarities was presented by **Antoine Laurent de Jessieu** in 1789.

Bentham and Hooker system of classification

Figure 5.5: George Bentham and J.D. Hooker

A widely followed natural system of classification considered the best was proposed by two English botanist **George Bentham** (1800 – 1884) and **Joseph Dalton Hooker** (1817–1911). The classification was published in a three volume work as "*Genera Plantarum*" (1862–1883) describing 202 families and 7569 genera and 97,205 species. In this system the seeded plants were classified into 3 major classes such as Dicotyledonae, Gymnospermae and Monocotyledonae.

Class I Dicotyledonae: Plants contain two cotyledons in their seed, leaves with reticulate venation, tap root system and tetramerous or pentamerous flowers come under this class. It includes three sub-classes – **Polypetalae, Gamopetalae** and **Monochlamydeae**.

Sub-class 1. Polypetalae: Plants with free petals and dichlamydeous flowers come under polypetalae. It is further divided into three series – **Thalamiflorae, Disciflorae** and **Calyciflorae**.

Series (i) Thalamiflorae: Plants having flowers with dome or conical shaped thalamus and superior ovary are included in this series. It includes 6 orders and 34 families.

Series (ii) Disciflorae: Flowers having prominent disc shaped thalamus with superior ovary come under this series. It includes 4 orders and 23 families.

Series (iii) Calyciflorae: It includes plants having flowers with cup shaped thalamus and with inferior or sometimes with half inferior ovary. Calyciflorae includes 5 orders and 27 families.

Sub-class 2. Gamopetalae: Plants with united petals, which are either partially or completely fused to one another and dichlamydeous are placed under Gamopetalae. It is further divided into three series – Inferae, Heteromerae and Bicarpellatae.

Series (i) Inferae: The flowers are epigynous and with inferior ovary. Inferae includes 3 orders and 9 families.

Series (ii) Heteromerae: The flowers are hypogynous, superior ovary and with more than two carpels. Heteromerae includes 3 orders and 12 families.

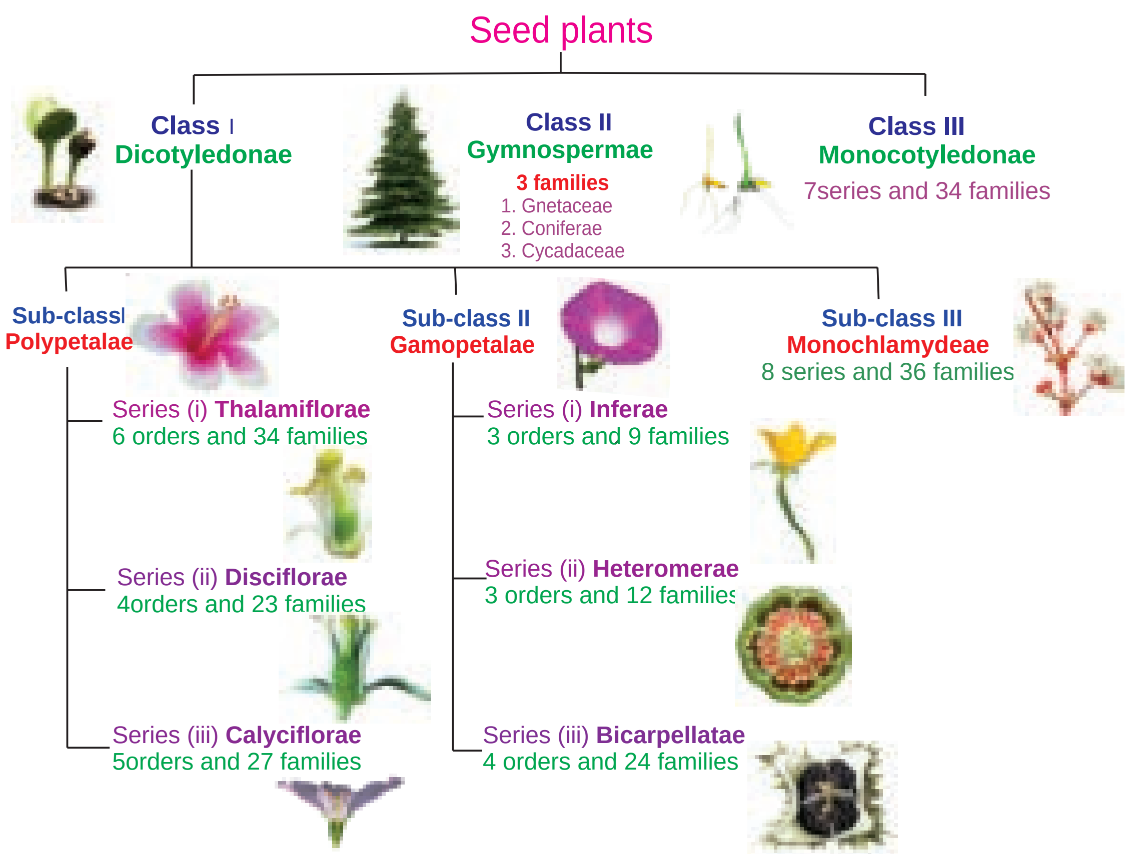


Figure 5.6: Bentham and Hooker system of classification

Series (iii) Bicarpellatae: The flowers are hypogynous, superior ovary and with two carpels. Bicarpellatae includes 4 orders and 24 families.

Sub-class 3. Monochlamydeae: Plants with incomplete flowers either apetalous or with undifferentiated calyx and corolla are placed under Monochlamydeae. The sepals and petals are not distinguished and they are called **perianth.** Sometimes both the whorls are absent. Monochlamydeae includes 8 series and 36 families.

Class II Gymnospermae: Plants that contain naked seeds come under this class. Gymnospermae includes three families – Gnetaceae, Coniferae and Cycadaceae.

Class III Monocotyledonae: Plants contain only one cotyledon in their seed, leaves with parallel venation, fibrous root system and trimerous flowers come under this class. The Monocotyledonae has 7 series and 34 families.

The Bentham and Hooker system of classification is still supposed to be the best system of classification. It has been widely practiced in colonial countries and herbaria of those countries were organised based on this system and is still used as a key for the identification of plants in some herbaria of the world due to the following reasons:

- Description of plants is quite accurate and reliable, because it is mainly based on personal studies from actual specimens and not mere comparisons of known **facts.**
- As it is easy to follow, it is used as a key for the identification of plants in several herbaria of the world.

Though it is a natural system, this system was not intended to be phylogenetic.

5.10.3 Phylogenetic system of classification

The publication of the ***Origin of Species*** (1859) by **Charles Darwin** has given stimulus for the emergence of phylogenetic system of classification.

I Adolph Engler and Karl A Prantl system of classification

Figure 5.7: Adolph Engler and Karl A Prantl

One of the earliest phylogenetic system of classification of the entire plant Kingdom was jointly proposed by two German botanists **Adolph Engler** (1844 -1930) and **Karl A Prantl** (1849 - 1893). They published their classification in a monumental work "***Die Naturelichen Pflanzen Familien***" in 23 volumes (1887-1915)

In this system of classification the plant kingdom was divided into 13 divisions. The first 11 divisions are Thallophytes, twelfth division is **Embryophyta Asiphonogama** (plants with embryos but no pollen tubes; Bryophytes and Pteridophytes) and the thirteenth division is **Embryophyta Siphonogama** (plants with embryos and pollen tubes) which includes seed plants.

II Arthur Cronquist system of classification

Arthur Cronquist (1919 - 1992) an eminent American taxonomist proposed phylogenetic classification of flowering plants based on a wide range of taxonomic characters including anatomical and phytochemical characters of phylogenetic importance. He has presented his classification in 1968 in his book titled "**The evolution and classification of flowering plants.**" His classification is broadly based on the Principles of phylogeny that finds acceptance with major contemporary authors.

Figure 5.9: Arthur Cronquist

Cronquist classified the angiosperms into two main classes **Magnoliopsida** (=dicotyledons) and **Liliopsida** (= monocotyledons). There are 6 subclasses, 64 orders, 320 families and about 165,000 species in Magnoliopsida, whereas in Liliopsida there are 5 sub classes, 19 orders, 66 families and about 50,000 species.

Cronquist system of classification also could not persist for a long time because, the system is not very useful for identification and cannot be adopted in herbaria due to its high phylogenetic nature.

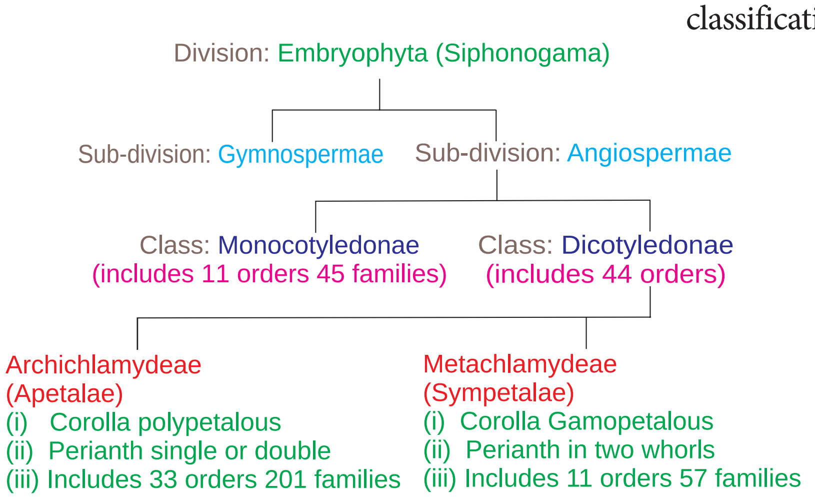


Figure 5.8: Outline of Engler and Prantl classification

5.10.4 Angiosperm phylogeny group (APG) classification

The most recent classification of flowering plants based on **phylogenetic data** was set in the last decade of twentieth century. Four versions of Angiosperm Phylogenetic Group classification (APG I, APG II, APG III & APG IV) have been published in 1998, 2003, 2009 and 2016 respectively. Each version supplants the previous version. Recognition of **monophyletic** group based on the information received from various disciplines such as gross morphology, anatomy, embryology, palynology, karyology, phytochemistry and more strongly on molecular data with respect to DNA sequences of two chloroplast

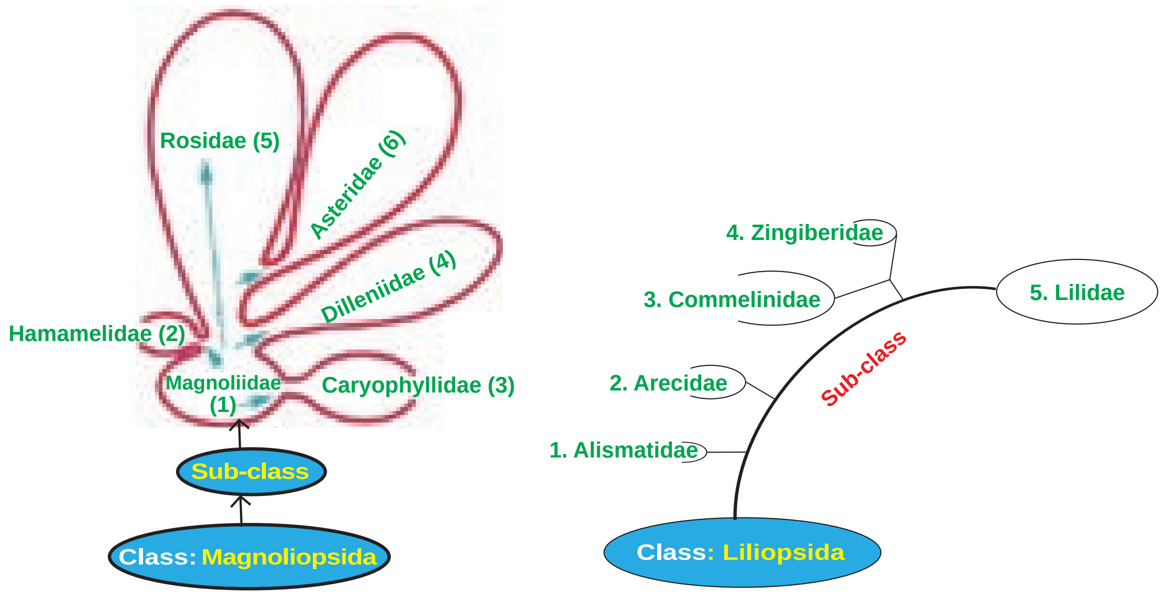


Figure 5.10: Diagramatic representation of class Magnoliopsida and Liliopsida.

genes (*atp*B and *rbc*L) and one nuclear gene (nuclear ribosomal 18s DNA).

The most recent updated version, APG IV (2016) recognised 64 orders and 416 families. Of these, 416 families 259 are represented in India.

The outline of APG IV classification is given below.

Angiosperms are classified into three clades early angiosperms, monocots and eudicots. Early angiosperms are classified into **8 orders** and **26 families** (**ANA**-clade + magnoliids + Chloranthales)

Amborellales
Nymphaeales
Austrobaileyales

- Seeds generally always with two cotyledons.
- Presence of ethereal oils.
- Leaves are always simple net-veined.
- Each floral whorls with many parts.
- Perianth usually spirally arranged or parts in threes.
- Stamens with broad filaments.
- Anthers tetrasporangiate.
- Pollen monosulcate.
- Nectaries are rare.
- Carpels usually free and
- Embryo very small.

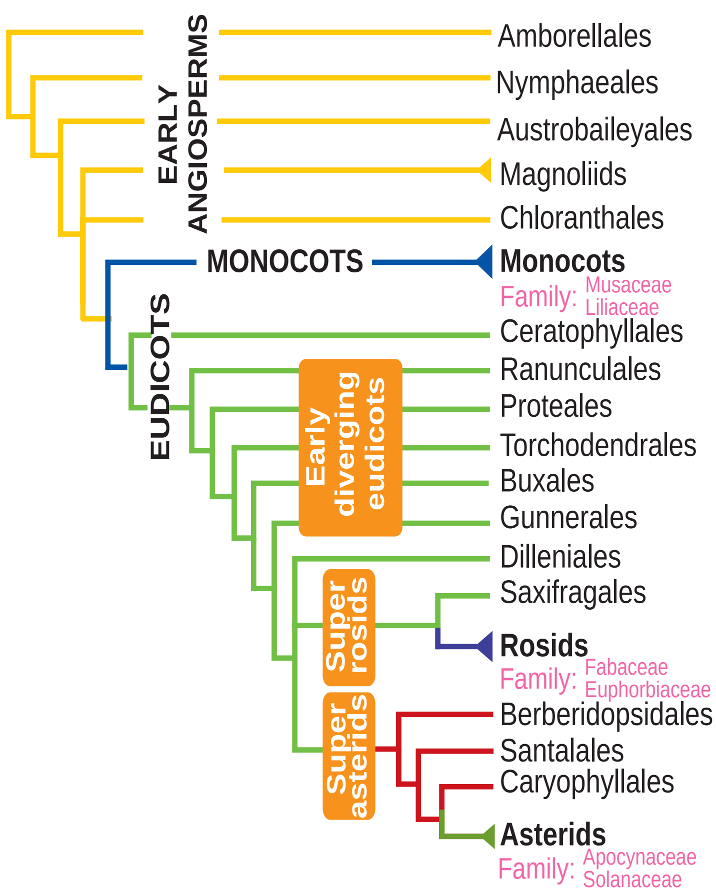


Figure 5.11: Simplified version of APG IV
(Source: Plant Gateway's The Global Flora, Vol. I January 2018)

Monocots are classified into 11 orders and 77 families (basal monocots + lilioids + commelinids)

- Seeds with single cotyledon.
- Primary root short-lived.

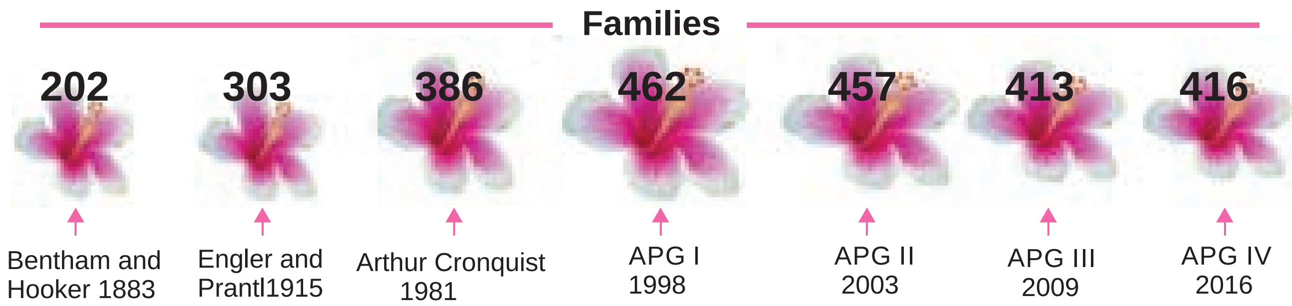


Figure 5.12: A timeline showing the history of classifying flowering plants into families. (Source: Royal Botanic Gardens Kew State of World's Plant 2017)

- Single adaxial prophyll.
- Ethereal oils rarely present.
- Mostly herbaceous, absence of vascular cambium.
- Vascular bundles are scattered in the stem.
- Leaf simple with parallel-veined.
- Floral parts usually in threes.
- Perianth often composed of tepals.
- Pollen monosulcate.
- Styles normally hollow and
- Successive microsporogenesis.

Eudicots are divided into 45 orders and 313 families (early diverging eudicots + super rosids + super asterids).

- Seeds with always two cotyledons.
- Nodes trilacunar with three leaf traces.
- Stomata anomocytic.
- Ethereal oils rarely present.
- Woody or herbaceous plants.
- Leaves simple or compound, usually net-veined.
- Flower parts mostly in twos, fours or fives.
- Microsporogenesis simultaneous.
- Style solid and
- Pollen tricolpate.

APG system is an evolving system that might undergo change periodically based on the new sets of data from various disciplines of Botany. It is the currently accepted system across the world and followed by all the leading taxonomic institutions and practising taxonomists. However, it is yet to percolate into the Indian botanical curriculum.

Classification reflects the state of our knowledge at a given point of time. It will continue to change as we acquire new information.

DO YOU KNOW?

A significant number of major herbaria, including Kew are changing the order of their collections in accordance with APG.

The influential world checklist of selected plant families (also from kew) is being updated to the APG III system.

A recent photographic survey of the plants of USA and Canada is organized according to the APG III system.

In UK, the latest edition of the standard flora of the British Isles written by Stace is based on the APG III system.

5.11 Modern trends in taxonomy

Taxonomists now accept that, the morphological characters alone should not be considered in systematic classification of plants. The complete knowledge of taxonomy is possible with the principles of various disciplines like Cytology, Genetics, Anatomy, Physiology, Geographical Distribution, Embryology, Ecology, Palynology, Phenology, Bio-Chemistry, Numerical Taxonomy and Transplant Experiments. These have been found to be useful in solving some of the taxonomical problems by providing additional characters. It has changed the face of classification from **alpha** (classical) to **omega** (modern kind). Thus the new systematic has evolved into a better taxonomy.

5.11.1 Chemotaxonomy

Proteins, amino acids, nucleic acids, peptides etc. are the most studied chemicals in chemotaxonomy. Chemotaxonomy is the scientific approach of classification of plants on the basis of their biochemical constituents. As proteins are more closely controlled by genes and less subjected to natural selection, it has been used at all hierarchical levels of classification starting from the rank of 'variety' up to the rank of division in plants.

The chemical characters can be divided into three main categories.

1. Easily visible characters like starch grains, silica.
2. Characters detected by chemical tests like phenolics, oil, fats, waxes.
3. Proteins.

Aims of chemotaxonomy

1. To develop taxonomic characters which may improve existing system of plant classification.
2. To improve present day knowledge of phylogeny of plants.

5.11.2 Biosystematics

Biosystematics is an "Experimental, ecological and cytotaxonomy" through which life forms are studied and their relationships are defined. The term biosystematics was introduced by **Camp** and **Gilly** in 1943. Many authors feel Biosystematics is closer to Cytogenetics and Ecology and much importance given not to classification but to evolution.

Aims of biosystematics

The aims of biosystematics are as follows:

1. To delimit the naturally occurring biotic community of plant species.
2. To establish the evolution of a group of taxa by understanding the evolutionary and phylogenetic trends.
3. To involve any type of data gathering based on modern concepts and not only on morphology and anatomy.
4. To recognize the various groups as separate biosystematic categories such as ecotypes, ecospecies, cenospecies and comparium.

5.11.3 Karyotaxonomy

Chromosomes are the carriers of genetic information. Increased knowledge about the chromosomes have been used for extensive biosystematic studies and resolving many taxonomic problems. Utilization of the characters and phenomena of cytology for the explanation of taxonomic problem is known as **cytotaxonomy** or **karyotaxonomy**. The characters of chromosome such as number, size, morphology and behaviour during meiosis have proved to be of taxonomic value.

5.11.4 Serotaxonomy (Immunotaxonomy)

Systematic serology or serotaxonomy had its origin towards the end of twentieth century with the discovery of serological reactions and development of the discipline of immunology. The classification of very similar plants by means of differences in the proteins they contain, to solve taxonomic problems is called **serotaxonomy**. **Smith** (1976) defined it as "**the study of the origins and properties of antisera.**"

Importance of serotaxonomy

It determines the degree of similarity between species, genera, families etc. by comparing the reactions of antigens from various plant taxa with antibodies raised against the antigen of a given taxon.

Example: 1. The assignment of *Phaseolus aureus* and *P. mungo* to the genus *Vigna* is strongly supported by serological evidence by **Chrispeels** and **Gartner**.

5.11.5 Molecular taxonomy (molecular systematics / molecular phylogenetics)

Molecular Taxonomy is the branch of phylogeny that analyses hereditary molecular differences, mainly in DNA sequences, to gain information and to establish genetic relationship between the members of different taxonomic categories. The advent of DNA cloning and sequencing methods have contributed immensely to the development of molecular taxonomy and population genetics over the years. These modern methods have revolutionised the field of molecular taxonomy and population genetics with improved analytical power and precision.

The results of a molecular phylogenetic analysis are expressed in the form of a tree called **phylogenetic tree.** Different molecular markers like allozymes, mitochondrial DNA, microsatellites, RFLP (Restriction Fragment Length Polymorphism), RAPD (Random amplified polymorphic DNA), AFLPs (Amplified Fragment Length Polymorphism), single nucleotide polymorphism- (SNP), microchips or arrays are used in analysis.

Uses of molecular taxonomy

1. Molecular taxonomy helps in establishing the relationship of different plant groups at DNA level.
2. It unlocks the treasure chest of information on evolutionary history of organisms.

RFLP (Restriction Fragment Length Polymorphism)

RFLPs is a molecular method of genetic analysis that allows identification of taxa based on unique patterns of restriction sites in specific regions of DNA. It refers to differences between taxa in restriction sites and therefore the lengths of fragments of DNA following cleavage with restriction enzymes.

Amplified Fragment Length Polymorphism (AFLP)

This method is similar to that of identifying RFLPs in that a restriction enzyme is used to cut DNA into numerous smaller pieces, each of which terminates in a characteristic nucleotide sequence due to the action of restriction enzymes.

AFLP is largely used for population genetics studies, but has been used in studies of closely related species and even in some cases, for higher level cladistic analysis.

Random Amplified Polymorphic DNA (RAPD)

It is a method to identify genetic markers using a randomly synthesized primer that will anneal (recombine (DNA) in the double stranded form) to complementary regions located in various locations of isolated DNA. If another complementary site is present on the opposing DNA strand at a distance that is not too great (within the limits of PCR) then the reaction will amplify this region of DNA.

RAPDs like microsatellites may often be used for genetic studies within species but may also be successfully employed in phylogenetic studies to address relationships within a species or between closely related species. However RAPD analysis has the major disadvantage that results are difficult to replicate and in that the homology of similar bands in different taxa may be nuclear.

Significance of Molecular Taxonomy

1. It helps to identify a very large number of species of plants and animals by the use of conserved molecular sequences.
2. Using DNA data evolutionary patterns of biodiversity are now investigated.
3. DNA taxonomy plays a vital role in phytogeography, which ultimately helps in genome mapping and biodiversity conservation.
4. DNA- based molecular markers used for designing DNA based molecular probes, have also been developed under the branch of molecular systematics.

5.11.6 DNA Barcoding

Have you seen how scanners are used in supermarkets to distinguish the **Universal**

Product Code (UPC)? In the same way we can also distinguish one species from another. DNA barcoding is a taxonomic method that uses a very short genetic sequence from a standard part of a genome. The genetic sequence used to identify a plant is known as "**DNA tags**" or "**DNA barcodes**". **Paul Hebert** in 2003 proposed '**DNA barcoding**' and he is considered as 'Father of barcoding'.

The gene region that is being used as an effective barcode in plants is present in two genes of the chloroplast, **matK** and **rbcL**, and have been approved as the barcode regions for plants.

Sequence of unknown species can be matched from submitted sequence in GenBank using Blast (web-programme for searching the closely related sequence).

Significance of DNA barcoding

1. DNA barcoding greatly helps in identification and classification of organism.
2. It aids in mapping the extent of biodiversity.

DNA barcoding techniques require a large database of sequences for comparison and prior knowledge of the barcoding region.

However, DNA barcoding is a helpful tool to determine the authenticity of botanical material in whole, cut or powdered form.

5.11.7 Differences between classical and modern taxonomy

Classical Taxonomy	Modern Taxonomy
It is called old systematics or Alpha (ὰ) taxonomy or Taxonomy	It is called Neosystematics or Biosystematics or Omega (Ω) taxonomy
It is pre Darwinean	It is post Darwinean
Species is considered as basic unit and is static	species is considered as dynamic entity and ever changing
Classification is mainly based on morphological characters	Classification is based on morphological, reproductive characters and phylogenetic (evolutionary) relationship of the organism
This system is based on the observation of a few samples/ individuals	This system is based on the observation of large number of samples/individuals

5.12 Cladistics

Analysis of the taxonomic data, and the types of characters that are used in classification have changed from time to time. Plants have been classified based on the morphology before the advancement of microscopes, which help in the inclusions of **sub microscopic** and **microscopic** features. A closer study is necessary while classifying closely related plants. Discovery of new finer molecular analytical techniques coupled with advanced software and computers has ushered in a new era of modern or phylogenetic classification.

The method of classifying organisms into monophyletic group of a common ancestor based on shared apomorphic characters is called **cladistics** (from Greek, *klados*- branch).

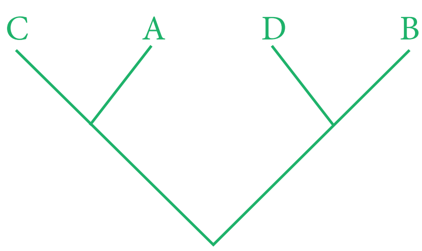
The outcome of a cladistic analysis is a **cladogram**, a tree-shaped diagram that represent the best hypothesis of phylogenetic relationships. Earlier generated cladograms were largely on the basis of morphological characters, but now genetic sequencing data and computational softwares are commonly used in phylogenetic analysis.

Cladistic analysis

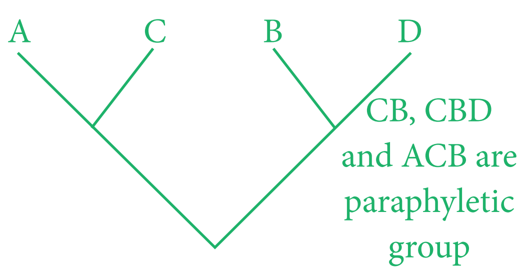
Cladistics is one of the primary methods of constructing phylogenies, or evolutionary histories. Cladistics uses shared, derived characters to group organisms into clades. These clades have atleast one shared, derived character found in their most recent common ancestor that is not found in other groups hence they are considered more closely related to each other. These shared characters can be morphological such as, leaf, flower, fruit, seed and so on; behavioural, like opening of flowers nocturnal/diurnal; molecular like, DNA or protein sequence and more.

Cladistics accept only **monophyletic groups**. **Paraphyletic** and **polyphyletic** taxa are occasionally considered when such taxa conveniently treated as one group for practical purposes. Example: dicots, sterculiaceae. Polyphyletic groups are rejected by cladistics.

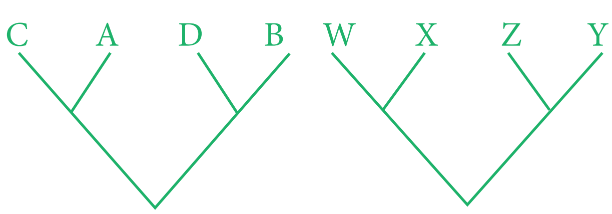
i. **Monophyletic group;** Taxa comprising all the descendants of a common ancestor.



ii. **Paraphyletic group;** Taxon that includes an ancestor but not all of the descendants of that ancestor.



iii. **Polyphyletic group;** Taxa that includes members from two different lineages.



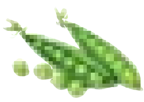
Need for cladistics

1. Cladistics is now the most commonly used and accepted method for creating phylogenetic system of classifications.
2. Cladistics produces a hypothesis about the relationship of organisms to predict the phylogeny
3. Cladistics helps to elucidate mechanism of evolution.

5.13 Selected Families of Angiosperms

Dicot Families

5.13.1 Family: Fabaceae (Pea family)



Systematic position

APG classification		Bentham and Hooker classification	
Kingdom	Plantae	Kingdom	Plantae
Clade	Angio-sperms	Class	Dicotyledonae
Clade	Eudicots	Sub-class	Polypetalae
Clade	Rosids	Series	Calyciflorae
Order	Fabales	Order	Rosales
Family	Fabaceae	Family	Fabaceae

General characters

Distribution: Fabaceae includes about 741 genera and more than 20,200 species. The members are cosmopolitan in distribution but abundant in tropical and subtropical regions.

Habit: All types of habits are represented in this family. Mostly herbs (*Crotalaria*), prostrate (*Indigofera enneaphylla*) erect (*Crotalaria verrucosa*), shrubs (*Cajanus cajan*), small trees (*Sesbania*), climbers (*Clitoria*), large tree (*Pongamia, Dalbergia*), woody climber (*Mucuna*), hydrophyte (*Aeschynomene aspera*) commonly called **pith plant.**


Root nodule

Root: Tap root system, roots are nodulated, have tubercles containing nitrogen – fixing bacteria (*Rhizobium leguminosarum)*

Stem: Aerial, herbaceous, woody (*Dalbergia*) twining or climbing (*Clitoria*).

Leaf: Leaf simple or unifoliate (*Desmodium gangeticum*) bifoliate (*Zornia diphylla,*), Trifoliate (*Lablab purpureus*), alternate, stipulate, leaf base, **pulvinate**, reticulate venation terminal leaflet modifies into a **tendril** in *Pisum sativum.*

Inflorescence: Raceme (*Crotalaria verrucosa*), panicle (*Dalbergia latifolia*) axillary solitary (*Clitoria ternatea*)

Flowers: Bracteate, bracteolate, pedicellete, complete, bisexual, pentamerous, heterochlamydeous, zygomorphic hypogynous or sometimes perigynous.

Calyx: Sepals 5, green, synsepalous, more or less united in a tube and persistant, valvate or imbricate, odd sepal is anterior in position.

Corolla: Petals 5, apopetalous, unequal and **papilionaceous**, **vexillary** or **descendingly imbricate** aestivation, all petals have claw at the base. The outer most petal is large called **standard petal** or **vexillum**, Lateral 2 petals are lanceolate and curved. They are called **wing petals** or **alae**. Anterior two petals are partly fused and are called **keel petals** or **carina** which encloses the stamens and pistil.

Androecium: Stamens 10, diadelphous, usually 9+1 (*Clitoria ternatea*). The odd stamen is posterior in position. In *Aeschynomene aspera*, the stamens are fused to form two bundles each containing five stamens (5)+(5). Stamens are **monadelphous** and **dimorphic** ie. 5 stamens have longer filaments and other 5 stamens have shorter filaments thus the stamens are found at two levels and the shape of anthers also varies in (*Crotalaria verrucosa)*. (5 anthers are long and lanceolate, and the other 5 anthers are short and blunt). Anthers are dithecous, basifixed and dehiscing longitudinally.

Gynoecium: Monocarpellary, unilocular, ovary superior, with two alternating rows of ovules on marginal placentation. Style simple and bent, stigma flattened or feathery.

Fruit: The characteristic fruit of Fabaceae is a legume (*Pisum sativum)*, sometimes indehiscent and rarely a lomentum (*Desmodium)*. In *Arachis hypogea* the fruit is ***geocarpic*** (fruits develops and matures under the soil). After fertilization the stipe of the ovary becomes meristematic and grows down into the soil. This ovary gets buried into the soil and develops into fruit.

Seed: Endospermic or non-endospermic (*Pisum sativum*), mostly **reniform**.

Botanical description of *Clitoria ternatea* (Sangu pushpam)

Habit: Twining climber

Root: Branched tap root system having nodules.

Stem: Aerial, weak stem and a twiner

Leaf: Imparipinnately compound, alternate, stipulate showing reticulate venation. Leaflets are stipellate. Petiolate and stipels are pulvinated.

Inflorescence: Solitary and axillary

Flower: Bracteate, bracteolate, bracteoles usually large, pedicellate, heterochlamydeous, complete, bisexual, pentamerous, zygomorphic and hypogynous.

Calyx: Sepals 5, synsepalous, green showing valvate aestivation. Odd sepal is anterior in position.

Corolla: Petals 5, white or blue apopetalous, irregular papilionaceous corolla showing descendingly imbricate aestivation.

Androecium: Stamens 10, diadelphous (9)+1, nine stamens fused to form a bundle and the tenth stamen is free. Anthers are dithecous, basifixed, introse and dechiscing by longitudinal slits.

Gynoecium: Monocarpellary, unilocular, with many ovules on mariginal placentation, ovary superior, style simple and incurved with feathery stigma.

Fruit: Legume

Seed: Non-endospermous, reniform.

Floral Formula:

Dt0Dtn0' .⚥.'M$_{*7+}$.E$_7$.C$_{*;+3}$.I$_{_3}$

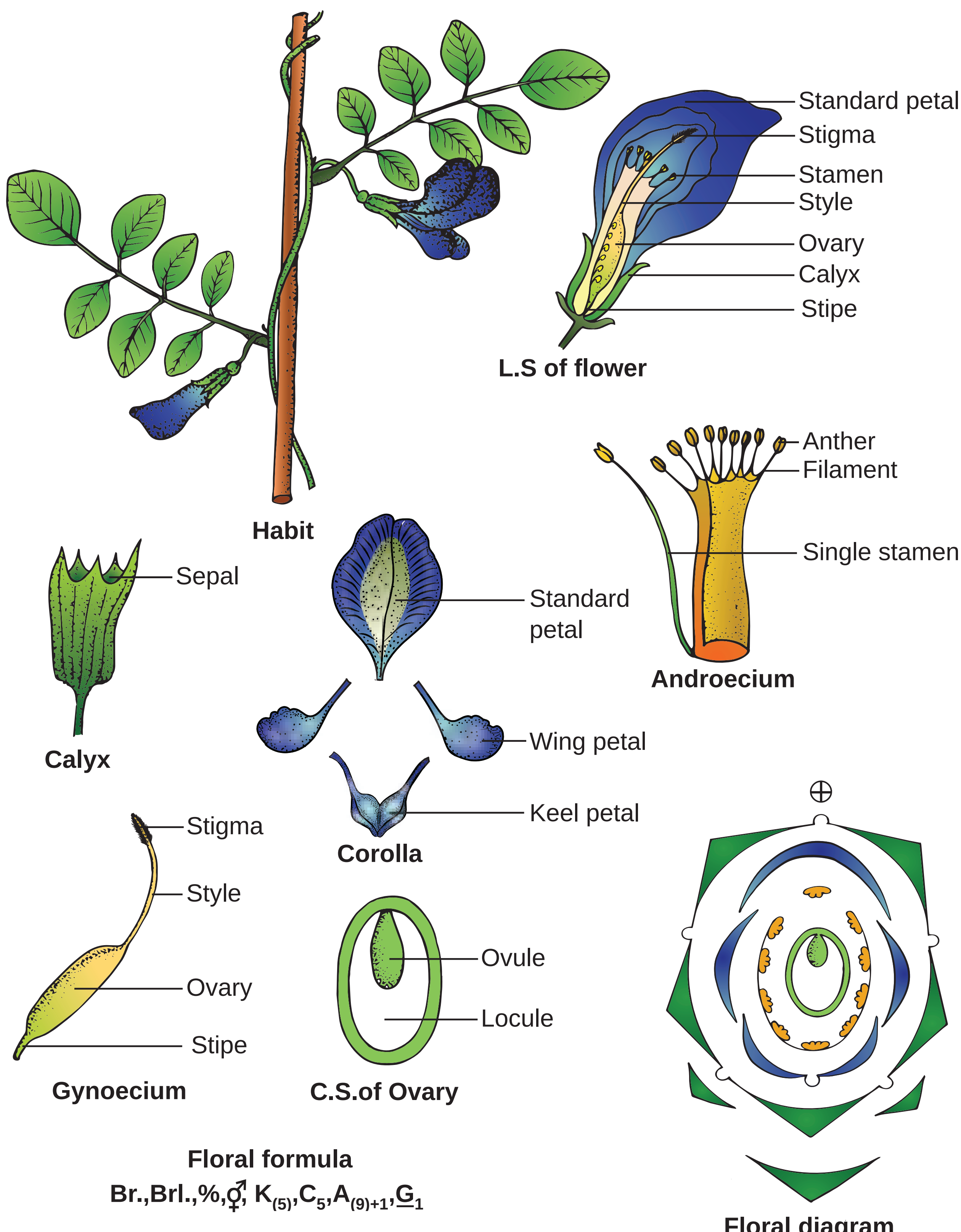


Figure 5.13: *Clitoria ternatea*

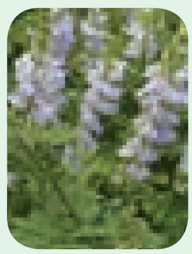
Economic Importance

Economic importance	Binomial	Useful part	Uses
Pulses	*Cajanus cajan* (Pigeon Pea) *Phaseolus vulgaris* (French bean) *Cicer arietinum* (Chick pea / Channa / கொண்டைக்கடலை) *Vigna mungo* (black gram / உளுந்து) *Vigna radiata* (green gram / பாசிப்பயறு) *Vigna unguiculata* (cow pea / தட்டைப்பயறு) *Glycine max* (soya bean) *Macrotyloma uniflorum* (Horse gram / கொள்ளு)	Seeds	Sources of protein and starch of our food.
Food plants	*Lablab purpureus* (field bean) *Sesbania grandiflora* (agathi) *Cyamopsis tetragonoloba* (cluster bean)	Tender fruits Leaves Tender fruits	Vegetable Greens Vegetable
Oil Plants	*Arachis hypogea* (ground nut) *Pongamia pinnata* (pungam)	Seeds Seeds	Oil extracted from the seeds is edible and used for cooking. Pongam oil has medicinal value and is used in the preparation of soap.
Timber Plants	*Dalbergia latifolia* (rose wood) *Pterocarpus santalinus* (red sandalwood) *P.marsupium* (வேங்கை)	Timber	Timber is used for making furniture, cabinet articles and as building materials.
Medicinal Plants	*Crotalaria albida* *Psoralea corylifolia* (கார்போக அரிசி) *Glycyrrhiza glabra* (Licorice root / அதிமதுரம்) *Mucuna pruriens* (பூனைக்காலி)	Roots Seeds Roots Seeds	Used as purgative Used in leprosy and leucoderma Immuno modulater Neurological remedy
Fibre Plants	*Crotalaria juncea* (sunhemp / சணப்பை) *Sesbania* sesban *(aegyptiaca)*	Stem fibres (Bast)	Used for making ropes.
Pith Plant	*Aeschynomene aspera*	Stem pith	Used for packing, handicraft and fishing floats
Dye Plants	*Indigofera tinctoria* (Avuri) *Clitoria ternatea* *Butea monosperma*	Leaves Flowers and seeds Flowers	Indigo dye obtained from leaves is used to colour printing and in paints. Blue dye is obtained Natural dye

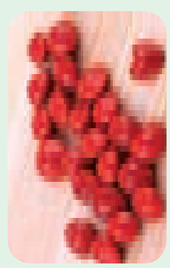
Economic importance	Binomial	Useful part	Uses
Ornamental Plants	*Butea frondosa* (Flame of the forest), *Clitoria ternatea*, *Lathyrus odoratus* (Sweet pea) and *Lupinus hirsutus* (Lupin)	Entire plant	Grown as ornamental plants.

Diabetes Remedy

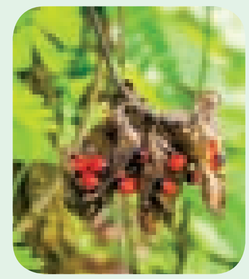
The aerial parts of *Galega officinalis* (Fabaceae) contains Metformin (dimethyl biguanide). It is now reputed to be the most widely prescribed agent in the treatment of diabetes all over the world.



The attractive seeds of *Adenanthera pavonina* (Family: Caesalpiniaceae) have been used as units of weight for the measures of gold throughout India.



The seeds of *Abrus precatorius* are used in necklaces and rosaries, but are extremely poisonous and can be fatal if ingested.



2016 INTERNATIONAL YEAR OF PULSES

The Food and Agriculture Organization (FAO) of the United Nations has been declared 2016 as the year for pulses, to make people more aware of the nutritional value of pulses.

5.13.2 Family: Solanaceae (Potato Family / Night shade family)

Systematic Position

APG system of classification		Bentham and Hooker system of classification	
Kingdom	Plantae	Kingdom	Plantae
Clade	Angiosperms	Class	Dicotyledonae
Clade	Eudicot	Subclass	Gamopetalae
Clade	Asterids	Series	Bicarpellatae
Clade	Solanales	Order	Polemoniales
Family	Solanaceae	Family	Solanaceae

General Characters

Distribution:

Family Solanaceae includes about 88 genera and about 2650 species, of these *Solanum* is the largest genus of the family with about 1500 species. Plants are worldwide in distribution but more abundant in South America.

Habit: Mostly annual herbs, shrubs, small trees (*Solanum violaceum*) lianas with prickles (*Solanum trilobatum*)

Root: Branched tap root system.

Stem: Herbaceous or woody; erect or twining, or creeping; sometimes modified into tubers (*Solanum tuberosum*) it is covered with Spines (*Solanum tuberosum)*

Leaves: Alternate, simple, rarely pinnately compound (*Solanum tuberosum* and *Lycopersicon esculentum*, exstipulate, opposite or sub-opposite in upper part, unicostate reticulate venation. Yellowish verbs present in *Solanum tuberosum*

Inflorescence: Generally axillary or terminal cymose (*Solanum*) or solitary flowers (*Datura stramonium*). Extra axillary scorpiod cyme called **rhiphidium** (*Solanum americanum*) solitary and axillary (*Datura* and *Nicotiana*) umbellate cyme (*Withania somnifera*).

Flowers: Bracteate or ebracteate, pedicellate, bisexual, heterochlamydeous, pentamerous actinomorphic or weakly zygomorphic due to oblique position of ovary, hypogynous.

Calyx: Sepals 5, Synsepalous, valvate persistent (*Solanum americanum*), often accrescent. (*Physalis*)

Corolla: Petals 5, sympetalous, rotate, tubular (*Solanum*) or bell- shaped (*Atropa*) or infundibuliform (*Petunia*) usually alternate with sepals; rarely bilipped and zygomorphic (*Schizanthus*) usually valvate, sometimes convolute (*Datura*).

Androecium: Stamens 5, epipetalous, filaments usually unequal in length, stamens only 2 in *Schizanthus* (others 3 are reduced to staminode), Anthers dithecous, dehisce longitudinally or poricidal.

Gynoecium: Bicarpellary, syncarpous obliquely placed, ovary superior, bilocular but looks tetralocular due to the formation of false septa, numerous ovules in each locule on axile placentation.

Fruit: A capsule or berry. (*Datura & Petunia, Lycopersicon esculentum, Capsicum*)

Seed: Endospermous.

Botanical description of *Datura metel*

Habit: Large, erect and stout herb.

Root: Branched tap root system.

Stem: Stem is hollow, green and herbaceous with strong odour.

Leaf: Simple, alternate, petiolate, entire or deeply lobed, glabrous exstipulate showing unicostate reticulate venation.

Inflorescence: Solitary and axillary cyme.

Flower: Flowers are large, greenish white, bracteate, ebracteolate, pedicellate, complete, heterochlamydeous, pentamerous, regular, actinomorphic, bisexual and hypogynous.

Calyx: Sepals 5, green synsepalous showing valvate aestivation. Calyx is mostly persistent, odd sepal is posterior in position.

Corolla: petals 5, greenish white, sympetalous, plicate (folded like a fan) showing twisted aestivation, funnel shaped with wide mouth and 10 lobed.

Androecium: Stamens 5, free from one another, epipetalous, alternipetalous and are inserted in the middle of the corolla tube. Anthers are basifixed, dithecous, with long filament, introse and longitudinally dehiscent.

Gynoecium: Ovary bicarpellary, syncarpous superior ovary, basically bilocular but tetralocular due to the formation of false septum. Carpels are obliquely placed and ovules on swollen axile placentation. Style simple long and filiform, stigma two lobed.

Fruit: Spinescent capsule opening by four apical valves with persistent calyx.

Seed: Endospermous.

Floral Formula:

Dt0Gdtn0 ⊕. ⚥. M_{*7+}. $\overbrace{E_{*7+}.C_{7}}$. $\underline{I}_{*4+}$

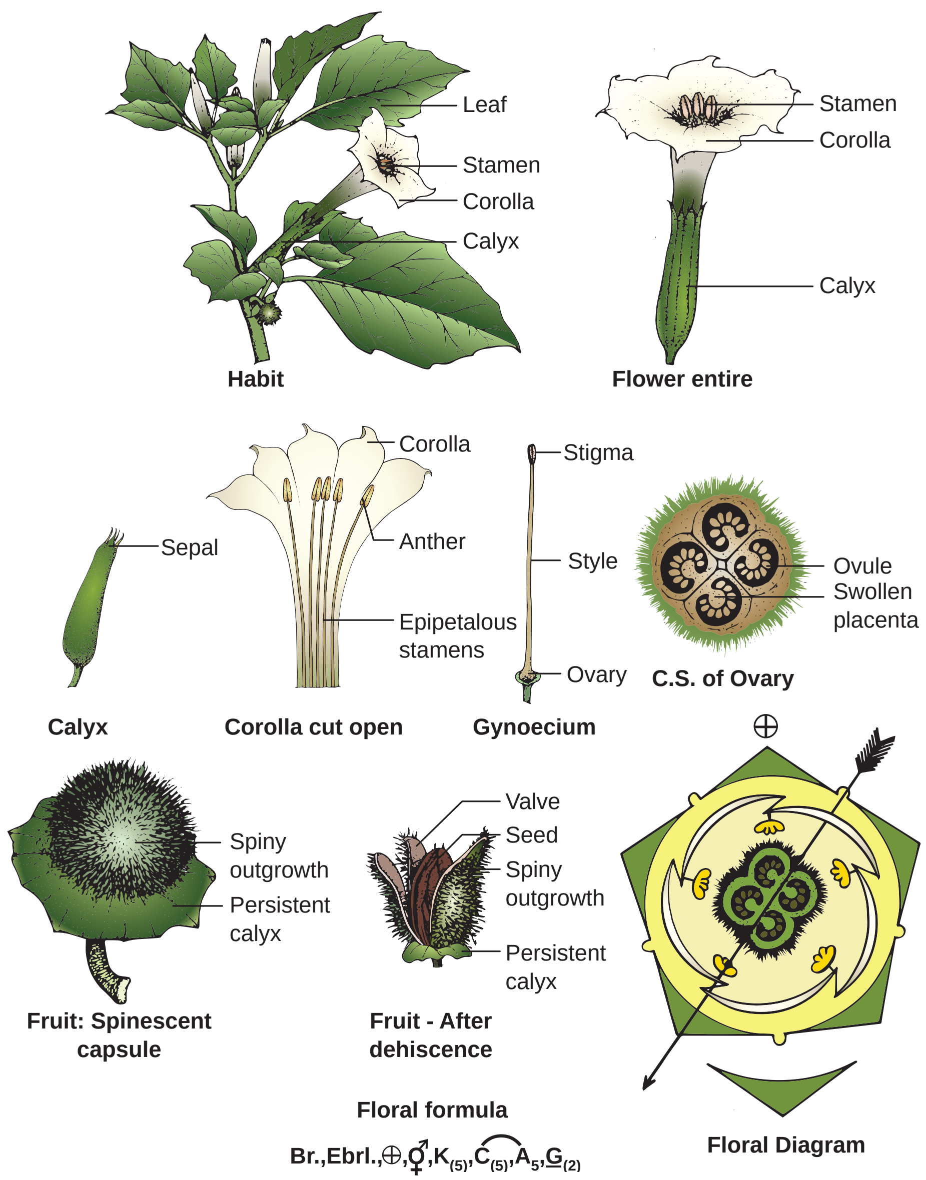
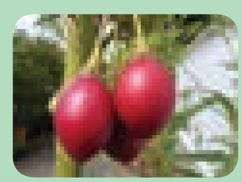


Figure 5.14: *Datura Metel*

Economic importance

Economic importance of the family solanaceae				
S.No.	**Economic importance**	**Binomial**	**Useful part**	**Uses**
1.	Food plant	*Solanum tuberosum* (potato)	Underground stem tubers	Used as vegetables and also used for the production of starch.
		Lycopersicon esculentum (tomato)	Ripened fruits	Used as delicious vegetable and eaten raw.
		Solanum melongena (brinjal)	Tender fruits	Cooked and eaten as vegetable.
		Capsicum annuum (bell peppers & chilli papers) *C. frutescens* (மிளகாய்)	Fruits	Used as vegetables and powdered chilli is the dried pulverized fruit which is used as spice to add pungency or piquancy and flavour to dishes.
		Physalis peruviana (cape gooseberry / சொடக்கு தக்காளி)	Fruit	Used as delicious fruit.

Economic importance of the family solanaceae

S.No.	Economic importance	Binomial	Useful part	Uses
2.	Medicinal plant	*Atropa belladonna* (deadly nightshade) *Datura stramonium* (ஊமத்தை) *Solanum trilobatum* (தூதுவளை) *Withania somnifera* (Ashwagandha / அமுக்காரா)	Roots Leaves and roots Leaves, flowers and berries Roots	A powerful alkaloid 'atropine' obtained from root is used in belladonna plasters, tinctures etc. for relieving pain and also for dialating pupils of eyes for eye –testing. Stramonium drug obtained from the leaves and roots of this is used to treat asthma and whooping cough. Used to treat cough. Used in curing cough and rheumatism.
3.	Tobacco	*Nicotiana tabaccum* (tobacco / புகையிலை)	Leaves are dried and made into tobacco.	Used in cigarette, beedi, hukkah, pipes as well as for chewing and snuffing, alkaloids like nicotine, nornicotine and anabasin are present in tobacco.
4.	Ornamental plants	*Cestrum diurnum* (Day Jasmine) *Cestrum nocturnum* (Night Jasmine) *Nicotiana alata Petunia hybrida, Schizanthus pinnatus*	Plant	Grown in garden as ornamental plants for their aesthetic nature. Do tomatoes come from a tree?  Solanum betaceum (Tree tomato)

5.13.3 Family: Liliaceae (Lily Family)

Systematic position

APG Classification		Bentham and Hooker Classification	
Kingdom	Plantae	Kingdom	Plantae
Clade	Angiosperms	Class	Monocotyledons
Clade	Monocots	Series	Coronarieae
Order	Liliales	Order	Liliales
Family	Liliaceae	Family	Liliaceae

Note: Liliaceae of Bentham and Hooker included *Allium, Gloriosa, Smilax, Asparagus, Scilla, Aloe, Dracaena* etc. Now under APG, it includes only ***Lilium*** and ***Tulipa***. All others are placed under different families.

General Characters

Distribution: Liliaceae are fairly large family comprising about 15 genera and 550 species. Members of this family are widely distributed over most part of the world.

Habit: Mostly perennial herbs persisting by means of a sympodial rhizome (*Polygonatum)*, by a bulb (*Lilium*) corm (*Colchicum*), shrubby or tree like (*Yucca* and *Dracaena*). Woody climbers, climbing with the help of stipular tendrils in *Smilax*. Trees in (*Xanthorrhoea),* succulents (*Aloe)*.

Root: Adventitious and fibrous, and typically contractile.

Stem: Stems usually bulbous, rhizomatous in some, aerial, erect (*Dracaena*) or climbing (*Smilax)* in *Ruscus* the ultimate branches are modified into phylloclades, In *Asparagus* stem is modified into cladodes and the leaves are reduced to scales.

Leaf: Leaves are radical (*Lilium*) or **cauline** (*Dracaena*), usually alternate, opposite (*Gloriosa*), sometimes fleshy and hollow, reduced to scales (*Ruscus* and *Asparagus*). The venation is parallel but in species of *Smilax* it is reticulate. Leaves are usually exstipulate, but in *Smilax*, two tendrils arise from the base of the leaf, which are considered modified stipules.

Inflorescence: Flowers are usually borne in simple or branched racemes (*Asphodelus*) spikes in *Aloe*, huge terminal panicle in *Yucca*, solitary and axillary in *Gloriosa*, solitary and terminal in *Tulipa.*

Flowers: Flowers are often showy, pedicellate, bracteate, ebracteolate, except *Dianella* and *Lilium*, bisexual, actinomorphic, trimerous, hypogynous, rarely unisexual (*Smilax*) and are dioecious, rarely tetramerous (*Maianthemum*), slightly zygomorphic (*Lilium*) and hypogynous.

Perianth: Tepals 6 biseriate arranged in two whorls of 3 each, apotepalous or rarely syntepalous as in *Aloe.* Usually petaloid or sometimes sepaloid, odd tepal of the outer whorl is anterior in position, valvate or imbricate, tepals more than six in *Paris quadrifolia*.

Androecium: Stamens 6, arranged in 2 whorls of 3 each, rarely stamens are 3 (*Ruscus*), 4 in *Maianthemum,* or up to 12, apostamenous, opposite to the tepals, sometimes epitepalous; filaments distinct or connate, anthers dithecous, basifixed or versatile, extrose, or introse, dehiscing usually by vertical slit and sometimes by terminal pores; rarely **synstamenous** (*Ruscus*).

Gynoecium: Tricarpallary, syncarpous, the odd carpel usually anterior, ovary superior, trilocular, with 2 rows of numerous ovules on axile placextation; rarely unilocular with parietal placentation, style usually one; stigmas 1 or 3; rarely the ovary is inferior (*Haemodorum*), nectar – secreting **septal glands** are present in the ovary.

Fruit: Fruit usually a septicidal or loculicidal capsule or a berry as in *Asparagus* and *Smilax.*

Botanical description of *Allium cepa*

(In APG classification, *Allium cepa* is placed under the family Amaryllidaceae)

Habit: Perennial herb with bulb.

Root: Fibrous adventitious root system

Stem: Underground bulb

Leaf: A cluster of radical leaves emerges from the underground bulb, cylindrical and fleshy having sheathy leaf bases with parallel venation.

Inflorescence: **Scapigerous** i.e. the inflorescence axis (peduncle) arising from the ground bearing a cluster of flowers at its apex. Pedicels are of equal length, arising from the apex of the peduncle which brings all flowers at the same level.

Flower: Small, white, bracteate, ebracteolate, pedicellate, complete, trimerous, actinomorphic and hypogynous. Flowers are protandrous.

Perianth: Tepals 6, white, arranged in two whorls of three each, syntepalous showing valvate aestivation.

Androecium: Stamens 6, arranged in two whorls of three each, epitepalous, apostamenous /free and opposite to tepals.

Anthers dithecous, basifixed, introse, and dehiscing longitudinally.

Gynoecium: Tricarpellary and syncarpous. Ovary superior, trilocular with two ovules in each locule on axile placentation. Style simple, slender with simple stigma.

Fruit: A loculicidal capsule.

Seed: Endospermous

Floral Formula:

$Br., Ebrl., \oplus, ⚥, \overparen{P_{(3+3)}\ A_{3+3}}, \underline{G}_{(3)}$

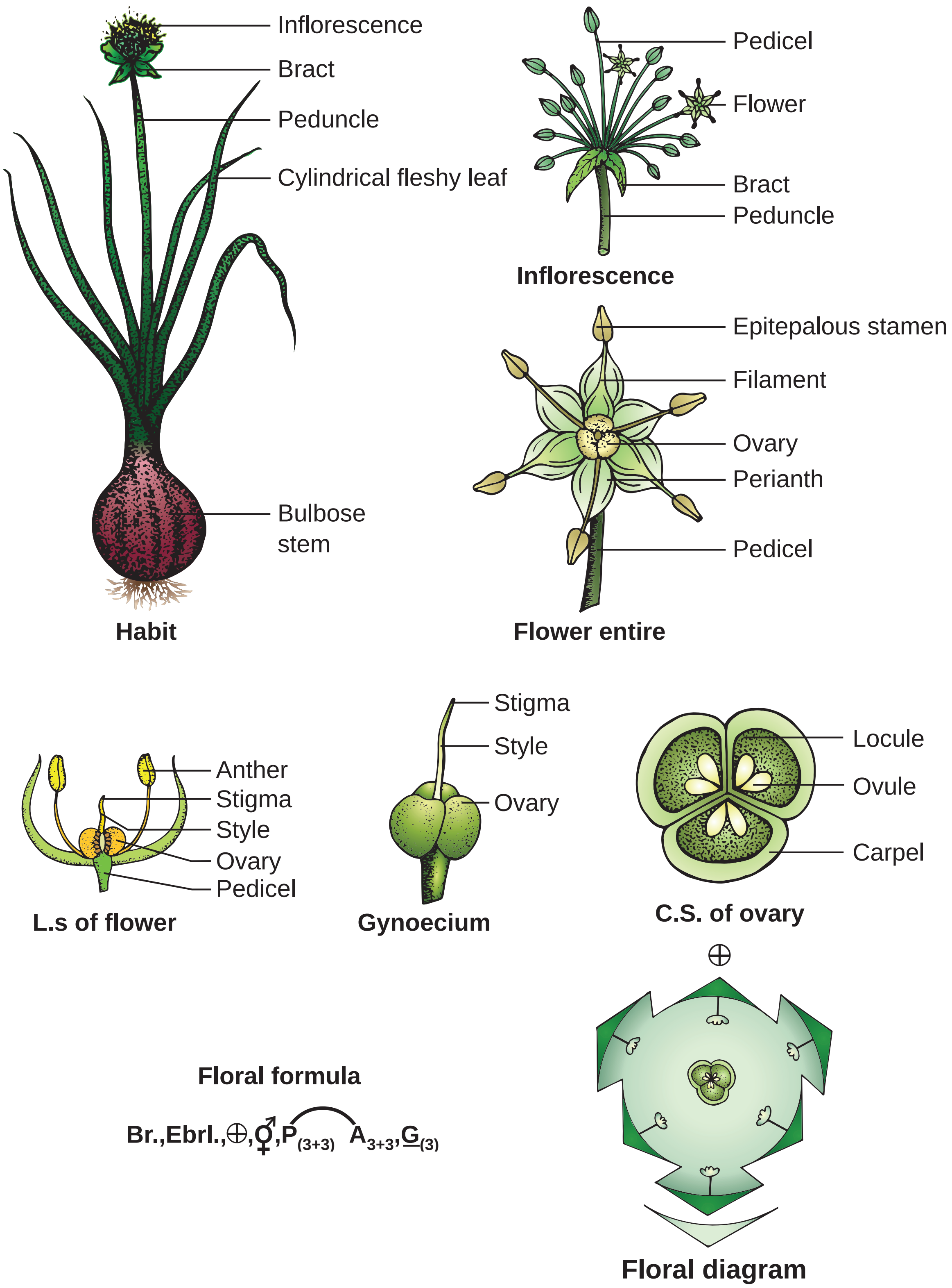


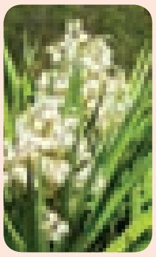
Figure 5.15: *Allium cepa*

Economic importance of the family Liliaceae

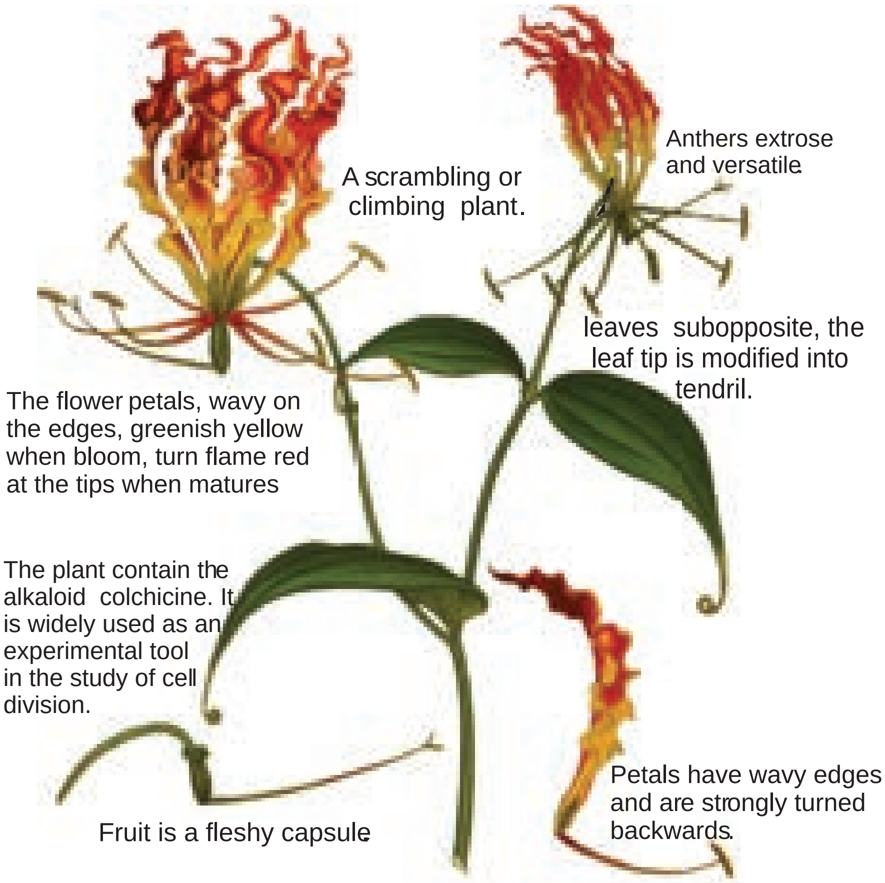
S.No	Economic importance	Binomial	Useful part	Uses
1	Food plant	*Allium cepa*	Bulbs	Used as vegetable, stimulative, diuretic, expectorant with bactericidal properties.
		Allium sativum	Bulbs	Used as condiment and also good for heart.
		Asparagus officinalis	Fleshy shoots	Used as vegetables.
2.	Medicinal plant	*Aloe vera*	Leaves	Gelatinous glycoside called aloin from succulent leaves are used in soothing lotions, piles and inflammations, hemorrhoidal salves and shampoos.
		Asparagus racemosus	Roots	Medicinal oil is prepared from the root is used for nervous and rheumatic complaints and also in skin diseases.
		Colchichum luteum	Roots	Used in the treatment of gout and rheumatism.
		Gloriosa superba	Tubers	Tubers helpful in promoting labour pains in women.
3.	Fibre yielding plant	*Phormium tenax*	Fibre	Used for cordage, fishing net, mattings, twines.
4.	Raticides	*Urginea indica*	Bulbs	Used for killing rats.
	Insecticides	*Veratrum album*	Bulbs	Used as insecticide.
5.	Polyploidy	*Colchicum luteum*	Corm	Colchicine (alkaloid) used to induce polyploidy.
6.	Ornamental plants	*Agapanthus africanus* (African Lily) *Gloriosa superba* (Malabar glory lily) *Lilium giganteum* *Ruscus aculeatus* (Butchers Broom) *Yucca alcifolia* and *Y.gloriosa*	Plant	Some of the well known garden ornamentals. **Can you identify this?** a. Name the family. b. Write the binomial. c. List the economic uses. 

DO YOU KNOW?

In *Yucca* the cross-pollination is carried out by special moth, *Pronuba yuccasella*. Fully opened flowers emit perfumes and are visited by the female moth, especially during nights. This moth collects a lot of pollen grains from one flower and visits another flower. Life history of this moth is intimately associated with the pollination mechanism in *Yucca*.



State Flower of Tamil Nadu
Gloriosa superba



The name of *Gloriosa superba* is composed of two greek words Gloriosa means full of glory, superba means superb. This plant was placed earlier in Liliaceae.

Summary

Taxonomy deals with the identification, naming and classification of plants. But systematics deals with evolutionary relationship between the organisms in addition to taxonomy. Taxonomic hierarchy was introduced by Carolus Linnaeus. It also includes ranks. Species is the fundamental unit of taxonomic classification. Species concept can be classified into two groups based on the process of evolution and product of evolution. There are three types of species, morphological, biological and phylogenetic species. Taxonomic aids are the tools for the taxonomic study such as keys, flora, revisions, catalogues, botanical gardens and herbaria. Botanical gardens serve different purposes. They have aesthetic value, offers scope for botanical research, conservation of rare species and propagation of many species. Botanical survey of India explores and documents biodiversity all over India. It has 11 regional centres in India. Herbarium preparation includes plant collection, documentation of field data, preparation of plant specimens, mounting and labelling. There are several national and international herbaria. National herbaria include MH, PCM, CAL etc. Kew herbarium is the world's largest one.

Classification is the basis for cataloguing and retrieving information about the tremendous diversity of flora. It helps us to know about different varieties, their phylogenetic relationship and exact position. Some important systems of classification are fall in to three types; artificial, natural and phylogenetic. Carolus Linnaeus outlined an artificial system of classification in "*Species Plantarum*" in 1753. The first scheme of classification based on overall similarities was presented by Antoine Laurent De Jessieu in 1789. A widely followed natural system of classification was proposed by George Bentham

(1800 - 1884) and Joseph Dalton Hooker. This system was not intended to be phylogenetic. One of the earliest phylogenetic systems of classification was jointly proposed by Adolf Engler and Karl A Prantl in a monumental work "***Die Naturelichen Pflanzen Familien***". Arthur Cronquist proposed phylogenetic classification of flowering plants based on a wide range of taxonomic characters including anatomical and phytochemical of phylogenetic importance in his book titled "The evolution and classification of flowering plants." Angiosperm phylogeny group (APG) classification is the most recent classification of flowering plants based on phylogenetic data. APG system is an evolving and currently accepted system across the world and followed by all the leading taxonomic institutions and practising taxonomists.

Cladistics is the methodology, used to classify organisms into monophyletic groups, consisting of all the descents of the common ancestors. The outcome of a cladistic analysis is a cladogram and is constructed to represent the best hypothesis of phylogenetic relationships. Chemotaxonomy is the scientific approach of classification of plants on the basis of their biochemical constituents in them. Utilization of the characters of chromosome for the taxonomic inference is known as karyotaxonomy. The application of serology in solving taxonomic problems is called serotaxonomy. Molecular Taxonomy is the branch of phylogeny that analyses hereditary molecular differences, mainly in DNA nuclear and chloroplast sequences, to gain information and to establish genetic relationship between the members of different taxonomic categories. Different molecular markers like allozymes, mitochondrial DNA, microsatellites, RAPDs, AFLPs, single nucleotide polymorphism-(SNP), microchips or arrays are used in analysis. Molecular Taxonomy unlocks the treasure chest of information on evolutionary history of organisms. It plays a vital role in phytogeography, which ultimately helps in genome mapping and biodiversity conservation. DNA barcoding is a taxonomic method that uses a very short genetic sequence from a standard part of a genome. It helps in identification of organisms.

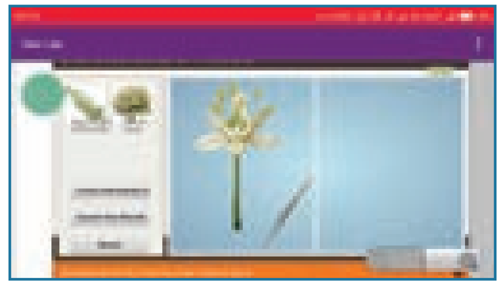
Evaluation

1. Phylogenetic classification is the most favoured classification because it reflects
   a. Comparative Anatomy
   b. Number of flowers produced
   c. Comparative cytology
   d. Evolutionary relationships
2. The taxonomy which involves the similarities and dissimilarities among the immune system of different taxa is termed as
   a. Chemotaxonomy
   b. Molecular systematics
   c. Serotaxonomy
   d. Numerical taxonomy
3. Which of the following is a flowering plant with nodules containing filamentous nitrogen fixing micro - organisms?
   a. *Crotalaria juncea*
   b. *Cycas revoluta*
   c. *Cicer arietinum*
   d. *Casuarina equisetifolia*
4. Flowers are zygomorphic in
   a. *Ceropegia* b. *Thevetia*
   c. *Datura* d. *Solanum*
5. What is the role of national gardens in conserving biodiversity – discuss
6. Where will you place the plants which contain two cotyledons with cup shaped thalamus?
7. Give the floral characters of *Clitoria ternatea*.
8. How will you distinguish Solanaceae members from Liliaceae members?

ICT Corner

Characteristics of flowers

Look inside the **Flower.** →

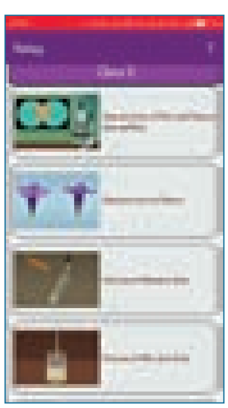


Steps

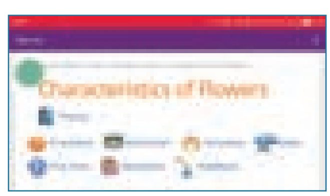
- Scan the QR code or go to google play store
- Type online labs and install it.
- Select biology and select Character of flower
- Click theory to know the basic about Character of flower
- Register yourself with mail-id and create password to access online lab simulations

Activity

- Select simulation and dissect the different flowers
- Record your observations



Step 1



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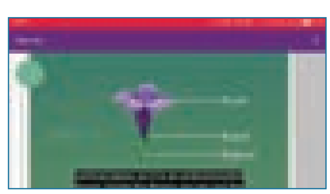

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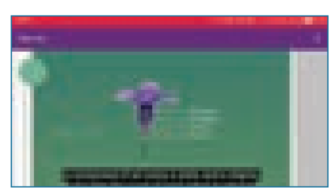

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* Pictures are indicative only

Unit III: Cell biology and Biomolecules

Chapter 6

Cell: The Unit of Life

Learning Objectives

The learner will be able to,

- *Understand the ideas of cell theory and the different concepts associated with it*
- *Recognize the basic structure of cell and differentiate the cells of animals, plants, bacteria and viruses*
- *Explain the structure and functions of cell organelles including nucleus*
- *Recognize the structure of chromosome and its types*

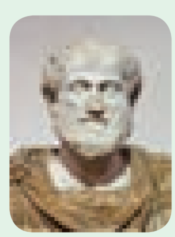
Chapter Outline

The word '*cell*' comes from the Latin word '*Celle*" which means 'a small compartment'. The word cell was first used by Robert Hooke (1662) therefore the term '*cell*' is as old as 300 years.

6.1. Discovery

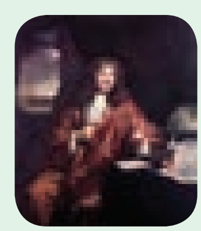
Aristotle (384-322BC), was the one who first recognised that animals and plants consists of organised structural units but unable to explain what it was. In 1660's **Robert Hooke** observed something which looks like 'honeycomb with a great numbers of little boxes' which was later called as '**cell**' from the cork tissue. In 1665, He compiled his work as **Micrographia**. Later, **Anton Van Leeuwenhoek** observed unicellular particles which he named as '***animalcules***'. **Robert Brown** (1831-39) described the spherical body in plant cell as nucleus. **H. J. Dutrochet** (1824), a French scientist, was the first to give an idea on cell theory. Later, **Matthias Schleiden** (German Botanist) and **Theodor Schwann** (German Zoologist) (1833) outlined the basic features of the cell theory. **Rudolf Virchow** (1858) explained the cell theory by adding a feature stating that all living cells arise from pre-existing living cells by 'cell division'.

Scientist



Aristotle (384–322BC)

Robert Hooke (1635–1703)



Antonie von Leeuwenhoek (1632–1723)

Schleiden (1804–1881) & Schwann (1810–1882)

Rudolf Virchow (1821–1902)

Figure 6.1

6.2. Microscopy

Microscope is an inevitable instrument in studying the cell and subcellular structures. It offers scope in studying microscopic organisms therefore it is named as microscope (mikros – small; skipein – to see) in Greek terminology. Compound microscope was invented by **Z. Jansen**.

Microscope basically works on the lens system and its properties of light and lens such as reflection, magnification and numerical aperture. The common light microscope which has many lenses are called as **compound microscope**. The microscope transmits visible light from sources to eye or camera through sample.

6.2.1 Bright field Microscope

Bright field microscope is the routinely used microscope in studying various aspects of cells. It allows light to pass directly through specimen and shows a well distinguished image from different portions of the specimen. The contrast can be increased by staining the specimen with reagent that reacts with cells and tissue components of the object.

The light rays are focused by condenser on to the specimen on a microslide placed upon the adjustable platform called **stage**. Light comes from the Compact Flourescent Lamp (CFL) or Light Emitting Diode (LED). Then it passes through two lens systems namely objective lens (closer to the object) and the eye piece (closer to eye). There are four objective lenses (5X, 10X, 45X and 100X) which can be rotated and fixed at certain point to get required magnification. It works on the principle of numerical aperture value and its own resolving power.

The first magnification of the microscope is done by the objective lens which is called **primary magnification** and it is real, inverted image. The second magnification of the microscope is obtained through eye piece lens called as **secondary magnification** and it is virtual and inverted image (Figure 6.2 a, b and c).

Resolution: The term resolving power or resolution refers to the ability of lenses to show the details of object lying between two points. It is the finest detail available from an object. It can be calculated using the following formula.

$$\text{Resolution} = \frac{0.61\lambda}{NA}$$

Where, λ= wavelength of the light and NA is the numerical aperture.

Numerical Aperture: It is an important optical constant associated with the optical lens denoting the ability to resolve. Higher the NA value greater will be the resolving power of the microscope.

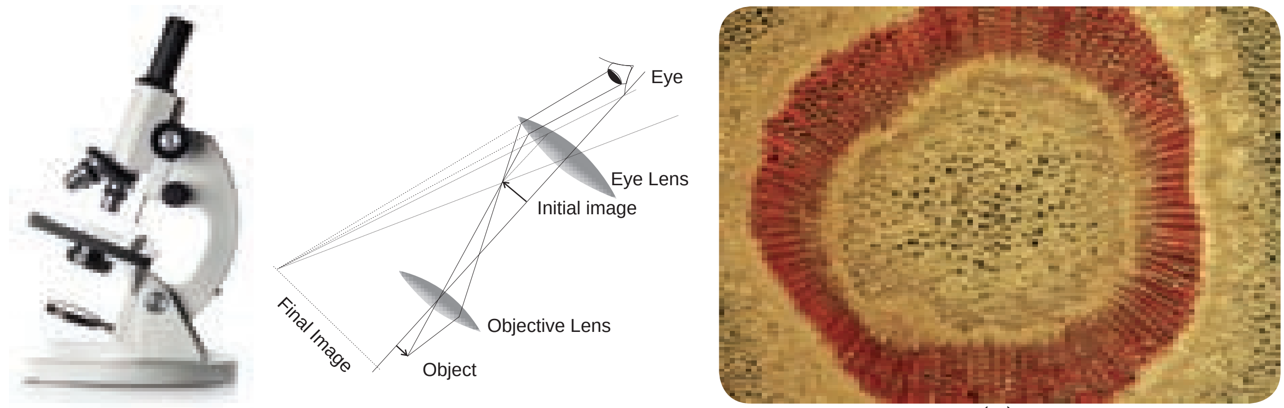
Magnification: The optical increase in size of an image is called magnification. It is calculated by the following formula

$$\text{Magnification} = \frac{\text{size of image seen with the microscope}}{\text{size of the image seen with normal eye}}$$

6.2.2 Electron Microscope

Electron Microscope was first introduced by **Ernest Ruska** (1931) and developed by **G Binning** and **H Roher** (1981). It is used to analyse the fine details of cell and organelles called ultrastructure. It uses beam of accelerated electrons as source of illumination and therefore the resolving power is 1,00,000 times greater than that of light microscope.

The specimen to be viewed under electron microscope is dehydrated and impregnated with electron opaque chemicals like gold or palladium. This is essential for withstanding electrons and also for contrast of the image.



(a) (b) (c)

Figure 6.2: a. Light microscope; **b.** Ray diagram - light path; c. Image taken using light microscope;

There are two kinds of electron microscopes namely:

1. Transmission Electron Microscope (TEM)
2. Scanning Electron Microscope (SEM)

1. Transmission electron microscope:

This is the most commonly used electron microscope which provides two dimensional image. The components of the microscope are as follows:

a. Electron generating system
b. Electron condensor
c. Specimen objective
d. Tube lens
e. Projector

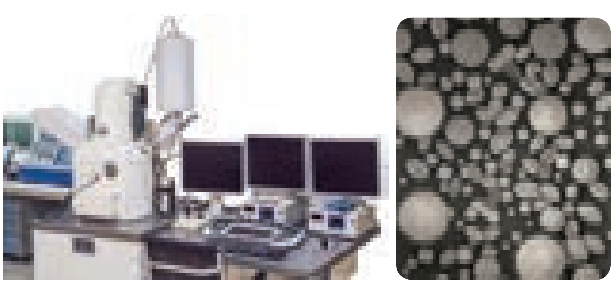
A beam of electron passes through the specimen to form an image on fluorescent screen. The magnification is 1–3 lakhs times and resolving power is 2–10 Å. It is used for studying detailed structrue of viruses, mycoplasma, cellular organelles, etc (Figure 6.3 a and b).

(a) (b)

Figure 6.3: a. Transmission electron microscope; b. Image of TEM

2. Scanning Electron Microscope:

This is used to obtain three dimensional image and has a lower resolving power than TEM. In this, electrons are focused by means of lenses into a very fine point. The interaction of electrons with the specimen results in the release of different forms of radiation (such as auger electrons, secondary electrons, back scattered electrons) from the surface of the specimen. These radiations are then captured by an appropriate detector, amplified and then imaged on fluorescent screen. The magnification is 2,00,000 times and resolution is 5–20 nm (Figure 6.4 a and b).



(a) (b)

Figure 6.4: a. Scanning electron microscope; b. Image of SEM

6.3. Cell Theory

In 1833, German botanist **Matthias Schleiden** and German zoologist **Theodor Schwann** proposed that all plants and animals are composed of cells and that cells were the basic building blocks of life.

Microscopic measurements:
The microscope also has facility to measure microscopic objects through a technique called '**micrometry**'. There are two scales involved for measuring.

1. Ocular Micrometre
2. Stage Micrometre

Ocular Micrometre: It is fixed inside the eye piece lens. It is a thin transparent glass disc where there are lines divided into 100 equal units. The scale has no value.

Stage Micrometre: This is a slide with a line divided into 100 units. The line is about 10mm. The distance between two adjacent lines is 10 µm. The known value of the stage micrometre is transferred to the ocular micrometre, thereby the measurement can be made using ocular micrometre.

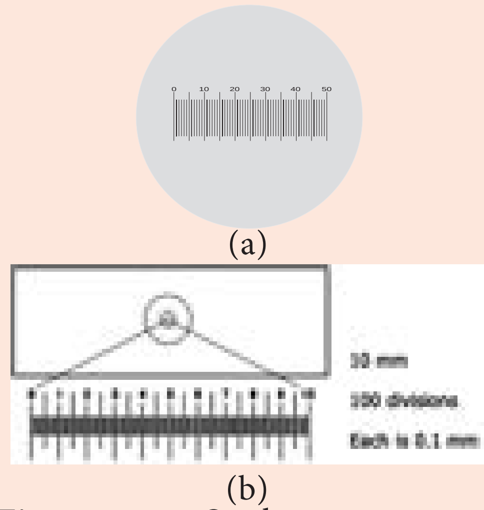


Figure 6.5: a. Ocular micrometre; b. Stage micrometre

The distance between two adjacent line of ocular meter $= \dfrac{\text{Number of stage divisions}}{\text{Number of ocular divisions}} \times 10$

These observations led to the formulation of modern cell theory.

- All organisms are made up of cells.
- New cells are formed by the division of pre-existing cells.
- Cells contains genetic material, which is passed on from parents to daughter cells.
- All metabolic reactions take place inside the cells.

6.3.1 Exception to Cell Theory

Viruses are puzzle in biology. Viruses, viroids and prions are the exception to cell theory. They lack protoplasm, the essential part of the cell and exists as obligate parasites which are sub-cellular in nature.

6.3.2 Protoplasm Theory

Corti first observed protoplasm. **Felix Dujardin** (1835) observed a living juice in animal cell and called it "**Sarcode**". **Purkinje** (1839) coined the term protoplasm for sap inside a plant cell. **Hugo Van Mohl** (1846) indicated importance of protoplasm.

Max Schultze (1861) established similarity between Protoplasm and Sarcode and proposed a theory which later on called "**Protoplasm Theory**" by **O. Hertwig** (1892). **Huxley** (1868) proposed Protoplasm as a "**physical basis of life**".

Protoplasm as a Colloidal System

Protoplasm is a complex colloidal system which was suggested by **Fisher** in 1894 and **Hardy** in 1899. It is primarily made of water and various other solutes of biological importance such as glucose, fatty acids, amino acids, minerals, vitamins, hormones and enzymes.

These solutes may be homogeneous (soluble in water) or heterogeneous mass (insoluble in water) which forms the basis for its colloidal nature.

Physical Properties of Protoplasm

The protoplasm exists either in semisolid (jelly-like) state called '**gel**' due to suspended particles and various chemical bonds or may be liquid state called '**sol**'.The colloidal protoplasm which is in gel form can change into sol form by **solation** and the sol can change into gel by **gelation**. These gel-sol conditions of colloidal system are prime basis for mechanical behaviour of cytoplasm.

1. Protoplasm is translucent, odourless and polyphasic fluid.
2. It is a crystal colloid solution which is a mixture of chemical substances forming crystalloid i.e. true solution (sugars, salts, acids, bases) and others forming colloidal solution (Proteins and lipids)
3. It is the most important property of the protoplasm by which it exhibits three main phenomena namely Brownian movement, amoeboid movement and cytoplasmic streaming or cyclosis. Viscosity of protoplasm is 2–20 centipoises. The Refractive index of the protoplasm is 1.4.
4. The pH of the protoplasm is around 6.8, contain 90% water (10% in dormant seeds)
5. Approximately 34 elements are present in protoplasm but only 13 elements are main or universal elements i.e. C, H, O, N, Cl, Ca, P, Na, K, S, Mg, I and Fe. Carbon, Hydrogen, Oxygen and Nitrogen form the 96% of protoplasm.
6. Protoplasm is neither a good nor a bad conductor of electricity. It forms a delimiting membrane in contact with water and solidifies when heated.
7. **Cohesiveness:** Particles or molecules of protoplasm are adhered with each other by forces, such as **Van der Waal's bonds**, that hold long chains of molecules together. This property varies with the strength of these forces.
8. **Contractility:** The contractility of protoplasm is important for the absorption and removal of water especially for stomatal operations.
9. **Surface tension:** The proteins and lipids of the protoplasm have less surface tension, hence they are found at the surface forming the membrane. On the other hand the chemical substances (NaCl) have high surface tension, so they occur in deeper parts of the protoplasm.

6.3.3 Cell sizes and shapes

Cell greatly vary in size, shape and also in function. Group of cells with similar structures are called **tissue** they integrate together to perform similar function, group of tissue join together to perform similar function called **organ**, group of organs with related function called **organ system**, organ system coordinating together to form an **organism**.

Shape

The shape of cell vary greatly from organism to organism and within the organism itself. In bacteria, cell shape vary from round (**cocci**) to rectangular (**rod**). In virus, shape of the envelope varies from round to hexagonal or '**T**' shaped. In fungi, globular to elongated cylindrical cells and the spores of fungi vary

DO YOU KNOW?

1 cm = 1/100 metre
1 mm = 1/1000 metre =1/10 cm
1 µm = 1/1000,000 metre = 1/10,000 cm
1 nm = 1/1,000,000,000 metre = 1/10,000,000 cm
1 A° = 1/10,000,000,000 metre =1/100,000,000 cm

or

1 m = 10^2cm = 10^3mm = 10^6µm = 10^9nm = 10^{10} A°

m = metre cm = centimetre mm = millimetre µm = micrometre
nm = nanometre A° =Angstrom

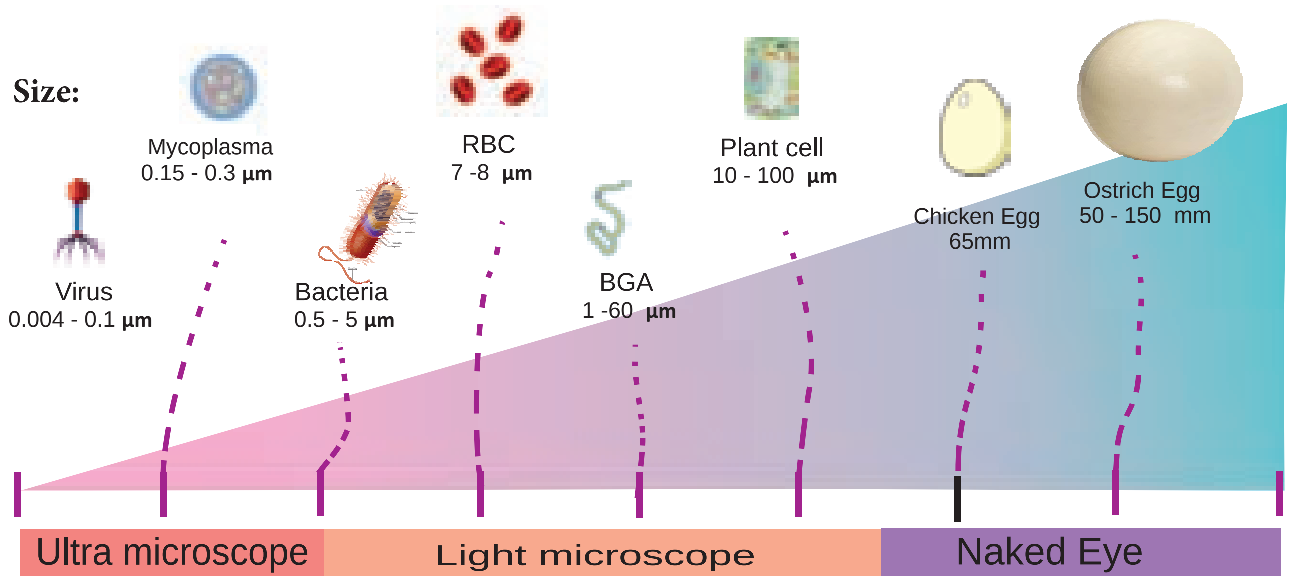


Figure 6.6: Cell size variation of few organisms

greatly in shape. In plants and animals cells vary in shape according to cell types such as parenchyma, mesophyll, palisade, tracheid, fiber, epithelium and others (Figure 6.6).

6.4. Types of cells

On the basis of the cellular organization and the nuclear characteristics, the cell can be classified into

- Prokaryotes
- Mesokaryotes and
- Eukaryotes

6.4.1 Prokaryotes

Those organisms with primitive nucleus are called as **prokaryotes** (*pro* – primitive; *karyon* – nucleus). The DNA lies in the 'nucleoid' which is not bound by the nuclear membrane and therefore it is not a true nucleus and is also a primitive type of nuclear material. The DNA is without histone proteins. Example: Bacteria, blue green algae, Mycoplasma, Rickettsiae and Spirochaetae.

6.4.2 Mesokaryotes

In the year 1966, scientist **Dodge** and his coworkers proposed another kind of organisms called **mesokaryotes**. These organisms which shares some of the characters of both prokaryotes and eukaryotes. In other words these are organisms intermediate between pro and eukaryotes. These contains well organized nucleus with nuclear membrane and the DNA is organized into chromosomes but without histone protein components divides through amitosis similar with prokaryotes. Certain Protozoa like **Noctiluca**, some phytoplanktons like *Gymnodinium*, *Peridinium* and Dinoflagellates are representatives of mesokaryotes.

6.4.3 Eukaryotes

Those organisms which have true nucleus are called **Eukaryotes** (*Eu* – True; *karyon* – nucleus). The DNA is associated with histones forming the chromosomes. Membrane bound organelles are present. Few organelles may have risen by **endosymbiosis** which is a cell living inside another cell. The Organelles like mitochondria and chloroplast well support this theory.

Origin of Eukaryotic cell:

Endosymbiont theory: Two eukaryotic organelles believed to be the descendants of the endosymbiotic prokaryotes. The ancestors of the eukaryotic cell engulfed a bacterium and the bacteria continued to function inside the host cell.

Comparison between types of cellular organisation

Features	Prokaryotes	Mesokaryotes	Eukaryotes
Size of the cell	~1-5µm	~5-10µm	~10-100µm
Nuclear character	Nucleoid, no true nucleus,	Nucleus with nuclear membrane	True nucleus with nuclear membrane
DNA	Usually circular without histone proteins	Usually linear but without histone proteins	Usually linear with histone proteins
RNA/Protein synthesis	Couples in cytoplasm	Similar with eukaryotes	RNA synthesis inside nucleus/ Protein synthesis in cytoplasm
Ribosomes	50S+ 30S	60S + 40S	60S + 40S
Organelles	Absent	Present	Numerous
Cell movement	Flagella	Gliding and flagella	Flagella and cilia
Organization	Usually single cell	Single and colony	Single, colonial and multicellular
Cell division	Binary fission	Binary fission	Mitosis and meiosis
Examples	Bacteria and Archaea	Dinoflagellate, Protozoa	Fungi, plants and animals

6.5. Plant and Animal cell

6.5.1 Ultra Structure of an Eukaryotic Cell

An eukaryotic cell is highly distinct in its organisation. It shows several variations in different organisms. For instance, eukaryotic cells in plants and animals vary greatly (Figure 6.7).

Figure 6.7: Animal and Plant cell

Animal Cell

Animal cells are surrounded by cell membrane or plasma membrane. Inside this membrane a gelatinous matrix called **protoplasm** is seen to contain nucleus and other organelles which include the endoplasmic reticulum, mitochondria, golgi bodies, centrioles, lysosomes, ribosomes and cytoskeleton.

Plant cell

A typical plant cell has prominent cell wall, a large central vacuole and plastids in addition to other organelles present in animal cell (Figure 6.8).

Figure 6.8: Ultra Structure of Plant Cell

6.5.2 Protoplasm

Protoplasm is the living content of cell that is surrounded by plasma membrane. It is a colourless material that exists throughout the cell together with cytoplasm, nucleus and other organelles. Protoplasm is composed of a mixture of small particles, such as

Difference between plant and animal cells

S. No	Plant cell	Animal Cell
1	Usually they are larger than animal cells	Usually smaller than plant cells
2	Cell wall present in addition to plasma membrane and consists of middle lamellae, primary and secondary walls	Cell wall absent
3	Plasmodesmata present	Plasmodesmata absent
4	Chloroplast present	Chloroplast absent
5	Vacuole large and permanent	Vacuole small and temporary
6	Tonoplast present around vacuole	Tonoplast absent
7	Centrioles absent except motile cells of lower plants	Centrioles present
8	Nucleus present along the periphery of the cell	Nucleus at the centre of the cell
9	Lysosomes are rare	Lysosomes present
10	Storage material is starch grains	Storage material is a glycogen granules

ions, amino acids, monosaccharides, water, macromolecules like nucleic acids, proteins, lipids and polysaccharides. It appears colourless, jelly like gelatinous, viscous elastic and granular. It appears foamy due to the presence of large number of vacuoles. It responds to the stimuli like heat, electric shock, chemicals and so on.

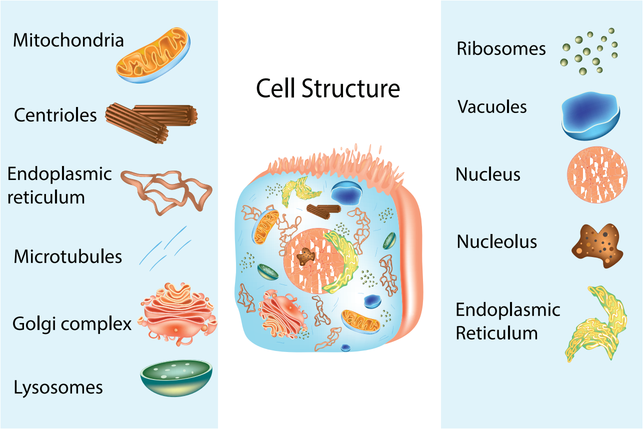


Figure 6.9: Cell structure and components

6.5.3 Cell Wall

Cell wall is the outermost protective cover of the cell. It is present in bacteria, fungi and plants whereas it is absent in animal cell. It was first observed by **Robert Hooke**. It is an actively growing portion. It is made up of different complex material in various organism. In bacteria it is composed of peptidoglycan, in fungi chitin and fungal cellulose, in algae cellulose, galactans and mannans. In plants it is made up of cellulose, hemicellulose, pectin, lignin, cutin, suberin and silica.

In plant, cell wall shows three distinct regions (a) Primary wall (b) Secondary wall (c) Middle lamellae (Figure 6.10).

a. Primary wall

It is the first layer inner to middle lamella, primarily consisting of loose network of cellulose microfibrils in a gel matrix. It is thin, elastic and extensible.In most plants the microfibrils are made up of cellulose oriented differently based on shape and thickness of the wall. The matrix of the primary wall is composed of hemicellulose, pectin, glycoprotein and water. Hemicellulose binds the microfibrils with matrix and glycoproteins control the orientation of microfibrils while pectin serves as filling material of the matrix. Cells such as parenchyma and meristems have only primary wall.

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b. Secondary wall

Secondary wall is laid during maturation of the cell. It plays a key role in determining the shape of a cell. It is thick, inelastic and is made up of cellulose and lignin. The secondary wall is divided into three sublayers termed as S_1, S_2 and S_3 where the cellulose microfibrils are compactly arranged with different orientation forming a laminated structure and the cell wall strength is increased.

c. Middle lamellae

It is the outermost layer made up of calcium and magnesium pectate, deposited at the time of cytokinesis. It is a thin amorphous layer which cements two adjacent cells. It is optically inactive (isotropic).

Plasmodesmata and Pits

Plasmodesmata act as a channel between the protoplasm of adjacent cells through which many substances pass through. Moreover, at few regions, the secondary wall layer is laid unevenly whereas the primary wall and middle lamellae are laid continuously such regions are called **pits**. The Pits of adjacent cells are opposite to each other. Each pit has a pit chamber and a pit membrane. The pit membrane has many minute pores and thus they are permeable. The pits are of two types namely simple and bordered pit.

Functions of cell wall

The cell wall plays a vital role in holding several important functions given below

1. Offers definite shape and rigidity to the cell.
2. Serves as barrier for several molecules to enter the cells.
3. Provides protection to the internal protoplasm against mechanical injury.
4. Prevents the bursting of cells by maintaining the osmotic pressure.
5. Plays a major role by acting as a mechanism of defense for the cells.

6.5.4 Cell Membrane

The cell membrane is also called **cell surface** (or) **plasma membrane**. It is a thin structure which holds the cytoplasmic content called '**cytosol**'. It is extremely thin (less than 10nm).

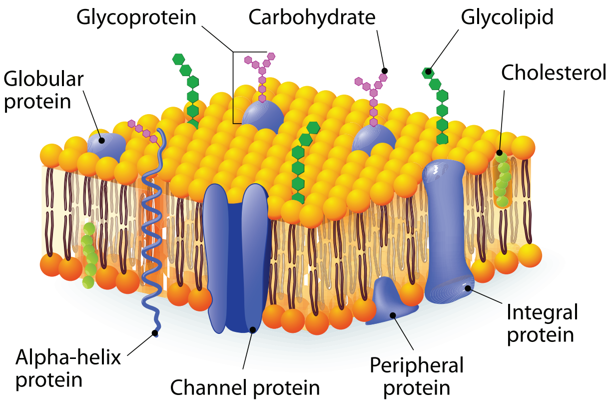
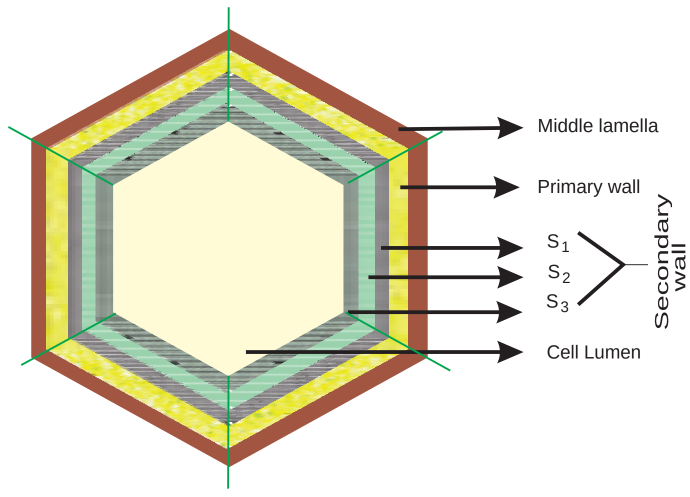
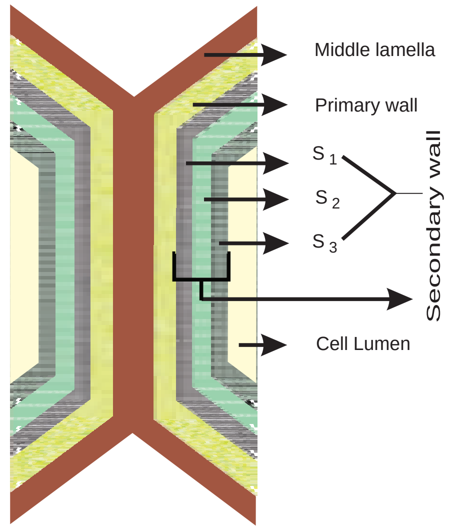


Figure 6.11: Model of Cell membrane



T.S. of a Plant cell (details of cell wall)



Portion enlarged with adjacent cells

Figure 6.10: Plant cell wall

Fluid Mosaic Model

Jonathan Singer and **Garth Nicolson** (1972) proposed fluid mosaic model.

It is made up of lipids and proteins together with a little amount of carbohydrate. The lipid membrane is made up of phospholipid. The phospholipid molecule has a hydrophobic tail and hydrophilic head. The hydrophobic tail repels water and hydrophilic head attracts water. The proteins of the membrane are globular proteins which are found intermingled between the lipid bilayer most of which are projecting beyond the lipid bilayer. These proteins are called as **integral proteins**. Few are superficially attached on either surface of the lipid bilayer which are called as **peripheral proteins**. The proteins are involved in transport of molecules across the membranes and also act as enzymes, receptors (or) antigens.

DO YOU KNOW?

Water-loving polar molecule are called hydrophilic molecule. They have polar phosphate group responsible for attracting water.

Water hating non-polar molecule are called as hydrophobic molecule. They have fatty acid which is non-polar which cannot attract water

Carbohydrate molecules of cell membrane are short chain polysaccharides. These are either bound with '**glycoproteins**' or '**glycolipids**' and form a '**glyocalyx**' (Figure 6.11).

The movement of membrane lipids from one side of the membrane to the other side by vertical movement is called **flip flopping** or **flip flop movement**. This movement takes place more slowly than lateral diffusion of lipid molecule. The Phospholipids can have flip flop movement because they have smaller polar regions, whereas the proteins cannot flip flop because the polar region is extensive.

Function of Cell Membrane

The functions of the cell membrane is enormous which includes cell signalling, transporting nutrients and water, preventing unwanted substances entering into the cell, and so on.

Cytoplasm

Cytoplasm is the main arena of various activities of a cell. It is the semifluid gelatinous substance that fills the cell. It is made up of eighty percent water and is usually clear and colourless. The cytoplasm is sometimes described as non nuclear content of protoplasm. The cytoplasm serves as a molecular soup where all the cellular organelles are suspended and bound together by a lipid bilayer plasma membrane. It constitutes dissolved nutrients, numerous salts and acids to dissolve waste products. It is a very good conductor of electricity. It gives support and protection to the cell organelles. It helps movement of the cellular materials around the cell through a process called **cytoplasmic streaming**. Further, most cellular activities such as many metabolic pathways including glycolysis and cell division occur in cytoplasm.

6.6 Cell Organelles

6.6.1 Endomembrane System

System of membranes in a eukaryotic cell, comprises the plasma membrane, nuclear membrane, endoplasmic reticulum, golgi apparatus, lysosomes and vacuolar membranes (tonoplast). Endomembranes are made up of phospholipids with embedded proteins that are similar to cell membrane which occur within the cytoplasm. The endomembrane system is evolved from the inward growth of cell membrane in the ancestors of the first eukaryotes (Figure 6.12).

6.6.2 Endoplasmic Reticulum

The largest of the internal membranes is called the **endoplasmic reticulum** (ER). The name endoplasmic reticulum was given by **K.R. Porter** (1948). It consists of double membrane. Morphologically the structure of endoplasmic reticulum consists of the following:

1. **Cisternae** are long, broad, flat, sac like structures arranged in parallel bundles or stacks to form lamella. The space between membranes of cisternae is filled with fluid.
2. **Vesicles** are oval membrane bound vacuolar structure.
3. **Tubules** are irregular in shape, branched, smooth walled, enclose a space

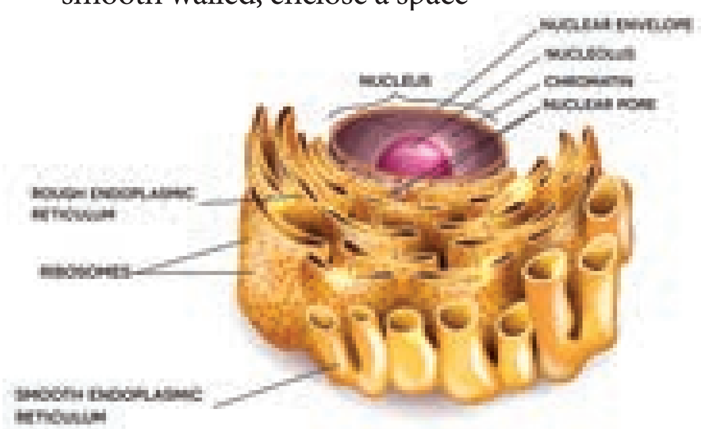


Figure 6.12: Structure of an Endoplasmic reticulum

Endoplasmic reticulum is associated with nuclear membrane and cell surface membrane. It forms a network in cytoplasm and gives mechanical support to the cell. Its chemical environment enables protein folding and undergo modification necessary for their function. Misfolded proteins are pulled out and are degraded in endoplasmic reticulum. When ribosomes are present in the outer surface of the membrane it is called as **rough endoplasmic reticulum(RER)**, when the ribosomes are absent in the endoplasmic reticulum it is called as **smooth Endoplasmic reticulum(SER)**. Rough endoplasmic reticulum is involved in protein synthesis and smooth endoplasmic reticulum are the sites of lipid synthesis. The smooth endoplasmic reticulum contains enzymes that detoxify lipid soluble drugs, certain chemicals and other harmful compounds.

6.6.3 Golgi Body (Dictyosomes)

In 1898, **Camillo Golgi** visualized a netlike reticulum of fibrils near the nucleus, were named as **Golgi bodies.** In plant cells they are found as smaller vesicles termed as **dictyosomes**. Golgi apparatus is a stack of flat membrane enclosed sacs. It consist of cisternae, tubules, vesicles and golgi vacuoles. In plants, the cisternae are 10-20 in number placed in piles separated from each other by a thin layer of inter cisternal cytoplasm often flat or curved. Peripheral edge of cisternae forms a network of tubules and vesicles. Tubules interconnect cisternae and are 30-50nm in dimension. Vesicles are large round or concave sac. They are pinched off from the tubules.They are smooth/ secretary or coated type. Golgi vacuoles are large spherical structures filled with granular or amorphous substance, some function like lysosomes. Golgi apparatus compartmentalises a series of steps leading to the production of functional protein.

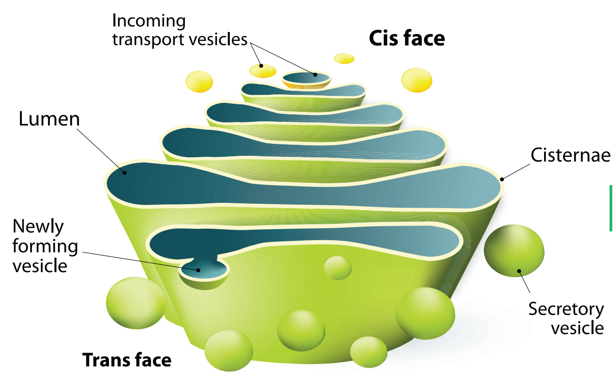


Figure 6.13: Structure of Golgi apparatus

Small pieces of rough endoplasmic reticulum are pinched off at the ends to form small vesicles. A number of these vesicles then join up and fuse together to make a Golgi body. Golgi complex plays a major role in post translational modification of proteins and glycosylation of lipids (Figure 6.13 and 6.14).

Functions:

- Production of glycoproteins and glycolipids
- Transporting and storing of lipids.
- Formation of lysosomes.
- Production of digestive enzymes.
- Cell plate and cell wall formation

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- Secretion of carbohydrates for the formation of plant cell walls and insect cuticles.
- **Zymogen granules** (proenzyme/precursor of all enzyme) are synthesised.

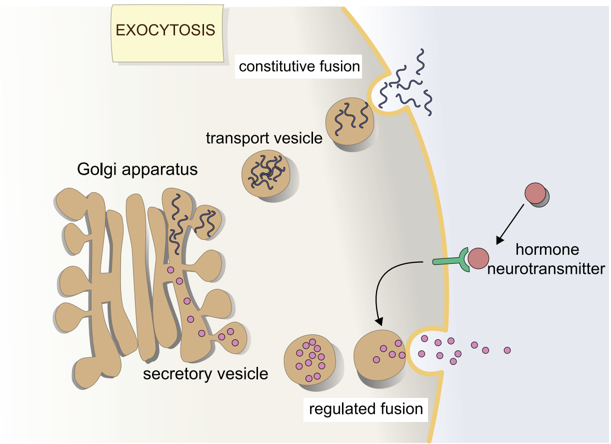


Figure 6.14: Exocytosis

6.6.4 Mitochondria

It was first observed by **A. Kolliker** (1880). **Altmann** (1894) named it as Bioplasts. Later **Benda** (1897, 1898), named as mitochondria. They are ovoid, rounded, rod shape and pleomorphic structures. Mitochondrion consists of double membrane, the outer and inner membrane. The outer membrane is smooth, highly permeable to small molecules and it contains proteins called **Porins**, which form channels that allows free diffusion of molecules smaller than about 1000 daltons and the inner membrane divides mitochondrion into two compartments, outer chamber between two membranes and the inner chamber is filled with matrix.

The inner membrane is convoluted (infoldings), called **crista** (plural: cristae). Cristae contain most of the enzymes for electron transport system. Inner chamber of the mitochondrion is filled with proteinaceous material called **mitochondrial matrix**. The Inner membrane consists of stalked particles called **elementary particles** or **Fernandez Moran particles, F1 particles** or **Oxysomes.** Each particle consists of a base, stem and a round head. In the head, ATP synthase is present for oxidative phosphorylation. Inner membrane is impermeable to most ions, small molecules and maintains the proton gradient that drives oxidative phosphorylation (Figure 6.15).

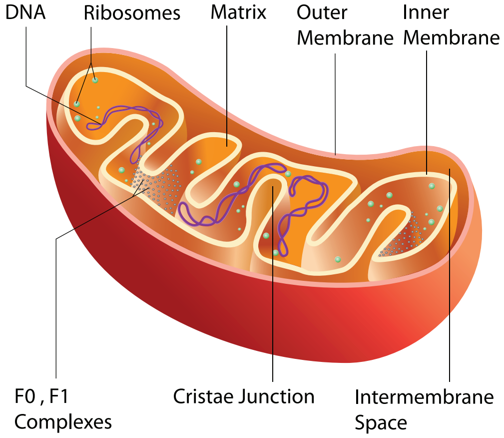


Figure 6.15: Structure of Mitochondria

Mitochondria contain 73% of proteins, 25-30% of lipids, 5-7 % of RNA, DNA (in traces) and enzymes (about 60 types). Mitochondria are called **Power house of a cell**, as they produce energy rich ATP.

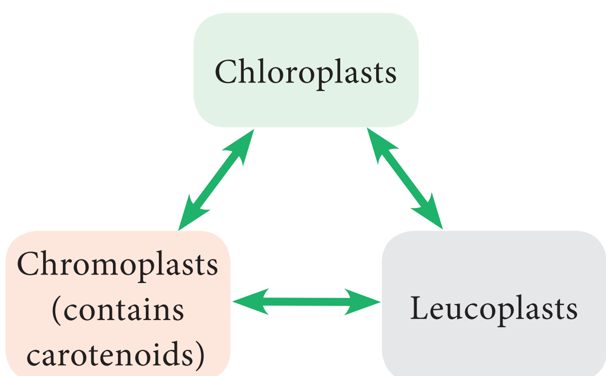
All the enzymes of Kreb's cycle are found in the matrix except succinate dehydrogenase. Mitochondria consist of circular DNA and 70S ribosome. They multiply by fission and replicates by strand displacement model. Because of the presence of DNAs it is semi-autonomous organelle. Unique characteristic of mitochondria is that they are inherited from female parent only. Mitochondrial DNA comparisons are used to trace human origins. It is also used to track and date recent evolutionary time because it mutates 5 to 10 time faster than DNA in the nucleus.

6.6.5 Plastids

The term plastid is derived from the Greek word ***Platikas*** (formed/moulded) and used by **A.F.U. Schimper** in 1885. He classified plastids into following types according to their structure, pigments and function. Plastids multiply by fission.

Plastids	
Chromoplasts	**Leucoplasts**
Coloured Plastids	Colourless plastids store food materials
Chloroplast Occurs in green algae and higher plants. Pigments chlorophyll *a* and *b*	**Amyloplast** – stores – starch
Phaeoplast Brown algae and dinoflagellates. Pigment-fucoxanthin	**Elaioplast** – store – lipids (oils). Seed of monocot and dicots.
Rhodoplast Red algae Pigment-Phycoerythrin	**Aleuroplast** (or) **Proteoplast** Stores – Protein

According to Schimper, different kind of plastids can transform into one another.



6.6.6 Chloroplast

Chloroplasts are vital organelle found in green plants. Chloroplast has a double membrane the outer membrane and the inner membrane separated by a space called **periplastidial space**. The space enclosed by the inner membrane of chloroplast is filled with gelatinous matrix, lipo-proteinaceous fluid called **stroma**. Inside the stroma there are flat interconnected sacs called **thylakoid**. The membrane of thylakoid enclose a space called **thylakoid lumen**.

Grana (singular: Granum) are formed when many of these thylakoids are stacked together like pile of coins. Light is absorbed and converted into chemical energy in the granum, which is used in stroma to prepare carbohydrates. Thylakoid contain chlorophyll pigments. The chloroplast contains osmophilic granules, 70s ribosomes, DNA (circular and non histone) and RNA. These chloroplast genome encodes approximately 30 proteins involved in photosynthesis including the components of photosystem I & II, cytochrome bf complex and ATP synthase. One of the subunits of RuBisco is encoded by chloroplast DNA. It is the major protein component of chloroplast stroma, single most abundant protein on earth. The thylakoid contain small, rounded photosynthetic units called **quantosomes**. Chloroplast is a semi-autonomous organelle and divides by fission (Figure 6.16).

Functions:

- Photosynthesis
- Light reactions takes place in granum,
- Dark reactions take place in stroma,
- Chloroplast is involved in photo-respiration.

6.6.7 Ribosome

Ribosomes were first observed by **George Palade** (1953) as dense particles or granules in the electron microscope. Electron microscopic observation reveals that ribosomes are composed of two rounded sub units, united together to form a complete unit. Mg^{2+} is required for structural cohesion of ribosomes. Biogenesis of ribosome is a *de nova* formation, auto replication and nucleolar origin. Each ribosome is made up of one small and one large sub-unit Ribosomes are the sites of protein synthesis in the cell. Ribosome is not a membrane bound organelle (Figure 6.17).

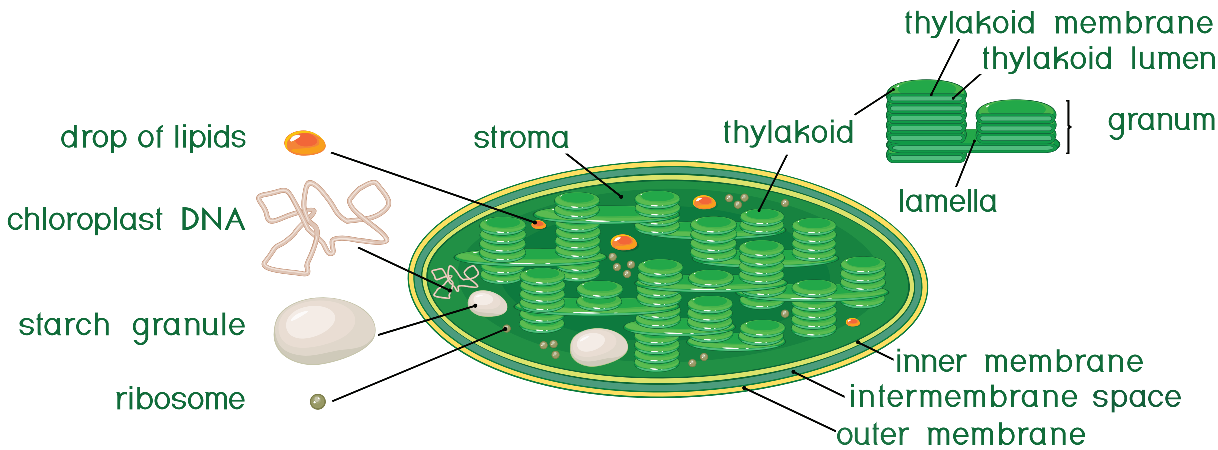


Figure 6.16: Structure of Chloroplast

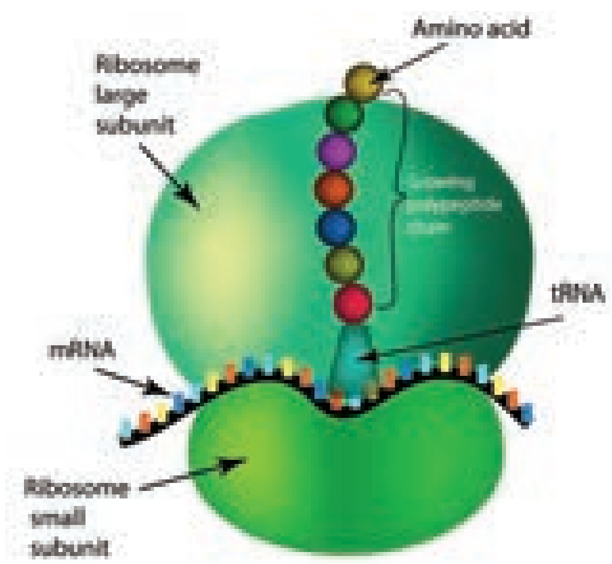


Figure 6.17: Structure of Ribosomes

> DO YOU KNOW?
>
> **Svedberg unit (s).**
>
> The size of ribosomes and their subunits are usually given in Svedberg unit (named after Theoder Svedberg, Swedish Chemist Noble Laureate 1929), a measure of a particle size dependent on the speed with which particle sediment in the ultracentrifuge.

Ribosome consists of RNA and protein: RNA 60 % and protein 40%. During protein synthesis, many ribosomes are attached to the single mRNA and is called **polysomes** or **polyribosomes**. The function of polysomes is the formation of several copies of a particular polypeptide during protein synthesis. They are free in non-protein synthesising cells. In protein synthesising cells they are linked together with the help of Mg^{2+} ions.

Types of Ribosomes

70S Ribosomes (sub unit 30S and 50S)	80S Ribosomes (sub units 40S and 60S)
3 RNA molecule (i) 16SrRNA in 30S subunit (ii) 23S and 5S in 50S large subunit **(Prokaryotic cells of bluegreen algae bacteria, mitochondria and chloroplast of many algae and higher plants)**	4 RNA molecule (i) 18SrRNA in 40S small subunit (ii) 28S, 5.8S and 5S in larger 60S subunit **(Eukaryotic cells of plants and animals)**

6.6.8 Lysosomes (Suicidal Bags of Cell)

Lysosomes were discovered by **Christian de Duve** (1953), these are known as **suicidal bags**. They are spherical bodies enclosed by a single unit membrane. They are found in eukaryotic cell. Lysosomes are small vacuoles formed when small pieces of golgi body are pinched off from its tubules.

They contain a variety of hydrolytic enzymes, that can digest material within the cell. The membrane around lysosome prevent these enzymes from digesting the cell itself (Figure 6.18).

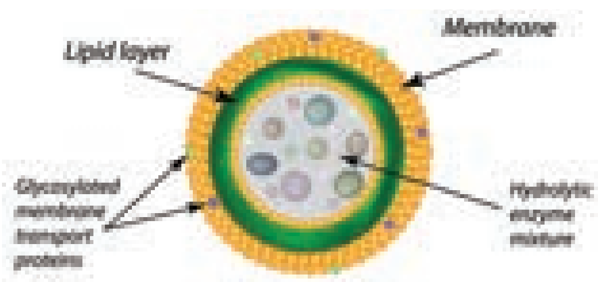


Figure 6.18: Structure of Lysosome

Functions:

- **Intracellular digestion:** They digest carbohydrates, proteins and lipids present in cytoplasm.
- **Autophagy:** During adverse condition they digest their own cell organelles like mitochondria and endoplasmic reticulum
- **Autolysis:** Lysosome causes self destruction of cell.
- **Ageing:** Lysosomes have autolytic enzymes that disrupts intracellular molecules.

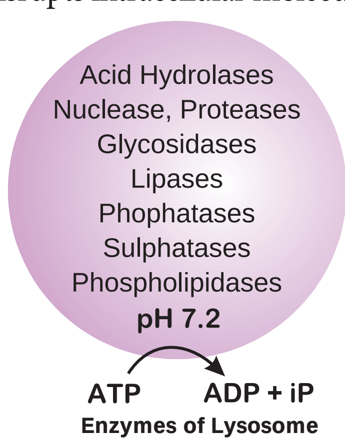


Figure 6.19: Enzymes of Lysosome

- **Phagocytosis:** Large cells or contents are engulfed and digested by macrophages, thus forming a phagosome in cytoplasm. These phagosome fuse with lysosome for further digestion.
- **Exocytosis:** Lysosomes release their enzymes outside the cell to digest other cells (Figure 6.19).

6.6.9 Microbodies

Eukaryotic cells contain many enzyme bearing membrane enclosed vesicles called **microbodies**. They are single unit membrane bound cell organelles. Example: Peroxisomes and glyoxysomes.

6.6.10 Peroxisomes

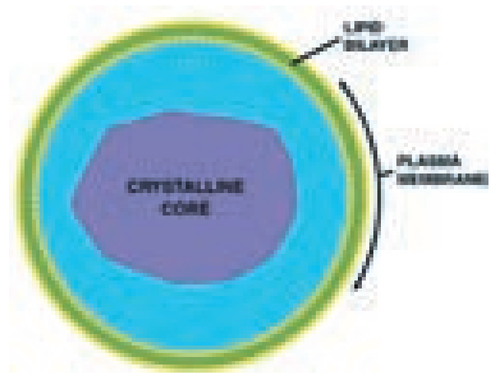


Figure 6.20: Structure of Peroxisome

Peroxisomes were identified as organelles by **Christian de Duve** (1967). Peroxisomes are small spherical bodies and single membrane bound organelle. It takes part in photorespiration and associated with glycolate metabolism. In plants, leaf cells have many peroxisomes. It is also commonly found in liver and kidney of mammals. These are also found in cells of protozoa and yeast (Figure 6.20).

6.6.11 Glyoxysomes

Glyoxysome was discovered by **Harry Beevers** (1961). It is a single membrane bound organelle. It is a sub cellular organelle and contains enzymes of glyoxylate pathway. β-oxidation of fatty acid occurs in glyoxysomes of germinating seeds Example: Castor seeds.

6.6.12 Sphaerosomes

It is spherical in shape and enclosed by single unit membrane. Example: Storage of fat in the endosperm cells of oil seeds.

6.6.13 Centrioles

Centrioles consists of nine triplet peripheral fibrils made up of tubulin. The central part of the centriole is called **hub**, is connected to the tubules of the peripheral triplets by radial spokes (9+0 pattern). The centriole form the basal body of cilia or flagella and spindle fibers which forms the spindle apparatus in animal cells. The membrane is absent in centriole (non-membranous organelle) (Figure 6.21).

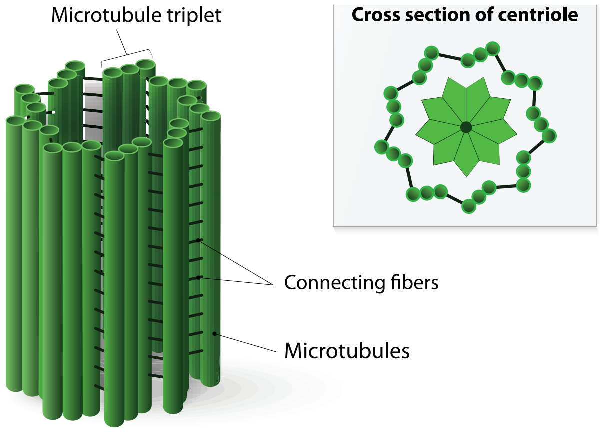


Figure 6.21: Structure of Centriole

6.6.14 Vacuoles

In plant cells vacuoles are large, bounded by a single unit membrane called **Tonoplast**. The Vacuoles contain cell sap, which is a solution of sugars, amino acids, mineral salts, waste chemical and anthocyanin pigments. Beetroot cells contain anthocyanin pigments in their vacuoles. Vacuoles accumulate products like tannins. The osmotic expansion of a cell kept in water is chiefly regulated by vacuole and the water enters the vacuole by osmosis.

The major function of plant vacuole is to maintain water pressure known as **turgor pressure**, which maintains the plant structure. Vacuoles organises itself into a storage/ sequestration compartment. Example: Vacuoles store, most of the sucrose of the cell.

i. Sugar in Sugar beet and Sugar cane.
ii. Malic acid in Apple.
iii. Acids in Citrus fruits.
iv. Flavonoid pigment cyanidin 3 rutinoside in the petals of *Antirrhinum*.

6.7. Nucleus

Nucleus is an important unit of cell which controls all activities of the cell. Nucleus holds the hereditary information. It is the largest among all cell organelles. It may be spherical, cuboidal, ellipsoidal or discoidal.

It is surrounded by a double membrane structure called **nuclear envelope**, which has the inner and outer membrane. The inner membrane is smooth without ribosomes and the outer membrane is rough by the presence of ribosomes and it continues with irregular and infrequent intervals with the endoplasmic reticulum. The membrane is perforated by pores known as **nuclear pores** which allows materials such as mRNA, ribosomal units, proteins and other macromolecules to pass in and out of the nucleus. The pores enclosed by circular structures called **annuli**. The pore and annuli form the **pore complex**. The space between two membranes is called **perinuclear space**.

DO YOU KNOW?

Chromatin is a viscous gelatinous substance that contains DNA, histone & non–histone proteins and RNA. H1, H2A, H2B, H3 and H4 are the different histones found in chromatin. It is formed by a series of repeated units called nucleosomes. Each nucleosome has a core of eight histone subunits.

Nuclear space is filled with **nucleoplasm**, a gelatinous matrix has uncondensed **chromatin** network and a conspicuous **nucleolius**. The Chromatin network is an uncoiled, indistinct and remain thread like during the interphase. It has little amount of RNA and DNA bound to histone proteins in eukaryotic cells (Figure 6.22).

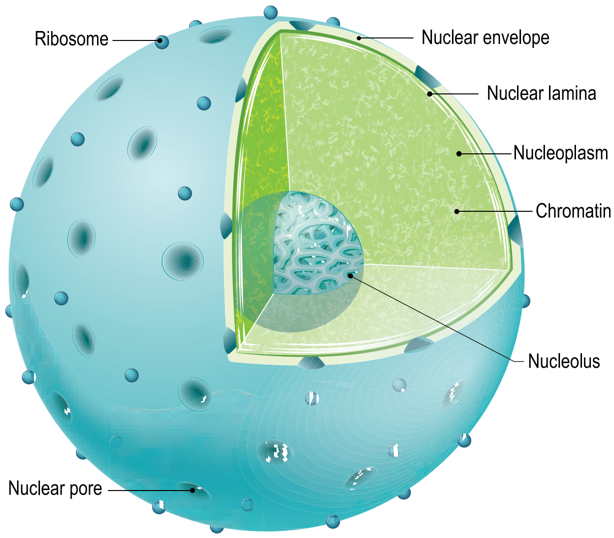


Figure 6.22: Structure of a Nucleus

During cell division chromatin is condensed into an organized form called **chromosome**. The portion an eukaryotic chromosome which is transcribed into mRNA contains active genes that are nottightly condensed during interphase is called **Euchromatin**. The portion of an eukaryotic chromosome that is not transcribed into mRNA which remains condensed during interphase and stains intensely is called **Heterochromatin. Nucleolus** is a small, dense, spherical structure either present singly or in multiples inside the nucleus and it's not membrane bound. Nucleoli possess genes for rRNA and tRNA.

Functions of the nucleus

- Controlling all cellular activities
- Storing the genetic or hereditary information.
- Coding the information from DNA for the production of enzymes and proteins.
- DNA duplication and transcription takes place in the nucleus.
- In nucleolus ribosomal biogenesis takes place.

6.7.1 Chromosomes

Strasburger (1875) first reported its present in eukaryotic cell and the term 'chromosome' was introduced by **Waldeyer** in 1888. **Bridges** (1916) first proved that chromosomes are the physical carriers of genes. It is made up of DNA and associated proteins.

Structure of chromosome

The chromosomes are composed of thread like strands called **chromatin** which is made up of DNA, protein and RNA. Each chromosome consists of two symmetrical structures called **chromatids**. During cell division the chromatids forms a well organized chromosomes with definite size and shape. They are identical and are called **sister chromatids.** A typical chromosome has narrow zones called **constrictions**. There are two types of constrictions, namely primary constriction and secondary constriction. The **primary constriction** is made up of **centromere** and kinetochore. Both the chromatids are united at centromere, whose number varies. The **monocentric** chromosome has one centromere and the **polycentric** chromosome has many centromeres. Centromere contains a complex system of protein fibres called **kinetochore**. Kinetochore is the region of chromosome which is attached to the spindle fibre during mitosis.

Besides primary there are few **secondary constrictions,** are present. Nucleoli develop from these secondary constrictions are called **nucleolar organizers**. Secondary constrictions contain the genes for ribosomal RNA which induce the formation of nucleoli and are called **nucleolar organizer regions** (Figure 6.23).

A **satellite** or SAT Chromosome is a short chromosomal segment or rounded body separated from main chromosome by a relatively elongated secondary constriction. It is a morphological entity in certain chromosomes.

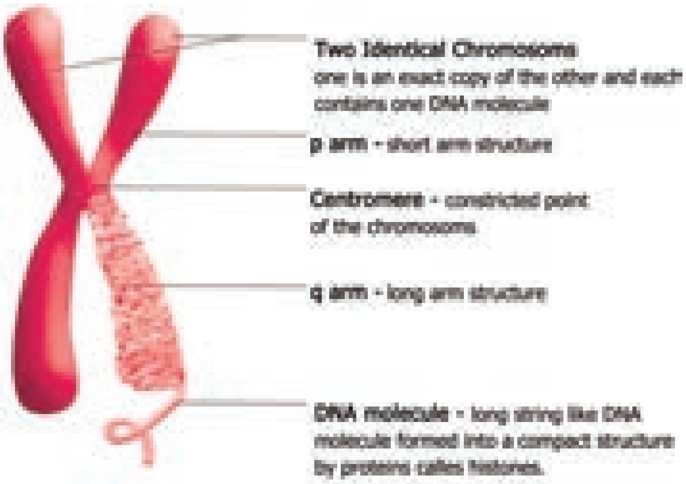


Figure 6.23: Structure of a Chromosome

Telomere is the terminal part of chromosome. It offers stability to the chromosome. DNA of the telomere has specific sequence of nucleotides. Telomere in all eukaryotes are composed of many repeats of short DNA sequences (**5'TTAGGG3'** sequence in *Neurospora crassa* and human beings). Maintenance of telomeres appears to be an important factor in determining the life span and reproductive capacity of cells, so studies of telomeres and telomerase have the promise of providing new insights into conditions such as ageing and cancer. Telomeres prevent the fusion of chromosomal ends with one another.

DO YOU KNOW?

Chromonema fibre: A chromatin fibre, 100 – 130 nm in diameter, an element of higher order packing within the chromosome. During prophase the chromosomal material becomes visible as very thin filament called chromonemata, which is called as chromatids in early stages of condensation. Chromatid and chromonema are the two names for the same structure a single linear DNA molecule with its associated proteins

Chromomeres: Chromomeres are bead like accumulations of chromatin material which are visible along interphase chromosomes. They can be seen in polytene chromosomes. At metaphase they are not visible.

Types of Chromosomes

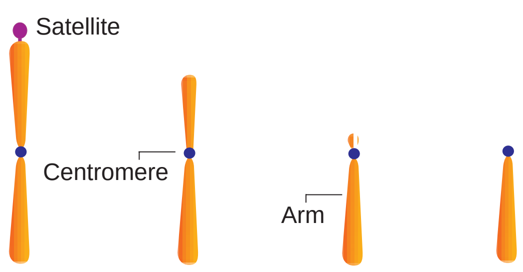


Figure 6.24: Types of chromosomes based on centromere

Based on the position of centromere, chromosomes are called **telocentric** (terminal centromere), **acrocentric** (terminal centromere capped by telomere), **sub metacentric** (centromere subterminal) and **metacentric** (centromere median). The eukaryotic chromosome may be rod shaped (telocentric and acrocentric), L-shaped (sub-metacentric) and V-shaped (metacentric) (Figure 6.24).

Based on the functions of chromosome it can be divided into **autosomes** and **sex chromosomes**.

Autosomes are present in all cells controlling somatic characteristics of an organism. In human diploid cell, 44 chromosomes are autosomes whereas two are sex chromosomes. Sex chromosomes are involved in the determination of sex.

Special types of chromosomes

These chromosomes are larger in size and are called **giant chromosomes** in certain plants and they are found in the suspensors of the embryo. The polytene chromosome and lamp brush chromosome occur in animals and are also called as **giant chromosomes.**

Polytene chromosomes observed in the salivary glands of Drosophila (fruit fly) by **E.G. Balbiani** in 1881. In larvae of many flies, midges (*Dipthera*) and some insects the interphase chromosomes duplicates and reduplicates without nuclear division. A single chromosome which is present in multiple copies form a structure called **polytene chromosome** which can be seen in light microscope. They are genetically active. There is a distinct alternating dark bands and light inter-bands. About 95% of DNA are present in bands and 5% in inter-bands. The polytene chromosome has extremely large puff called **Balbiani rings** which is seen in Chironomous larvae. It is also known as **chromosomal puff**. Puffing of bands are the sites of intense RNA synthesis. As this chromosome occurs in the salivary gland it is known as **salivary gland chromosomes**. Gene expression, transcription of genes and RNA synthesis occurs in the bands along the polytene chromosomes.

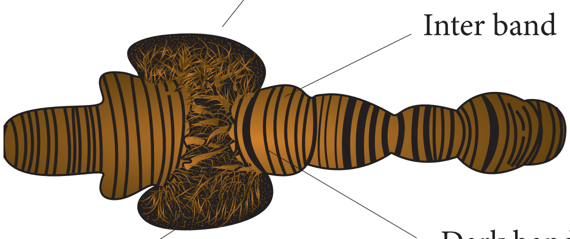


Figure 6.25: Polytene chromosomes

Lampbrush chromosomes occur at the diplotene stage of first meiotic prophase in oocytes of an animal **Salamandar** and in giant nucleus of the unicellular alga *Acetabularia*. It was first observed by **Flemming** in 1882. The highly condensed chromosome forms the chromosomal axis, from which lateral loops of DNA extend as a result of intense RNA synthesis.

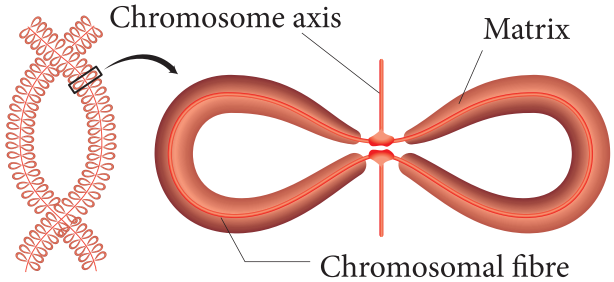


Figure 6.26: Lampbrush chromosomes

6.8. Flagella

6.8.1 Prokaryotic Flagellum

Bacterial flagella are helical appendages helps in motility. They are much thinner than flagella or cilia of eukaryotes. The filament contains a protein called **flagellin**. The structure consists of a basal body associated with cytoplasmic membrane and cell wall with short hook and helical filament. Bacteria rotates their helical flagella and propels rings present in the basal body which are involved in the rotary motor that spins the flagellum.

Check your grasp ?

When E.coli are cultured in medium rich in glucose they lack flagella. When grown in nutritionally poor medium they possess flagella. What does this indicate about the value of flagella?

Flagella is essential to seek out a nutritionally more favourable environment.

Structure of flagella in Bacteria

The gram positive bacteria contain only two basal rings. S-ring is attached to the inside of peptidoglycan and M-ring is attached to the cell membrane. In Gram negative bacteria two pairs of rings proximal and distal ring are connected by a central rod. They are L-Lipopolysaccharide ring, P-Peptidoglycan ring, S-Super membrane ring and M-membrane ring. The outer pair L and P rings is attached to cell wall and the inner pair S and M rings attached to cell membrane (Figure 6.27).

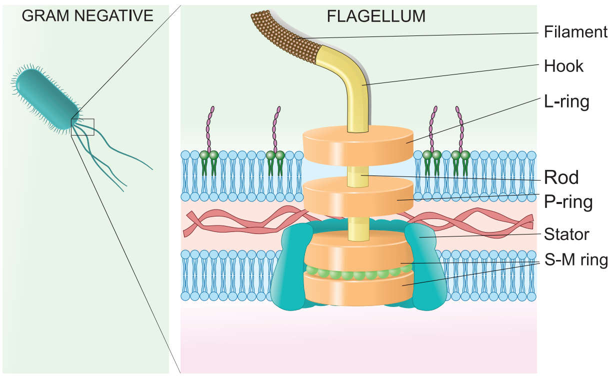


Figure 6.27: Structure of Bacterial Flagellum

Mechanism of flagellar movement – proton motive force

In flagellar rotation only proton movements are involved and not ATP. Protons flowing back into the cell through the basal body rings of each flagellum drives it to rotate. These rings constitute the rotary motor.The proton motive force (The force derived from the electrical potential and the hydrogen ion gradient across the cytoplasmic membrane) drives the flagellar motor. For the rotation of flagellum the energy is derived from proton gradient across the plasma membrane generated by oxidative phosphorylation. In bacteria flagellar motor is located in the plasma membrane where the oxidative phosphorylation takes place.Therefore, plasma membrane is a site of generation of proton motive force.

6.8.2 Eukaryotic Flagellum– Cell Motility

Structure

Eukaryotic Flagella are enclosed by unit membrane and it arises from a basal body. Flagella is composed of outer nine pairs of microtubules with two microtubules in its centre (9+2 arrangement). Flagella are microtubule projection of the plasma membrane. Flagellum is longer than cilium (as long as 200μm). The structure of flagellum has an axoneme made up microtubules and protein tubulin (Figure 6.28).

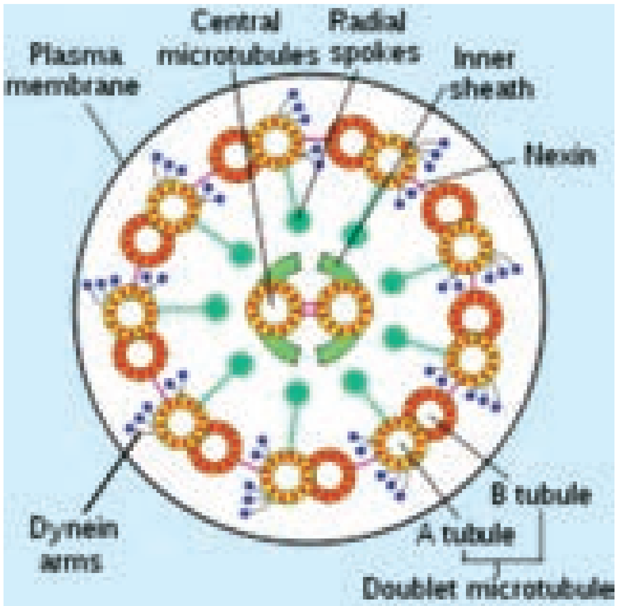


Figure 6.28: Structure of Eukaryotic flagellum

Movement

Outer microtubule doublet is associated with axonemal dynein which generates force for movement. The movement is ATP driven. The interaction between tubulin and dynein is the mechanism for the contraction of cilia and flagella. Dynein molecules uses energy from ATP to shift the adjacent microtubules. This movement bends the cilium or flagellum.

6.8.3 Cilia

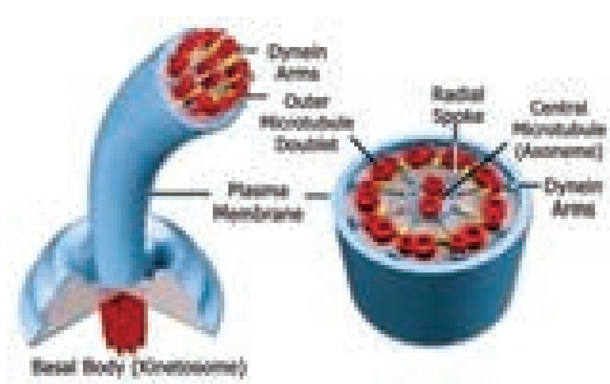


Figure 6.29: Structure of Cilia & flagella

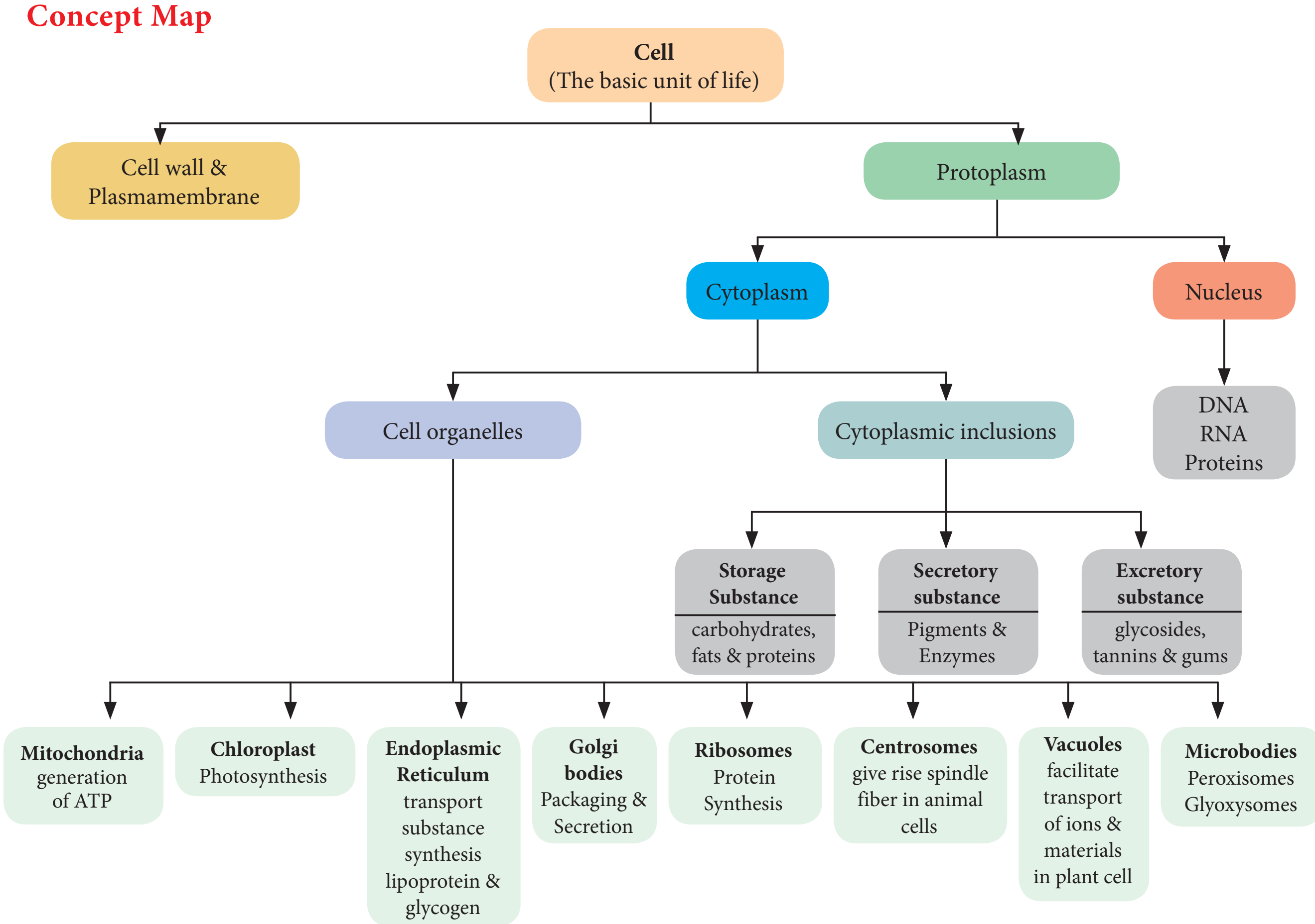
Cilia (plural) are short cellular, numerous microtubule bound projections of plasma membrane. Cilium (singular) is membrane bound structure made up of basal body, rootlets, basal plate and shaft. The shaft or **axoneme** consists of nine pairs of microtubule doublets, arranged in a circle along the periphery with a two central tubules, (**9+2**) arrangement of microtubules is present. Microtubules are made up of tubulin. The motor protein **dynein** connects the outer microtubule pair and links them to the central pair. Nexin links the peripheral doublets of microtubules (Figure 6.29).

Summary

Cell is the fundamental unit of all organisms which was identified 300 years ago. Microscope offers scope for observing smaller objects and organisms. It works on the principle of light and lenses. Different microscope offers clarity in observing objects depending on the features to be observed. Micrometric techniques are used in measurement of microscopic objects. Electron microscopes are used in understanding the ultra-structural details of cell. Cell theory and doctrine states that all organism are made up of cell and it contains genetic material. Protoplasm theory explains nature and different properties of protoplasm. Cell size and shape differ from type of tissue or organs and organisms. Based on cellular organization and nuclear characters the organisms are classified into prokaryote, eukaryote and mesokaryote.

Key difference between plant cell and animal cell is the cell wall. Protoplasm is the colourless mass includes the cytoplasm, cell organelles and nucleus. Cell wall is the outermost protective covering with three regions primary, secondary wall and middle lamellae. Cell membrane holds the cytoplasmic content called **cytosol**. Cytoplasm includes the matrix and the cell organelles excluding nucleus. Endomembrane system includes endoplasmic reticulum, golgi apparatus, chloroplast, lysosomes, vacuoles, nuclear membrane and plasma membrane. Nucleus is the control unit of the cell, it carries hereditary information. Chromosomes are made up of DNA and associated proteins. Bacterial flagella are made up of helical polymers of a protein called **flagellin**. Proton motive force are involved in flagellar rotation. In Eukaryotes flagella are made up microtubules and protein called **dynein** and **nexin** and the movement is driven by ATP.

Concept Map



Evaluation

1. The two subunits of ribosomes remain united at critical ion level of
   a. Magnesium
   b. Calcium
   c. Sodium
   d. Ferrous
2. Sequences of which of the following is used to know the phylogeny.
   a. mRNA   b. rRNA
   c. tRNA   d. Hn RNA
3. Many cells function properly and divide mitotically even though they do not have.
   a. Plasma membrane   b. cytoskeleton
   c. mitochondria   d. Plastids
4. Keeping in view the fluid mosaic model for the structure of cell membrane, which one of the following statements is correct with respect to the movement of lipids and proteins from one lipid monolayer to the other.
   a. Neither lipid nor proteins can flip-flop
   b. Both lipid and proteins can flip flop
   c. While lipids can rarely flip-flop proteins cannot
   d. While proteins can flip-flop lipids cannot
5. Match the columns and identify the correct option:

Column-I	Column-II
(a) Thylakoids	(i) Disc-shaped sacs in Golgi apparatus
(b) Cristae	(ii) Condensed structure of DNA
(c) Cisternae	(iii) Flat membranous sacs in stroma
(d) Chromatin	(iv) Infoldings in mitochondria

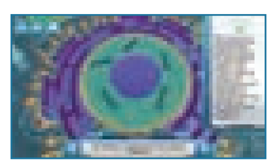
	(a)	(b)	(c)	(d)
(1)	(iii)	(iv)	(ii)	(i)
(2)	(iv)	(iii)	(i)	(ii)
(3)	(iii)	(iv)	(i)	(ii)
(4)	(iii)	(i)	(iv)	(ii)

6. Bring out the significance of Transmission Electron Microscope.
7. State the protoplasm theory.
8. Distinguish between prokaryotes and eukaryotes.
9. Difference between plant and animal cell.
10. Draw the ultra structure of plant cell.

ICT Corner

Cell structure

Cell-The unit of Life →



Steps
- Scan the QR code & install the app from Android app store
- Open the app & move the cell organelles by moving left bottom button
- Select the cell organelles by pointer
- Play the audio notes of cell organelles by click the right center button
- Use pointer & observe the structure of cell organelles

Activity
- Observe the structures of cell organelles and record it.

Step 1

Step 2

Step 4

Step 3

Step 5

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

* Pictures are indicative only

Unit III: Cell biology and Biomolecules

Chapter 7

Cell Cycle

Learning Objectives

The learner will be able to,

- *Outline the cell cycle and different stages in cell division.*
- *Recognise the importance of mitosis in the production of genetically identical cells.*
- *Have an insight on the significant of mitosis and meiosis.*
- *Familiarize the behaviour of chromosomes in plants and animal cells during meiosis.*

Chapter Outline

DO YOU KNOW?

Neurons can be replaced!

Stem cells in the human brain - most neurons are in G_0 and do not divide. As neurons and neuroglia die or injured they are replaced by neural stem cells

One of the most important features of the living cells is their power to grow and divide. New cells are formed by the division of pre-existing cells. Cells increase in number by cell division. The parent cell divides and passes on genetic material to the daughter cells.

7.1 Nuclear Divisions

There are two types of nuclear division, as **mitosis** and **meiosis**. In mitosis, the daughter cells formed will have the same number of chromosomes as the parent cell, typically diploid (2n) state. Mitosis is the nuclear division that occurs when cells grow or when cells need to be replaced and when organism reproduces asexually.

In meiosis, the daughter cells contain half the number of chromosomes of the parent cell and is known as **haploid state (n)**.

Whichever division takes place, it is normally followed by division of the cytoplasm to form separate cells, called as **cytokinesis**.

Edouard Van Beneden, a Belgian cytologist, embryologist and marine biologist. He was Professor of Zoology at the University of Liège. He contributed to cytogenetics by his works on the roundworm *Ascaris*. In his work he discovered how chromosomes organized meiosis (the production of gametes).

7.2 Cell Cycle

Definition: A series of events leading to the formation of new cell is known as **cell cycle**. The series of events include several phases.

History of a Cell

Table 7.1: History of Cell		
Year	**Scientist**	**Events**
1665	Robert Hooke	Coined word “Cell”
1670–74	Anthony van Leeuwenhoek	First living cells observed in microscope - Structure of bacteria
1831–33	Robert Brown	Presence of nucleus in cells of orchid roots
1839	Jan Evangelista Purkyne (J.E. Purkinje)	Coined “protoplasm”
1838–39	Schleiden & Schwann	Cell theory
1858	Rudolph Ludwig Carl Virchow	Cell theory ‘*omnis cellula e cellula*’
1873	Anton Schneider	Described chromosomes (Nuclear filaments) for the first time
1882	Walther Flemming	Coined the word mitosis; chromosome behaviour
1883	Edouard Van Beneden	Cell division in round worm
1888	Theodor Boveri	Centrosome; Chromosome Theory

7.2.1 Duration of Cell Cycle

Different kinds of cells have varied duration for cell cycle phases. Eukaryotic cell divides every 24 hours. The cell cycle is divided into mitosis and interphase. In a cell cycle 95% is spent for interphase whereas the mitosis and cytokinesis last only for an hour.

Table 7.2: Cell cycle of a proliferating human cell	
Phase	**Time duration (in hrs)**
G_1	11
S	8
G_2	4
M	1

The different phases of cell cycle are as follows (Figure 7.1).

7.2.2 Interphase

Longest part of the cell cycle, but it is of extremely variable length. At first glance the nucleus appears to be resting but this is not the case at all. The chromosomes previously visible as thread like structure, have dispersed. Now they are actively involved in protein synthesis, at least for most of the interphase.

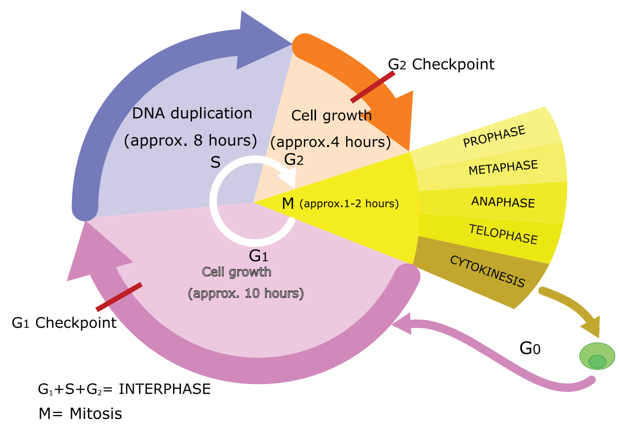


Figure 7.1: Cell cycle

> C-Value is the amount in picograms of DNA contained within a haploid nucleus.

7.2.3 G_1 Phase

The first gap phase – 2C amount of DNA in cells of G_1. Cells become metabolically active and grows by producing proteins, lipids, carbohydrates and cell organelles including mitochondria and endoplasmic reticulum. Many checkpoints control the cell cycle. The check point are also called as the **restriction point.** First check point at the end of G_1, determines a cells fate whether it will continue in the cell cycle and divide or enter a stage called $\mathbf{G_0}$ a quiescent stage, probably as specified cell or die. Cells are arrested in G_1 due to:

- Nutrient deprivation
- Lack of growth factors or density dependant inhibition
- Undergo metabolic changes and enter into G_0 state.

Biochemicals inside cell activates the cell division. The proteins called **kinases** and cyclins activate genes and their proteins to perform cell division. Cyclins act as major checkpoint which operates in G_1 to determine whether or not a cell divides.

DO YOU KNOW?

Dolly

Since the DNA of cells in G_0, do not replicate. Researchers are able to fuse the donor cells from a sheep's mammary glands into G_0 state by culturing in the nutrient free state. The G_0 donor nucleus synchronised with cytoplasm of the recipient egg, which developed into the clone Dolly.

7.2.4 G_0 Phase

Some cells exit G_1 and enters a quiescent stage called $\mathbf{G_0}$, where the cell remains metabolically active without proliferation. Cells can exist for long periods in G_0 phase. In G_0, cells cease growth with reduced rate of RNA and protein synthesis. The G_0 phase is not permanent. Mature neuron and skeletal muscle cell remain permanently in G_0. Many cells in animals remains in G_0 unless called on to proliferate by appropriate growth factors or other extracellular signals. G_0 cells are not dormant.

7.2.5 S phase – Synthesis phase – cells with intermediate amounts of DNA.

Growth of the cell continues as replication of DNA occur, protein molecules called **histones** are synthesised and attach to the DNA. The centrioles duplicate in the cytoplasm. DNA content increases from 2C to 4C.

7.2.6 G_2 – The second Gap phase – 4C amount of DNA in cells of G_2 and mitosis

Cell growth continues by protein and cell organelle synthesis, mitochondria and chloroplasts divide. DNA content remains as 4C. Tubulin is synthesised and microtubules are formed. Microtubles organise to form spindle fibre. The spindle begins to form and nuclear division follows.

One of the proteins synthesized only in the G_2 period is known as **Maturation Promoting Factor (MPF)**. It brings about condensation of interphase chromosomes into the mitotic form.

DNA damage checkpoints operates in G_1 S and G_2 phases of the cell cycle.

7.3 Cell Division

7.3.1 Amitosis (Direct Cell Division)

Amitosis is also called **direct** or **incipient cell division**. Here there is no spindle formation and chromatin material does not condense. It consist of two steps: (Figure 7.2).

Figure 7.2: Amitosis

❖ **Karyokinesis:**
- Involves division of nucleus.
- Nucleus develops a constriction at the center and becomes dumbell shaped.
- Constriction deepens and divides the nucleus into two.

❖ **Cytokinesis:**
- Involves division of cytoplasm.
- Plasma membrane develops a constriction along nuclear constriction.
- It deepens centripetally and finally divides the cell into two cells.

Example: Cells of mammalian cartilage, macronucleus of *Paramecium* and old degenerating cells of higher plants.

Drawbacks of Amitosis
- Causes unequal distribution of chromosomes.
- Can lead to abnormalities in metabolism and reproduction.

7.3.2 Mitosis
Mitosis occurs in shoot and root tips and other meristematic tissues of plants associated with growth. The number of chromosomes in the parent and the daughter (Progeny) cells remain the same so it is also called as **equational division**.

7.3.3 Closed and Open Mitosis
In closed mitosis, the nuclear envelope remains intact and chromosomes migrate to opposite poles of a spindle within the nucleus (Figure 7.3).

Example: Many single celled eukaryotes including yeast and slime molds.

In open mitosis, the nuclear envelope breaks down and then reforms around the 2 sets of separated chromosome.

Example: Most plants and animals

- Some animals are able to regenerate whole parts of the body.

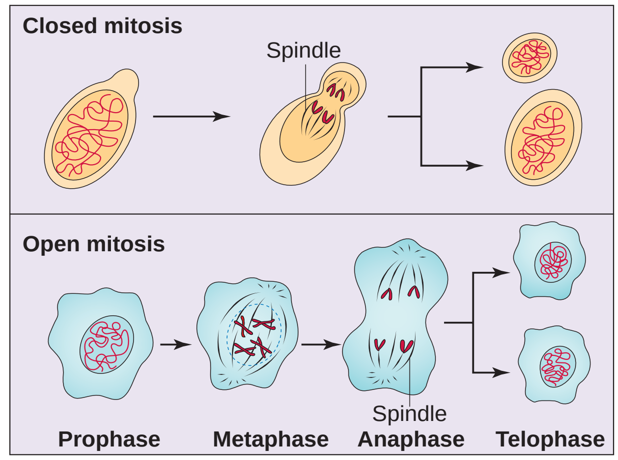


Figure 7.3: Closed and Open mitosis

Mitosis is divided into four stages prophase, metaphase, anaphase and telophase (Figure 7.6).

Prophase

Prophase is the longest phase in mitosis. Chromosomes become visible as long thin thread like structure, condenses to form compact mitotic chromosomes. In plant cells initiation of spindle fibres takes place, nucleolus disappears. Nuclear envelope breaks down. Golgi apparatus and endoplasmic reticulum disappear.

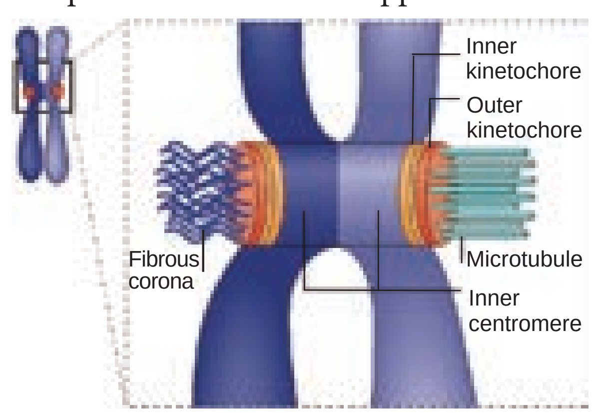


Figure 7.4: Centromere

In animal cell the centrioles extend a radial array of microtubules (Figure 7.4) and reach the poles of the cell. This arrangement of microtubules is called **an aster**. Plant cells do not form asters.

Metaphase

Chromosomes (two sister chromatids) are attached to the spindle fibres by kinetochore of the centromere. The spindle fibres are made up of tubulin. The alignment of chromosome into compact group at the equator of the cell is known as **metaphase plate**. This is the stage where the chromosomal morphology can be easily studied.

Kinetochore is a DNA–Protein complex present at the centromere where microtubules are attached. It is a trilaminar disc like plate.

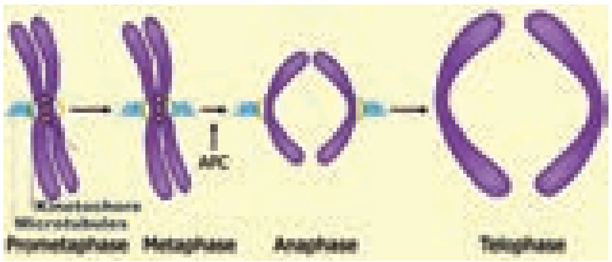


Figure 7.5: Anaphase promoting complex cyclosome

Anaphase

Each chromosome splits simultaneously and two daughter chromatids begin to migrate towards two opposite poles of a cell. Each centromere splits longitudinally into two, freeing the two sister chromatids from each other. When sister chromatids separate the actual partitioning of the replicated genome is complete.

APC (Anaphase Promoting Complex) is a cluster of proteins that induces the breaking down of cohesion proteins which leads to the separation of chromatids during mitosis (Figure 7.5). Thus it helps in the transition of metaphase to anaphase.

Telophase

Two sets of daughter chromosomes reach opposite poles of the cell and mitotic spindle disappears. Division of genetic material is completed during karyokinesis, followed by cytokinesis (division of cytoplasm). Nucleolus and nuclear membranes reforms. Nuclear membrane form around each set of **chromosomes**. Now the chromosomes decondense. In plants, phragmoplast are formed between the daughter cells. Cell plate is formed between the two daughter cells, reconstruction of cell wall takes place. Finally cells are separated by the distribution of organelles, macromolecules into two newly formed daughter cells.

7.3.4 Cytokinesis

Cytokinesis in Animal Cells

It is a contractile process. The ring consists of a bundle of microfilaments assembled from **actin** and **myosin**. This fibril generates a contractile force, that draws the ring inward forming a cleavage furrow in the cell. Thus it divides the cell into two.

> **Check your grasp!**
> What effect does mitosis have on transcription?
> During mitosis transcription stops.

Cytokinesis in Plant Cell

Division of the cytoplasm often starts during telophase. In plants, cell plate grows from centre towards lateral walls.

Phragmoplast contains microtubules, actin filaments and vesicles from golgi apparatus and ER. Microtubule of the pharagmoplast move to the equator, fuse to form a new plasma membrane and the materials which are placed

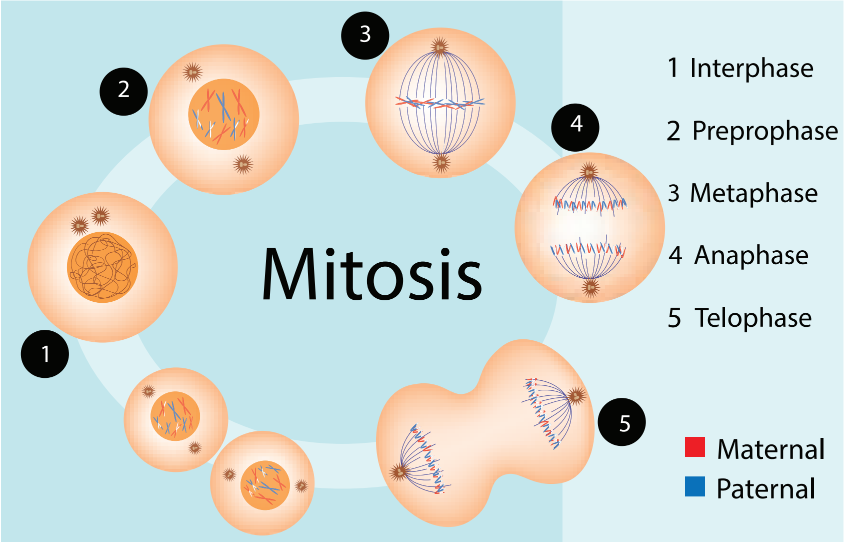


Figure 7.6: Mitosis

there becomes new cell wall. The first stage of cell wall construction is a line dividing the newly forming cells called a **cell plate**. The cell plate eventually stretches right across the cell forming the middle lamella. Cellulose builds up on each side of the middle lamella to form the cell walls of two new plant cells.

Activity

Squash preparation of onion root tip to visualize and study various stages of mitosis.

A Culture of animal cells in which the cell cycles were asynchronous was incubated with 3H-Thymidine for 10 minutes. Autoradiography showed that 50% of the cells were labelled. If the cell cycle time (generation time) was 16 hrs how long was the S period?

Length of the S period = Fraction of cells in DNA replication × generation time

Length of the S period = 0.5 × 16 hours = 8 hours

DO YOU KNOW? Skin cells and the cells lining our gut are constantly dying and are being replaced by identical cells.

7.3.5 Significance of Mitosis

Exact copy of the parent cell is produced by mitosis (genetically identical).

1. **Genetic stability** – daughter cells are genetically identical to parent cells.
2. **Growth** – as multicellular organisms grow, the number of cells making up their tissue increases. The new cells must be identical to the existing ones.
3. **Repair of tissues** - damaged cells must be replaced by identical new cells by mitosis.
4. **Asexual reproduction** – asexual reproduction results in offspring that are identical to the parent. Example Yeast and Amoeba.
5. In flowering plants, structure such as bulbs, corms, tubers, rhizomes and runners are produced by mitotic division. When they separate from the parent, they form a new individual.
   The production of large numbers of offsprings in a short period of time, is possible only by mitosis. In genetic engineering and biotechnology, tissues are grown by mitosis (i.e. in tissue culture).
6. **Regeneration** – Arms of star fish.

7.3.6 Meiosis

In Greek *meioum* means to reduce. Meiosis is unique because of synapsis, homologous recombination and reduction division. Meiosis takes place in the reproductive organs. It results in the formation of gametes with half the normal chromosome number.

Haploid sperms are made in testes; haploid eggs are made in ovaries of animals.

In flowering plants meiosis occurs during microsporogenesis in anthers and megasporogenesis in ovule. In contrast to mitosis, meiosis produces cells that are not genetically identical. So meiosis has a key role in producing new genetic types which results in genetic variation.

Stages in Meiosis

Meiosis can be studied under two divisions i.e., meiosis I and meiosis II. As with mitosis, the cell is said to be in interphase when it is not dividing.

Prophase I is the longest and most complex stage in meiosis. Pairing of homologous chromosomes (bivalents) take place.

Meiosis I-Reduction Division

Prophase I – Prophase I is of longer duration and it is divided into 5 substages – Leptotene, Zygotene, Pachytene, Diplotene and Diakinesis (Figure 7.7).

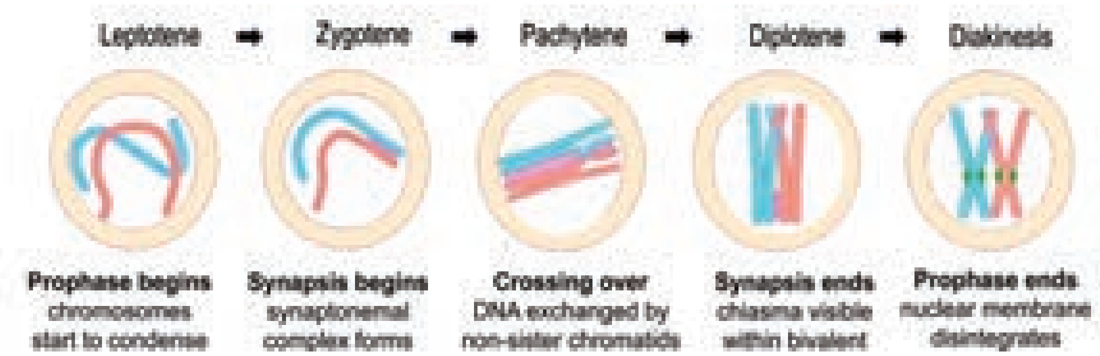


Figure 7.7: Prophase I

Leptotene – Chromosomes are visible under light microscope. Condensation of chromosomes takes place. Paired sister chromatids begin to condense.

Zygotene – Pairing of homologous chromosomes takes place and it is known as **synapsis**. Chromosome synapsis is made by the formation of synaptonemal complex. The complex formed by the homologous chromosomes are called as **bivalent (tetrads)**.

Pachytene – At this stage bivalent chromosomes are clearly visible as tetrads. Bivalent of meiosis I consists of 4 chromatids and 2 centromeres. Synapsis is completed and recombination nodules appear at a site where crossing over takes place between non-sister chromatids of homologous chromosome. Recombination of homologous chromosomes is completed by the end of the stage but the chromosomes are linked at the sites of crossing over. This is mediated by the enzyme recombinase.

Diplotene – Synaptonemal complex disassembled and dissolves. The homologous chromosomes remain attached at one or more points where crossing over has taken place. These points of attachment where 'X' shaped structures occur at the sites of crossing over is called **Chiasmata**. Chiasmata are chromatin structures at sites where recombination has been taken place. They are specialised chromosomal structures that hold the homologous chromosomes together. Sister chromatids remain closely associated whereas the homologous chromosomes tend to separate from each other but are held together by chiasmata. This substage may last for days or years depending on the sex and organism.

Diakinesis – Terminalisation of chiasmata, homologous chromosomes become short and condensed. Nucleolus and nuclear envelope disappears. Spindle fibres assemble.

Metaphase I

Spindle fibres are attached to the centromeres of the two homologous chromosomes. Bivalent (pairs of homologous chromosomes) aligned at the equator of the cell known as **metaphase plate**.

The random distribution of homologous chromosomes in a cell in Metaphase I is called **independent assortment**.

Anaphase I

Homologous chromosomes are separated from each other by shortening of spindle fibers. Each homologous chromosomes with its two chromatids and undivided centromere move towards the opposite poles of the cells. The actual reduction in the number of chromosomes takes place at this stage. Homologous chromosomes which move to the opposite poles are either paternal or maternal in origin. Sister chromatids remain attached with their centromeres.

Telophase I

Haploid set of chromosomes are present at each pole. The formation of two daughter cells, each with haploid number of chromosomes takes place. Nuclei reassembled. Nuclear envelope forms around the chromosome and the chromosomes becomes uncoiled. Nucleolus reappears.

In plants after karyokinesis, cytokinesis takes place by which two daughter cells are formed by the cell plate between 2 groups of chromosomes known as **dyad of cells (haploid)**.

The stage between the two meiotic divisions is called **interkinesis** which is short-lived.

Meiosis II – Equational division.

This division is otherwise called **mitotic meiosis** because it resembles mitosis. Since it includes all the stages of mitotic divisions.

Prophase II

The chromosome with 2 chromatids becomes short, condensed, thick and becomes visible. New spindle develops at right angles to the cell axis. Nuclear membrane and nucleolus disappear.

Metaphase II

Chromosome arranged at the equatorial plane of the spindle. Microtubules of spindle gets attached to the centromere of sister chromatids.

Anaphase II

Sister chromatids separate. The daughter chromosomes move to the opposite poles due to shortening of spindle fibres. Centromere of each chromosome split, allowing to move towards opposite poles of the cells holding the sister chromatids.

Telophase II

Four groups of chromosomes are organised into four haploid nuclei. The spindle disappears. Nuclear envelope, nucleolus reappear.

After karyokinesis, cytokinesis follows and four haploid daughter cells are formed, called **tetrads**.

7.3.7 Significance of Meiosis

- This maintains a definite constant number of chromosomes in organisms.
- Crossing over takes place and exchange of genetic material leads to variations among species. These variations are the raw materials to evolution. Meiosis leads to genetic variability by partitioning different combinations of genes into gametes through independent assortment.
- Adaptation of organisms to various environmental stress.

Table 7.3: Difference between mitosis in Plants and Animals

Plants	Animals
Centrioles are absent	Centrioles are present
Asters are not formed	Asters are formed
Cell division involves the formation of a cell plate	Cell division involves furrowing and cleavage of cytoplasm
Occurs mainly at meristem	Occurs in tissues throughout the body

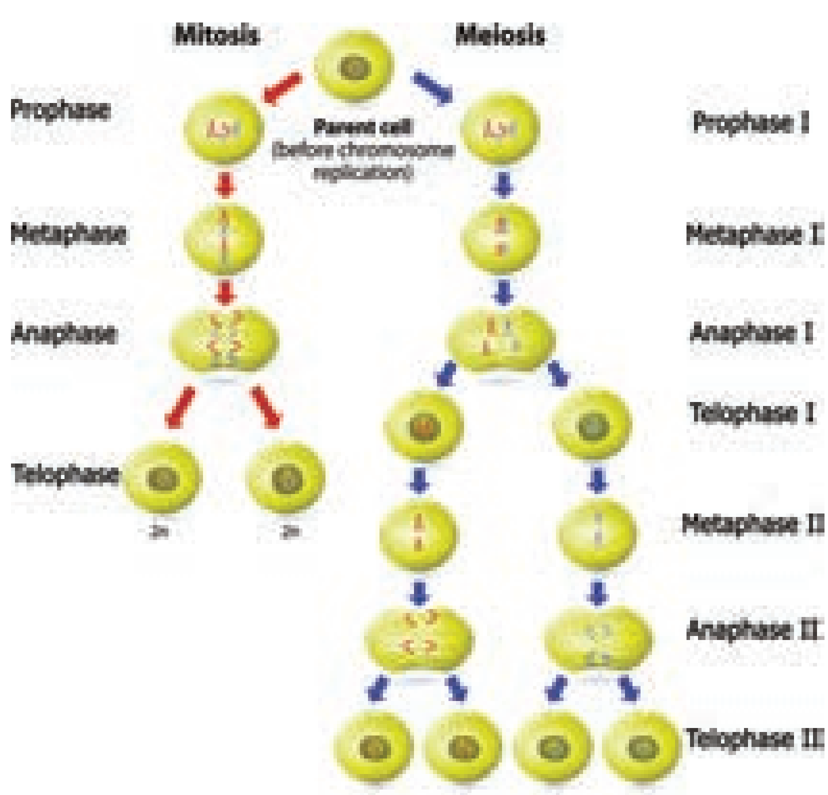
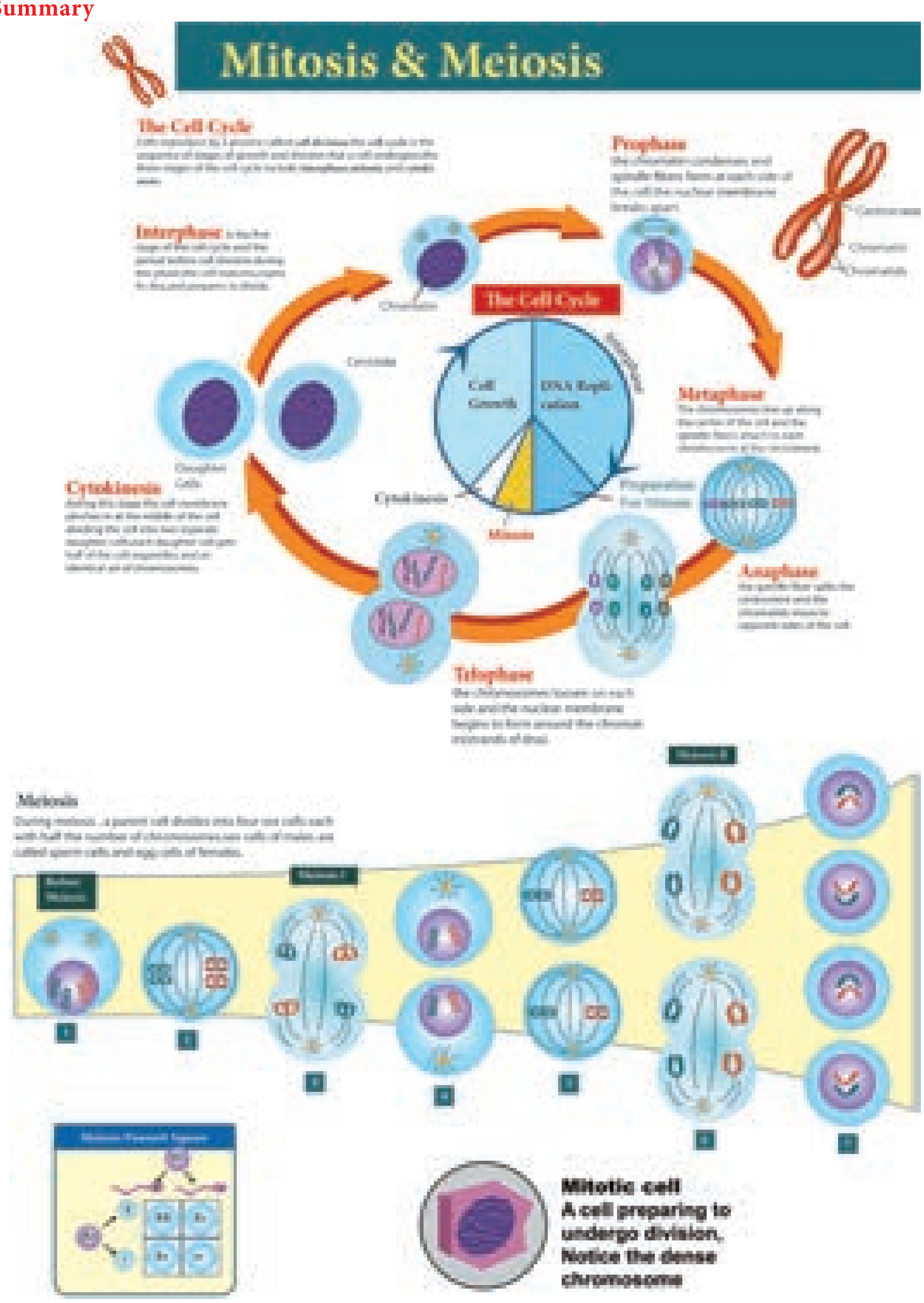


Figure 7.8: Meiosis

Table 7.4: Difference Between Mitosis and Meiosis (Figure 7.8)	
Mitosis	**Meiosis**
One division	Two divisions
Number of chromosome remain the same	Number of chromosomes is halved
Homologous chromosomes line up separately on the metaphase plate	Homologous chromosomes line up in pairs at the metaphase plate
Homologous chromosome do not pair up	Homologous chromosome pairup to form bivalent
Chiasmata do not form and crossing over never occurs	Chiasmata form and crossingover occurs
Daughter cells are genetically identical	Daughter cells are genetically different from parent cell
Two daughter cells are formed	Four daughter cells are formed

Summary



Evaluation

1. The correct sequence in cell cycle is
   a. S-M-G1-G2
   b. S-G1-G2-M
   c. G1-S-G2-M
   d. M-G-G2-S
2. If mitotic division is restricted in G1 phase of the cell cycle then the condition is known as
   a. S Phase b. G2 Phase
   c. M Phase d. G_0 Phase
3. Anaphase promoting complex APC is a protein degradation machinery necessary for proper mitosis of animal cells. If APC is defective in human cell, which of the following is expected to occur?
   a. Chromosomes will be fragmented
   b. Chromosomes will not condense
   c. Chromosomes will not segregate
   d. Recombination of chromosomes will occur
4. In S phase of the cell cycle
   a. Amount of DNA doubles in each cell
   b. Amount of DNA remains same in each cell
   c. Chromosome number is increased
   d. Amount of DNA is reduced to half in each cell
5. Centromere is required for
   a. transcription
   b. crossing over
   c. Cytoplasmic cleavage
   d. movement of chromosome towards pole
6. Synapsis occur between
   a. mRNA and ribosomes
   b. spindle fibres and centromeres
   c. two homologous chromosomes
   d. a male and a female gamete
7. In meiosis crossing over is initiated at
   a. Diplotene c. Leptotene
   b. Pachytene d. Zygotene
8. Colchicine prevents the mitosis of the cells at which of the following stage
   a. Anaphase c. Prophase
   b. Metaphase d. interphase
9. The paring of homologous chromosomes on meiosis is known as
   a. Bivalent c. Disjunction
   b. Synapsis d. Synergids
10. Write any three significance of mitosis.
11. Differentiate between mitosis and meiosis.
12. Given an account of G_0 phase.
13. Differentiate cytokinesis in plant cells and animal cells.
14. Write about Pachytene and Diplotene of Prophase I.

ICT Corner

Cell Division

How do cells are multiply?


Step 1


Step 3


Step 2


Step 4

Steps

- Scan the QR code
- Click Mitosis and start the animation press play
- Select mitosis in the top of the page – play it - use forward button to slow down
- Select meiosis in the top of the page – play it - use forward button to slow down

Activity

- Select meiosis and cell cycle.
- Record your observations.

URL: https://www.cellsalive.com/

* Pictures are indicative only

Unit III: Cell biology and Biomolecules

Chapter
8

Biomolecules

Learning Objectives

The learner will be able to,

- *Recognise the basic structure of carbohydrates, proteins, lipids and nucleic acids and differentiate the various pattern of classification with respect to structure.*
- *Familiarise with the general structure of amino acids and its classification based on the functional group.*
- *know the structure and classification of enzymes properties*
- *Understand lipids as a biomolecule and discuss the properties of lipids.*
- *Have a deeper knowledge about structure of nucleic acids.*

Chapter Outline

8.1 Water
8.2 Primary and Secondary Metabolites
8.3 Carbohydrates
8.4 Lipids
8.5 Proteins
8.6 Enzymes
8.7 Nucleic Acids

Having learnt the structure of the cell, we can now understand that each component of the cell is responsible for a specific function. The cell components are made of collection of molecules called as **cellular pool**, which consists of both inorganic and organic compounds. Inorganic compounds include salts, mineral ions and water.

Organic compounds include carbohydrates, lipids, amino acids, proteins, nucleotides, hormones and vitamins. Some organic molecules remain in colloidal form in the aqueous intracellular fluid. Others exist in non-aqueous phases like the lipid membrane and cell walls. The cell maintains this pool by the intake and elimination of specific molecules (Figure 8.1).

Biomolecules

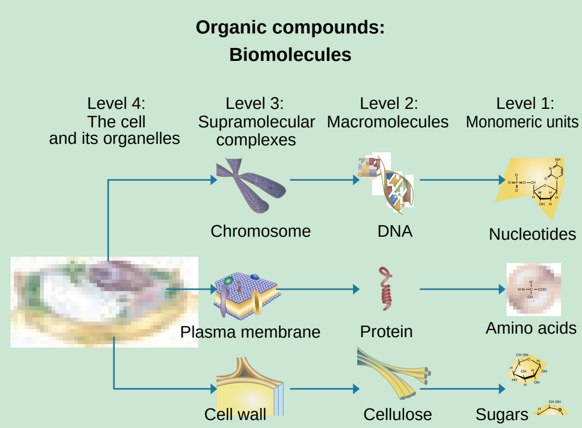


Figure 8.1: Components of cell

The minerals essential for plant growth are of two types: **macronutrients**, which are required in larger amounts (Eg. potassium, phosphorus, calcium, magnesium, sulphur and iron) and **micronutrients**, which are required in trace amounts Eg. cobalt, zinc, boron, copper, molybdenum and manganese are essential for enzyme action. Example, Manganese is required for activity of enzyme needed for synthesis of oligosaccharides and glycoproteins. Molybdenum is necessary for fixation of nitrogen by enzyme nitrogenase.

Component	% of the total cellular mass
Water	70
Proteins	15
Carbohydrates	3
Lipids	2
Nucleic acids	6
Ions	4

8.1 Water

Water is the most abundant component in living organisms. Life on earth is inevitably linked to water. Water makes up 70% of human cell and upto 95% of mass of a plant cell (Figure 8.2).

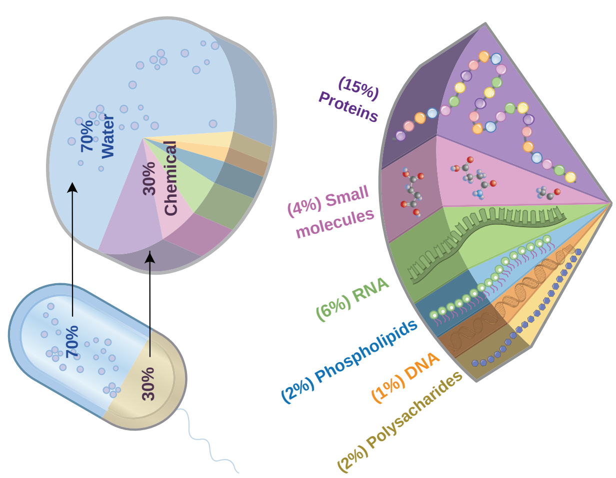


Figure 8.2: Percentage of biomolecules in cell

8.1.1 Chemistry of Water

Water is a tiny polar molecule that can readily pass through membranes. Two electronegative atoms of oxygen share a hydrogen bonds of two water molecule. Thus, they can stick together by cohesion and results in lattice formation (Figure 8.3).

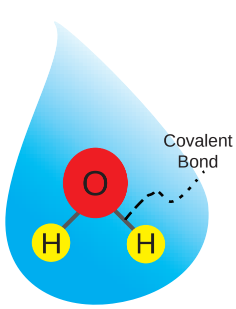


Figure 8.3: Water molecule

8.1.2 Properties of Water

- Adhesion and cohesion property
- High latent heat of vaporisation
- High melting and boiling point
- Universal solvent
- Specific heat capacity

8.2 Primary and Secondary Metabolites

Most plants, fungi and other microbes synthesizes a number of organic compounds called as **metabolites** which are intermediates and products of metabolism. The term metabolite is usually restricted to small molecules. It can be catergorized into two types namely primary and secondary metabolites based on their role in metabolic process (Figure 8.4).

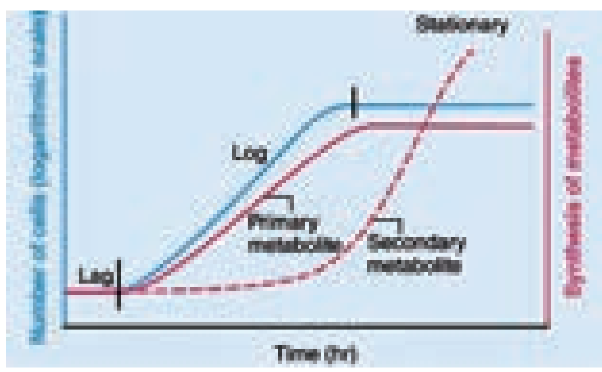


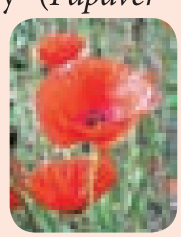
Figure 8.4: Synthesis of metabolites during growth

Primary metabolites are those that are required for the basic metabolic processes like photosynthesis, respiration, protein and lipid metabolism of living organisms.

Secondary metabolites does not show any direct function in growth and development of organisms.

DO YOU KNOW?

Morphine is the first alkaloid to be found. It comes from the plant Opium poppy (*Papaver somniferum*). It is used as a pain reliever in patients with severe pain levels and cough suppressant.



Metabolites	Examples
Primary	
Enzymes	protease, lipase, peroxidase
Amino acid	proline, leucine
Organic acid	acetic acid, lactic acid
Vitamins	A, B, C
Secondary	
Pigments	carotenoids, anthocyanins
Alkaloids	morphine, codeine
Essential oil	lemon grass oil, rose oil
Toxins	abrin, ricin
Lectins	concanavalin A
Drugs	vinblastin, curcumin
Polymeric substances	rubber, gums, cellulose

8.2.1 Organic Molecules

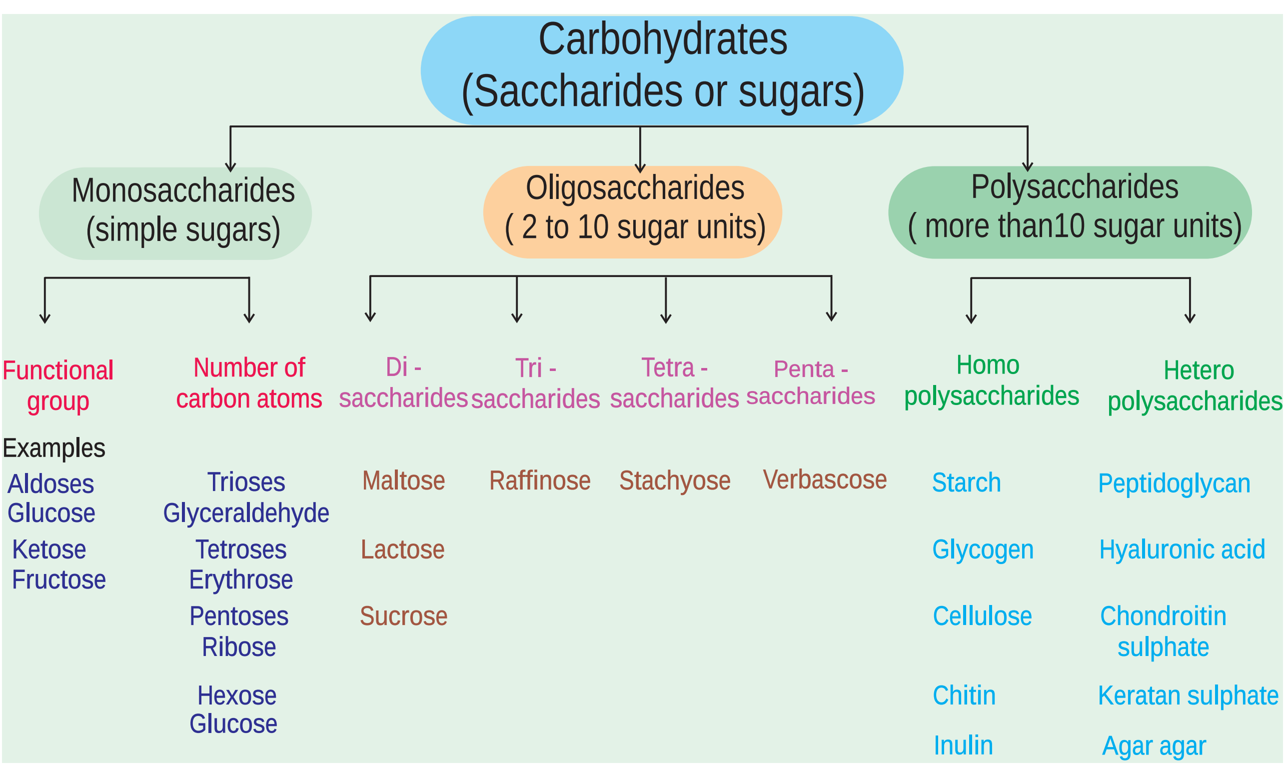
Organic molecules may be small and simple. These simple molecules assemble and form large and complex molecules called **macromolecules**. These include four main classes – carbohydrates, lipids, proteins and nucleic acids. All macromolecules except lipids are formed by the process of polymerisation, a process in which repeating subunits termed monomers are bound into chains of different lengths. These chains of monomers are called **polymers**.

8.3 Carbohydrates

Carbohydrates are organic compounds made of carbon and water. Thus one molecule of water combines with a carbon atom to form CH_2O and is repeated several (n) times to form **$(CH_2O)_n$** where n is an integer ranging from 3–7. These are also called as **saccharides**. The common term sugar refers to a simple carbohydrate such as a monosaccharide or disaccharide that tastes sweet are soluble in water (Figure 8.7).

8.3.1 Monosaccharides – The Simple Sugars

Monosaccharides are relatively small molecules constituting single sugar unit.



Classification of Carbohydrates

Glucose has a chemical formula of $C_6H_{12}O_6$. It is a six carbon molecule and hence is called as **hexose.**

All monosaccharides contain one or two functional groups. Some are aldehydes, Eg: glucose and are referred as **aldoses**; other are ketones, Eg: fructose and are referred as **ketoses**.

DO YOU KNOW?

Glucose is one of the most well-known molecules due to its nature as an essential nutrient for human health. You ingest glucose in your food, and then your body uses blood to carry the glucose to the cells of every organ for the purpose of energy production.

8.3.2 Disaccharides

Disaccharides are formed when **two monosaccharides** join together. An example is **sucrose**. Sucrose is formed from a molecule of α-glucose and a molecule of fructose. This is a condensation reaction releasing water. The bond formed between the glucose and fructose molecule by removal of water is called **glycosidic bond**. This is another example of strong, covalent bond.

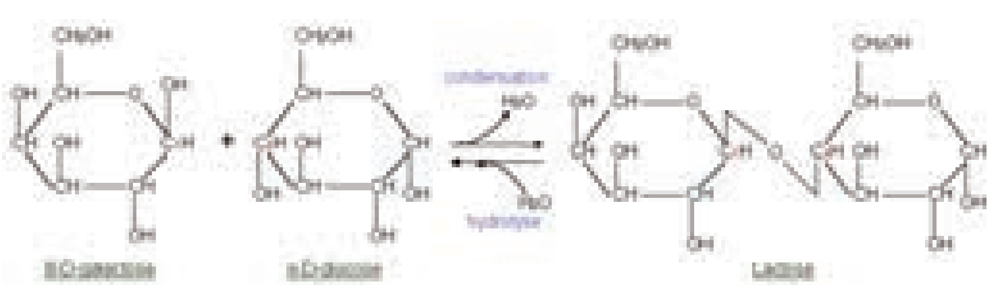


Figure 8.5: structure of carbohydrates

In the reverse process, a disaccharide is digested to the component monosaccharide in a hydrolysis reaction. This reaction involves addition of a water (hydro) molecule and splitting (lysis) of the glycosidic bond.

8.3.3 Polysaccharides

These are made of **hundreds of monosaccharide units**. Polysaccharides also called "**Glycans**". Long chain of branched or unbranched monosaccharides are held together by glycosidic bonds. Polysaccharide is an example of giant molecule, a macromolecule and consists of only one type of monomer. Polysaccharides are insoluble in water and are sweetless. **Cellulose** is an example built from repeated units of glucose monomer (Figure 8.6).

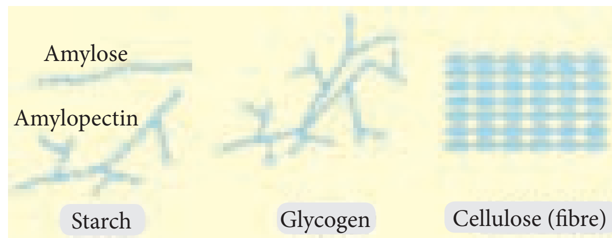


Figure 8.6: Branched and linear polysaccharides

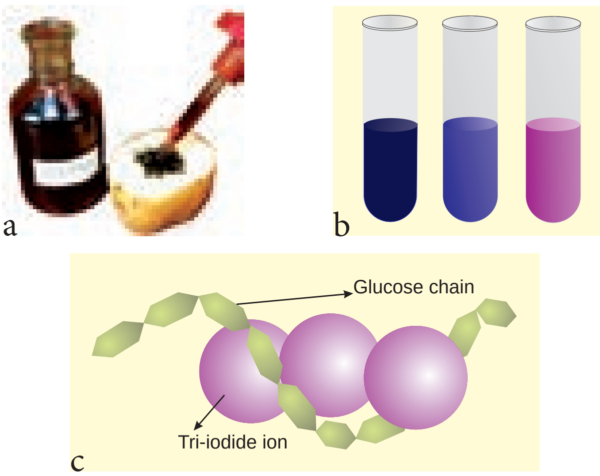
Depending on the function, polysaccharides are of two types - **storage polysaccharide and structural polysaccharide.**

8.3.4 Starch

Starch is a storage polysaccharide made up of repeated units of **amylose and amylopectin**. Starch grains are made up of successive layers of amylose and amylopectin, which can be seen as growth rings. Amylose is a linear, unbranched polymer which makes up 80% of starch. Amylopectin is a polymer with some 1, 6 linkages that gives it a branched structure.

8.3.5 Test for Starch

We test the presence of starch by adding a solution of iodine in potassium iodide. Iodine molecules fit nearly into the starch helix, producing a **blue-black colour**.



Test for starch

a. Test on potato; b. test on starch at varied concentrations; c. starch – iodine reaction

8.3.6 Celluloses

Cellulose is a structural polysaccharide made up of thousands of glucose units. In this case, β-glucose units are held together by 1,4 glycosidic linkage, forming long unbranched chains. Cellulose fibres are straight and uncoiled. It has many industrial uses which include cellulose fibres as cotton, nitrocellulose for explosives, cellulose acetate for fibres of multiple uses and cellophane for packing (Figure 8.7).

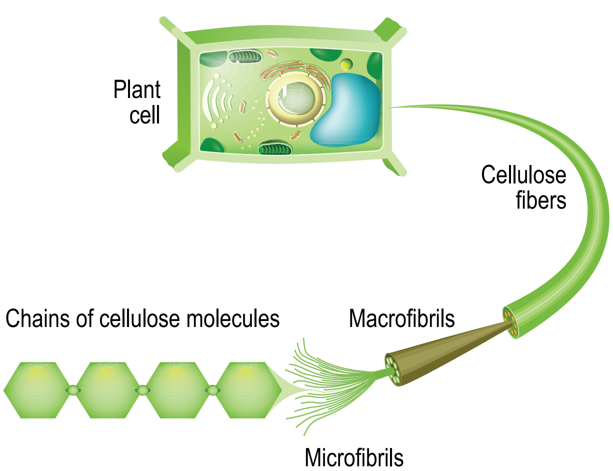


Figure 8.7: Cellulose molecule

8.3.7 Chitin

Chitin is a homo polysaccharide with amino acids added to form **mucopolysaccharide.** The basic unit is a nitrogen containing glucose derivative known as **N-acetyl glucosamine.** It forms the exoskeleton of insects and other arthropods. It is also present in the cell walls of fungi (Figure 8.8).

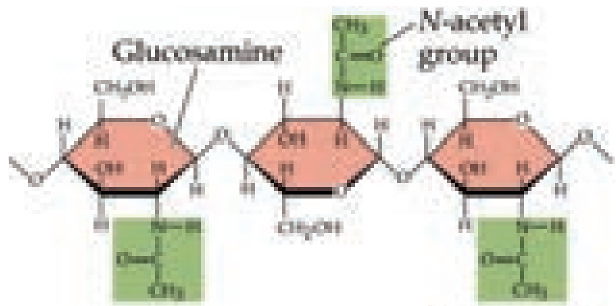


Figure 8.8: Structure of Chitin molecule

DO YOU KNOW?

Do mushroom cells have cell wall?

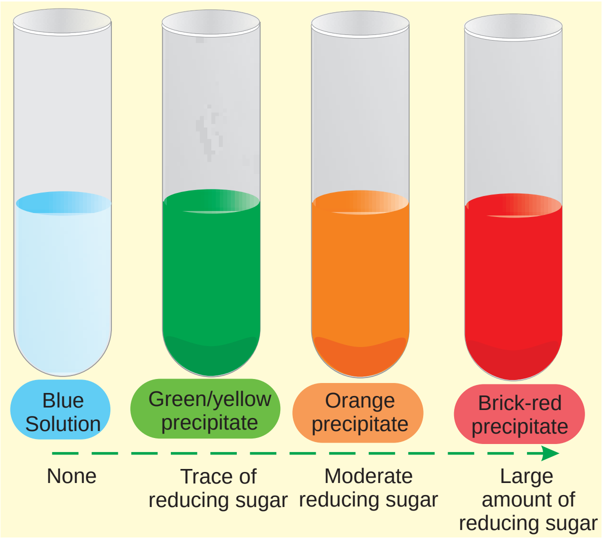
8.3.8 Test for Reducing Sugars

Aldoses and ketoses are reducing sugars. This means that, when heated with an alkaline solution of copper (II) sulphate (a blue solution called **benedict's solution**), the aldehyde or ketone group reduces Cu^{2+} ions to Cu^{+} ions forming brick red precipitate of copper(I) oxide. In the process, the aldehyde or ketone group is oxidised to a carboxyl group (–COOH). This reaction is used as test for reducing sugar and is known as **Benedict's test.** The results of benedict's test depends on concentration of the sugar. If there is no reducing sugar it remains blue.

- Sucrose is not a reducing sugar
- The greater the concentration of reducing sugar, the more is the precipitate formed and greater is the colour change.

Other Sugar Compounds

Other Polysaccharides	Structure	Functions
Inulin	Polymer of fructose	It is not metabolised in the human body and is readily filtered through the kidney
Hyaluronic acid	Heteropolymer of d glucuronic acid and D-N acetyl glucosamine	It accounts for the toughness and flexibility of cartilage and tendon
Agar	Mucopolysaccharide from red algae	Used as solidifying agent in culture medium in laboratory
Heparin	Glycosamino glycan contains variably sulphated disaccharide unit present in liver	Used as an anticoagulant
Chondroitin sulphate	Sulphated glycosaminoglycan composed of altering sugars (N-acetylglucosamine and glucuronic acid)	Dietery supplement for treatment of osteoarthritis
Keratan sulphate	Sulphated glycosaminoglycan and is a structural carbohydrate	Acts as cushion to absorb mechanical shock



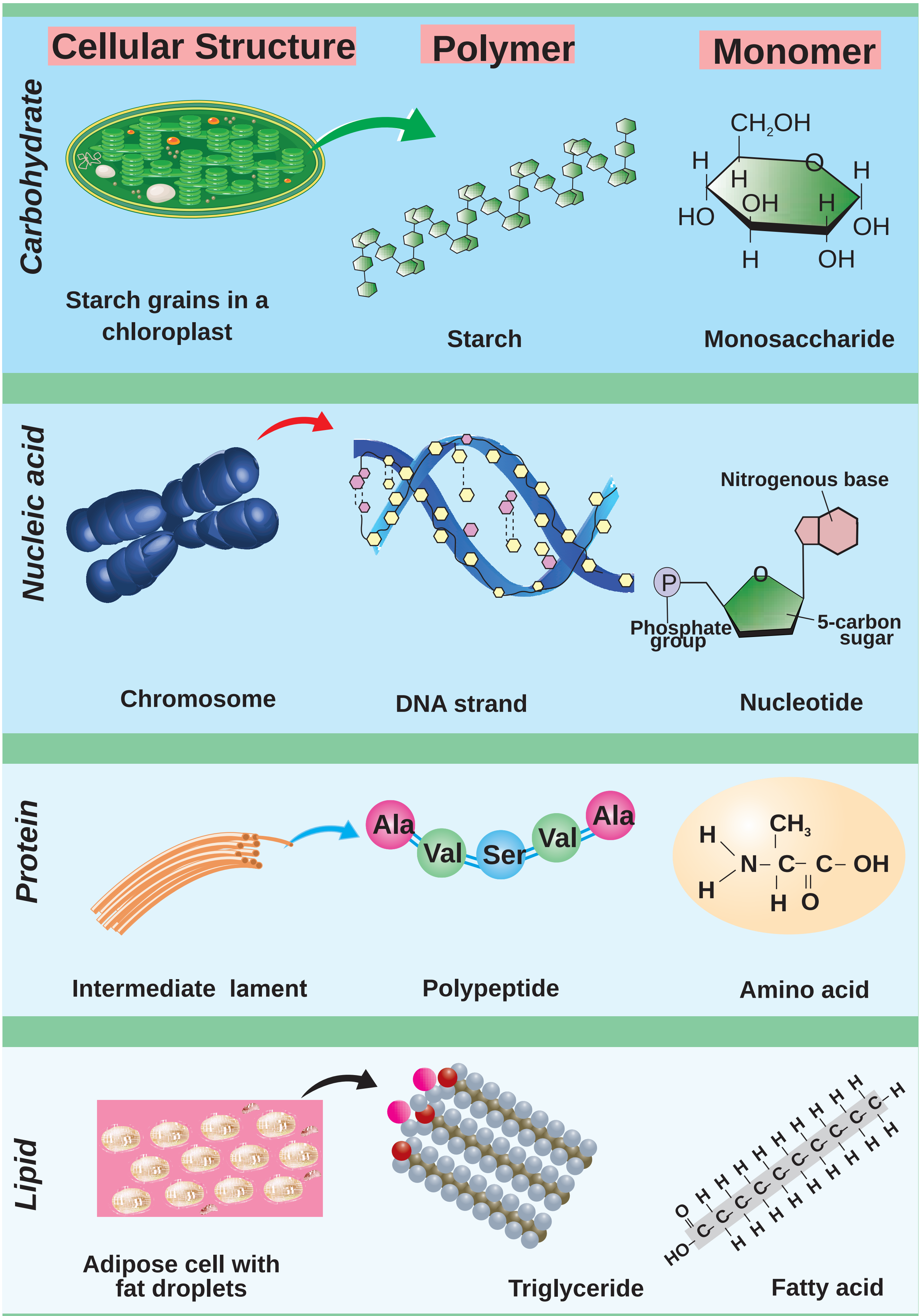
Test for sugar

8.4 Lipids

The term lipid is derived from *greek* word lipos, meaning fat. These substances are not soluble in polar solvent such as water but soluble in non-polar solvents such as benzene, ether, chloroform. This is because they contain long hydrocarbon chains that are non-polar and thus are hydrophobic. The main groups of compounds classified as lipids are triglycerides, phospholipids, steroids and waxes.

8.4.1 Triglycerides

Triglycerides are composed of single molecule of glycerol bound to 3 fatty acids. These include fats and oils. Fatty acids are long chain hydrocarbons with a carboxyl group at one end which binds to one of the hydroxyl groups of glycerol, thus forming an ester bond. Fatty acids are structural unit of lipids and are carboxylic acid of long chain hydrocarbons. The hydrocarbon can vary in length from 4 – 24 carbons and the fat may be saturated or unsaturated. In saturated fatty acids the hydrocarbon chain is single bonded (Eg. palmitic acid, stearic acid) and in unsaturated fatty acids (Eg. oleic acid, linoleic acid) the hydrocarbon chain is double bonded (one/two/three). In general solid fats are saturated and oils are unsaturated, in which most are globules.



Cellular Structure
Polymer
Monomer
Carbohydrate
Starch grains in a chloroplast
Starch
CH2OH
H
O
H
H
HO
OH
H
OH
H
OH
Monosaccharide
Nucleic acid
Nitrogenous base
P
O
Phosphate group
5-carbon sugar
Chromosome
DNA strand
Nucleotide
Protein
Ala
Val
Ser
Val
Ala
CH3
H
N- C- C- OH
H
H O
Intermediate lament
Polypeptide
Amino acid
Lipid
Adipose cell with fat droplets
Triglyceride
Fatty acid

8.5 Proteins

Proteins are the most diverse of all macromolecule. Proteins make up 2/3 of total dry mass of a cell. The term protein was coined by **Gerardus Johannes Mulder** and is derived form a *greek* word proteos which means of the first rank.

Amino acids are building blocks of proteins. There are about 20 different amino acids exist naturally. All amino acids have a basic skeleton consisting of a carbon (a-carbon) linked to a basic amino group.

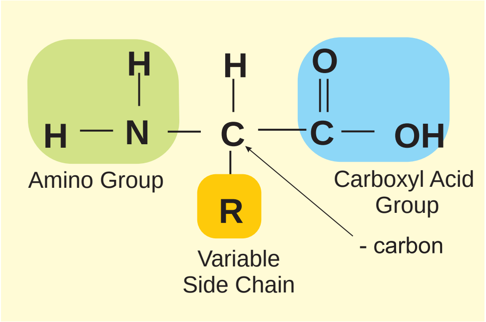


Figure 8.9: Structure of basic amino acid

(NH_2), an acidic carboxylic group (COOH) and a hydrogen atom (H) and side chain or variable R group. The amino acid is both an acid and a base and hence is called **amphoteric**.

A **zwitterion** also called as **dipolar ion**, is a molecule with two or more functional groups, of which at least one has a positive and other has a negative electrical charge and the net charge of the entire molecule is zero. The pH at which this happens is known as the **isoelectric point** (Figure 8.10).

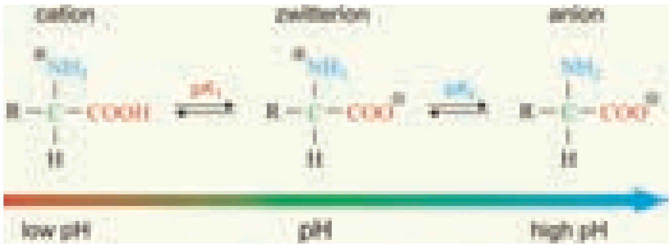


Figure 8.10: Structure of amino acid

8.5.1 Classification of Amino acids

Based on the R group amino acids are classified as acidic, basic, polar, non-polar.

The amino group of one amino acid reacts with carboxyl group of other amino acid, forming a **peptide bond**. Two amino acids can react together with the loss of water to form a **dipeptide**. Long strings of amino acids linked by peptide bonds are called **polypeptides**. In 1953, Fred Sanger first sequenced the Insulin protein (Figure 8.11 a and b).

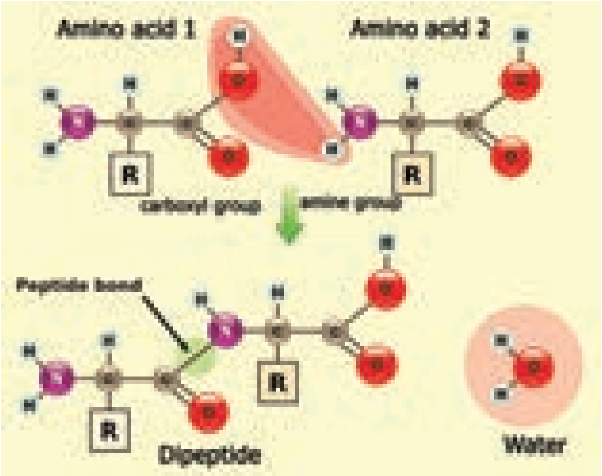


Figure 8.11(a): Formation of peptide bond

Linus Pauling and Robert Corey in 1951 proposed the α-helix and β sheet secondary structures of proteins. They were awarded Nobel prize in 1954

DO YOU KNOW?

First protein Insulin was sequenced by Fred Sange.

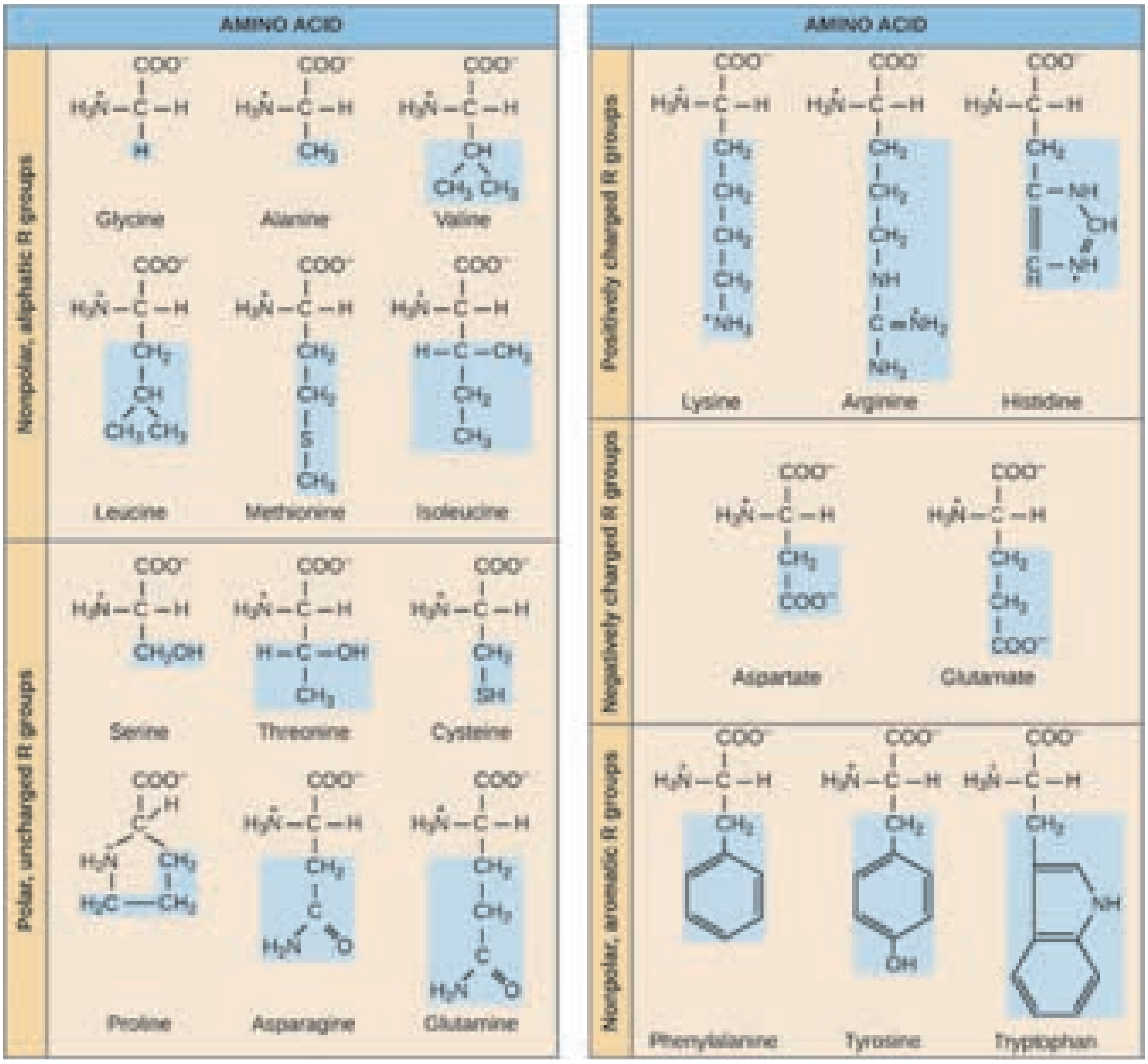


Figure 8.11(b): Classification of Amino Acids

8.5.2 Structure of Protein

Protein are synthesised on the ribosome as a linear sequence of amino acids which are held together by peptide bonds. After synthesis, the protein attains conformational change into a specific 3D form for proper functioning. According to the mode of folding, four levels of protein organisation have been recognised namely primary, secondary, tertiary and quaternary (Figure 8.12).

- The **primary structure** is linear arrangement of amino acids in a polypeptide chain.
- **Secondary structure** arises when various functional groups are exposed on outer surface of the molecular interaction by forming hydrogen bonds. This causes the aminoacid chain to twist into coiled configuration called α-**helix** or to fold into a flat β-pleated sheets.
- **Tertiary protein structure** arises when the secondary level proteins fold into globular structure called domains.
- **Quaternary protein structure** may be assumed by some complex proteins in which more than one polypeptide forms a large multiunit protein. The individual polypeptide chains of the protein are called **subunits** and the active protein itself is called a **multimer.**

For example: Enzymes serve as catalyst for chemical reactions in cell and are non-specific. Antibodies are complex glycoproteins with specific regions of attachment for various organisms.

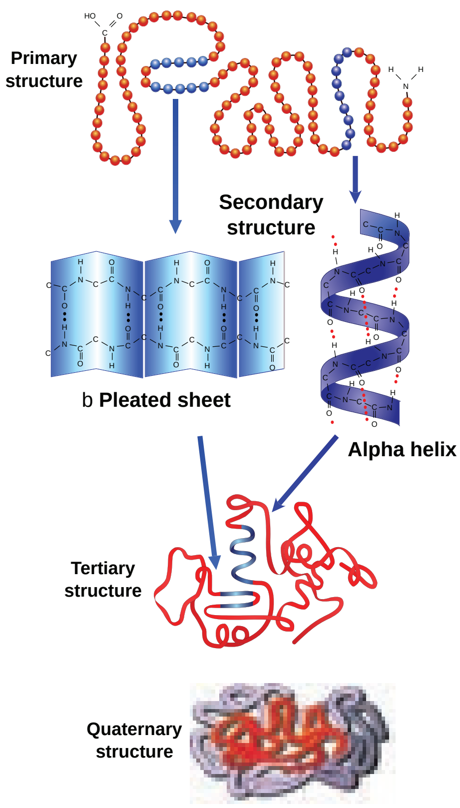


Figure 8.12: Structure of Protein

8.5.3 Protein Denaturation

Denaturation is the loss of 3D structure of protein. Exposure to heat causes atoms to vibrate violently, and this disrupts the hydrogen and ionic bonds. Under these conditions, protein molecules become elongated, disorganised strands. Agents such as soap, detergents, acid, alcohol and some disinfectants disrupt the interchain bond and cause the molecule to be non-functional (Figure 8.13).

Christian Anfinsen explained denaturation of proteins by heat treatment leading to breakage of non-covalent bond.

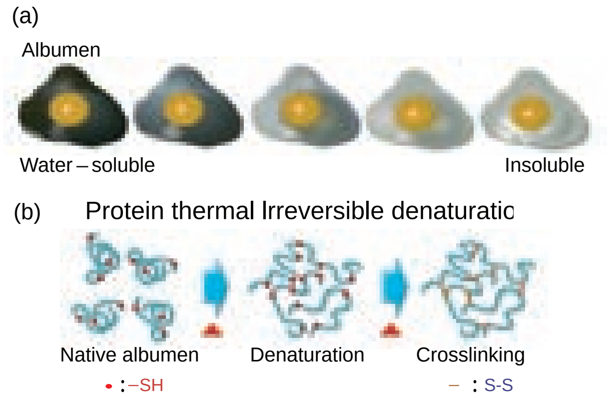


Figure 8.13: Protein denaturation

8.5.4 Protein Bonding

There are four types of chemical bonds

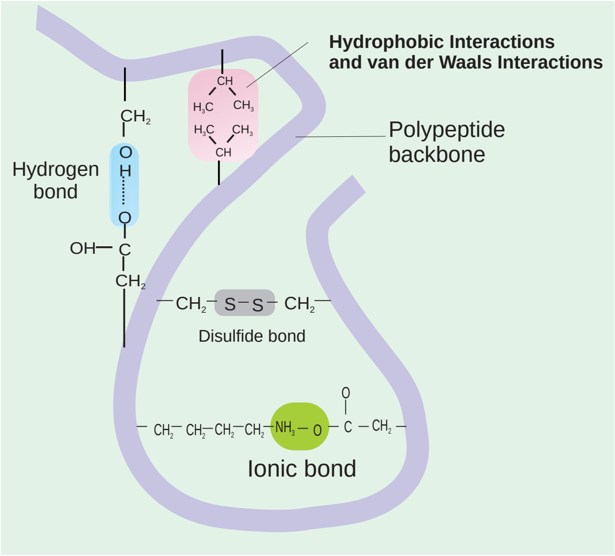


Figure 8.14: Protein bonding

Hydrogen Bond

It is formed between some hydrogen atoms of oxygen and nitrogen in polypeptide chain. The hydrogen atoms have a small positive charge and oxygen and nitrogen have small negative charge. Opposite charges attract to form hydrogen bonds.

Though these bonds are weak, large number of them maintains the molecule in 3D shape (Figure 8.14).

Ionic Bond

It is formed between any charged groups that are not joined together by peptide bond. It is stronger than hydrogen bond and can be broken by changes in pH and temperature.

Disulfide Bond

Some amino acids like cysteine and methionine have sulphur. These form disulphide bridge between sulphur atoms and amino acids.

Hydrophobic Bond

This bond helps some protein to maintain structure. When globular proteins are in solution, their hydrophobic groups point inwards away from water.

8.5.5 Test for Proteins

The biuret test is used as an indicator for presence of protein as it gives a purple colour in the presence of peptide bonds (–C–N–). To protein solution, an equal quantity of sodium hydroxide solution is added and mixed. Then a few drops of 0.5% copper (II) sulphate is added with gentle mixing. A distinct purple colour develops without heating (Figure 8.15 a and b).

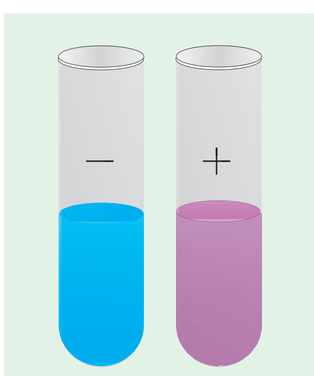


Figure 8.15(a): Biuret test

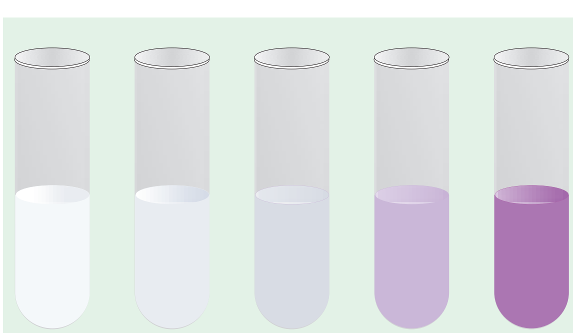


Figure 8.15(b): Colour intensity increases with increase in concentration

DO YOU KNOW?

The more the distance between the sulphur atoms, the more the proteins bend; the more the hair curls.

8.6 Enzymes

Enzymes are globular proteins that catalyse the many thousands of metabolic reactions taking place within cells and organism. The molecules involved in such reactions are metabolites. Metabolism consists of chains and cycles of enzyme-catalysed reactions, such as respiration, photosynthesis, protein synthesis and other pathways. These reactions are classified as

- **anabolic** (building up of organic molecules). Synthesis of proteins from amino acids and synthesis of polysaccharides from simple sugars are examples of anabolic reactions.
- **catabolic** (breaking down of larger molecules). Digestion of complex foods and the breaking down of sugar in respiration are examples of catabolic reactions (Figure 8.16).

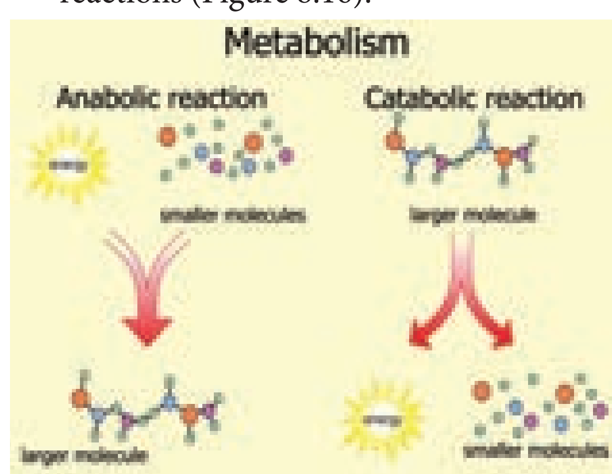


Figure 8.16: Enzyme reaction

Enzymes can be **extracellular enzyme** as secreted and work externally exported from cells. Eg. digestive enzymes; or **intracellular enzymes** that remain within cells and work there. These are found inside organelles or within cells. Eg. insulin.

8.6.1 Properties of Enzyme

- All are globular proteins.
- They act as catalysts and effective even in small quantity.
- They remain unchanged at the end of the reaction.
- They are highly specific.
- They have an active site where the reaction takes place.
- Enzymes lower activation energy of the reaction they catalyse.

> DO YOU KNOW?
> **RUBISCO** is the abundant protein in the whole biosphere

As molecules react, they become unstable, high energy intermediates. But they are in this transition state only momentarily. Energy is required to raise molecules to this transition state and this minimum energy needed is called the **activation energy**. This could be explained schematically by 'boulder on hillside' model of activation energy (Figure 8.17).

8.6.2 Lock and Key Mechanism of Enzyme

In a enzyme catalysed reaction, the starting substance is the substrate. It is converted to the product. The substrate binds to the specially formed pocket in the enzyme – **the active site**, this is called **lock and key mechanism** of enzyme action. As the enzyme and substrate form a **ES complex**, the substrate is raised in energy to a transition state and then breaks down into products plus unchanged enzyme (Figure 8.18).

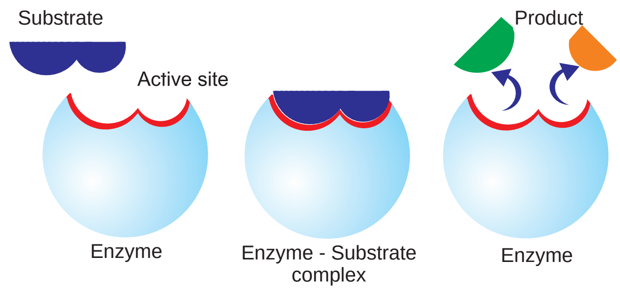
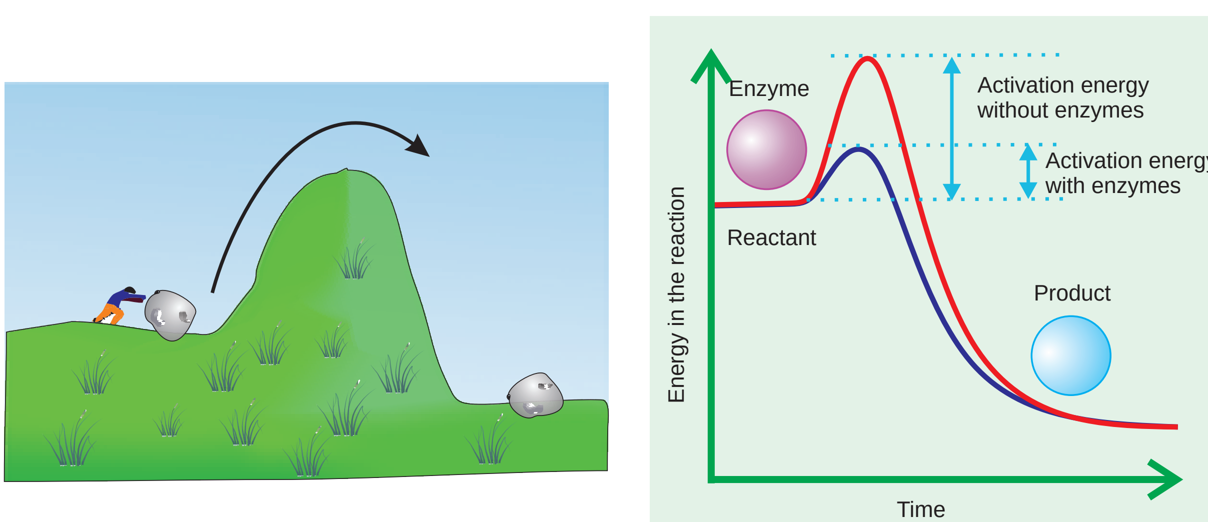


Figure 8.18: Enzyme mechanism

8.6.3 Enzyme Cofactors

Many enzymes require non-protein components called **cofactors** for their efficient activity. Cofactors may vary from simple inorganic ions to complex organic molecules. They are of three types: **inorganic ions, prosthetic groups and coenzymes** (Figure 8.19).

- **Holoenzyme** – active enzyme with its non protein component.
- **Apoenzyme** – the inactive enzyme without its non protein component.



This graph shows the activation energies of a reaction with and without enzymes

Figure 8.17: Activation energy

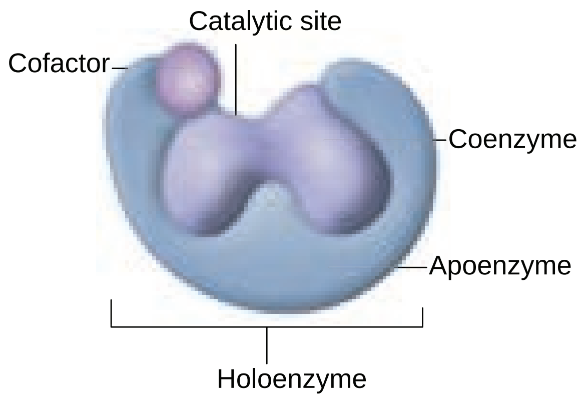


Figure 8.19: Enzyme components

- **Inorganic ions** help to increase the rate of reaction catalysed by enzymes. Example: Salivary amylase activity is increased in the presence of chloride ions.
- **Prosthetic groups** are organic molecules that assist in catalytic function of an enzyme. Flavin adenine dinucleotide (FAD) contains riboflavin (vit B2), the function of which is to accept hydrogen. 'Haem' is an iron-containing prosthetic group with an iron atom at its centre.
- **Coenzymes** are organic compounds which act as cofactors but do not remain attached to the enzyme. The essential chemical components of many coenzymes are vitamins. Eg. NAD, NADP, Coenzyme A, ATP

DO YOU KNOW?

Ribozyme - Non Protein Enzyme - A Ribozyme, also called as catalytic RNA; is a ribonucleic acid that acts as enzyme. It is found in ribosomes

8.6.4 Classification of Enzymes

Enzymes are classified into six groups based on their mode of action.

Enzymes	Mode of action	General scheme of reaction	Example
Oxidoreductase	Oxidation and reduction (redox) reactions	$A_{red} + B_{ox} \longrightarrow A_{ox} + B_{red}$	Dehydrogenase
Transferase	Transfer a group of atoms from one molecule to another	$A - B + C \longrightarrow A + C - B$	Transaminase, phosphotransfer-ase
Hydrolases	Hydrolysis of substrate by addition of water molecule	$A - B + H_2O \longrightarrow A - H + B - OH$	Digestive enzymes
Isomerase	Control the conversion of one isomer to another by transferring a group of atoms from one molecule to another	$A - B - C \longrightarrow A - C - B$	Isomerase
Lyase	Break chemical bond without addition of water	$A - B \longrightarrow A + B$	Decarboxylase
Ligase	Formation of new chemical bonds using ATP as a source of energy	$A + B + ATP \longrightarrow A - B + ADP + Pi$	DNA ligase

8.6.5 Uses of Enzymes

Enzyme	Source	Application
Bacterial protease	Bacillus	Biological detergents
Bacterial glucose isomerase	Bacillus	Fructose syrup manufacture
Fungal lactase	Kluyvero-myces	Breaking down of lactose to glucose and galactose
Amylases	Aspergillus	Removal of starch in woven cloth production

8.7 Nucleic Acids

As we know DNA and RNA are the two kinds of nucleic acids. These were originally isolated from cell nucleus. They are present in all known **cells** and **viruses** with special coded genetic programme with detailed and specific instructions for each organism heredity.

DNA and RNA are polymers of monomers called **nucleotides**, each of which is composed of a nitrogen base, a pentose sugar and a phosphate. A purine or a pyrimidine and a ribose or deoxyribose sugar is called **nucleoside**. A nitrogenous base is linked to pentose sugar through n-glycosidic linkage and forms a nucleoside. When a phosphate group is attached to a nucleoside it is called a **nucleotide**. The nitrogen base is a heterocyclic compound that can be either a **purine** (two rings) or a **pyrimidine** (one ring). There are **2 types of purines – adenine (A) and guanine (G) and 3 types of pyrimidines – cytosine (C), thymine (T) and uracil (U)** (Figure 8.20 and 21).

A characteristic feature that differentiates DNA from RNA is that DNA contains nitrogen bases such as Adenine, guanine, thymine (5-methyl uracil) and cytosine and the RNA contains nitrogen bases such as adenine, guanine, cytosine and uracil instead of thymine. The nitrogen base is covalently bonded to the sugar ribose in RNA and to deoxyribose (ribose with one oxygen removed from C_2) in DNA. Phosphate group is a derivative of (PO_4^{3-}) phosphoric acid, and forms phosphodiester linkages with sugar molecule (Figure 8.22).

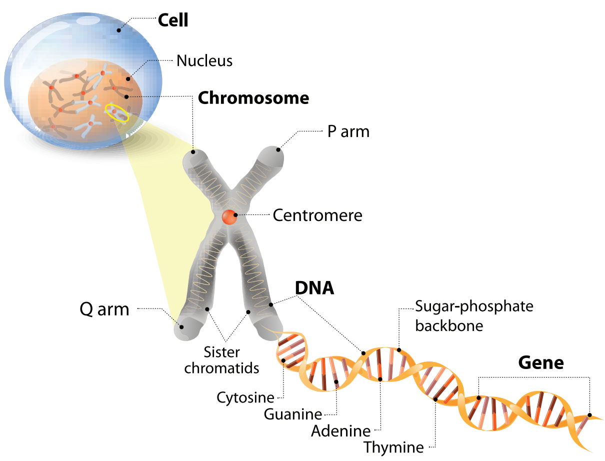


Figure 8.20: Position of DNA in the cell

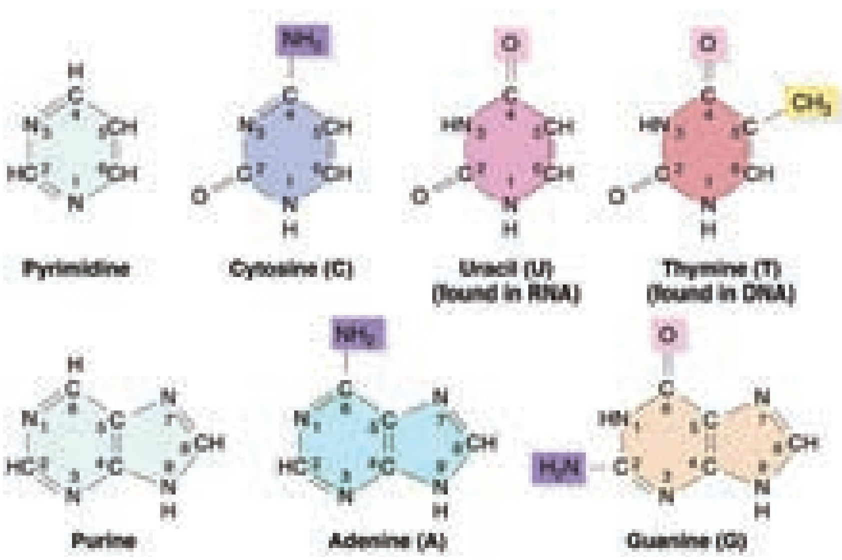


Figure 8.21: Structure of nucleic acid component

DO YOU KNOW?

Telomerase - A ribonucleic Protein.

Telomere protects the end of the chromosomes from damage. Telomerase is a ribonucleo protein also called as terminal transferase.

8.7.1 Formation of Dinucleotide and Polynucleotide

Two nucleotides join to form **dinucleotide** that are linked through 3′-5′ phosphodiester linkage by condensation between phosphate groups of one with sugar of other. This is repeated many times to make **polynucleotide**.

Nucleoside	Nucleotide
It is a combination of base and sugar.	It is a combination of nucleoside and phosphoric acid.
Examples	**Examples**
Adenosine = Adenine + Ribose	Adenylic acid = Adenosine + Phosphoric acid
Guanosine = Guanine + Ribose	Guanylic acid = Guanosine + Phosphoric acid
Cytidine = Cytosine + Ribose	Cytidylic acid = Cytidine + Phosphoric acid
Deoxythymidine = Thymine + Deoxyribose	Uridylic acid = Uridine + Phosphoric acid

DO YOU KNOW?

Friedrich Miescher *was the first to isolate a non-protein substance in nuclei of pus cells and named it as* '**Nuclein**'.

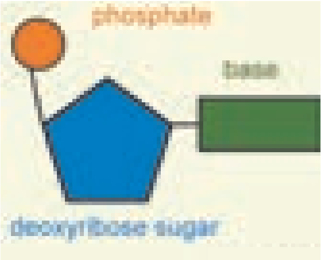


Figure 8.22: Basic component of DNA and RNA

8.7.2 Structure of DNA

Watson and Crick shared the **Nobel Prize** in **1962** for their discovery, along with **Maurice Wilkins**, who had produced the crystallographic data supporting the model. **Rosalind Franklin** (1920–1958) had earlier produced the first clear crystallographic evidence for a helical structure. **James Watson** and **Francis Crick** of Cavendish laboratory in Cambridge built a scale model of double helical structure of DNA which is the most prevalent form of DNA, the **B-DNA**. This is the secondary structure of DNA.

Figure 8.23: Watson and Crick

As proposed by **James Watson and Francis Crick**, DNA consists of right handed double helix with 2 helical polynucleotide chains that are coiled around a common axis to form right handed B form of DNA. The coils are held together by hydrogen bonds which occur between complementary pairs of nitrogenous bases. The sugar is called **2′-deoxyribose** because there is no hydroxyl at position 2′. Adenine and thiamine base pairs has two hydrogen bonds while guanine and cytosine base pairs have three hydrogen bonds.

As published by **Erwin Chargaff** in 1949, a purine pairs with pyrimidine and vice versa**.** Adenine (A) always pairs with Thymine (T) by double bond and Guanine (G) always pairs with Cytosine (C) by triple bond.

Figure 8.24: Rosalind franklin

Figure 8.25: Erwin Chargaff

DO YOU KNOW?

In 1950s, **Maurice Wilkins and Rosalind Franklin** *of Kings College, London studied the X-ray crystallography and revealed experimental data on the structure of DNA*

8.7.3 Features of DNA

- If one strand runs in the 5′-3′ direction, the other runs in 3′-5′ direction and thus are antiparallel (they run in opposite direction). The 5′ end has the phosphate group and 3'end has the OH group.
- The angle at which the two sugars protrude from the base pairs is about 120°, for the narrow angle and 240° for the wide angle. The narrow angle between the sugars generates a **minor groove** and the large angle on the other edge generates **major groove.**
- Each base is 0.34 nm apart and a complete turn of the helix comprises 3.4 nm or 10 base pairs per turn in the predominant B form of DNA.
- DNA helical structure has a diameter of 20 A° and a pitch of about 34 A°. X-ray crystal study of DNA takes a stack of about 10 bp to go completely around the helix (360°).
- Thermodynamic stability of the helix and specificity of base pairing includes (i) the hydrogen bonds between the complementary bases of the double helix (ii) stacking interaction between bases tend to stack about each other perpendicular to the direction of helical axis. Electron cloud interactions (∏ – ∏) between the bases in the helical stacks contribute to the stability of the double helix.
- The phosphodiester linkages gives an inherent polarity to the DNA helix. They form strong covalent bonds, gives the strength and stability to the polynucleotide chain (Figure 8.32).

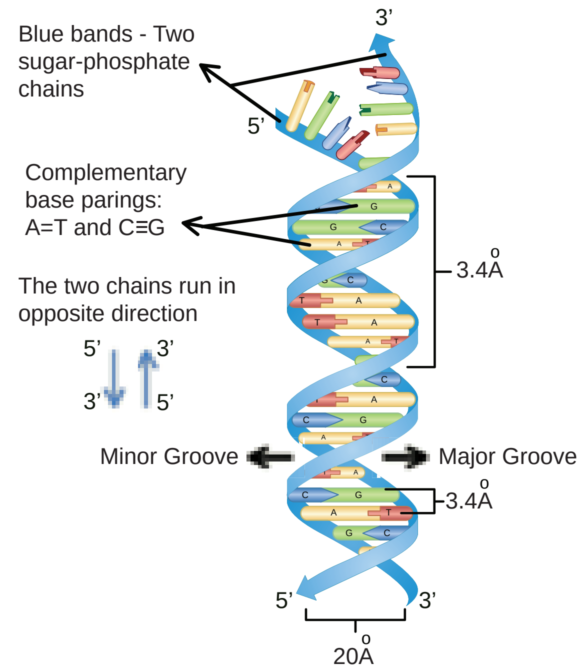


Figure 8.26: Structure of DNA

- Plectonemic coiling - the two strands of the DNA are wrapped around each other in a helix, making it impossible to simply move them apart without breaking the entire structure. Whereas in paranemic coiling the two strands simply lie alongside one another, making them easier to pull apart.
- Based on the helix and the distance between each turns, the DNA is of three forms – **A DNA, B DNA and Z DNA** (Figure 8.27).

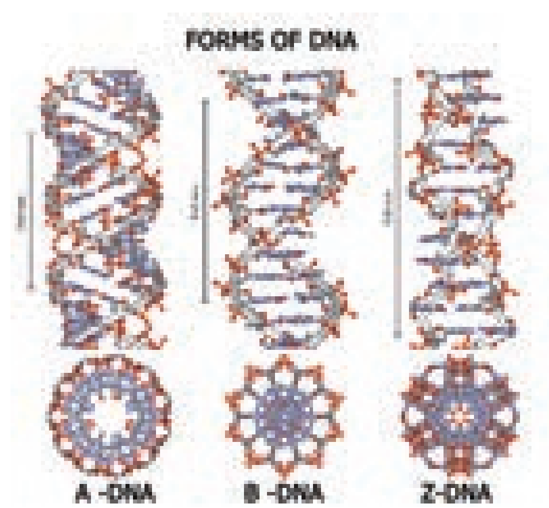


Figure 8.27: Forms of DNA

8.7.4 Ribonucleic Acid (RNA)

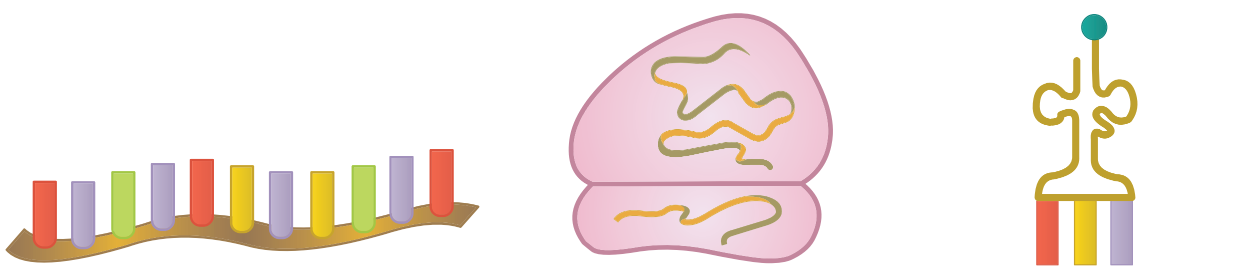
Ribonucleic acid (**RNA**) is a polymeric molecule essential in various biological roles in

Feature	B-DNA	A-DNA	Z-DNA
Type of helix	Right-handed	Right-handed	Left-handed
Helical diameter (nm)	2.37	2.55	1.84
Rise per base pair (nm)	0.34	0.29	0.37
Distance per complete turn (pitch) (nm)	3.4	3.2	4.5
Number of base pairs per complete turn	10	11	12
Topology of major groove	Wide, deep	Narrow, deep	Flat
Topology of minor groove	Narrow, shallow	Broad, shallow	Narrow, deep

coding, decoding, regulation and expression of genes. RNA is single stranded and is unstable when compared to DNA.

8.7.5 Types of RNA

- **mRNA (messenger RNA):** Single stranded, carries a copy of instructions for assembling amino acids into proteins. It is very unstable and comprises 5% of total RNA polymer. Prokaryotic mRNA (Polycistronic) carry coding sequences for many polypeptides. Eukaryotic mRNA (Monocistronic) contains information for only one polypeptide.
- **tRNA (transfer RNA):** Translates the code from mRNA and transfers amino acids to the ribosome to build proteins. It is highly folded into an elaborate 3D structure and comprises about 15% of total RNA. It is also called as **soluble RNA**.
- **rRNA (ribosomal RNA):** Single stranded, metabolically stable, make up the two subunits of ribosomes. It constitutes 80% of the total RNA. It is a polymer with varied length from 120–3000 nucleotides and gives ribosomes their shape. Genes for rRNA are highly conserved and employed for phylogenetic studies (Figure 8.28).



Messenger **RNA** (m**RNA**)　　Ribosomal **RNA** (r**RNA**)　　Transfer **RNA** (t**RNA**)

Figure 8.28: Types of RNA

Summary

- ❖ **Cells** are composed of water, inorganic compounds and organic molecules. The biomolecules of the cells include carbohydrates, lipids, proteins, enzymes and nucleic acids.
- ❖ **Carbohydrates** include simple sugars (monosaccharides) and polysaccharides. Polysaccharide serve as storage forms of sugar and structural components of cell.
- ❖ **Lipids** are the principle components of cell membrane, and they serve as energy storage and signalling molecules.
- ❖ **Proteins** are polymers of 20 different amino acids, each of which has a distinct side chain with specific chemical properties. Each protein has a unique aminoacid sequence which determines its 3D structure.

❖ **Nucleic acids** are the principle information molecules of the cell. Both DNA and RNA are polymers of purine and pyrimidine nucleotides.

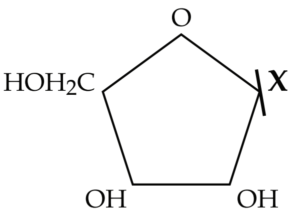
Evaluation

1. The most basic amino acid is
   a. Arginine
   b. Histidine
   c. Glycine
   d. Glutamine

2. An example of feedback inhibition is
   a. Cyanide action on cytochrome
   b. Sulpha drug on folic acid synthesiser bacteria
   c. Allosteric inhibition of hexokinase by glucose-6-phosphate
   d. The inhibition of succinic dehydrogenase by malonate

3. Proteins perform many physiological functions. For example some functions as enzymes. One of the following represents an additional function that some proteins discharge:
   a. Antibiotics
   b. Pigment conferring colour to skin
   c. Pigments making colours of flowers
   d. Hormones

4. Given below is the diagrammatic representation of one of the categories of small molecular weight organic compounds in the living tissues. Identify the category shown & one blank component " X" in it.



Category	Compound
Cholesterol	Guanine
Amino acid	NH_2
Nucleotide	Adenine
Nucleoside	Uracil

5. Distinguish between nitrogenous base and a base found in inorganic chemistry.

6. Write the characteristic feature of DNA.

7. Explain the structure and function of different types of RNA.

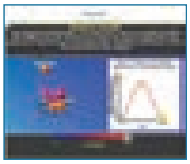
ICT Corner

ENZYMES

Steps
- Scan the QR code
- Click Enzymatic
- Start a new game
- Select yes if you using touch screen mobile / tablet
- Tap or click here
- Click experiments

Activity
- Move the slide to change temperature
- Go to next concept
- Try Quiz after experiments

Bio Catalyst →



Step 1

Step 3

Step 2

Step 4

URL: https://www.biomanbio.com/HTML5GamesandLabs/LifeChemgames/ lifechem.html

* Pictures are indicative only

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 tissues and their functions.*
- *Describes the various type of tissue system*
- *Interpret cross sections and longitudinal sections of dicot and monocot root, stem and leaf.*
- *Compare the internal organization of dicot root and monocot root.*

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.

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.**

The Tissues

A Tissue is a group of cells that are alike in origin, structure and function. The study of tissues 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**)

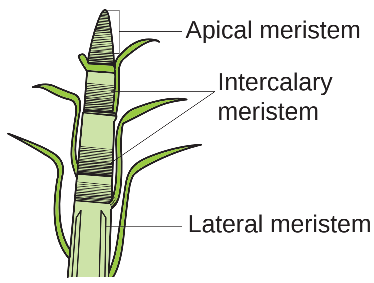


Figure 9.1: Different types of meristems on the basis of position in plant body

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

- The meristematic cells are isodiametric and they may be, oval, spherical or polygonal in shape.
- They generally have dense cytoplasm with prominent nucleus.
- Generally the vacuoles are either small or absent.
- Their cell wall is thin, elastic and 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.

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 is 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.

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 initials 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 permenant tissues. It is responsible for elongation of internodes.	**Secondary meristem** It is derived during later stage of development of the plant body. It produces cork cambium and interfascicular cambium.	**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.		**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

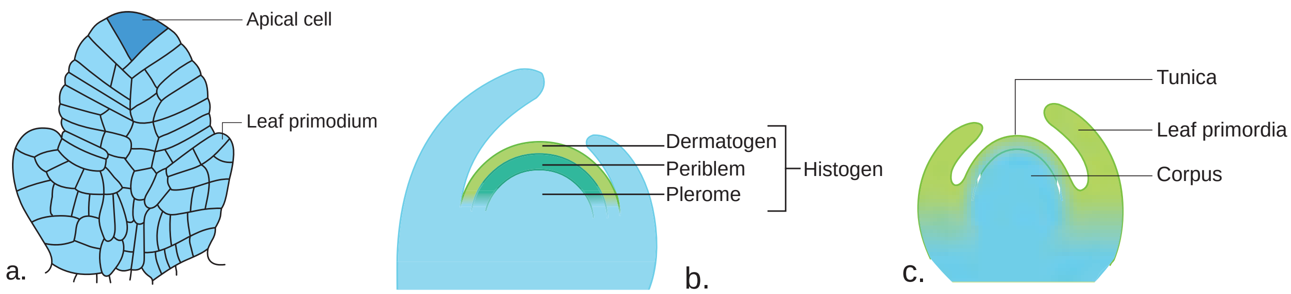


Figure 9.2: Shoot apical meristem a) Apical cell theory, b) Histogen theory, c) Shoot Tunica corpus theory

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 the outermost layer. It gives rise to epidermis.
2. **Periblem:** It is middle layer. That gives rise to cortex.
3. **Plerome:** It is innermost layer. Which gives rise to stele

Tunica Corpus Theory

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

Two zones of tissues are found in apical meris tem.

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 are 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,

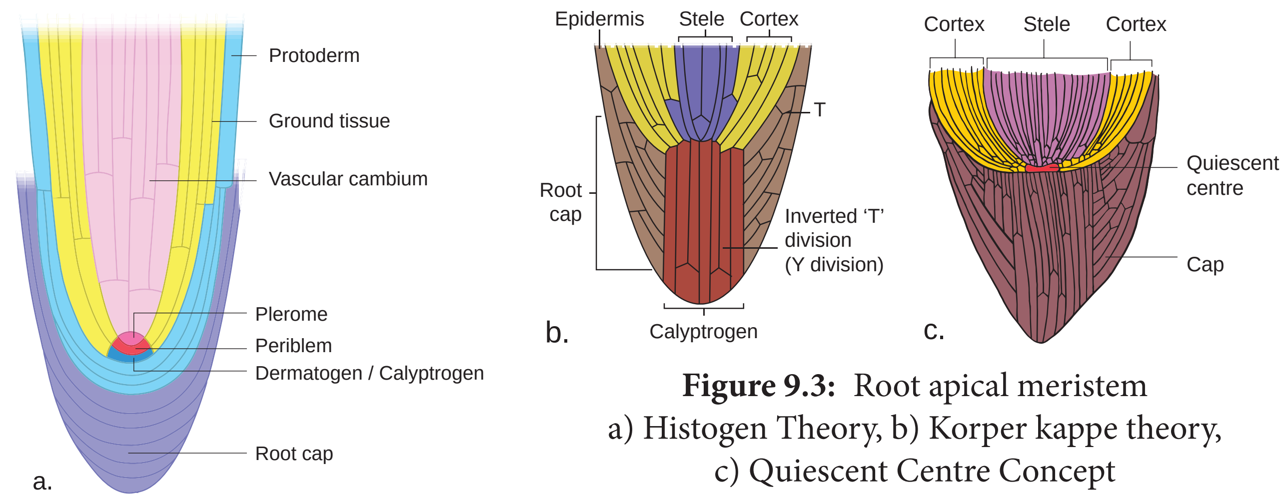


Figure 9.3: Root apical meristem
a) Histogen Theory, b) Korper kappe theory,
c) Quiescent Centre Concept

i. **Dermatogen:** It is the outermost layer. It gives rise to root epidermis.
ii. **Periblem:** It is the 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.

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. This 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. The tissue normally has prominent intercellular spaces and may store various types of materials like, water, air, ergastic substances.

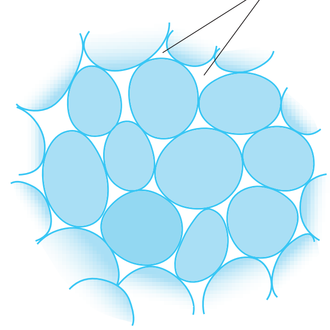


Figure 9.4: Parenchyma

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.

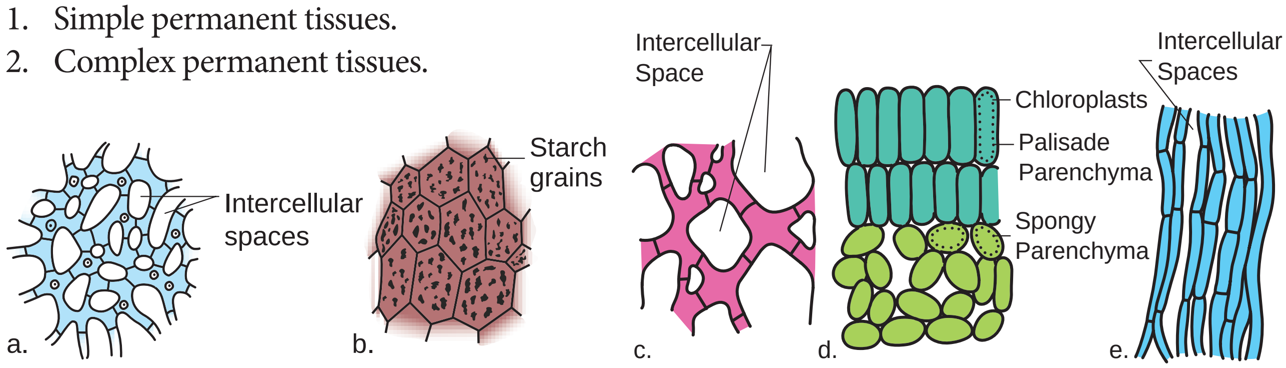


Figure 9.5: Types of Parenchyma
a) Aerenchyma, b) Storage parenchyma c) Stellate parenchyma, d) Chlorenchyma, e) Prosenchyma

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

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

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

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

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

Parenchyma

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 meet. Example: Hypodermis of *Datura* and *Nicotiana*

2. Lacunar collenchyma
The collenchyma cells are irregularly arranged. Cell wall is thickened 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 thickened only at tangential wall. devoid of thickened at radial walls. These thickening appear as successsive tangential layers. Example: Hypodermis of Helianthus

Diagramatic structures

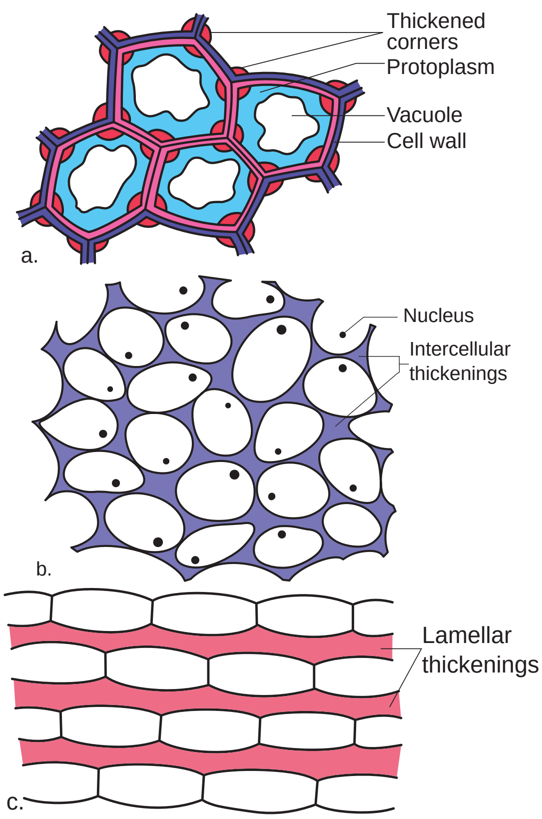


Figure 9.6: Types of Collenchyma
a) Angular collenchyma, b) Lacunar collenchyma, c) Lamellar collenchyma

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 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. 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.

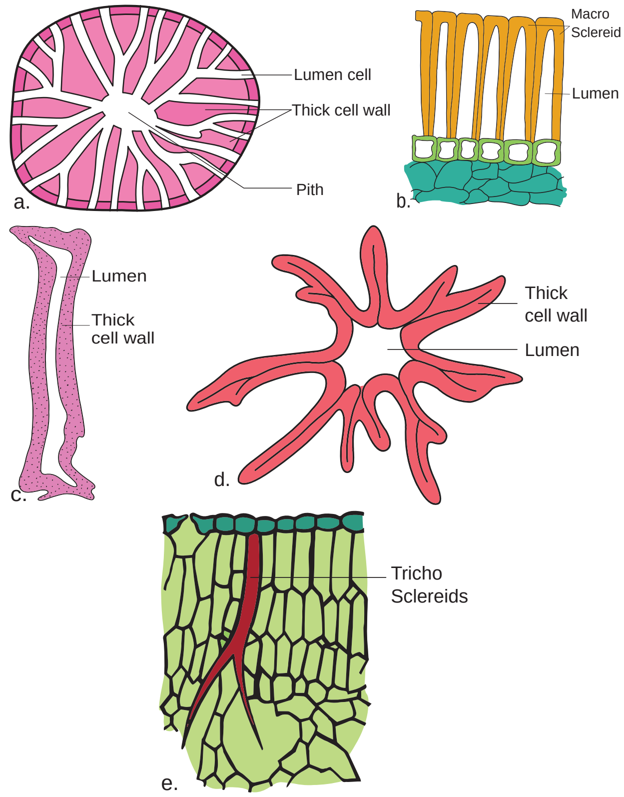


Figure 9.7: Types of sclereids
a) Brachysclereids, b) Macrosclereids, c) Osteosclereids, d) Astrosclereids, e) Trichosclereids

Types of Sclereids

1. Brachysclereids 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 from 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*.

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.

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

Fibres are of five types

1. 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 two types. a. Libriform fibres b. Fibre tracheids

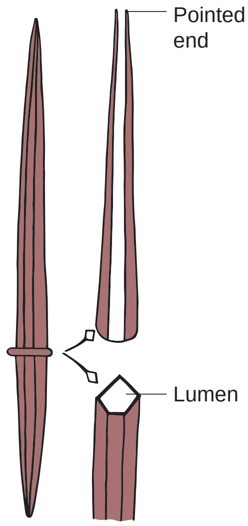


Figure 9.9 T.S of fibre

2. 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.

3. 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.

4. Mesocarp Fibres

Fibres obtained from the mesocarp of drupes like coconut.

5. 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 or Hadrome

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

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.

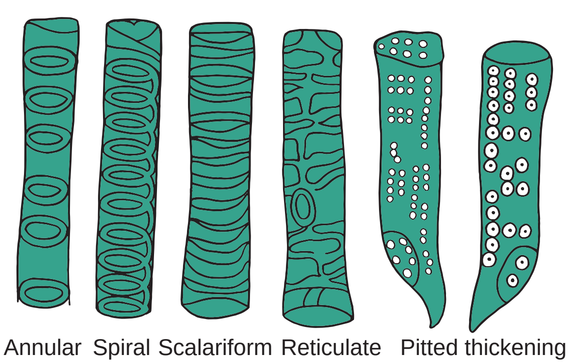


Figure 9.10: Types of secondary wall thickenings in tracheids and vessels

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.

DO YOU KNOW?

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 to leptome

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.

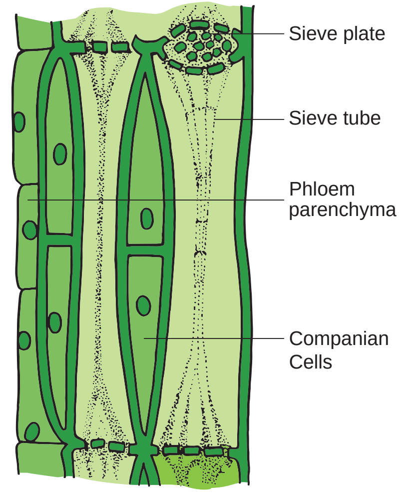


Figure 9.11: Different types of phloemelements

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.

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: *Coconut*
5. Leaf fibres: *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.

DO YOU KNOW?

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

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

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

Difference Between Collenchyma and Sclerenchyma

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

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.

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*. It is made up of single layer of parenchyma cells which are arranged compactly without intercellular spaces. Although epidermis is a continuous outer layer, it is interrupted by stomata in many plants.

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).*** 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.

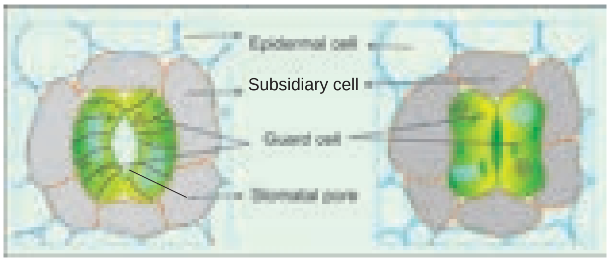


Figure 9.12: (a) Stoma with bean-shaped guard cells. (b) Stoma with dumb-bell shaped guard cells

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.

Epidermal Outgrowths

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

> **DO YOU KNOW?** The trichomes on the leaves of insectivorous plants secrete mucopolysaccharides 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.

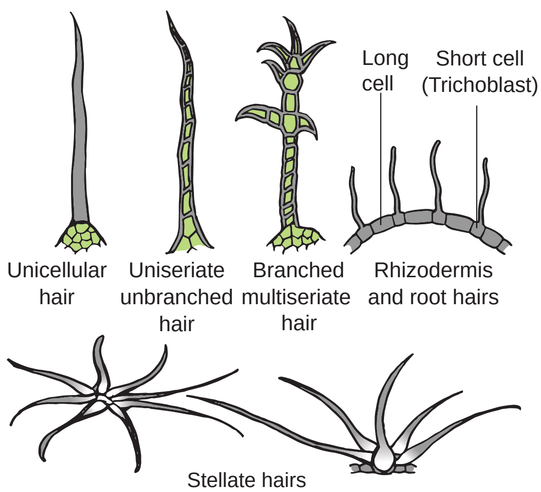


Figure 9.13: Types of Trichomes

Prickles

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

Figure 9.14: 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.

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.

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.

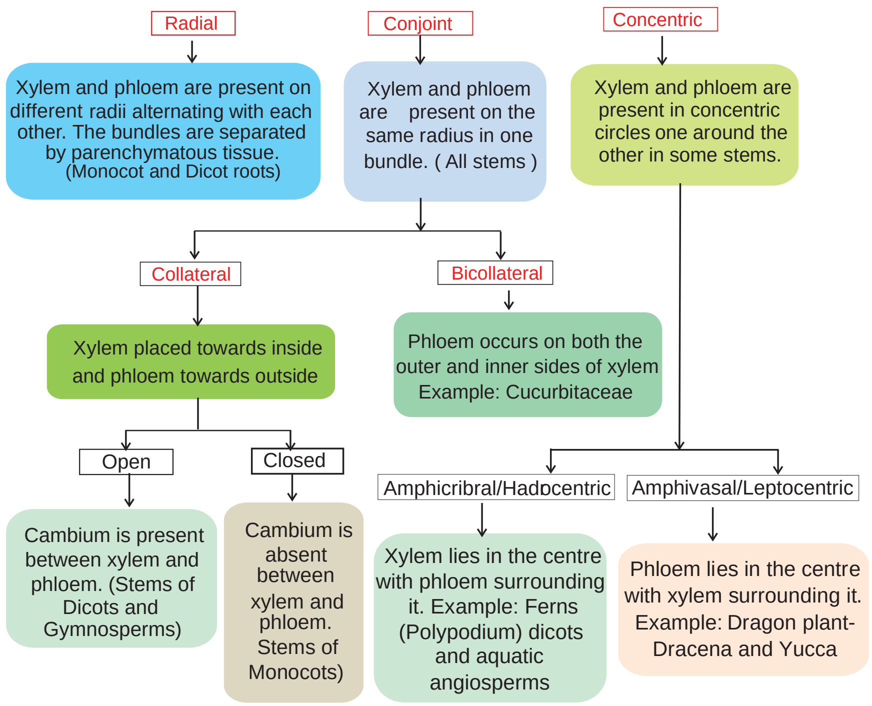
9.6 Vascular Tissue System

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.

Types of vascular Bundles



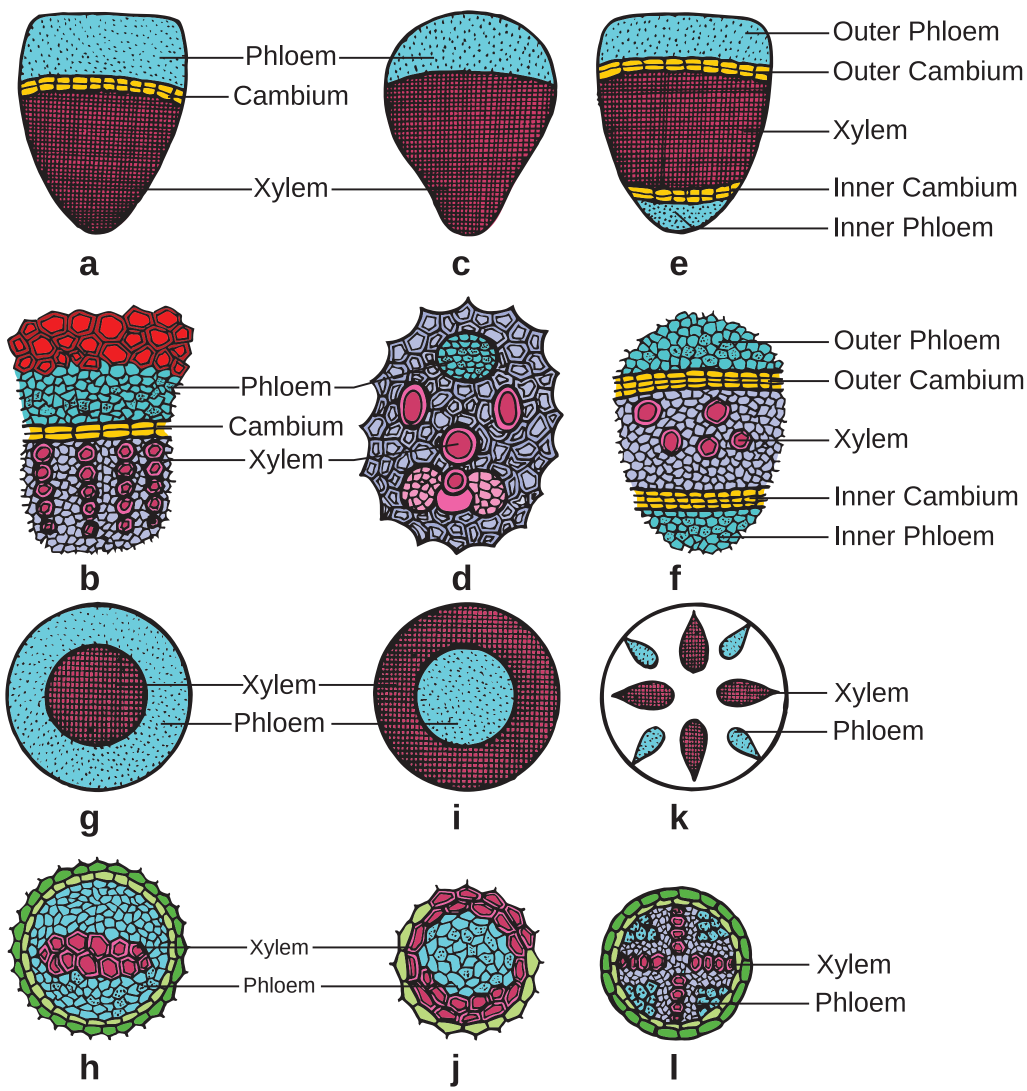


Figure 9.15: Types of vascular bundles (**a**) and (**b**) - Conjoint, collateral and open; (**c**) and (**d**) - Conjoint, collateral and closed (**e**) and (**f**) - Conjoint, bicollateral and open; (**g**) and (**h**) - Concentric and amphicribral; (**i**) and (**j**) - Concentric and amphivasal; (**k**) and (**l**) - Radial

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

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.

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.

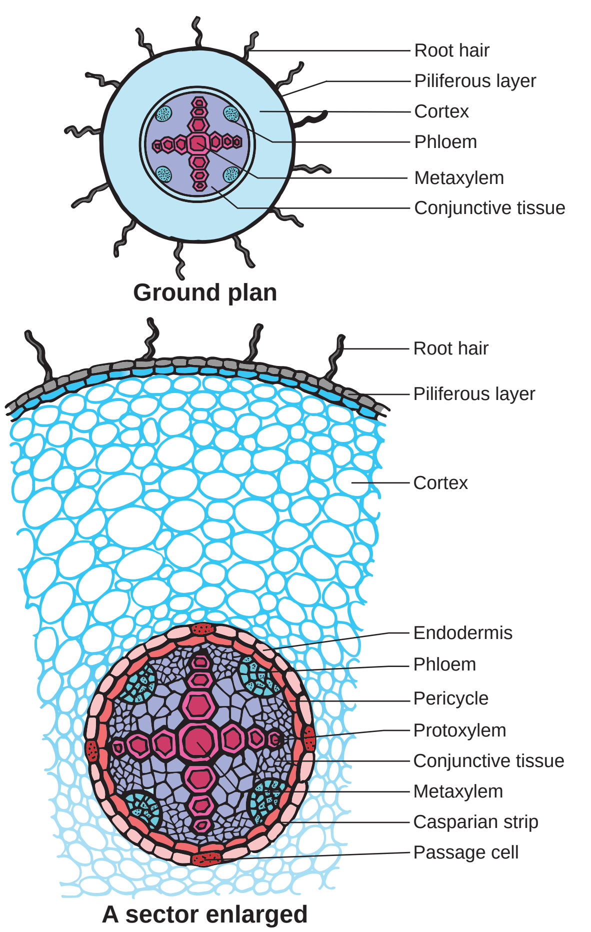


Figure 9.16: T.S. of Dicot root (Bean root)

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.

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.

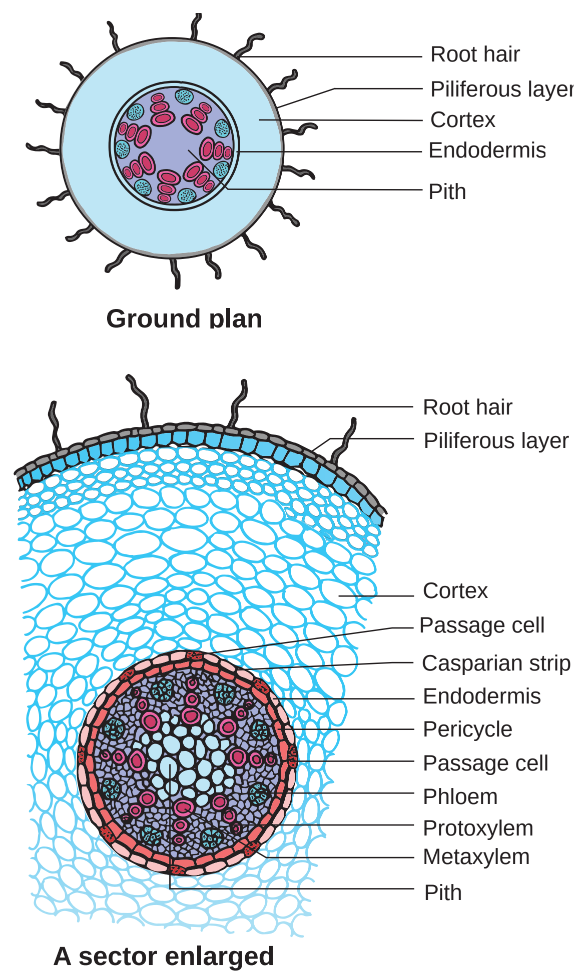


Figure 9.17: T.S of Monocot root (Maize root)

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 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.

Anatomical differences between dicot root and monocot root

S.No.	Characters	Dicot root	Monocot root
1.	Pericycle	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

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.

Primary Structure of Dicot Stem (Sunflower stem)
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. 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 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.

Stele
The central part of the stem inner to the endodermis is known as **stele**. It consists of pericycle, 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
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 or medulla
The large central portion of the stem is called **pith**. It is composed of parenchyma cells

with intercellular spaces. The pith extends between the vascular bundles. are called primary pith rays or primary medullary rays. Function of the pith is **storage of food.**

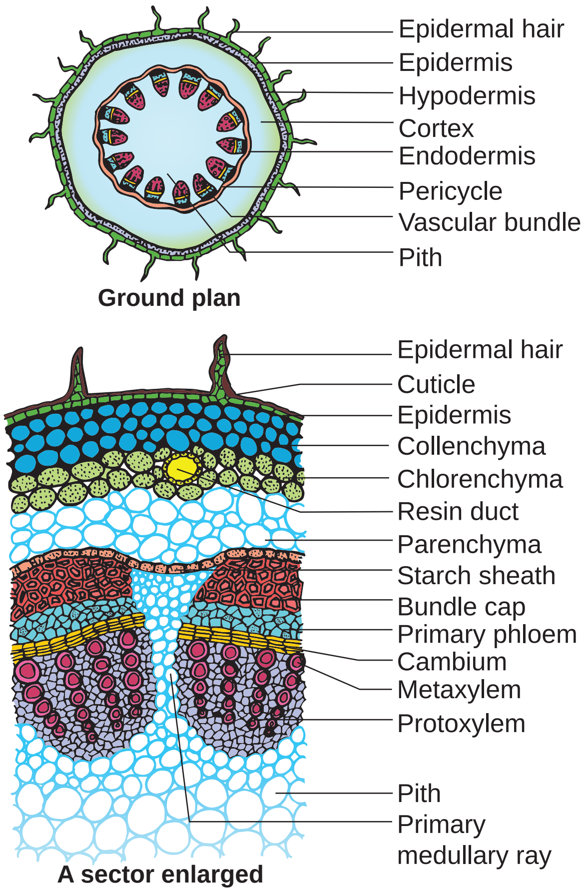


Figure 9.18: T. S of Dicot Stem (Sunflower stem)

Primary Structure of 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.

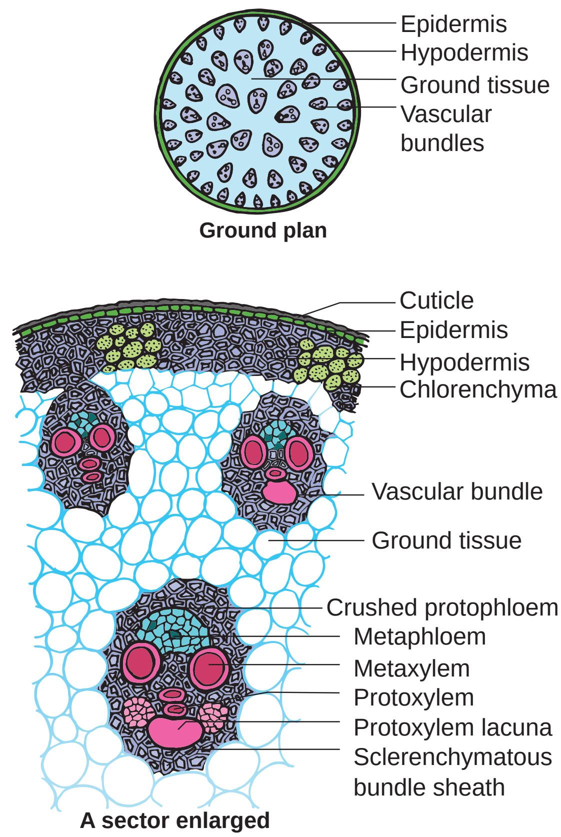


Figure 9.19: T.S. of Monocot stem (Maize stem)

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

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.

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**.

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.

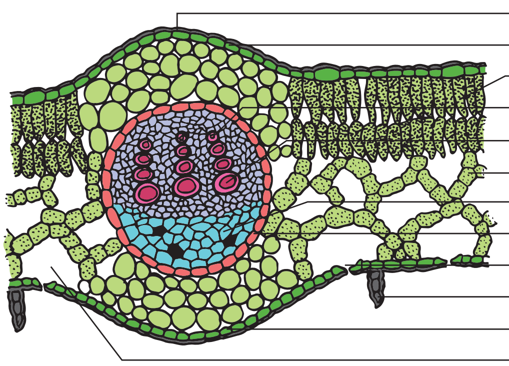


Figure 9.22: T.S. of Dicot Leaf (Sunflower)

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**.

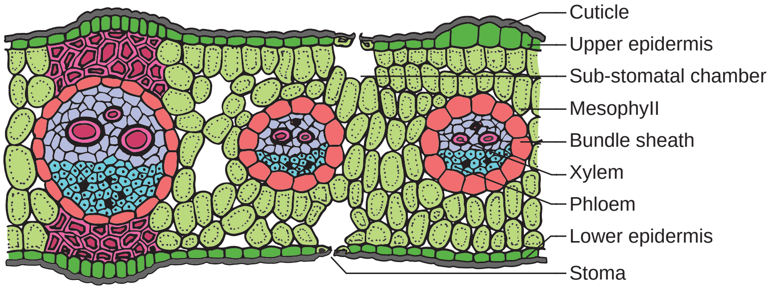


Figure 9.21: T.S. of monocot leaf (Grass)

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.

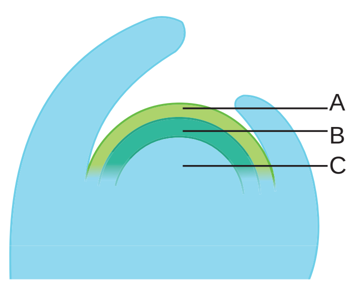
In the primary structure, the outermost layer of the root is called piliferous layer. Cortex consists of only parenchyma cells. All the tissues present inside endodermis comprise the stele. In dicot (Example: bean) root, xylem is tetrach. Its phloem patch consists of sieve tubes, companion cells and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

Evaluation

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



   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 c. i and iii only
   b. ii 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.

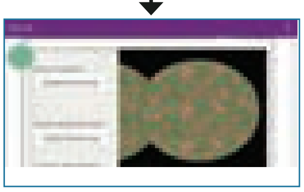
a. i, ii and iii only
b. ii, iii and iv only
c. i, ii and iv only
d. All of these

3. In Gymnosperms, the activity of sieve cells 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.**

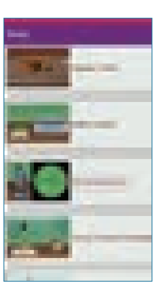


Steps

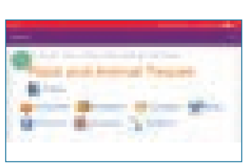
- Scan the QR code or go to Google play store
- Type online labs and install it.
- Select biology and select plant and animal tissues
- Click free sign up and provide your basic information with valid mail-Id
- Login with your registered mail id and password
- Choose theory tab to know the basic about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

Activity

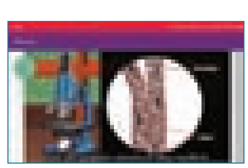
- Choose simulation tab and view the section of plant parts under microscope



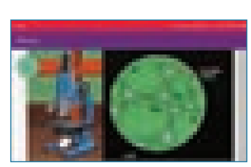
Step 1



Step 2



Step 3



Step 4

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.*
- *Explain secondary growth in dicot roots.*

Chapter Outline

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, fibres, 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)

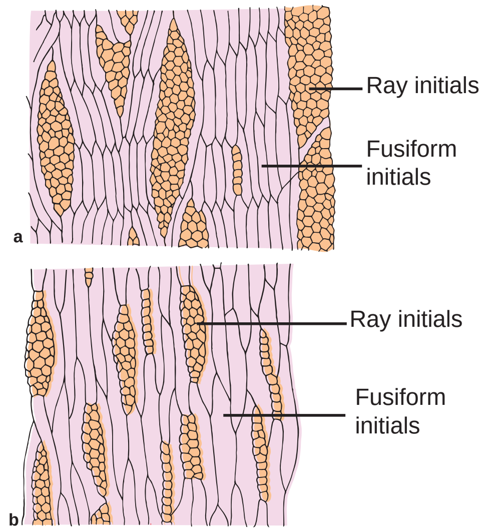


Figure 10.2: Tangential longitudinal section (TLS) of cambium (a) Storied cambium (b) Non-storied cambium

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.

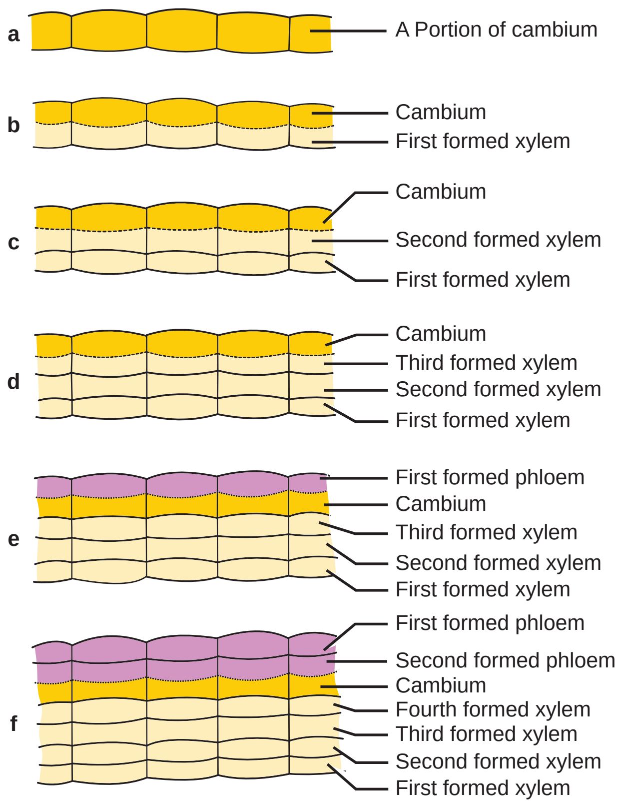


Figure 10.3: Diagrammatic representation of vascular cambial activity (a–f)

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.

> DO YOU KNOW?
> **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*.

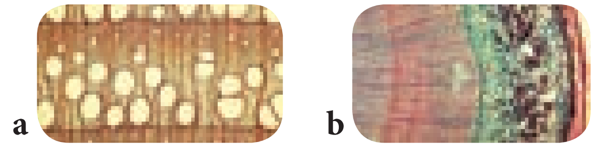


Figure 10.4: Structure of porous (a) and non-porous wood (b)

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

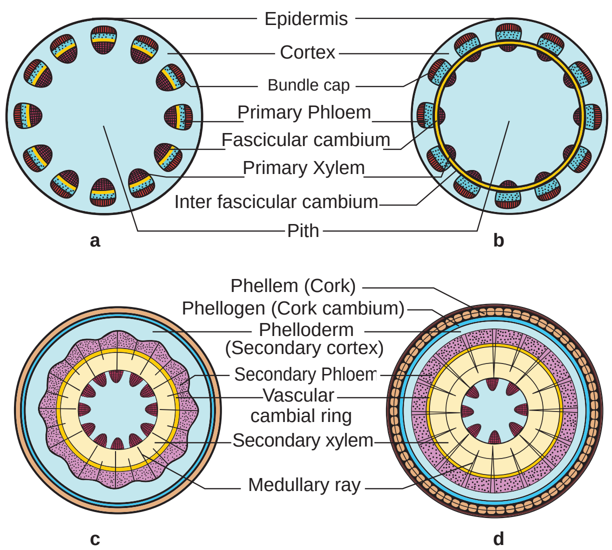


Figure 10.5: Secondary growth in dicot stem (diagrammatic) - stages in transverse section (a–d)

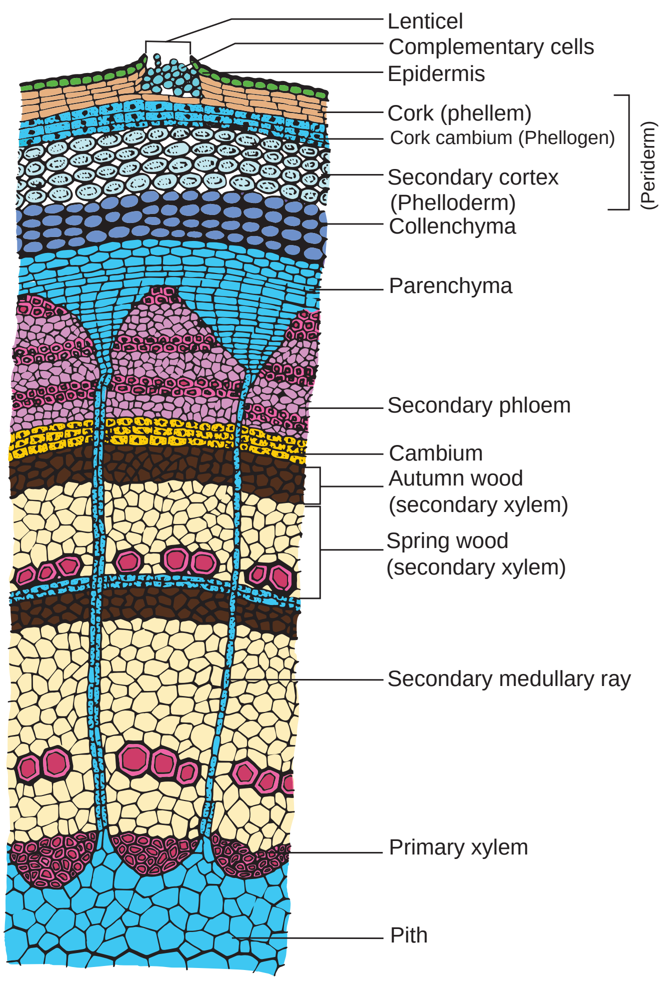


Figure 10.6: Secondary growth in two year old dicot stem – A portion enlarged

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.

> **DO YOU KNOW?**
>
> - 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.

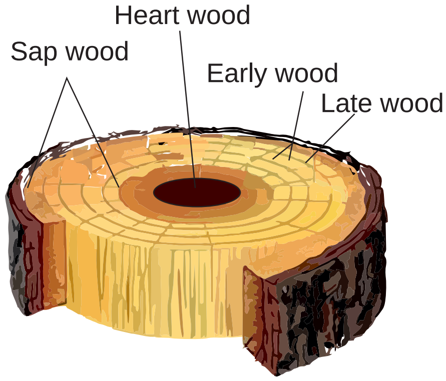
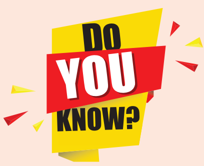
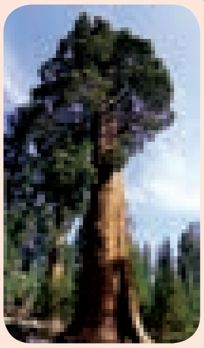


Figure 10.7: Structure of wood – Image shows early wood and late wood



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



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 a 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.

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*

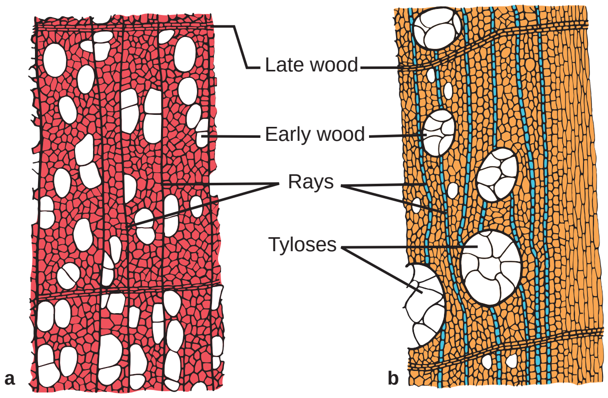


Figure 10.8: Transverse section of wood showing. a. Diffuse porous. b. Ring porous

> **DO YOU KNOW?** 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**.

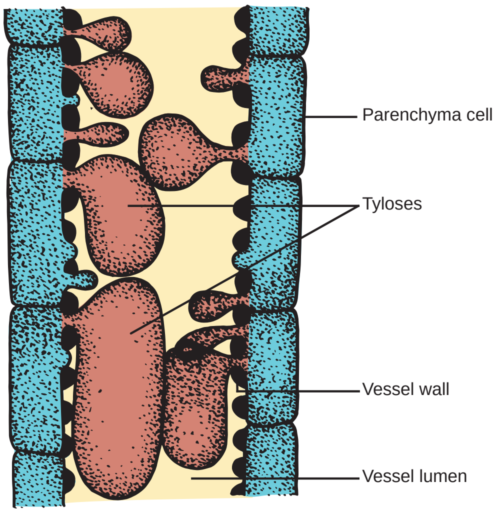


Figure 10.9: Structure of tyloses

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.

> **DO YOU KNOW?** 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.

> **DO YOU KNOW?** 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.

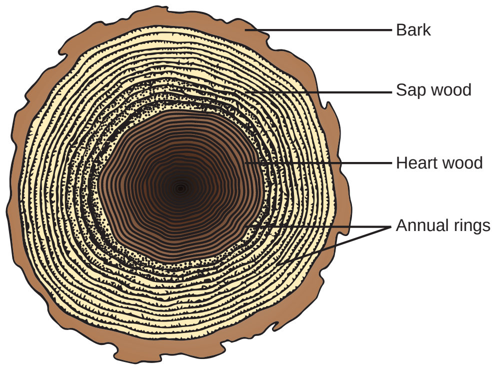


Figure 10.10: Cross - section of wood showing annual ring

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 pale coloured	It is dark 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

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 usitatissimum*
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)

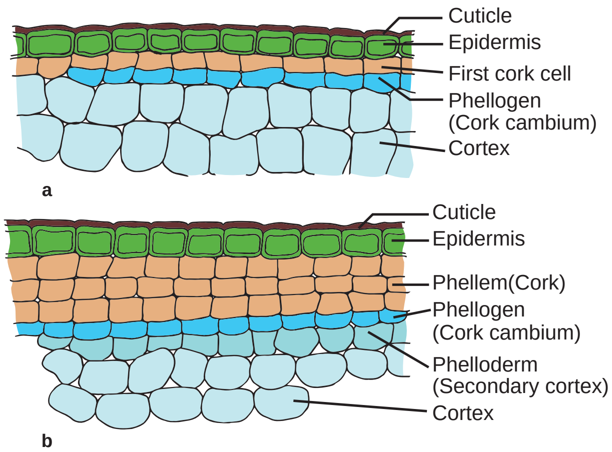


Figure 10.11: The cross section of periderm (a–b)

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.

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.

DO YOU KNOW?

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 multiseriate nonsuberized cells in periderm.

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 10.12: *Quercus* Tree-showing ring bark

Figure 10.13: 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**.

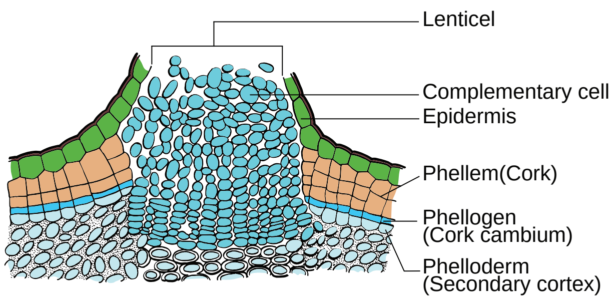


Figure 10.14: Structure of Lenticel

10.2 Secondary Growth in Dicot root

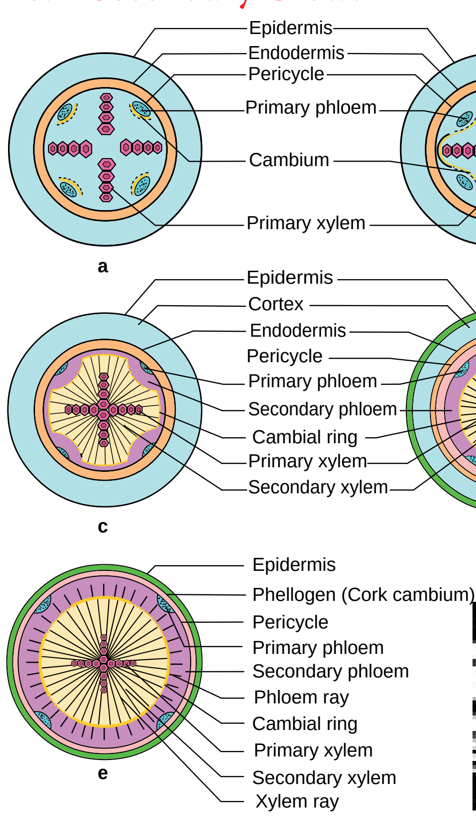


Figure 10.15: Different stages of the secondary growth (diagrammatic) in a typical dicot root (a–e)

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.

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 pericycle. (intrastealar in origin)
More amount of cork is produced as stem is aboveground	Generally, less amount of cork is produced as root is underground.
Lenticels of periderm are prominent.	Lenticels of periderm are not very prominent.

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 is classified into various types. Based on respectively on the presence or absence of vessels, - porous and non-porous wood. Based on the wood formed during seasons, - spring wood and autumn wood. The spring and autumn wood, together is called **annual ring**. 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

1. Consider the following statements

   In spring season vascular cambium

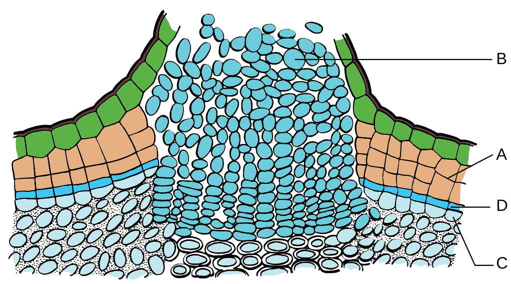
   i. is less active
   ii. produces a large number of xylary elements
   iii. forms vessels with wide cavities of these,

   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. Phellem b. Phellogen
   c. Xylem d. Vascular cambium

5. What is the fate of primary xylem in a dicot stem showing extensive secondary growth?

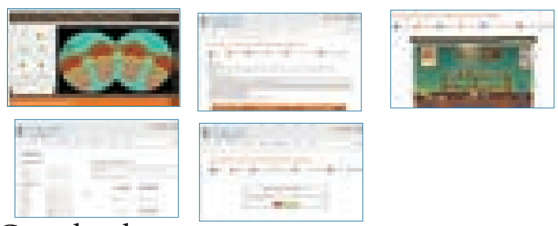
   a. It is retained in the centre of the axis
   b. It gets crushed
   c. May or may not get crushed
   d. It gets surrounded by primary phloem

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.

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

* 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

11.1 Types of transport
11.2 Cell to Cell transport
11.3 Plant water relations
11.4 Absorption of water
11.5 Ascent of Sap
11.6 Transpiration
11.7 Translocation of organic solutes
11.8 Mineral absorption

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.

11.1 Types of Transport

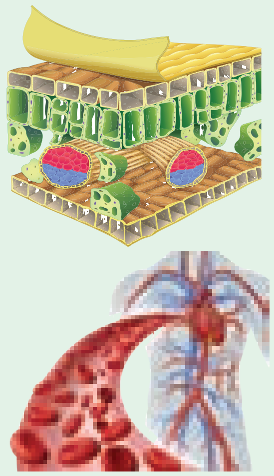
Transport is the process of moving water, minerals and food to all parts of the plant body. Conducting tissues such as xylem and phloem play an important role in this.

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.

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.

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:

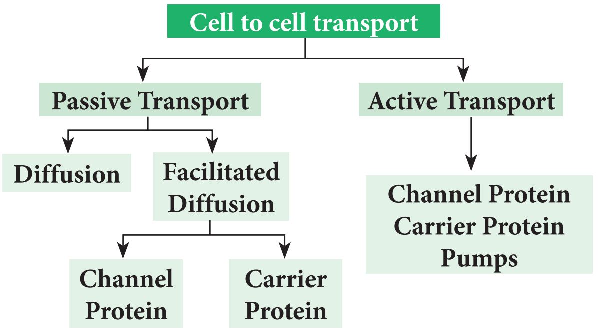


Figure 11.1: Cell to cell transport

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).

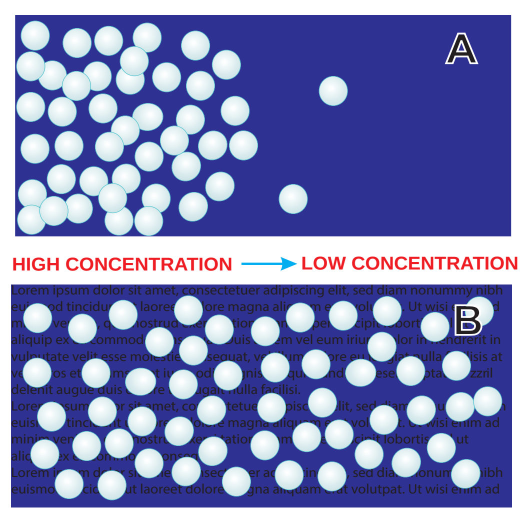


Figure 11.2: Distribution of molecules in diffusion (A) Initial stage (B) Final stage

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.
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.

DO YOU KNOW?

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, cutinised 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 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.

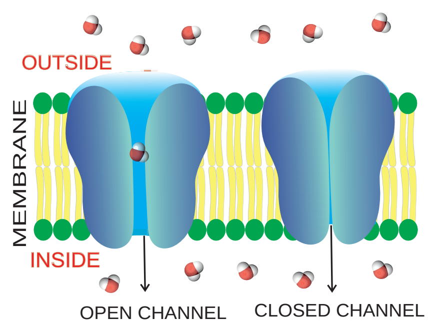


Figure 11.3: Aquaporin

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.

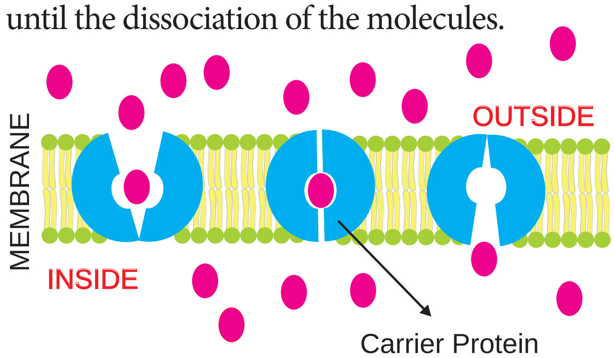


Figure 11.4: Carrier Protein

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.**

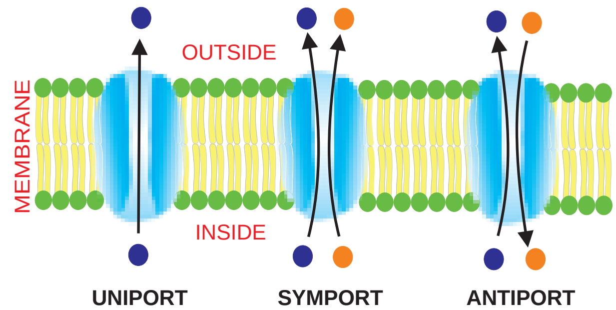
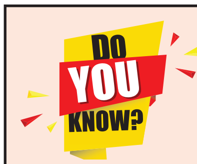


Figure 11.5: Direction of transport

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 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.



Discovery of Aquaporin

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

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.

DO YOU KNOW?

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 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 in comparison with another solution.

Thistle funnel experiment

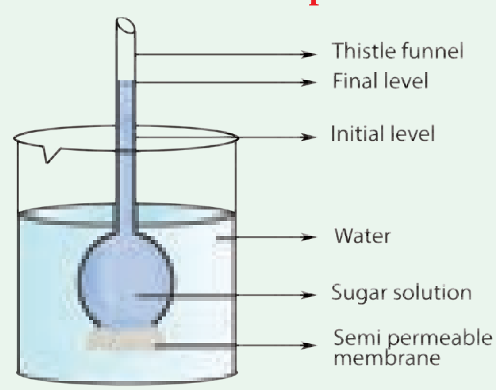


Figure 11.6: Thistle Funnel Experiment

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?

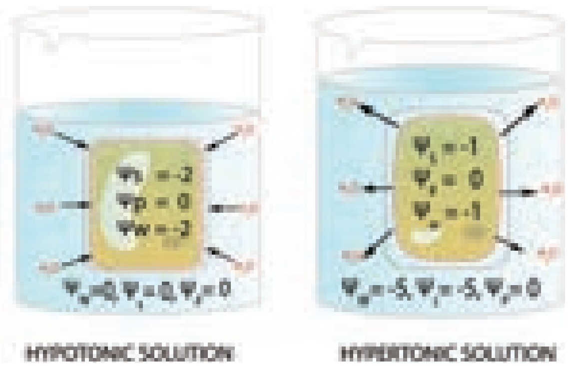


Figure 11.7: Types of solution based on concentration

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

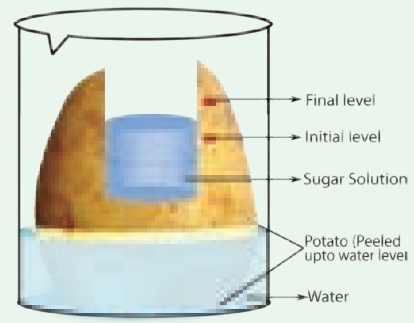


Figure 11.8: Demonstration of Endosmosis by Potato Osmoscope

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).

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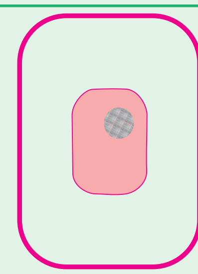
Table 11.2: Difference between plasmolysis types.

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.
		

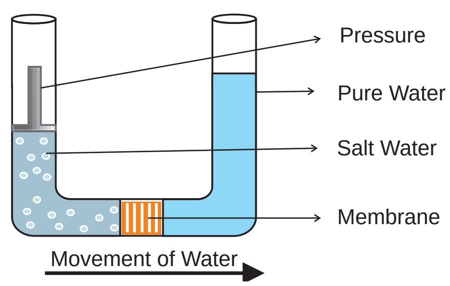


Figure 11.9: Reverse Osmosis

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

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).

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).

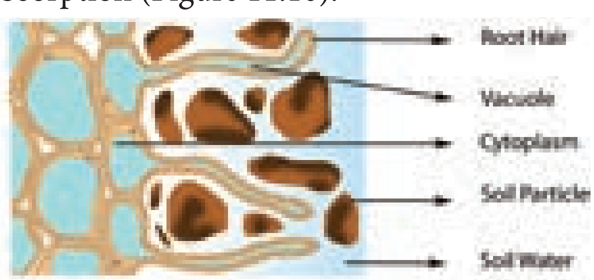


Figure 11.10: Structure of Root Hair

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

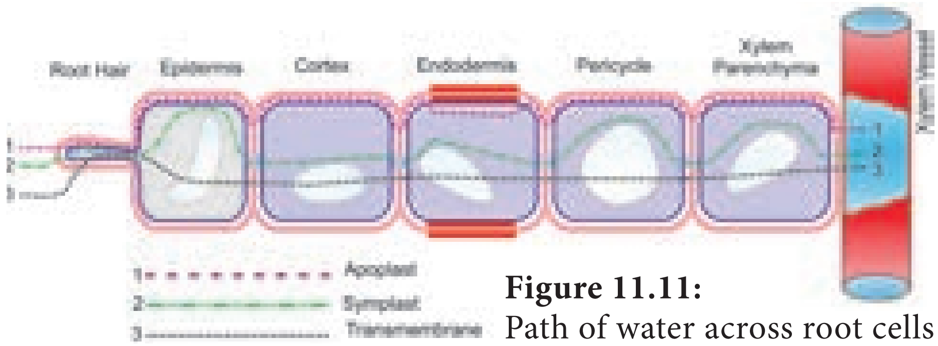


Figure 11.11:
Path of water across root cells

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.

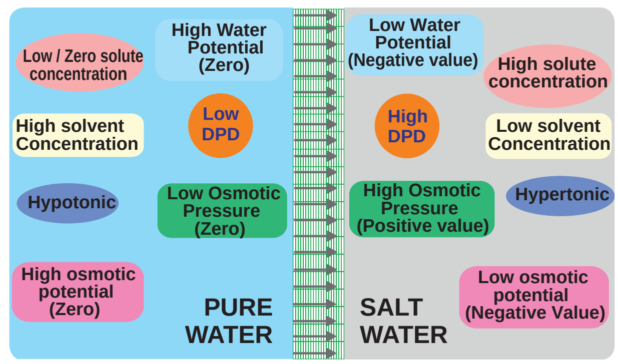
11.4.3 Mechanism of Water Absorption

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.

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



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.

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.**

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.

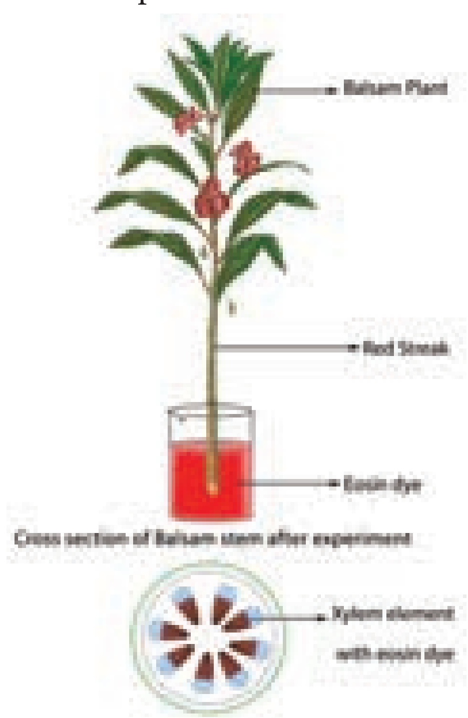


Figure 11.12: Balsam plant and eosin dye experiment

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.

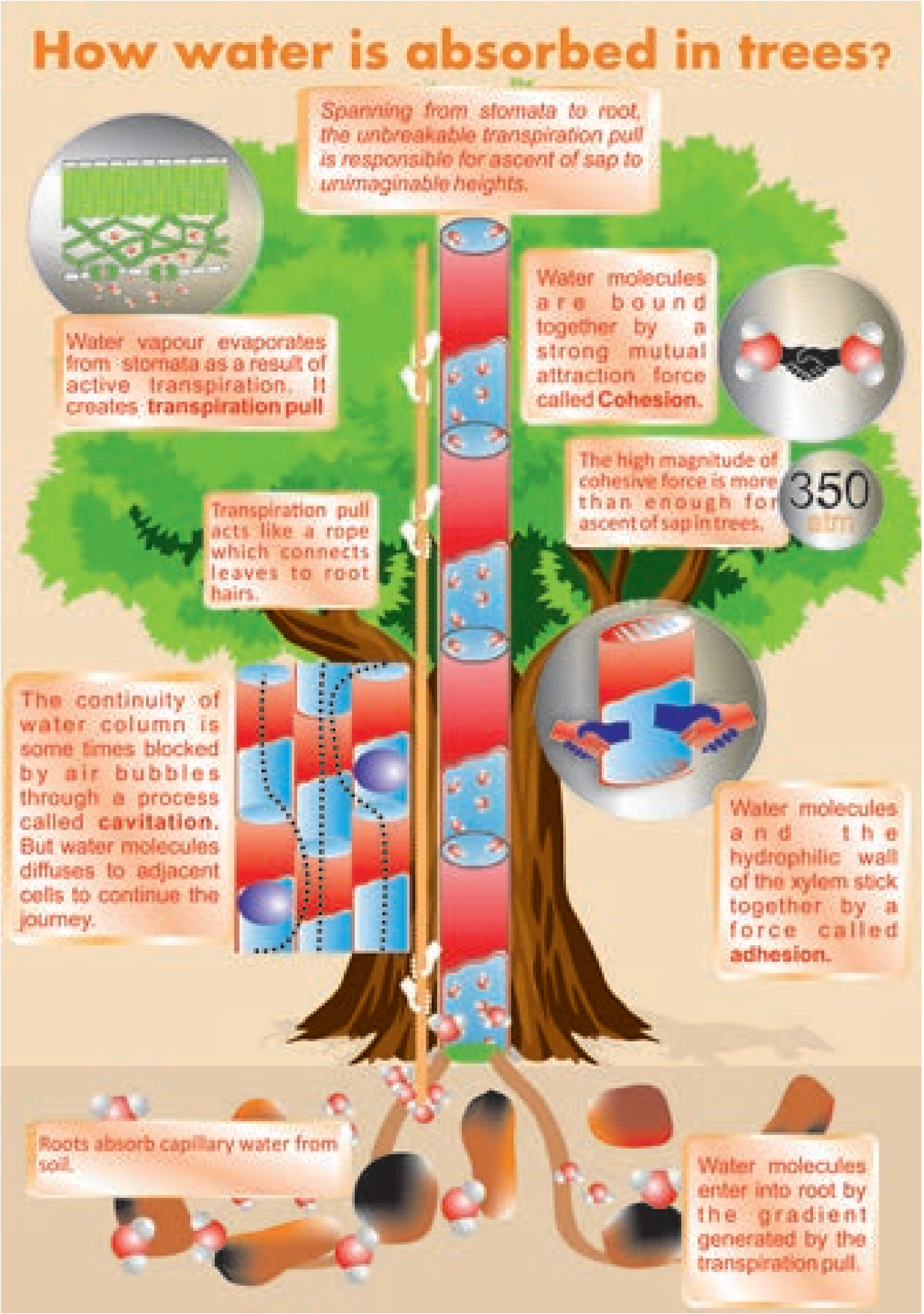
ii. There is no relationship between the ascent of sap and root pressure. For example, in summer, the rate of the ascent of sap is more due to transpiration in spite of the fact that root pressure is very low. On the other hand, in winter when the rate of ascent of sap is low, a high root pressure is 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.


How water is absorbed in trees?
Spanning from stomata to root, the unbreakable transpiration pull is responsible for ascent of sap to unimaginable heights.
Water vapour evaporates from stomata as a result of active transpiration. It creates transpiration pull
Water molecules are bound together by a strong mutual attraction force called Cohesion.
The high magnitude of cohesive force is more than enough for ascent of sap in trees.
350 atm
Transpiration pull acts like a rope which connects leaves to root hairs.
The continuity of water column is some times blocked by air bubbles through a process called cavitation. But water molecules diffuses to adjacent cells to continue the journey.
Water molecules and the hydrophilic wall of the xylem stick together by a force called adhesion.
Roots absorb capillary water from soil.
Water molecules enter into root by the gradient generated by the transpiration pull.

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.**

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 square mm. 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.

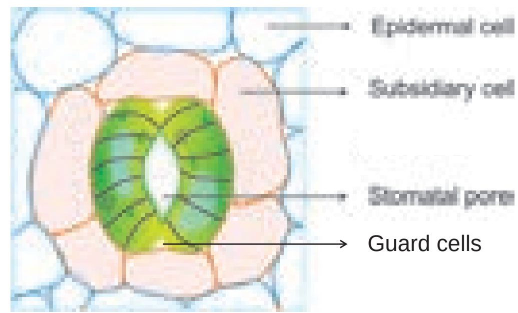


Figure 11.14: Structure of Stomata

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).

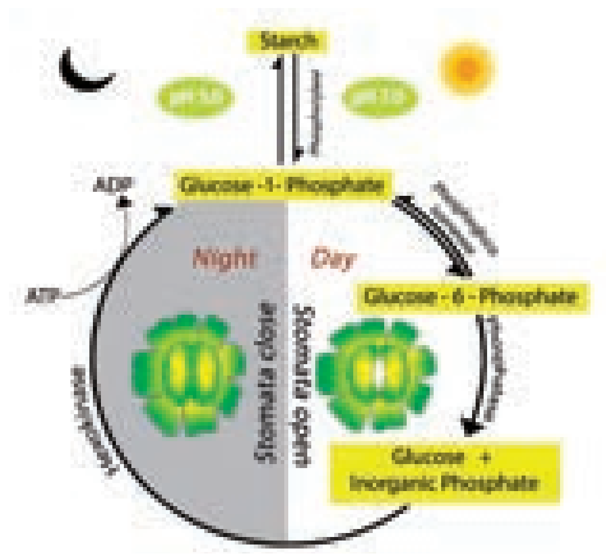


Figure 11.15: Steward Scheme

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.

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:

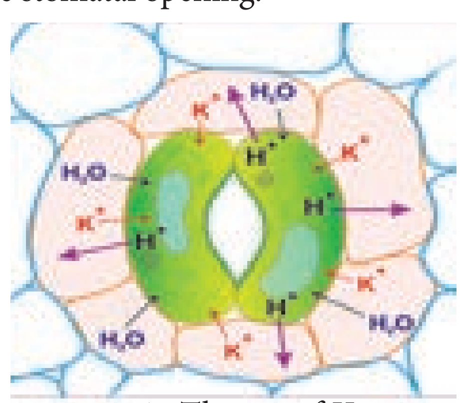


Figure 11.16: Theory of K^+ transport Opening of stomata

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

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).

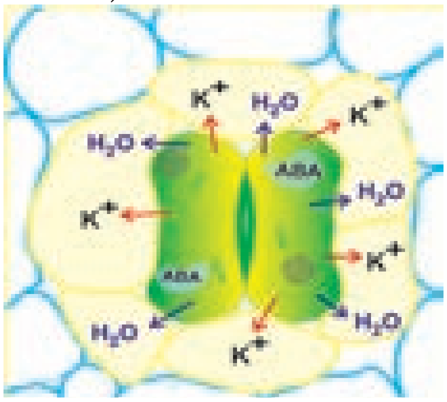


Figure 11.17: Theory of K^+ transport Closing of stomata

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

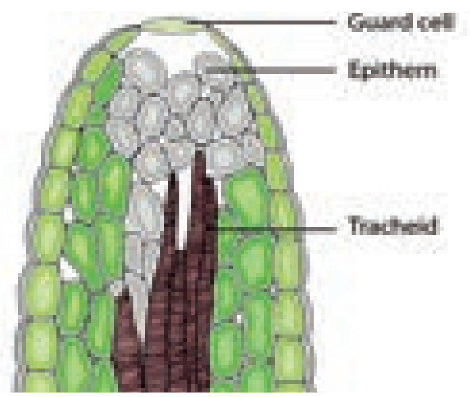


Figure 11.18: Structure of Hydathode

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.

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

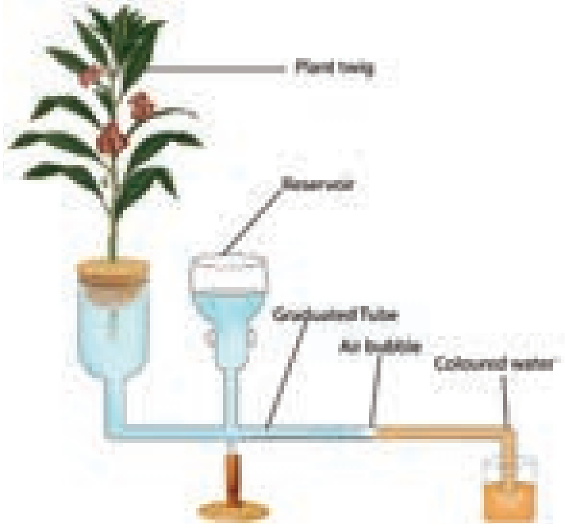


Figure 11.19: Ganongs Potometer

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 rely 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

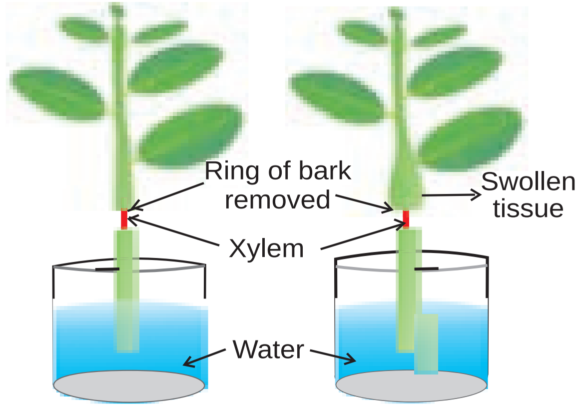


Figure 11.20: Ringing experiment

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.

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.

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

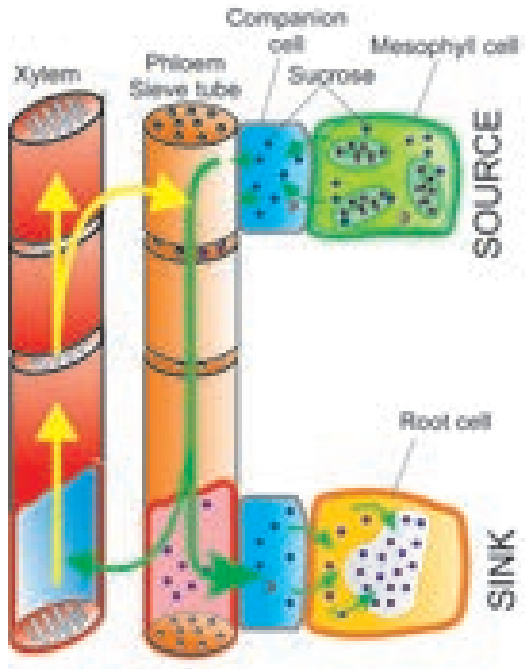


Figure 11.21: Source and Sink

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.

i. Sieve tube conducts **sucrose** only. But the *photosynthate* in chloroplast mostly in the form of starch or triose-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.

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.

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.

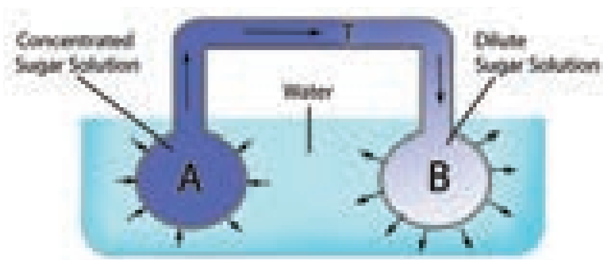


Figure 11.22: A model demonstrating the Mass flow hyphothesis

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.

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:**

Figure 11.23: 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).

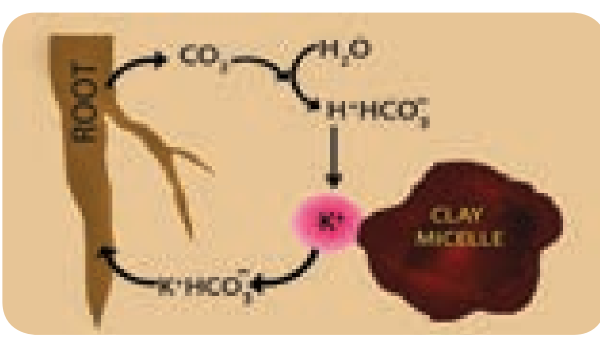


Figure 11.24: Carbonic Acid Exchange theory

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).

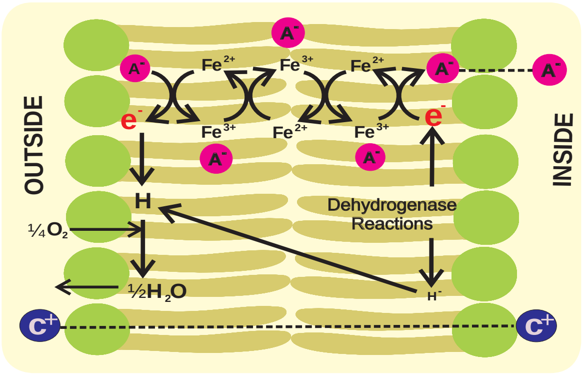


Figure 11.26: Cytochrome Pump theory

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.

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.

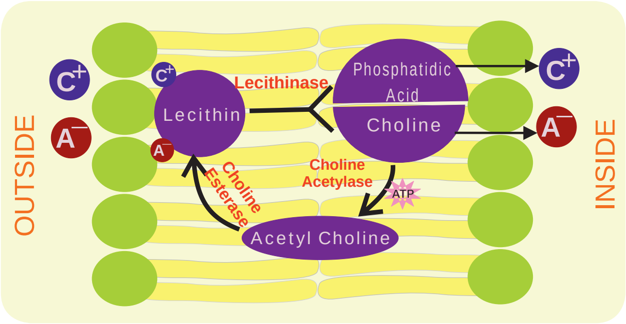


Figure 11.27: Protein-Lecithin theory

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?

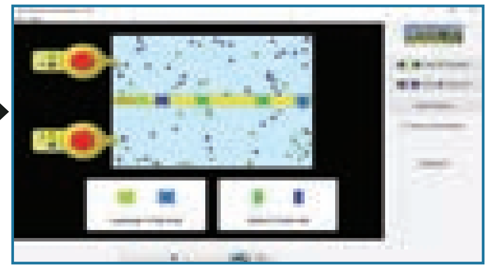
9. What are the parameters which control water potential?

10. An artificial cell made of selectively permeable membrane immersed in a beaker (in the figure). Read the values and answer the following questions?
    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, is the process endosmosis or exosmosis? Give reasons

ICT Corner

Membrane transport

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

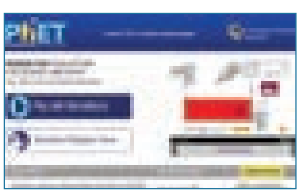


Steps

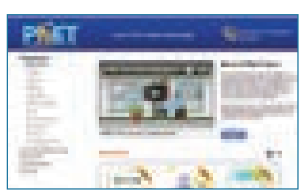
- Open PhET:
  Method 1: By scanning the QR Code given
  Method 2: Through Google – Open PhET by typing PhET
- Select play with simulation & enter
- Click Biology – select Membrane Channels & run
- Select Membrane channel in PhET
- Select round molecule and pump it by pressing red button in one column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

Activity

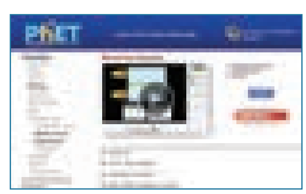
- Use leakage channel and gated channel in closed and open position and observe the molecules movement.



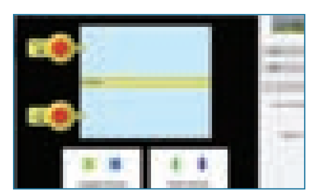
Step 1



Step 2



Step 3



Step 4

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https://phet.colorado.edu/

* Pictures are indicative only

Unit V: Plant Physiology (Functional Organisation)

Chapter 12

Mineral Nutrition

Learning Objectives

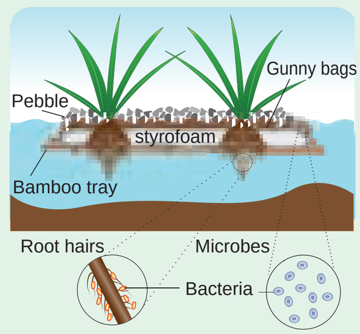
The learner will be able to,

- *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

12.1 Classification of Minerals
12.2 Functions, mode of absorption, deficiency symptoms of Macronutrients
12.3 Functions, mode of absorption and deficiency symptoms of Micronutrients
12.4 Deficiency Diseases and symptoms
12.5 Critical Concentration and Toxicity of minerals
12.6 Hydroponics and Aeroponics
12.7 Nitrogen Fixation
12.8 Nitrogen Cycle and Nitrogen Metabolism
12.9 Special Modes of Nutrition

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 alike. Just spend some time to observe the 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 requirements

Essential elements are classified as **Macro-nutrients, 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 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).

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

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

on young leaves due to the immobile nature of minerals

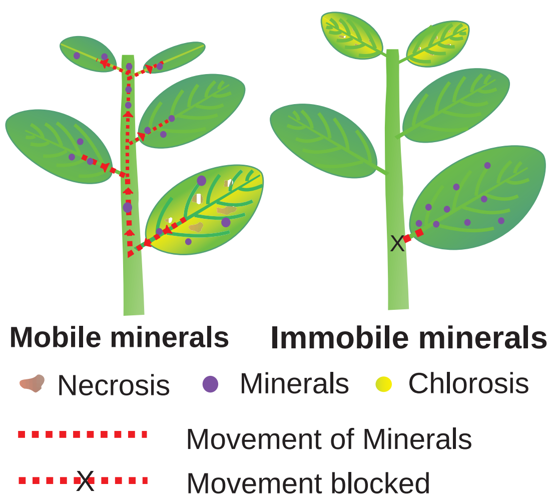


Figure 12.1: Mobility of Minerals

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.

DO YOU KNOW?

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.

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. Absorbtion of Fe^{2+} ions are comparitively more than 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.

DO YOU KNOW?

Calmodulin

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

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)

12.4 Deficiency diseases and symptoms

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

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 Beet root and Internal cork of apple	Boron
10. Whiptail of cauliflower and cabbage	Molybdenum
11. Curled leaf margin	Potassium

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.

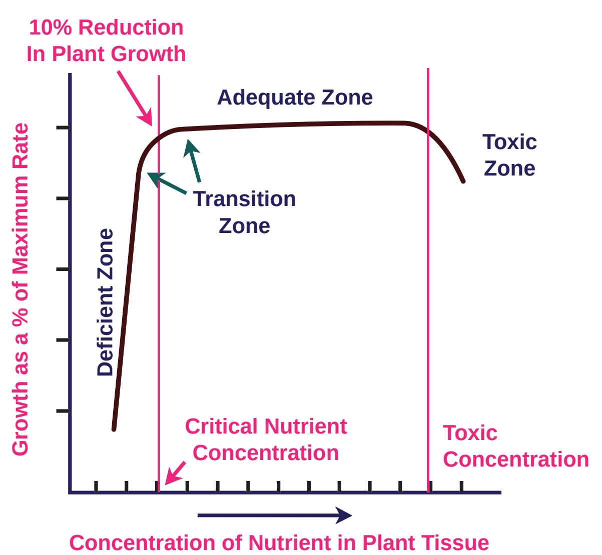


Figure 12.2: Critical Concentration

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, 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).

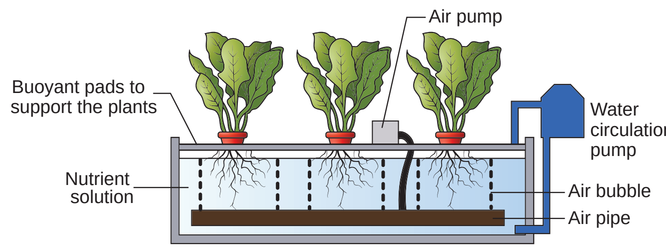


Figure 12.3: Hydroponics

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).

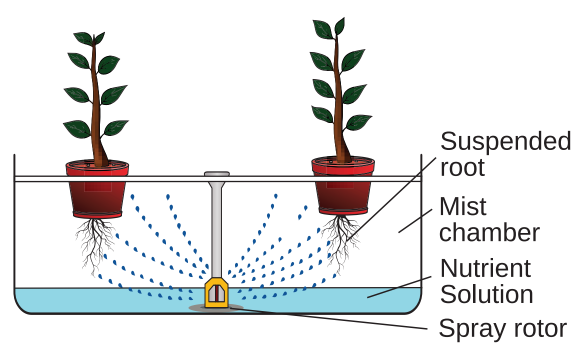


Figure 12.4: Aeroponics

12.7 Nitrogen Fixation

Inspiring act of nature is self-regulation. As all living organisms act as tools for biogeochemical 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 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).

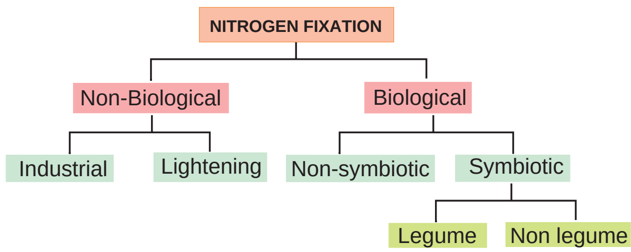


Figure 12.5: Nitrogen fixation

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.

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).

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.

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 12.6: 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, Beijerinckia 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.

Overall equation:

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

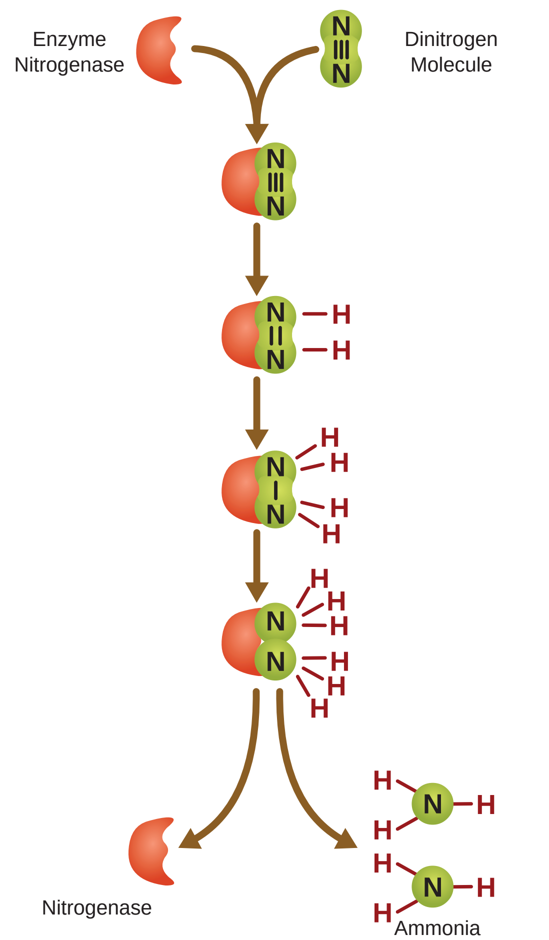


Figure 12.7: Nitrogenase enzyme function

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.

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

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

3. Nitrate Assimilation

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

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

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

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*.

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

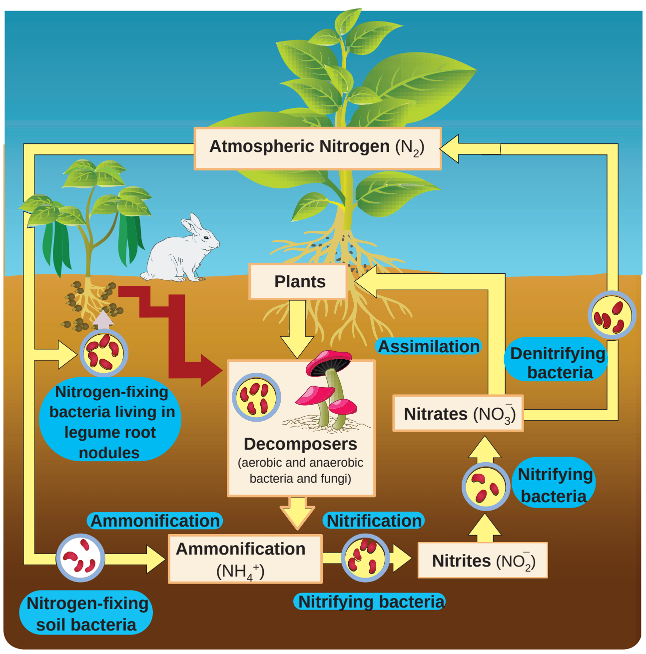


Figure 12.8: Nitrogen Cycle

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.

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

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)

$$\underset{\text{Amino acid 1}}{\begin{matrix} R1 \\ | \\ CH\text{–}NH_3^+ \\ | \\ COO^- \end{matrix}} + \underset{\text{Keto acid 2}}{\begin{matrix} R2 \\ | \\ C=O \\ | \\ COO^- \end{matrix}} = \underset{\text{Keto acid 1}}{\begin{matrix} R1 \\ | \\ C=O \\ | \\ COO^- \end{matrix}} + \underset{\text{Amino acid 2}}{\begin{matrix} R2 \\ | \\ CH\text{–}NH_3^+ \\ | \\ COO^- \end{matrix}}$$

3. Catalytic Amination: (GS/GOGAT Pathway)

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

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

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

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

(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.

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).

Figure 12.10: Parasitic Mode of Nutrition

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

Figure 12.11: Symbiotic mode of nutrition

12.9.4 Insectivorous mode of nutrition

Plants which are growing in nitrogen deficient areas develop insectivorous habit to resolve nitrogen deficiency. These plants obtain nitrogen from the insects

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 leaves with tentacles that secrete sticky digestive fluid which looks like a sundew and attracts insects.

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 and traps the insects.(Figure 12.12).

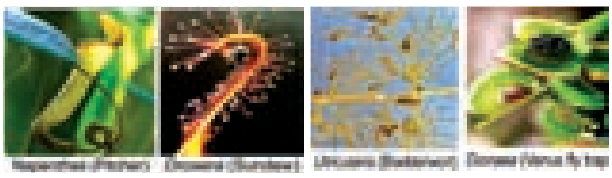


Figure 12.12: Insectivorous mode of nutrition

DO YOU KNOW?

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 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

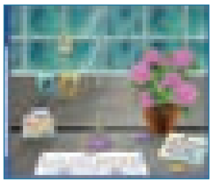
5. Identify the correct statement
i. Sulphur is essential for amino acids Cystine and Methionine
ii. Low level of N, K, S and Mo affect the cell division
iii. Non-leguminous plant Alnus which contain bacterium *Frankia*
iv. Denitrification carried out by nitrosomonas and nitrobacter.
a. I, II are correct
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

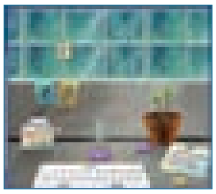
Role of Minerals In Plant Growth

Let's try to make the **plant blossom** →



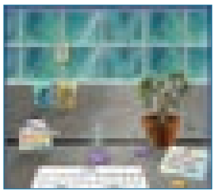
Steps
- Scan the QR code
- Start a new game
- Add lime
- Test the Soil pH by test the sample press grows
- Do it for combination of minerals

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

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.*

Chapter Outline

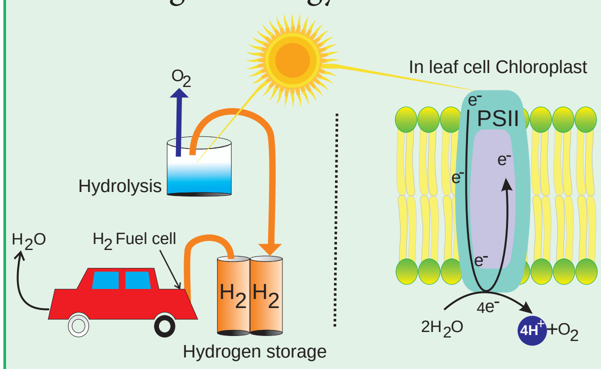
Life on earth is made up of organic compounds. How do we get these organic compounds? Ultimately, plants are the main source of all kinds of carbon compounds in this planet. We directly or indirectly depend on plants for this. Plants are the major machinery which produce organic compounds like carbohydrates, lipids, proteins, nucleic acids and other biomolecules.

Though man has reached the glory of achievements still he is not able to imitate 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

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.



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 Definition, Significance and Site of Photosynthesis

13.1.1 Definition of Photosynthesis

Photosynthesis is referred as photochemical oxidation and reduction reactions carried out with the 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:

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

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.

13.1.2 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.

13.1.3 Site of Photosynthesis

Chloroplasts are the main site of photosynthesis and both energy yielding process (Light reaction) and fixation of carbon di oxide (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 A°. A colloidal and proteinaceous matrix called stroma is present inside.

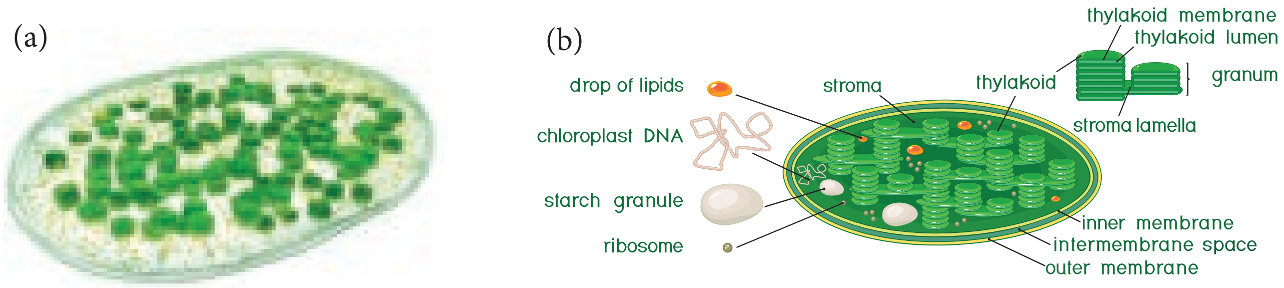


Figure 13.1: (a) 3D view of chloroplast (b) Sectional view of chloroplast

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 solar energy. Stroma contains enzyme which reduces carbon di oxide into carbohydrates. In Cyanobacteria thylakoid lies freely in cytoplasm without envelope (Figure 13.1).

13.2 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).

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, Fuco-xanthin (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		

13.2.1 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 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.

13.2.2 Carotenoids

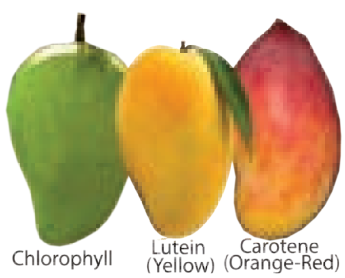


Figure 13.2: Changes in Fruit colour due to difference in pigmentation

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 13.2).

i. Carotenes:

Orange, Red, Yellow and Brownish pigments, hydrocarbons (Lipids) and most of them are tetraterpenes($C_{40}H_{56}$). 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.

13.2.3 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).

13.3 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

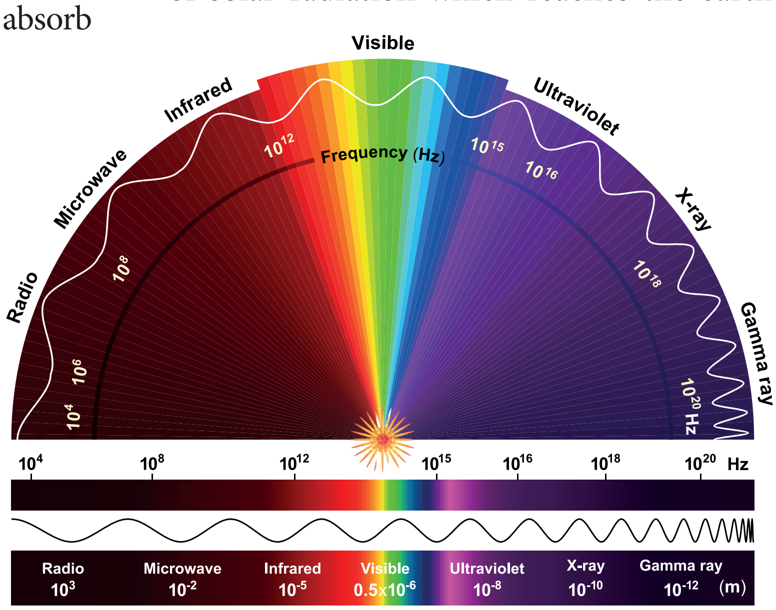


Figure 13.4: Electromagnetic Spectrum

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 more energy than longer wavelength. Electromagnetic spectrum consists of 7 types of radiations such as gamma rays, X rays, U-V rays, Visible light spectrum, infrared rays, electric rays and radio rays (Figure 13. 4).

DO YOU KNOW?

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 13.5).

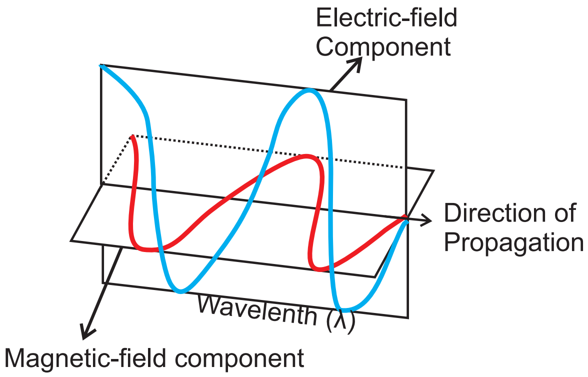


Figure 13.5: Oscillation of electric and magnetic vectors in light

Separation of Chlorophyll 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).

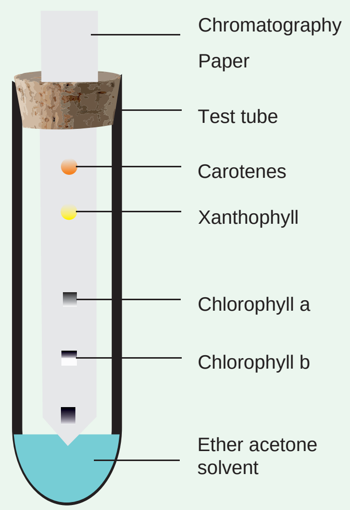


Figure 13.3: Paper Chromatography

13.4 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 13.6) **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 %.

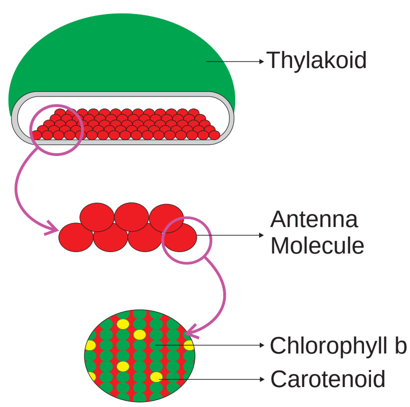


Figure 13.6: Quantasome

13.5 Absorption Spectrum and Action Spectrum

13.5.1 Absorption Spectrum

The term absorption refers to complete retention of light, without reflection or 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.

13.5.2 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 13.7).

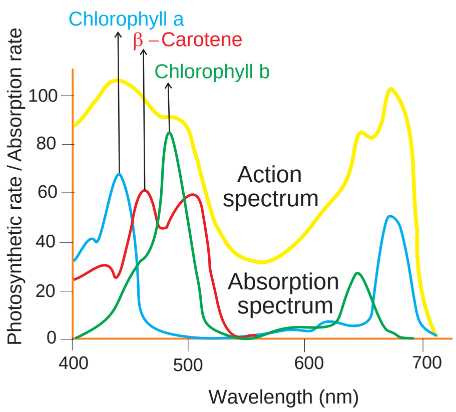


Figure 13.7: Absorption and action spectrum

13.6 Emerson's Experiments and Hill's Reaction

13.6.1 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.**

13.6.2 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 13.8).

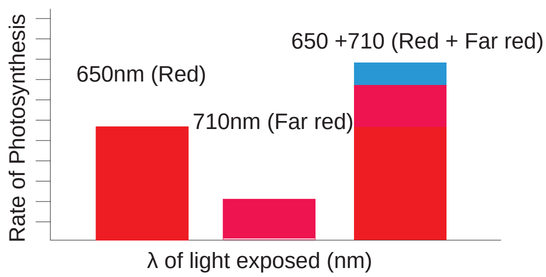


Figure 13.8: Emerson's Enhancement Effect

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).

13.6.3 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).

13.7 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.

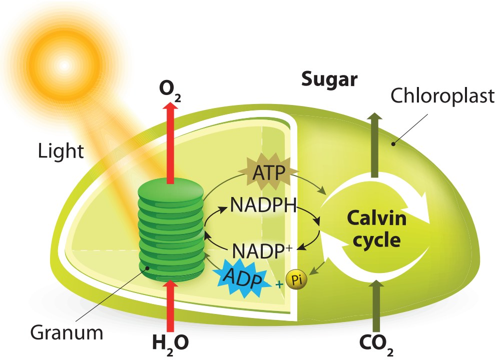


Figure 13.9: Light and Dark Reaction

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 13.9).

13.8 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**.

13.8.1 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 13.10).
- 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).
- 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.

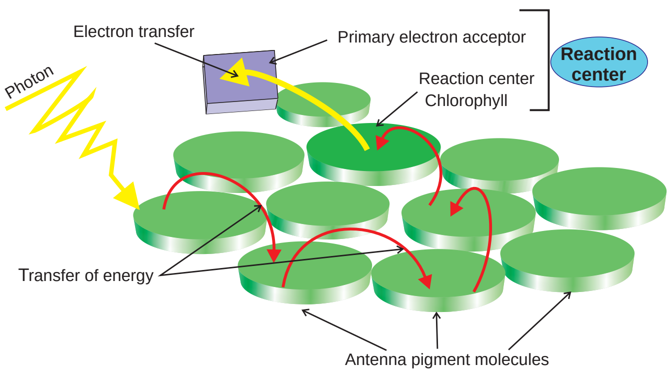


Figure 13.10: Photosystem

13.9 Photo chemical 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.

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

13.9.1 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 (Figure 13.11).

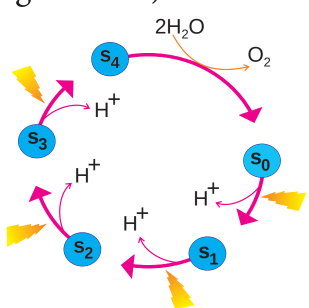


Figure 13.11: Oxygen Evolving Complex (OEC)

$$4\,H_2O \longrightarrow 4\,H^+ + 4\,OH^-$$
$$4\,OH^- \longrightarrow 2\,H_2O + O_2 + 4\,e^-$$
$$2H_2O \longrightarrow 4\,H^+ + O_2 + 4\,e^-$$

13.9.2 Electron Transport Chain of 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 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 utilizes energy from ETC and converts ADP and inorganic phosphate (P_i) into ATP (Figure 13.12).

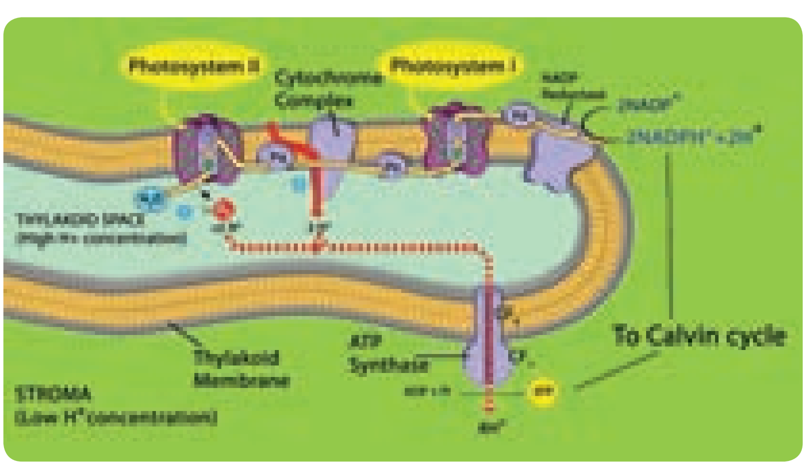


Figure 13.12: Electron Transport Chain in Chloroplast

13.10 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.

13.10.1 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 13.13).

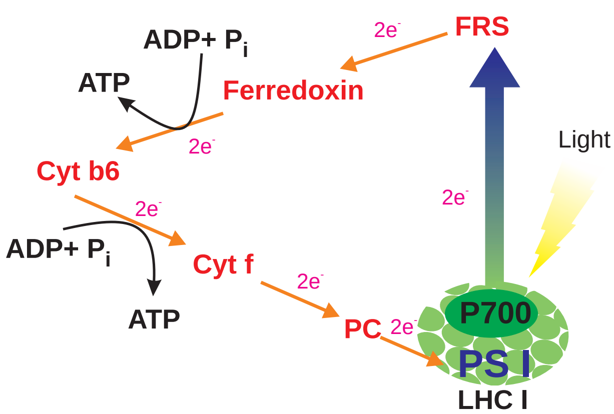


Figure 13.13: Cyclic Photophosphorylation

13.10.2 Non-Cyclic Photophosphorylation

When photons are activated reaction centre of pigment system II(P680), electrons 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 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 13.14).

13.10.3 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^+.

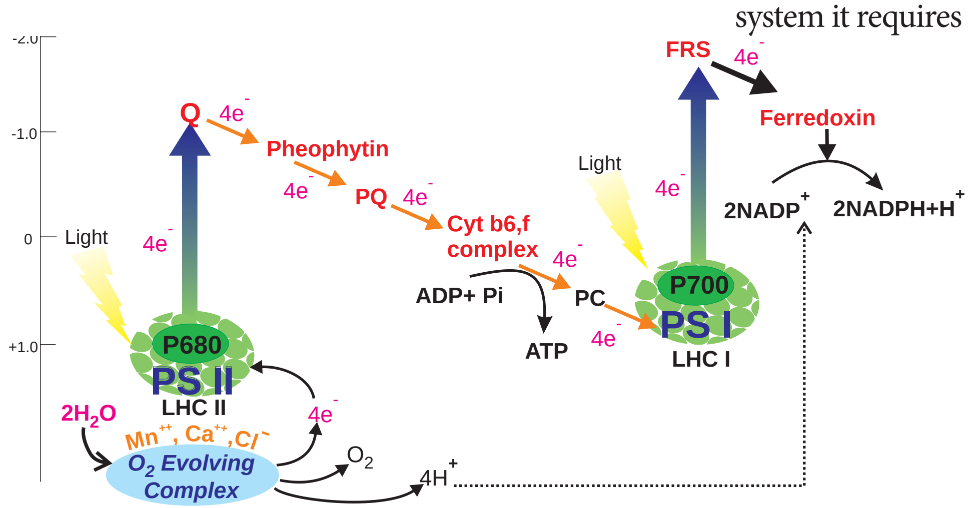


Figure 13.14: Non-Cyclic Photophosphorylation

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 di chloro di methyl urea (DCMU)	8. It is sensitive to DCMU and inhibits electron flow

- 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?

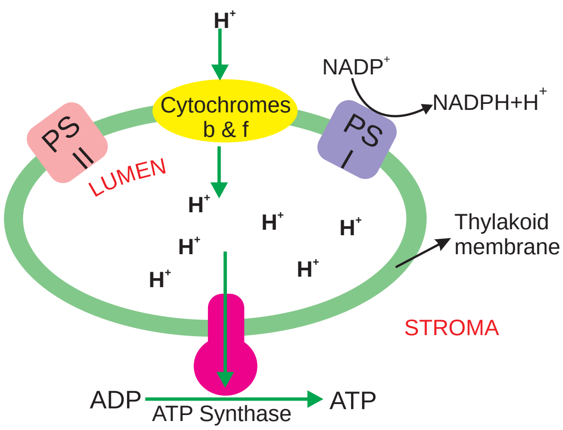


Figure 13.15: Chemiosmotic Theory

13.10.4 Chemiosmotic Theory

Chemiosmosis 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 Cyto-chrome 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 13.15).

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.

13.11 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 di oxide 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 di oxide 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.

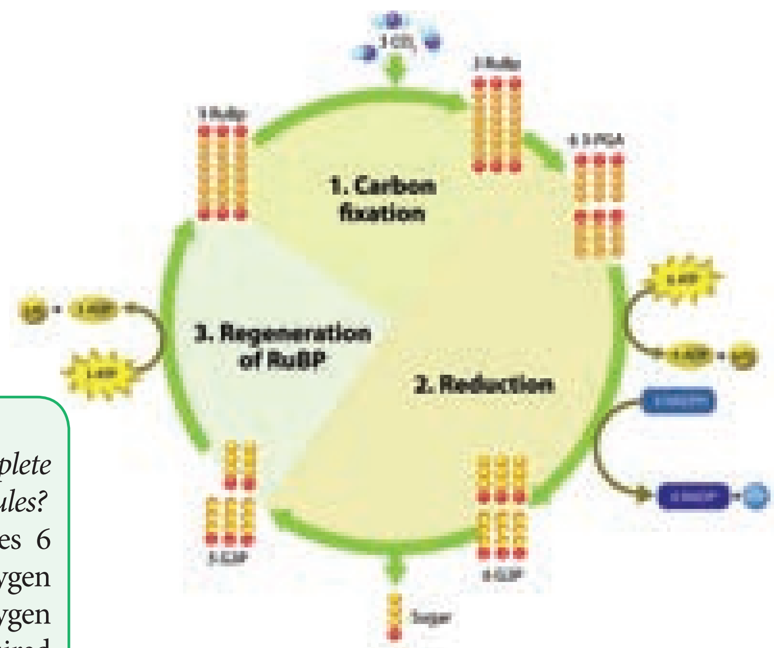


Figure 13.16: Phases of Calvin Cycle

> **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.

Dark reaction consists of three phases: (Figure 13.16).

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 13.17).

$$RUBP + CO_2 \xrightarrow{\text{Rubisco}} 2 \text{ molecules PGA}$$

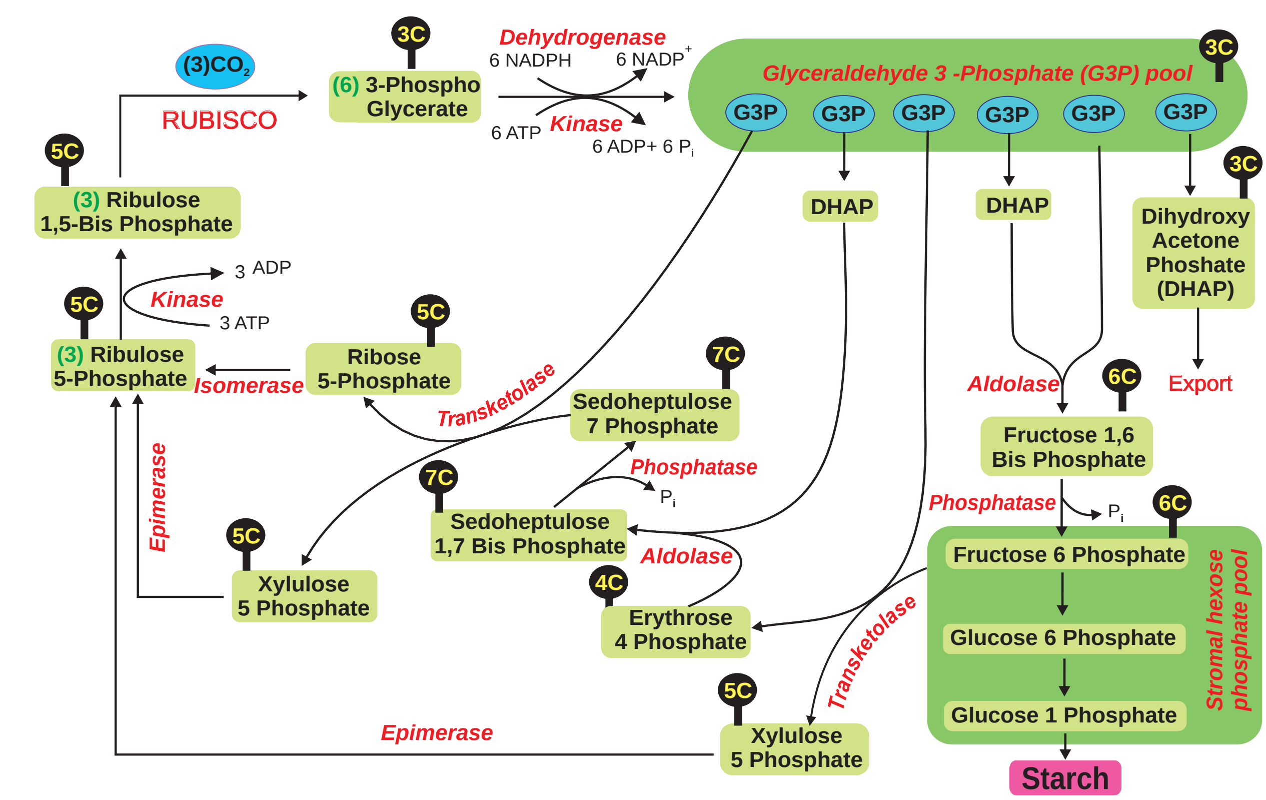


Figure 13.17: Calvin cycle

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 di hydroxy acetone phosphate (DHAP).

$$\text{PGA} \xrightarrow[\text{ATP} \;\rightarrow\; \text{ADP}]{\text{PGA Kinase}} \text{1,3 bisphosphoglyceric acid}$$

$$\text{1,3 bisphosphoglceric acid} \xrightarrow{\text{NADPH + H}^+ \;\rightarrow\; \text{NADP}^+} \text{Glyceraldehyde-3-Phosphate}$$

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.

$$\text{RU5P} \xrightarrow{\text{ATP} \;\rightarrow\; \text{ADP}} \text{RUBP}$$

Overall equation for dark reaction:

$$6CO_2 + 18ATP + 12NADPH + H^+ \longrightarrow C_6H_{12}O_6 + 6H_2O + 18ADP + 18Pi + 12NADP^+$$

DO YOU KNOW?

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.

13.12 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 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 13.18). Carbon dioxide fixation takes place in two places one in mesophyll and another in bundle sheath cell (di carboxylation 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.

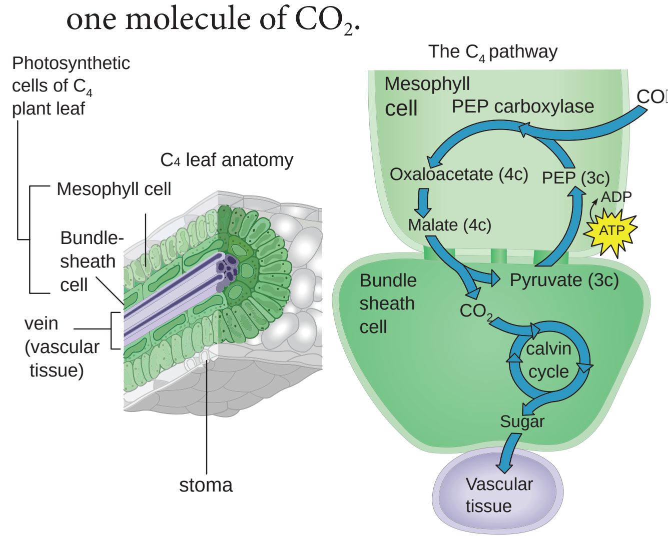


Figure 13.18: C_4 Cycle

13.12.1 Stage: I Mesophyll Cells

$$\underset{\text{(PEP) (3C)}}{\text{Phosphoenol Pyruvate}} + CO_2 \xrightarrow{\text{PEP carboxylase}} \text{Oxaloacetic acid (OAA) (4C)}$$

Oxaloacetic acid (OAA) is converted into malic acid or aspartic acid and is transported to the bundle sheath cells through plasmodesmata.

13.12.2 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).

DO YOU KNOW?

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.

13.12.3 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.

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 $25^{\circ}C$	7. Optimum temperature 30° to $45^{\circ}C$
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. Example: Paddy, Wheat, Potato and so on	12. 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.

13.13 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 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 (Figure13.19).

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.

13.14 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

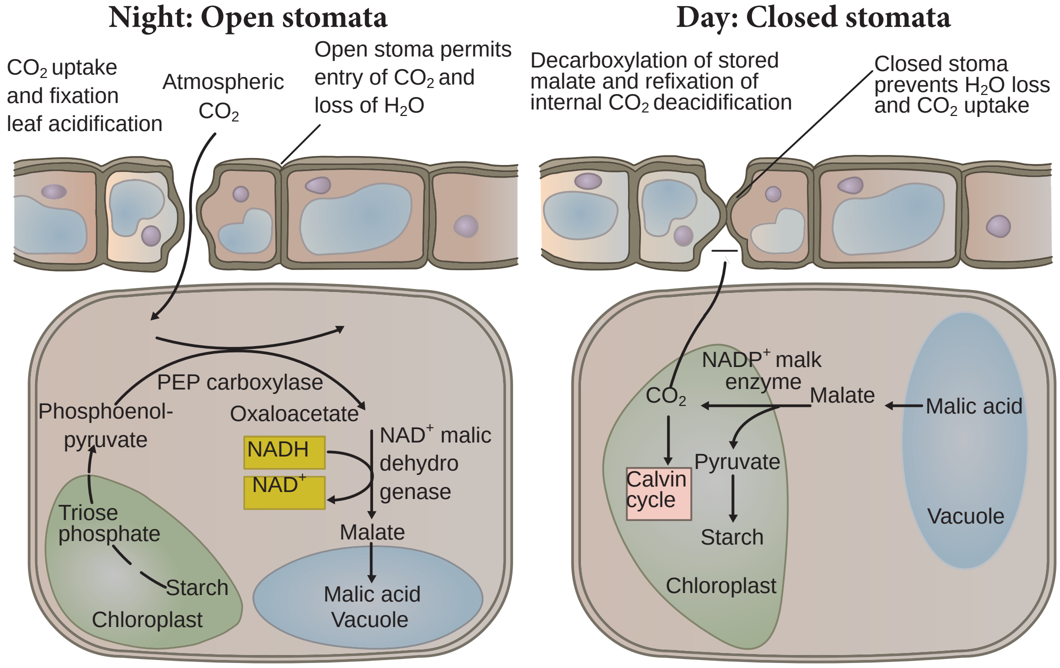


Figure 13.19: CAM cycle

and increase of O_2(Table 13.5). This 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 util ising 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 13.20).

13.15.1 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.

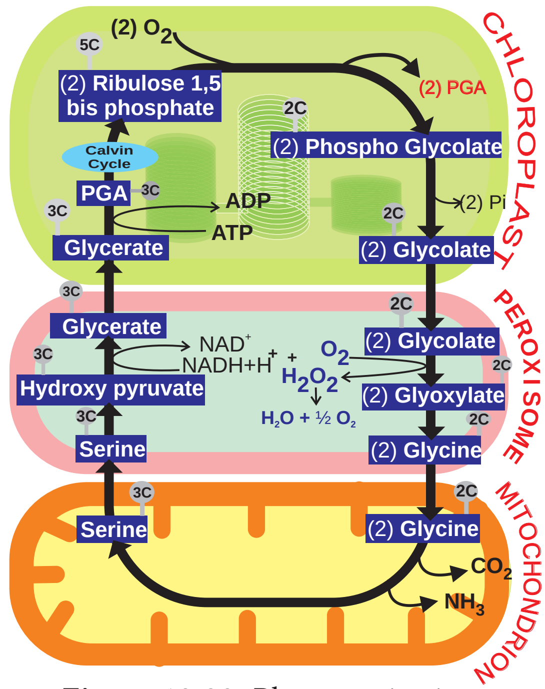


Figure 13.20: Photorespiration

13.15.2 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.

13.15 Factors affecting Photosynthesis

In 1860, **Sachs** gave three cardinal points theory explaining minimum, optimum and maximum factors that control photosynthesis.

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

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 13.21).

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.

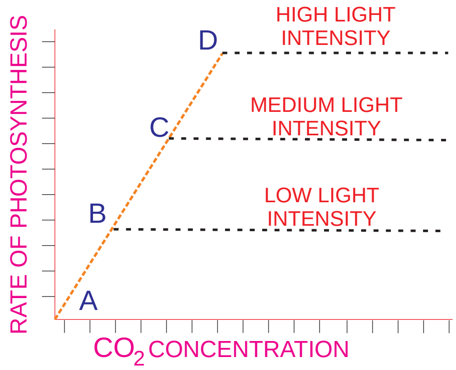


Figure 13.21: Blackman's Law of Limiting Factors

13.15.1. 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 photosynthesis 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 13.22).

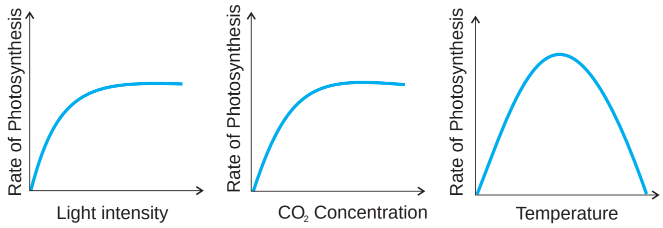


Figure 13.22: Factors affecting Photosynthesis

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.

13.15.2 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.

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.

13.16 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.*

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

2. Purple sulphur bacteria. Example: *Thiospirillum* and *Chromatium*.
3. Purple non-sulphur bacteria. Example: *Rhodopseudomonas* and *Rhodospirillum*.

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 13.23).

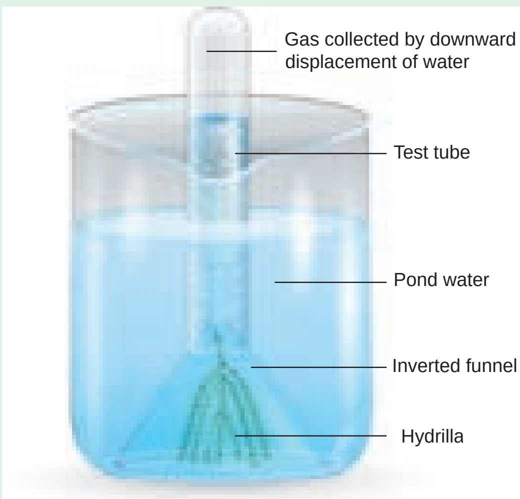


Figure 13.23: Test tube funnel experiment

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

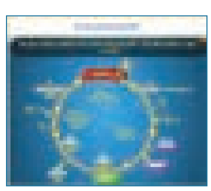
   a. PS II, plastoquinone, cytochrome, PS I, ferredoxin.
   b. PS I, plastoquinone, cytochrome, PS II ferredoxin.
   c. PS II, ferredoxin, plastoquinone, cytochrome, PS I.
   d. PS II, plastoquinone, cytochrome, PS II, ferredoxin.

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

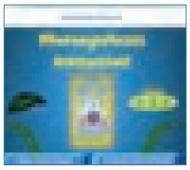
Photosynthesis

Let's play **photosynthesis**

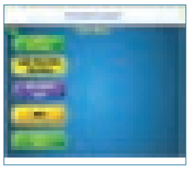


Steps
- Scan the QR code
- Start a new game and tap
- Click light dependent reaction and follow the steps
- After completion – move back and Click Calvin cycle reaction and follow the steps

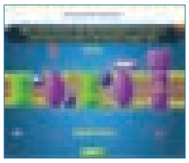
Activity
- Observe the cycle and record it
- Check your grasp by click the Quiz tap
- Conclude your observations.



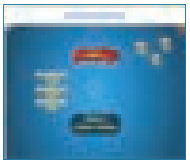
Step 1



Step 2



Step 3



Step 4

Web URL:
https://biomanbio.com/HTML5GamesandLabs/PhotoRespgames/photointeractivehtml5page.html

* Pictures are indicative only

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.*

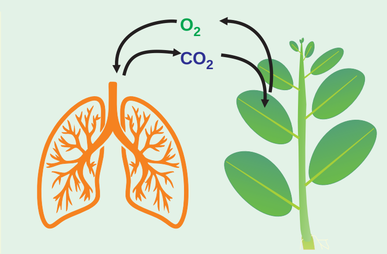
Chapter Outline

14.1 Gaseous exchange
14.2 Structure of ATP
14.3 Redox reactions
14.4 Types of Respiration
14.5 Stages of Respiration
14.6 Respiratory Quotient
14.7 Anaerobic Respiration
14.8 Factors Affecting Respiration
14.9 Pentose Phosphate Pathway

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.

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.



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

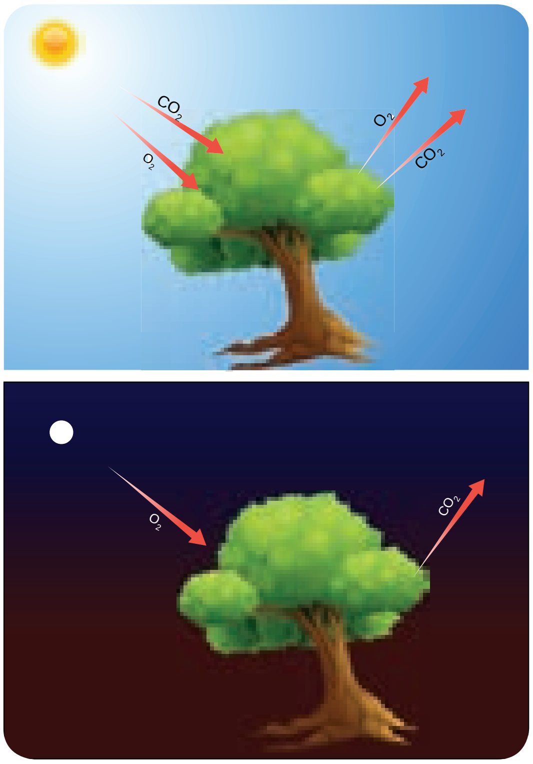


Figure 14.1: Gaseous exchange in plants

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)

(1K cal = 4.184 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 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.

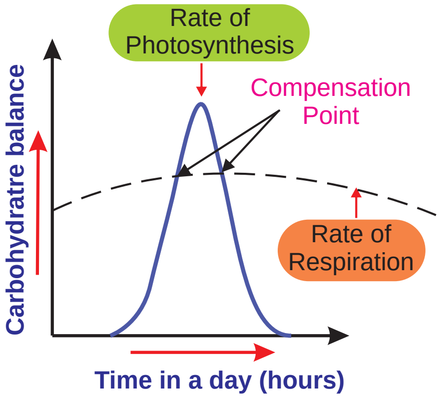


Figure 14.2: Compensation point

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).

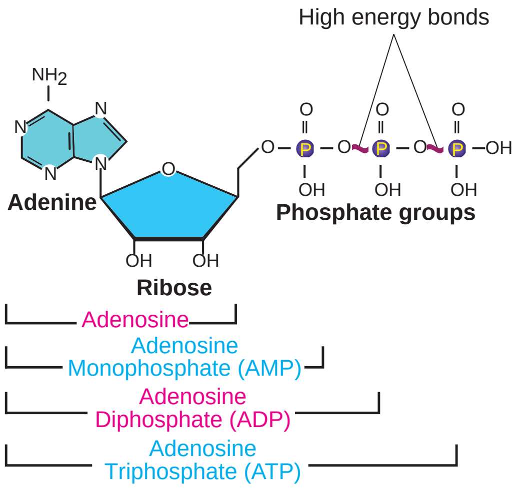


Figure 14.3: Molecular structure of ATP

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.

14.4 Types of Respiration

Respiration is classified into two types as aerobic and anaerobic respiration (Figure 14.4)

Handy mnemonic

LEO the lion says GER

LEO - Loss of Electrons is Oxidation

GER - Gain of Electrons is Reduction

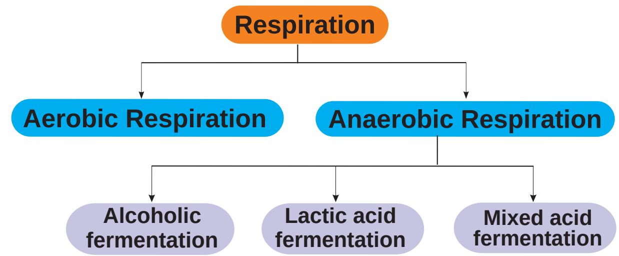


Figure 14.4: Types of Respiration

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

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.

> **DO YOU KNOW?** 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).

14.5 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.
4. Electron transport chain to tranfer electrons remove hydrogen ions and tranfer electrons from the products of glycolysis, link reaction and Krebs cycle It takes place in mitochondrial inner membrane to release ATP with water molecule by terminal oxidation (Figure 14.5).

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.

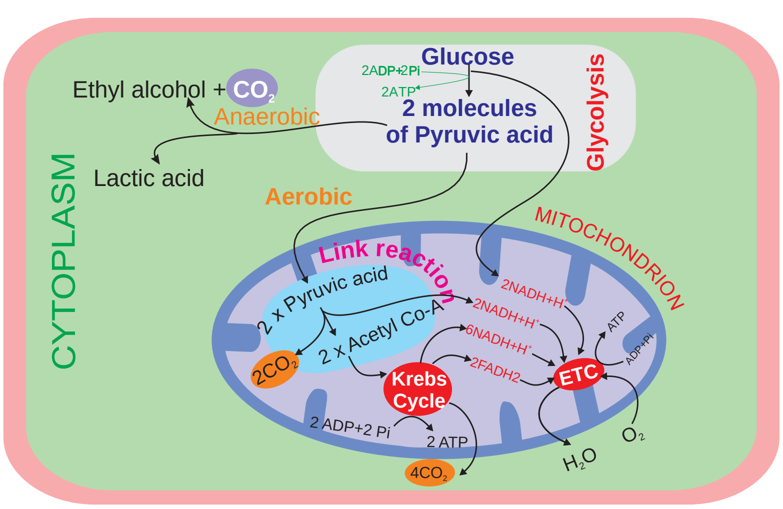


Figure 14.5: Overall stages of Respiration

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**

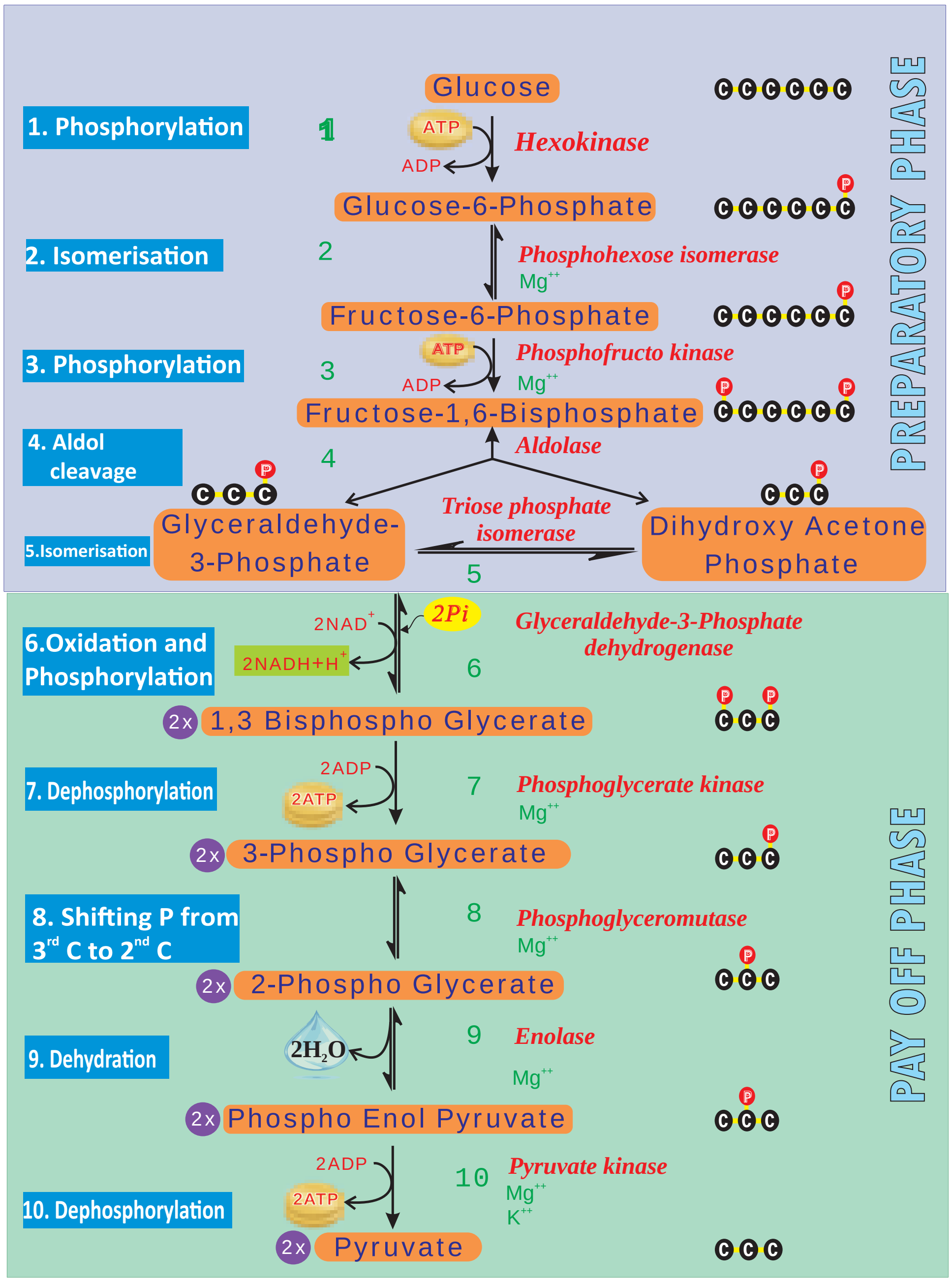


Figure 14.6: Glycolysis or EMP pathway

or **direct phosphorylation** or **trans phosphorylation**. During the reaction at step 9, 2 phospho 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

$$2x\ CH_3COCOOH + 2NAD^+ + 2CoA \xrightarrow[\text{complex/ } Mg^{++}]{\text{Pyruvate dehydrogenase}} 2xCH_3CO.CoA + 2NADH + 2H^+ + 2CO_2\uparrow$$

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).

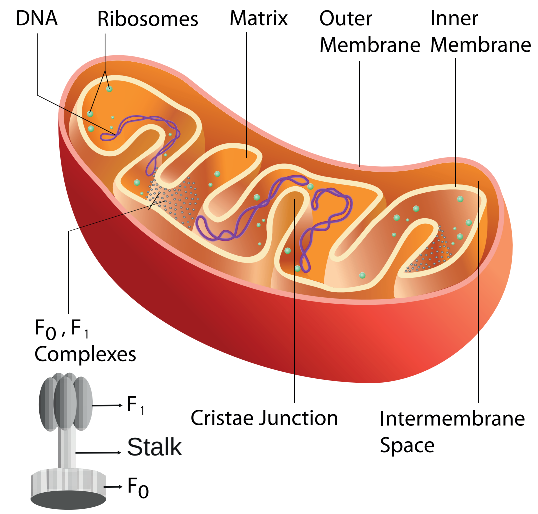


Figure 14.7: Structure of Mitochondrion

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.

TCA cycle starts with condensation of acetyl CoA with oxaloacetate in the presence of water to yield citrate or citric

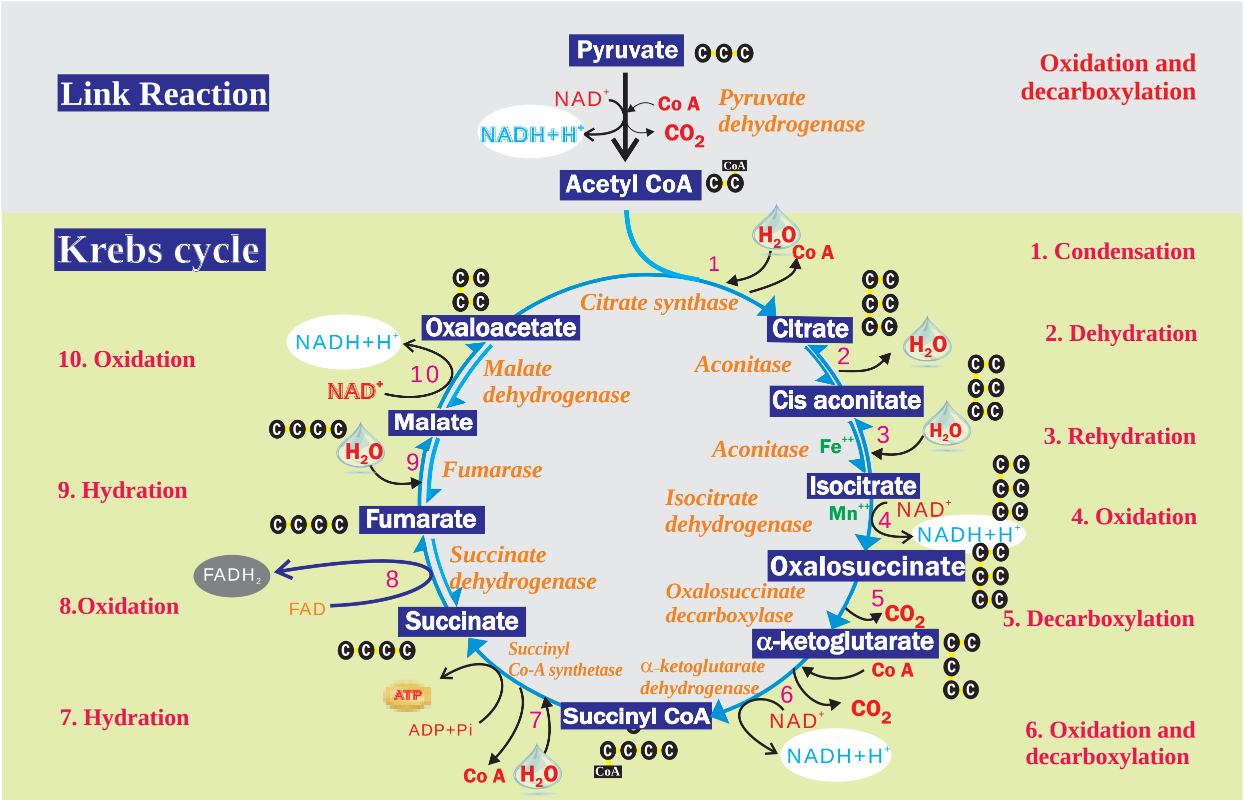


Figure 14.8: Krebs cycle or Citric acid cycle

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 steps (4, 6, 10) in this cycle NAD^+ is reduced to NADH+ H^+ and at step 8 (Figure14.8) where FAD is reduced to $FADH_2$.

The summary of link reaction and Krebs cycle in Mitochondria is

$$\text{Pyruvic acid} + 4NAD^+ + FAD + 4H_2O + ADP+Pi \xrightarrow{\text{Mitochondrial matrix.}} 3CO_2 + 4NADH+4H^+ + FADH_2 + H_2O+ATP.$$

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.

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).

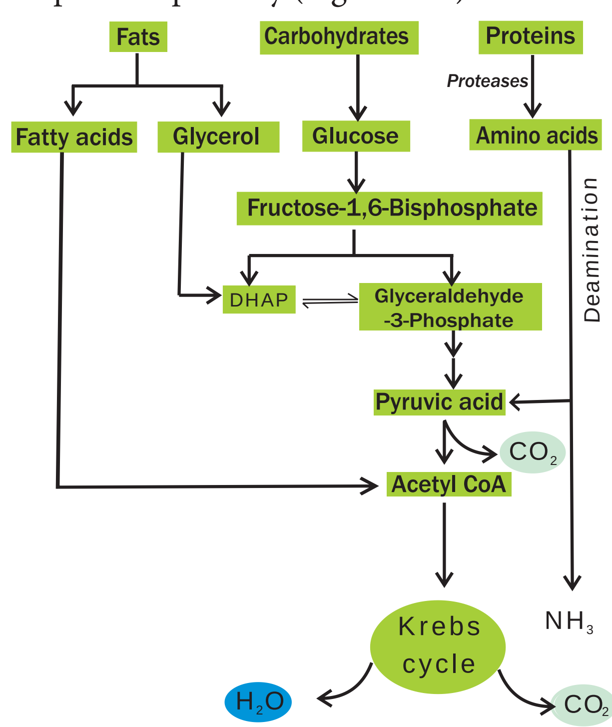


Figure 14.9: Alternative substrates for respiration

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. 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^+. Because mitochondrial inner membrane cannot allow NADH molecules directly into the matrix.

Ubiquinone (UQ) or Coenzyme Quinone (CoQ) 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.

$$\text{Succinate} + UQ \rightarrow \text{Fumarate} + UQH_2$$

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.

$$UQH_2 + 2\text{Cyt c}_{\text{oxidised}} \rightleftharpoons UQ + 2\text{Cyt c}_{\text{reduced}} + 2H^+$$

DO YOU KNOW?

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 (Cytochome 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).

$$2\text{Cyt c}_{\text{oxidised}} + 2H^+ + 1/2\ O_2 \rightleftharpoons 2\text{Cyt c}_{\text{reduced}} + H_2O$$

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.

DO YOU KNOW?

The synthesis of glucose from certain non-carbohydrate carbon substrates such as proteins and lipids are called **gluconeogenesis.**

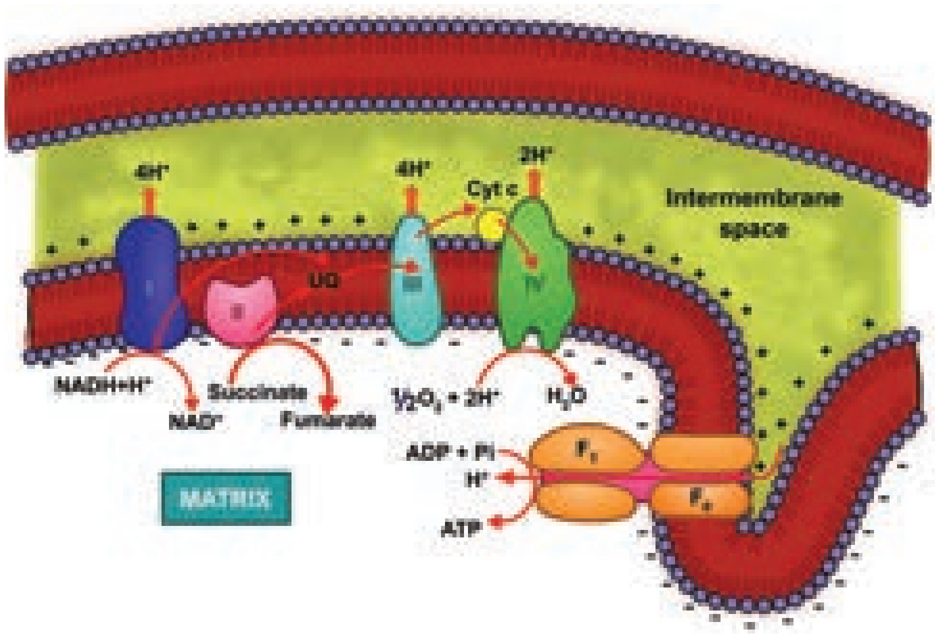


Figure 14.10: Electron Transport Chain and Terminal Oxidation

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 × 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 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.

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.

DO YOU KNOW?

Abnormal rise in respiratory rate of ripening in fruits is called **Climacteric**. Examples are apple, banana, mango, papaya, pear.

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.

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 × 2 = 4)	0	6
Link reaction	2	0	2 (2 × 3 = 6)	0	6
Krebs cycle	4	2	6 (6 × 3 = 18)	2 (2 × 2 = 4)	24
Total	**6**	**4 ATPs**	**28 ATPs**	**4 ATPs**	**36 ATPs**

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.

DO YOU KNOW?

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.

Peter Mitchel, a British Bio-chemist received Nobel prize for Chemistry in 1978 for his work on the coupling of oxidation and phosphorylation in mitochondria.

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 *Opuntia*, *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.

$$\underset{\text{Glucose}}{2C_6H_{12}O_6} + 3O_2 \longrightarrow \underset{\text{Malic acid}}{3C_4H_6O_5} + 3H_2O + \text{Energy}$$

$$\begin{matrix}\text{RQ of glucose}\\ \text{in succulents}\end{matrix} = \frac{\text{zero molecule of } CO_2}{3 \text{ molecules of } O_2}$$

$$= 0 \text{ (zero)}$$

4. When respiratory substrate is protein or fat, then RQ will be less than unity.

$$\underset{\text{Tripalmitin(Fat)}}{2(C_{51}H_{98}O_6)} + 145O_2 \longrightarrow 102CO_2\uparrow + 98H_2O + \text{Energy}$$

$$\begin{matrix}\text{RQ of}\\ \text{Tripalmitin}\end{matrix} = \frac{102 \text{ molecules of } CO_2}{145 \text{ molecules of } O_2}$$

$$= 0.7 \text{ (less than unity)}$$

5. When respiratory substrate is an organic acid the value of RQ will be more than unity.

$$\underset{\text{Malic acid}}{C_4H_6O_5} + 3O_2 \longrightarrow 4CO_2\uparrow + 3H_2O + \text{Energy}$$

$$\begin{matrix}\text{RQ of}\\ \text{malic acid}\end{matrix} = \frac{4 \text{ molecules of } CO_2}{3 \text{ molecules of } O_2}$$

$$= 1.33 \text{ (more than unity)}$$

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.

DO YOU KNOW?

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.

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

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

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

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:

(i) $2CH_3COCOOH \xrightarrow[\text{TPP}]{\text{Pyruvate decarboxylase}} 2CH_3CHO + 2CO_2\uparrow$

Pyruvic acid → Acetaldehyde

(ii) $2CH_3CHO + 2NADH + 2H^+ \xrightarrow{\text{Alcohol dehydrogenase}} 2CH_3CH_2OH + 2NAD^+$

Acetaldehyde → Ethyl alcohol

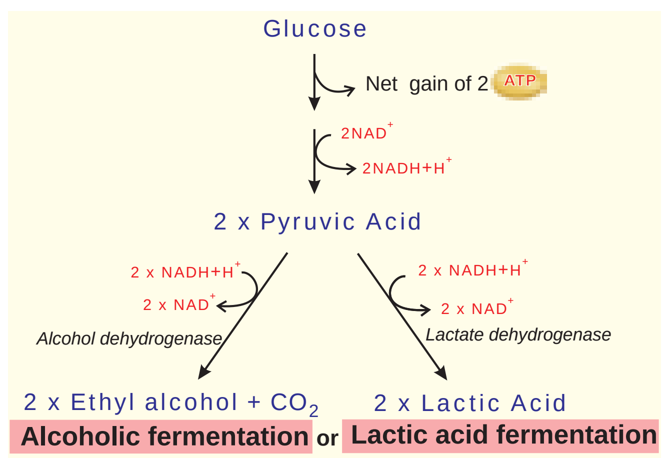


Figure 14.12: Anaerobic Respiration

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).

2. Lactic acid fermentation

Some bacteria (*Bacillus*), fungi and muscles of vertebrates produce lactic acid from pyruvic acid (Table 14.3).

$$\underset{\text{Pyruvic acid}}{2CH_3COCOOH} + 2NADH + 2H^+ \xrightarrow{\text{Lactate dehydrogenase}} \underset{\text{Lactic acid}}{2CH_3CHOHCOOH} + 2NAD^+$$

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).
2. Limited number of ATP molecules is generated per glucose molecule (Table 14.4).
3. It is characterized by the production of CO_2 and it is used for Carbon fixation in photosynthesis.

Table 14.4: 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

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).

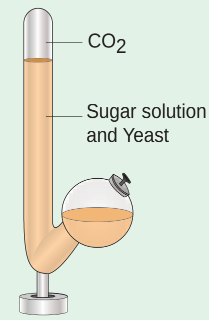


Figure 14.13: Kuhne's fermentation experiment

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).

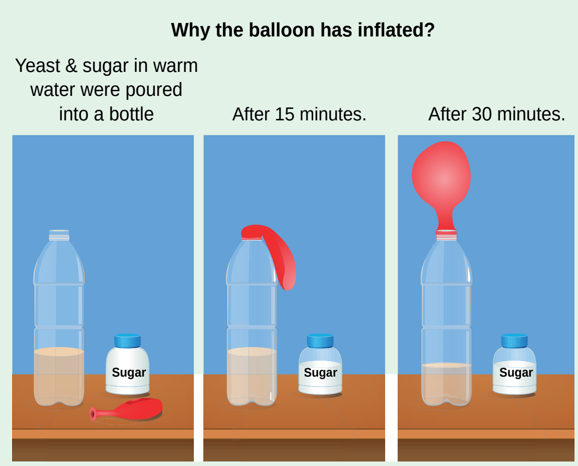
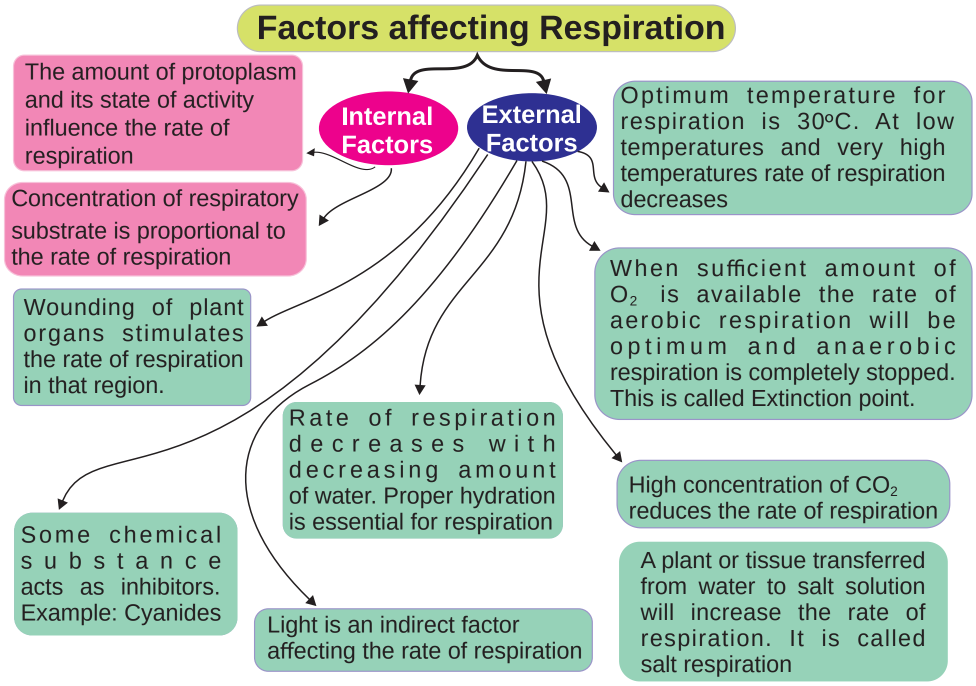


Figure: 14.14: Air balloon activity

14.8 Factors Affecting Respiration



Check your grasp!

- Why Microorganisms respire anaerobically?
- Does anaerobic respiration take place in higher plants?

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).

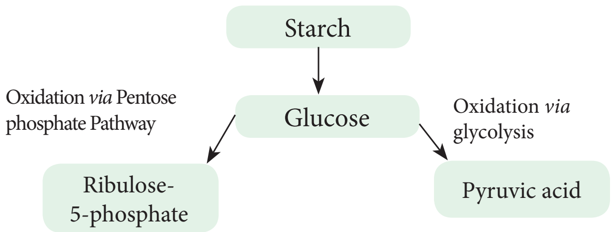


Figure 14.15: Fate of Glucose in HMP shunt and Glycolysis

ItisalsoknownasHexosemonophosphate**Hexosemonophosphate 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 regene-rated (Figure 14.16). The overall reaction is:

$$\textbf{6 x Glucose-6-Phosphate} + \textbf{12NADP}^+ + \textbf{6H}_2\textbf{O}$$
$$\downarrow$$
$$\textbf{5 x Glucose-6-Phosphate} + \textbf{6CO}_2 + \textbf{Pi} + \textbf{12NADPH} + \textbf{12H}^+$$

The net result of complete oxidation of one glucose-6-phosphate yield $6CO_2$ and 12NADPH + H^+. The oxidative pentose

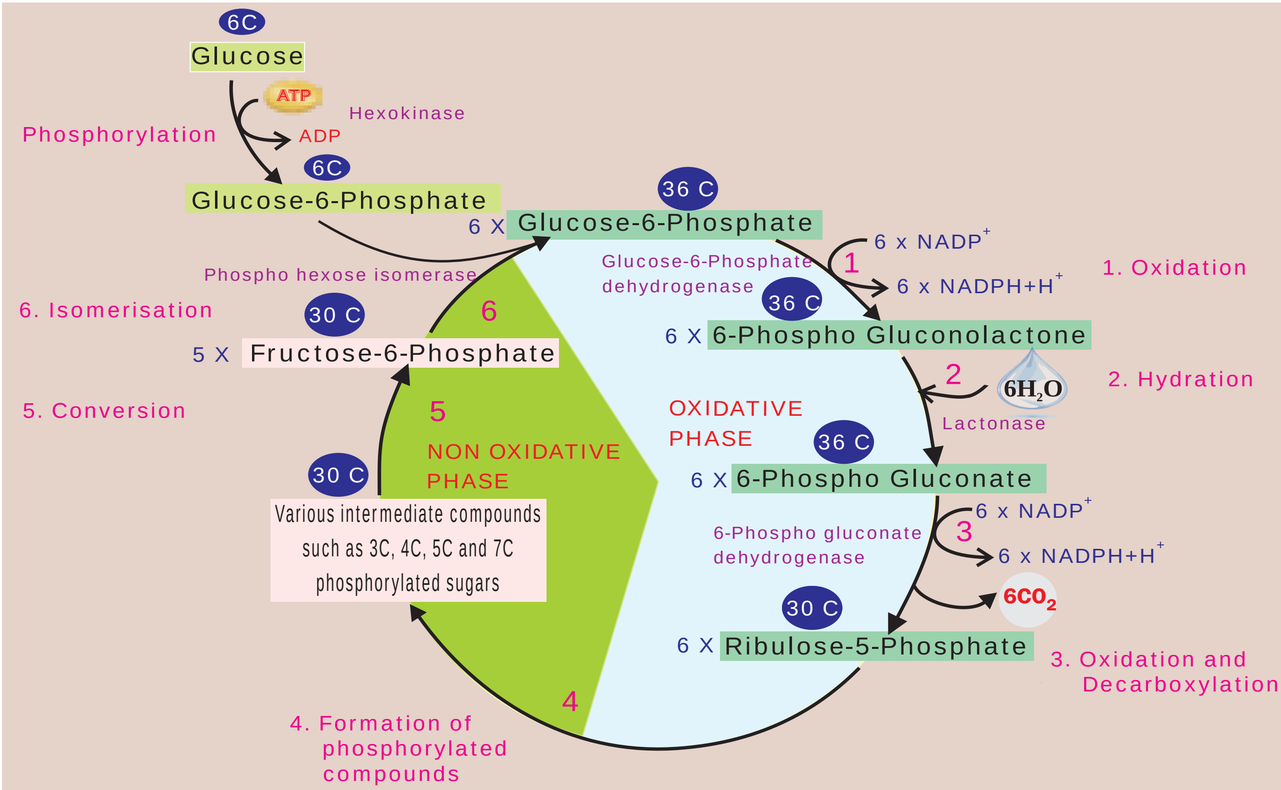


Figure 14.16: Pentose phosphate pathway or HMP shunt

phosphate pathway is controlled by glucose-6-phosphate dehydrogenase enzyme which is inhibited by high ratio of NADPH to $NADP^+$.

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.
5. It plays a role on fixation of Co_2 in photosynthesis through RUBP

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.

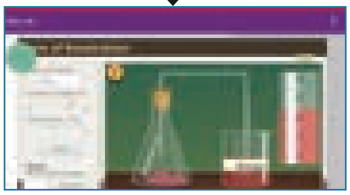
Evaluation

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**



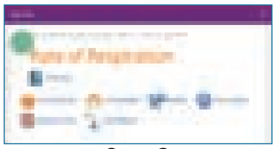
Steps

- 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

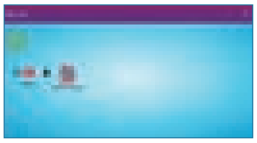
Activity

- Press simulation to do the rate of respiration.
- Conclude your observations.

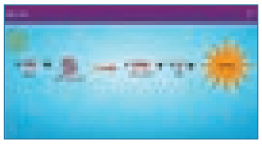
Step 1



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

* Pictures are indicative only

Chapter 15

Unit V: Plant Physiology (Functional Organisation)

Plant Growth and Development

Learning Objectives

The learner will be able to,

- *Define growth.*
- *List out and differentiate the phases of growth.*
- *Explain the structure, precursor, bioassay and physiological effects of plant growth regulators.*

Chapter Outline

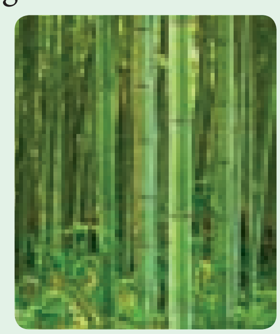
The Banyan tree continues to grow for thousands of years and some others particularly annual plants cease growth within a season or within a year. Can you understand the reasons? How does a zygote give rise to an embryo and an embryo to a seedling? How does a new plant structure arise from the pre-existing 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?

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.

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**.
- 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 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 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.

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.

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 15.1).

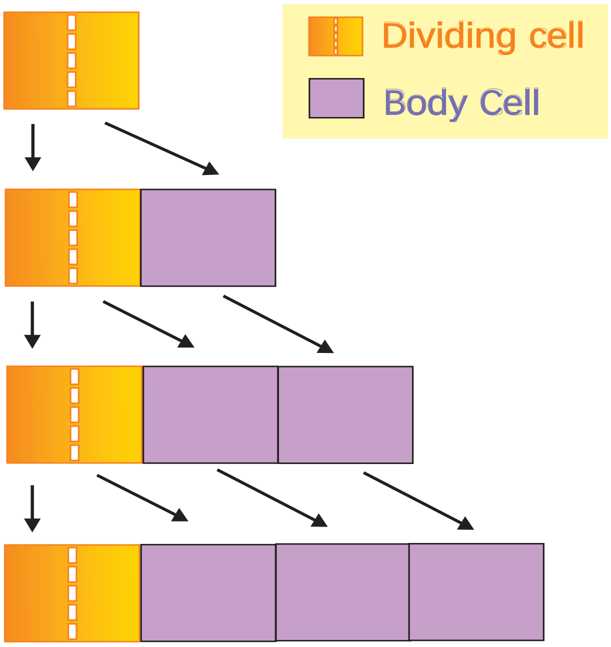


Figure 15.1: Arithmetic Growth Rate

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 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 15.2, on plotting the hight of the plant against time a linear curve is obtained. Mathematically it is expressed as:

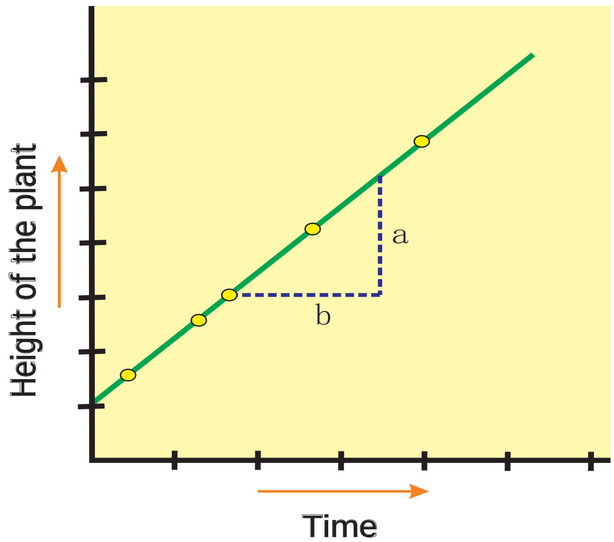


Figure 15.2: Constant Linear Growth

$L_t = L_o + rt$

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 15.3, 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,

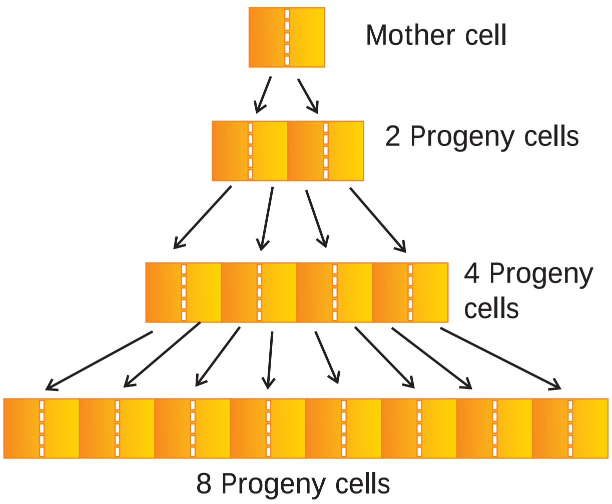


Figure 15.3: Geometric growth

$W_1 = W_0 e^{rt}$

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 15.4). Plants are thus a mixture of older, mature cells and young, dividing cells.

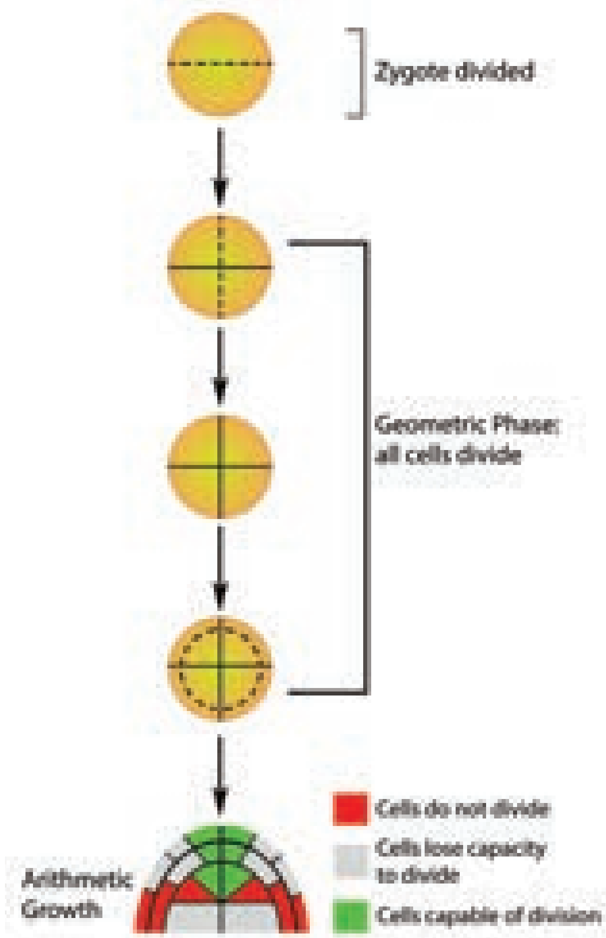


Figure 15.4: Arithmetic and geometric growth of embryo

Quantitative comparisons between the growth of living system can also be made in two ways and is explained in the table 1.

In figure 15.5, 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 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.

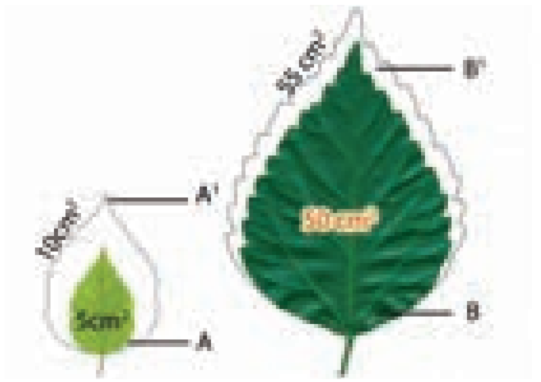


Figure 15.5: Diagrammatic comparision of absolute and relative growth rates

Measurement of Growth

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 15.6). 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 distance travelled by the pointer is 10 and the radius of the pulley is 4 inches and the length of the pint is 20 inches, the actual grown is measured as follows:

Actual growth in length = (Distance travelled by the pointer × radius of the pulley) / Length of the pointer.

For example,
actual growth in length =
(10 × 4 inches)/ 20 inches = 2 inches

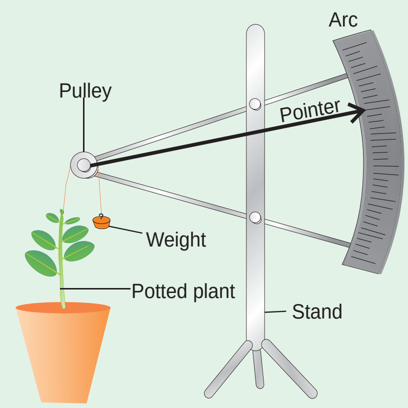


Figure 15.6: Arc auxanometer

15.2 Plant Growth Regulators

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 source and a detailed flow diagram is given in Figure 15.7.

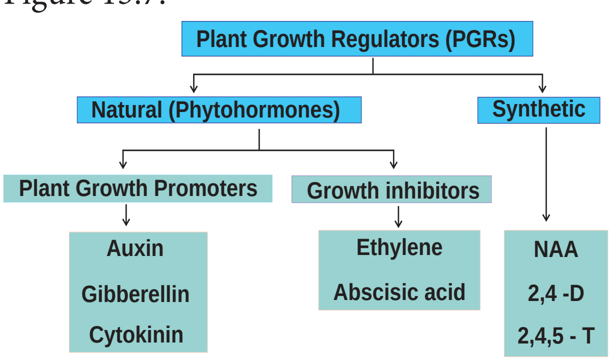


Figure 15.7: Classification of Plant Growth Regulators

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)

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.

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.

Types of Auxin

Natural

Auxin occuring in plants are called "Natural auxin"

1. Indole Acetic Acid (IAA)
2. Indole Propionic Acid (IPA)
3. Indole Butyric Acid (IBA)
4. Phenyl Acetic Acid (PAA)

Synthetic

These are synthesized artificially and have properties like Auxin.

1. 2,4-Dichloro Phenoxy Acetic Acid (2,4-D)
2. 2,4,5-Trichloro Phenoxy Acetic Acid (2,4,5-T)
3. Napthalene Acetic Acid (NAA)

(i) Free auxin

They move out of tissues as they are easily diffusible. Example: IAA.

(ii) Bound Auxin

They are not diffusible. Example: IAA.

4. Precursor

The amino acid Tryptophan is the precursor of IAA and zinc is required for its synthesis.

5. Chemical structure

Auxin has similar chemical structure of IAA.

6. 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.

7. 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 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 15.8).

8. Physiological Effects

- They promote cell elongation in stem and coleoptile.
- At higher concentrations auxins inhibit the elongation of roots but extermely lower concentrations promotes growth of root.
- 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 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.

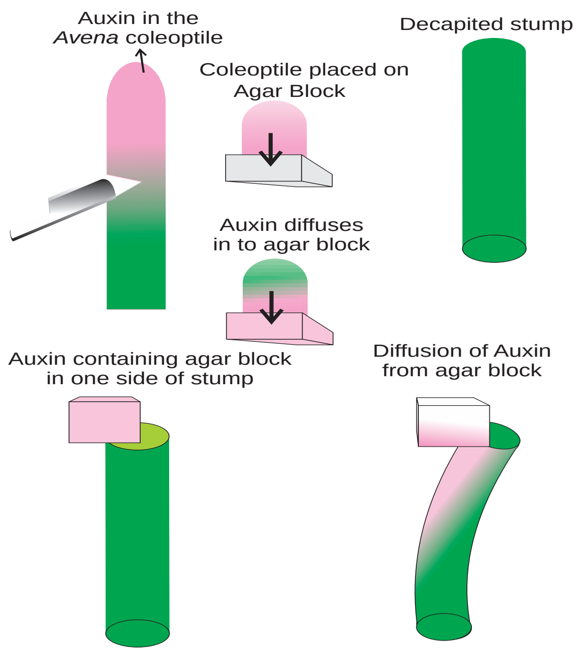


Figure 15.8: *Avena* Curvature Test

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.

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.

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. Epicotyl length is measured and as such, GA stimulating epicotyl growth can be seen.

7. Physiological Effects

- It produces extraordinary elongation of stem caused by cell division and cell elongation.
- Rosette plants (genetic dwarfism) exhibit excessive internodal growth when they are treated with gibberellins. This sudden elongation of stem followed by flowering by the application of gibberellin is called bolting (Figure 15.9).
- Gibberellin breaks dormancy in potato tubers.
- Many biennials usually flower during second year of their growth. For flowering in the first year it self these plants should be treated with gibberellins.
- Formation of seedless fruits without fertilization is induced by gibberellins Example: Seedless tomato, apple and cucumber.
- 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.

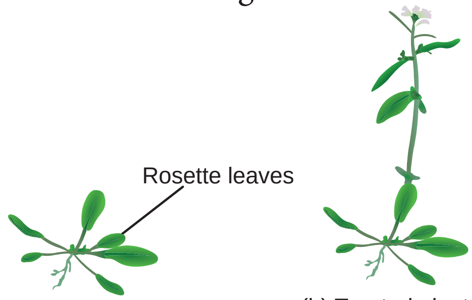


Figure 15.9: Bolting

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, Letham introduced the term cytokinin. In 1964, Letham 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

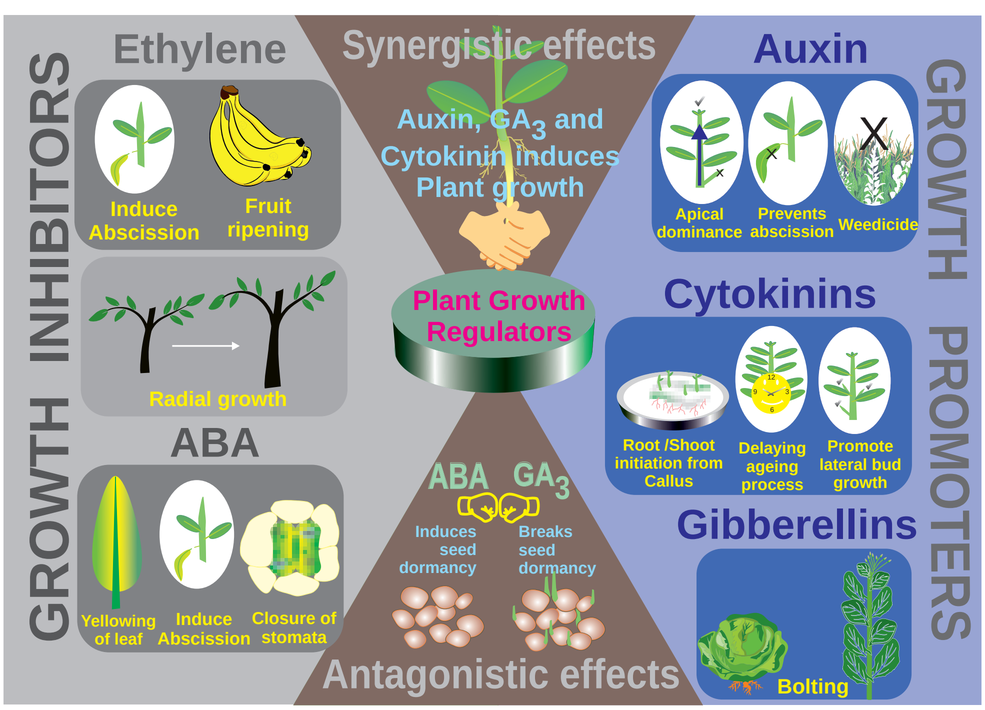
- Cytokinin promotes cell division in the presence of auxin (IAA).
- Cytokinin induces cell enlargement associated with IAA and gibberellins
- Cytokinin can break the dormancy of certain light-sensitive seeds like tobacco and induces seed germination.
- Cytokinin promotes the growth of lateral bud in 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.



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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 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).
- Growth of lateral roots and root hairs. This increases the absorption surface of the plant roots.
- Ethylene normally reduces flowering in plants except in Pine apple and Mango.

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.
- 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.
- In Cannabis sativa, induces male flower formation on female plants.
- It promotes sprouting in storage organs like Potato.
- 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

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 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*.

iii. **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 15.10).

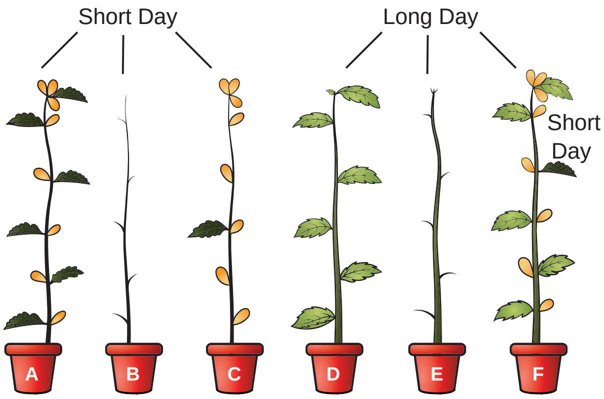
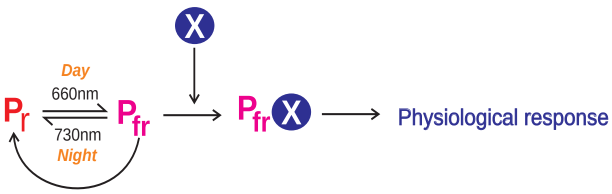


Figure 15.10: Experiment on Cocklebur plant showing photoperiodic stimulus

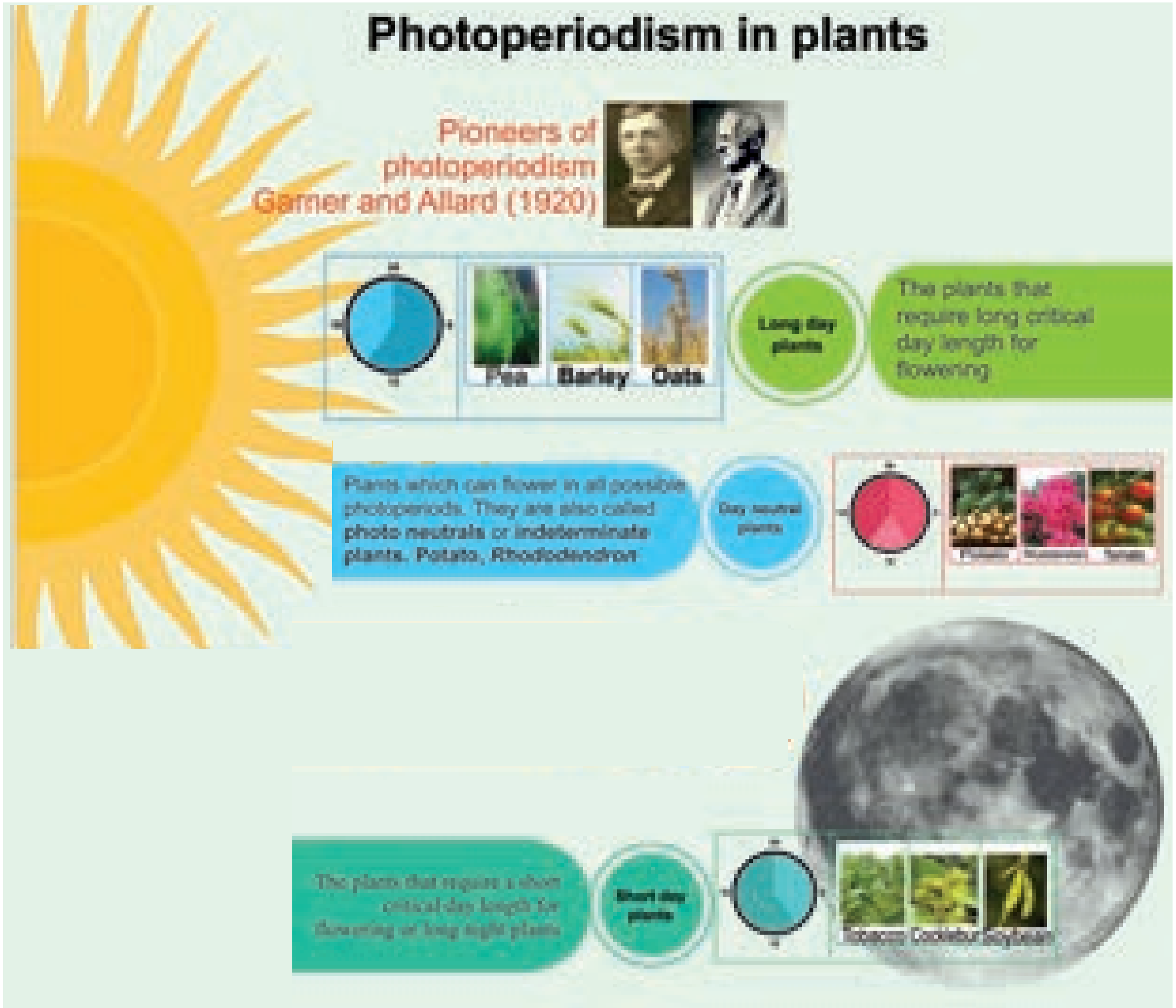
4. Importance of photoperiodism

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: (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 15.11).

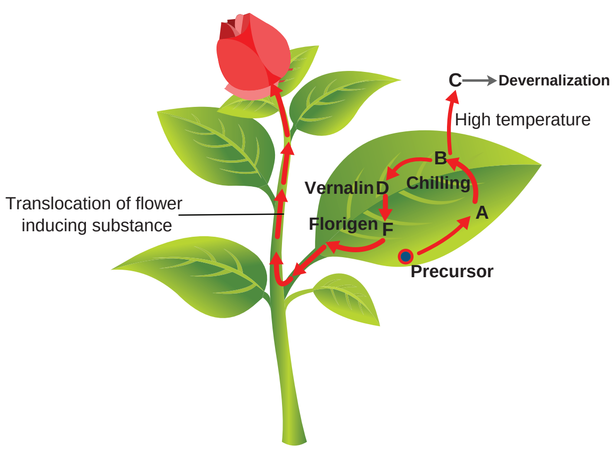


Figure 15.11: Vernalization and Flowering

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.

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.

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 15.12). Example: Maize, Pea.

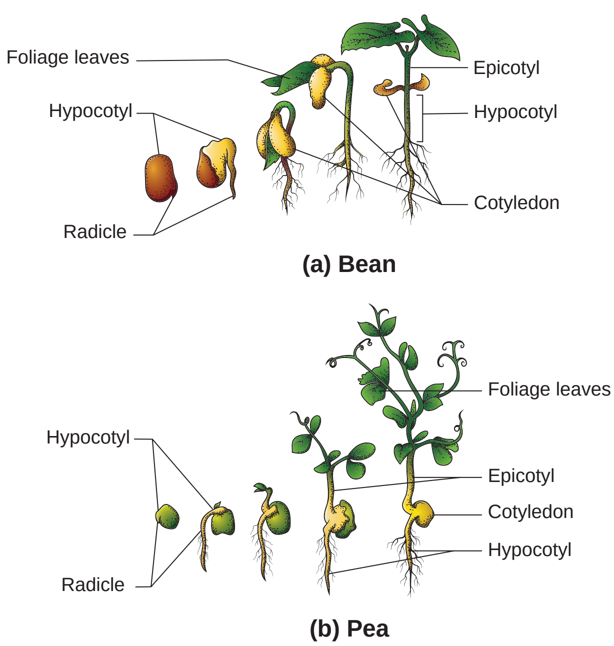


Figure 15.12: (a) Epigeal Germination
(b) Hypogeal Germination

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.

> The branch of botany which deals with ageing, abscission and senescence is called **Phytogerontology**

1. Types of Senescence

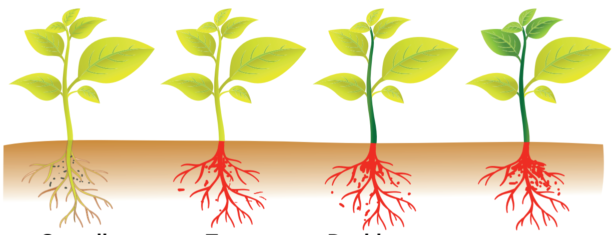


Figure 15.13: Different types of senescence in plants

Leopold (1961) has recognised four types of senescence:

i. Overall senescence
ii. Top senescence
iii. Deciduous senescence
iv. Progressive senescence

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 15.13).

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.
- 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 15.14).

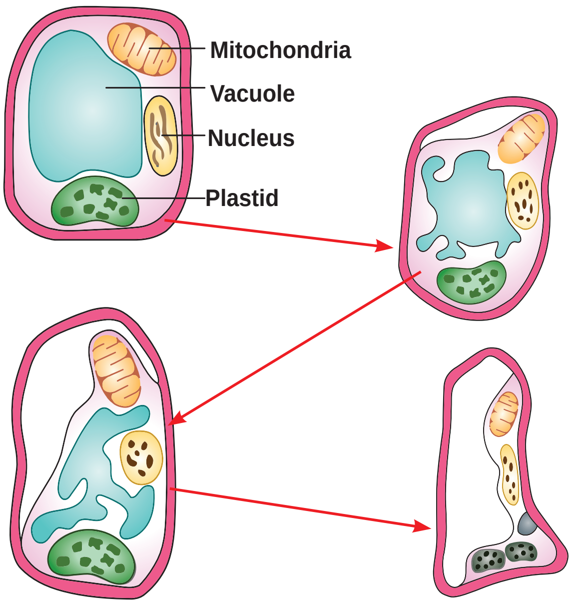


Figure 15.14: Programmed cell death

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.

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 15.15).

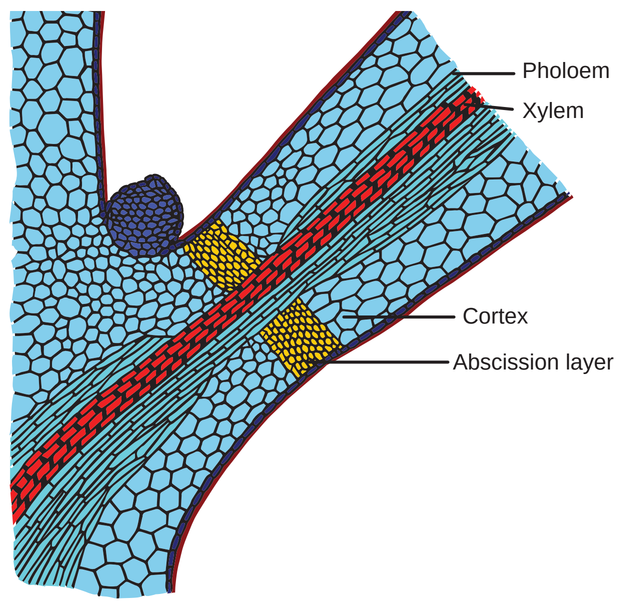


Figure 15.15: L.S of petiolar base showing abscission layer

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.

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 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. 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^oC to 5^oC). 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

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. 1.5inches b. 6 inches
   c. 12 inches d. 30 inches

3. _________ is the powerful growth inhibitor
   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. Which one of the following method are used to break the seed dormancy?
   a) Scarification b) Impaction
   c) Stratification d) All the above.

7. Write the physiological effects of Cytokinins.

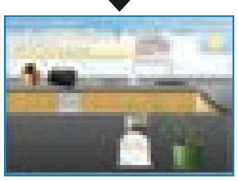
8. Describe the mechanism of photoperiodic induction of flowering.

9. Give a brief account on Programmed Cell Death (PCD)

ICT Corner

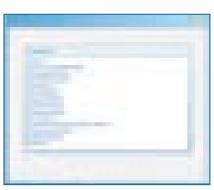
How do Plants respond to different stimuli?

Let's Stimulate **the Plants.**

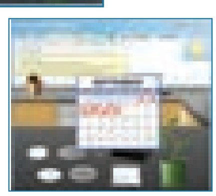


Steps
- Scan the QR code
- Click Exploring plant responses
- Select items and complete the check list
- Follow the procedure – 1 to 10 steps
- Record your prediction and not your observation in lab note – Right top

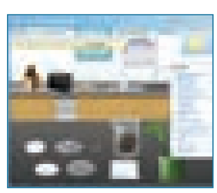
Activity
- Observe the movements of plant seedlings and plant parts.
- Conclude your observations.



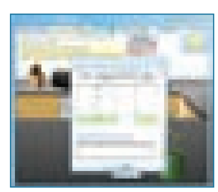
Step 1



Step 2



Step 3



Step 4

Web URL: https://www.classzone.com/books/hs/ca/sc/bio_07/virtual_labs/virtualLabs.html * 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.
Acetyl CoA	Small, water-soluble metabolite comprising an acetyl group linked to coenzyme A (CoA).
Action Spectrum	A graphic representation showing the rate of photosynthesis at different wavelengths of light is called action spectrum
Active site	Region of an enzyme molecule where the substrate binds and undergoes a catalyzed reaction.
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
Akinetes	Thick walled, dormant, non motile asexual spores.
Aleurone	Outer layer of the endosperm
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.
Anamorph	Asexual or imperfect state of fungi
Anisogamy	Fusion of morphologically and physiologically dissimilar gametes
Apical cell theory	Single apical cell growing into whole plant
Apogamy	Formation of sporophyte from the gametophytic tissue without the fusion of gametes.
Apospory	Development of the gametophyte from the sporophyte without the formation of spores
Axil Parenchyma	Parenchyma arranged longitudinally along the axis
Balausto	Fleshy in dehiscent fruit
Basal body	Structure at the base of cilia and flagella from which microtubules forming the axoneme radiate
Biosphere	The region of earth on which life exist
Buffer	A solution of the acid and base form of a compound that undergoes little change in pH when small quantities of strong acid or base are added.
Callose	Sieve pores are blocked by substances called callose
Carbonic acid	A weak acidic solution of carbon-di-oxide dissolved in water
Carcinogen	Any chemical or physical agent that can cause cancer when cells or organism s are exposed to it.
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.
Chemotaxonomy	Classification based on the biochemical constituents of plants
Chlorosis	Breakdown of chlorophylls leads to yellowing of leaves
Clades	Group of species comprising common ancestor and its descendants
Cladistics	Methodology used to classify organisms into monophyletic group

Closed vascular bundle	Cambium absent between xylem and phloem Example: Monocot stem
Codon	Sequence of three nucleotides in DNA or mRNA that specifies a particular amino acid during protein synthesis; also called triplet
Coenocytic condition	Aseptate, multinucleate condition
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.
Dalton	Unit of molecular mass approximately equal to the mass of a hydrogen atom (1.66 × 10–24 g)
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.
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.
Endosperm	Nutritive tissue for the embryo
Endospore	Thick walled, resting spores
Eusporangiate	Sporangium formed from a group of initials
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.
Fossil	The remains or impression of plant or animal of the past geological age
Gametophyte	The haploid plant body
Gelatin	An animal-based product used as a gelling agent.
Genome	Complete set of genes in an organism
Germ	Protein rich embryo
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
Heterospory	Production of spores of different sizes: megaspores and microspores
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.
Karyogamy	Fusion of nucleus
Karyotype	Number, sizes, and shapes of the entire set of metaphase chromosomes of a eukaryotic cell.

Km	A parameter that describes the affinity of an enzyme for its substrate and equals the substrate concentration that yields the half-maximal reaction rate;
Leptome	Phloem – by Haberlandt
Leptosporangiate	Sporangium formed from a single initial
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
Microgreens	Young vegetable greens add flavour in culinary
Monograph	Complete account of a taxon of any rank
Monosulcate	Pollen grain with single furrow or pores
Mycobank	Online database documenting new mycological names
Necrosis	Death of tissue
Non heme iron	An iron porphyrin prosthetic group of heme proteins from plant origin
Nucleoid	Genetic material of bacterium
Nutation	The growing stems of twiner and tendrils show automatic movement
Oogamy	Fusion of morphologically and physiologically dissimilar gametes
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.
Parthenocarphy	Fruit developed without fertilization
Pendulous	Hanging downward loosely or freely (like catkin)
Petrifaction	A process of fossil formation through infiltration of minerals over a long period
pH	A measure of the acidity or alkalinity of a solution defined as the negative logarithm of the hydrogen ion concentration in moles per liter
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.
Phylogeny	Evolution of group of organisms
Phytochrome	A photo reversible proteinaceous plant pigment in very low concentration that absorbs red and far red light which controls flowering.
Pistillode	Sterile pistil
Pitted thickening	Uniformly thick except at their pits
Plasmogamy	Fusion of cytoplasm
Pluriocular	An ovary with two or more locus
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
Prophage	The integrated phage DNA with host DNA

Protologue	Set of information associated with the scientific name of a taxon at its first valid publication containing the entire original material regarding the taxon
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
Rachilla	Central axis of a spikelet
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
Sporophyte	Diploid plant body
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
Teloemorph	Sexual or perfect state of the fungi
Thallospores	Asedual spores formed due to the fragmentation of hyphae
Trichoblasts	One type of epidermal cells that is also called short cell
Trichomes	Unicellular or multicellular appendages
Triplicate	Pollen grain with three furrows or pores
Tunica-carpus theory	Two zones of apical meristem Tunica and Carpus
X-Ray crystallography	Most commonly used technique for determining the three-dimensional structure of macromolecules (particularly proteins and nucleic acids) by passing x-rays
Xylos	Wood
Zoospore	Motile, asexual spores
Zygospore	Thick walled diploid resting spores

English – Tamil Terminology

Abscission	உதிர்தல்
Abscission zone	உதிரும் அடுக்கு
Absorption spectrum	ஒளி ஈர்ப்பு நிறமாலை
Acropetal succession (arrangement)	நுனி நோக்கிய வரிசை
Action spectrum	ஒளி செயல்திறன் நிறமாலை
Activated diffusion	மேம்படுத்தப்பட்ட பரவல்
Active transport	ஆற்றல்சார் கடத்தல்
Adhesion	ஒட்டிணைவு
Aeroponics	காற்றூடக வளர்ப்பு
Aggregatte fruit	திரள்கனி
Akinetes	உறக்க நகராவித்து
Anabolic	சேர்க்கைச் செயல்
Anamorph	பாலிலாநிலை
Anisogamy	சமமற்ற கேமீட்களின் இணைவு
Annual rings	ஆண்டு வளையங்கள்
Antenna molecules	ஏற்பி மூலக்கூறுகள்
Anthrophytes	பூக்கும் தாவரங்களின் முன்னோடிகள்
Apical cell theory	நுனி செல் கொள்கை
Apogamy	பாலிணைவின்மை
Apospory	குன்றலில்லா வித்துத்தன்மை
Arbitary marker	தன்னிச்சையான குறிப்பான்
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
Basipetal succession	அடி நோக்கிய வரிசை
Bicollateral vascular bundle	இருபக்க ஒருங்கமைந்த வாஸ்குலக் கற்றை
Biosequestration	உயிர்வளி தனிமைப்படுத்துதல்
Biosphere	உயிர்க்கோளம்
Biosynthetic phase	உயிர்மதோற்ற நிலை
Brown heart disease	மைய கருக்கல் நோய்
Buttress root	பலகை வேர்
Callus	திசுத்திரள்
Carbon di oxide compensation point	கார்பன்-டை-ஆக்ஸைட் ஈடு செய்யும் புள்ளி
Carbon fixation	கார்பன் நிலைநிறுத்தம்
Carrier protein	தாங்கிப் புரதம்/கொண்டு செல்லும் புரதம்
Catabolic	சிதைக்கும் செயல்
Catalytic amination	வினையூக்க அமைனோவாக்கம்

Cavitation	குமிழாதல்
Centrifugal	மையம் விலகியது
Centripetal	மையம் நோக்கியது
Channel protein	கால்வாய் புரதம்
Chelating agents	பிணைக்கும் காரணி
Chemiosmotic theory	வேதி சவ்வூடு பரவல் கோட்பாடு
Chlorophyll	பச்சையம்
Chloroplast	பசுங்கணிகம்
Chlorosis	பச்சைய சோகை
Cladogram	கிளை வரைபடம்
Closed collateral vascular bundles	மூடிய ஒருங்கமைந்த வாஸ்குலக் கற்றைகள்
Coenocytic	பல்உட்கரு நிலை
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
Conjugation	இணைவு
Core complex	மைய ஆதார கூட்டமைப்பு
Cotyledons	விதையிலைகள்
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
Dry dehiscent fruit	உலர் வெடிகனி
Dry indehiscent fruit	உலர் வெடியாக்கனி
Efflux	அயனி வெளிப்புகல்
Electro magnetic spectrum	மின்காந்த நிறமாலை
Electron transport chain	எலக்ட்ரான் கடத்து சங்கிலி
Embryo	கரு
Emerson's enhancement effect	எமர்சனுடைய மேம் படுத்தப்பட்ட விளைவு
Endergonic	ஆற்றல் ஏற்கும் வினை
Endosperm	கருவூண்திசு
Endospores	அகவித்துகள்

Endosymbiotic hypothesis	அக கூட்டுயிர் கோட்பாடு
Eukaryote	உண்மை உட்கரு உயிரி
Eusporangiate	உண்மை வித்தகத்தன்மை
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
Fossil	தொல்லுயிரெச்சம்
Funicle	சூல்காம்பு
Gametophyte	கேமீட்டக தாவரம்
Gene marker	மரபணு குறிப்பான்
Genome	மரபணுத் தொகுப்பு
Geocarpic fruit	புவிபுதை கனி/நிலத்தகத்துக் கனி
Geometric growth	ஜியோமித வளர்ச்சி
Geophytes	நிலத்தகத்துத் தூண்சேர் தாவரம்
Grand period of growth	மொத்த வளர்ச்சிக் காலம்
Growth rate	பெரும வளர்ச்சி வீதம்
Gynobasic	சூற்பை அடி சூலகத்தண்டு
Halophiles	உவர்நாட்டவுயிரிகள்
Halophytes	உவர்நிலை தாவரங்கள்
Heart wood	வைரக்கட்டை
Heliophytes	ஒளியை விரும்பும் தாவரங்கள்
Heterospory	மாற்று வித்தகத்தன்மை
Histogen theory	ஹிஸ்டோஜன் கொள்கை
Histogenesis	ஹிஸ்டோஜெனிசிஸ்
HMP shunt	HMP மாற்றுவழிப் பாதை
Homeostasis	சமச்சீர் நிலை
Hydathode	நீர்கசிவுத் துளை
Hydrochory	நீர்மூலம் பரவுதல்
Hydroponics	நீர் ஊடக வளர்ப்பு
Imbibition	உள்ளீர்த்தல்
Indeterminate	வரம்பற்ற வளர்ச்சி
Influx	அயனி உட்புகல்
Interveinal chlorosis	நரம்பிடை பச்சைய சோகை
Irritability	உறுத்துணர்ச்சி
Isogamy	ஒத்த கேமீட்களின் இணைவு
Isomerisation	மாற்றியமாதல்
Karyogamy	உட்கரு இணைவு
Karyokinesis	காரியோகைனசிஸ்
Lag phase	உருவாக்க நிலை
Leaf primodium	இலைத்தோற்றுவி
Legume / Pod	விதைப்பை
Lenticel	பட்டைத்துளை
Leptosporangiate	மெலி வித்தகத்தன்மை
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	ஊடக உட்திறன்
Maturation promoting factor (MPF)	முதிர்ச்சியை ஊக்கப்படுத்தும் காரணி
Merosity	எண்ணிக்கை அமைவு
Metabolism	வளர்சிதைமாற்றம்
Micro nutrients	நுண் ஊட்ட மூலங்கள்
Middle Lamella	இடைமென் அடுக்கு
Mineral Nutrition	கனிம ஊட்டம்
Mitochondrial matrix	மைட்டோகாண்ட்ரிய உட்கூழ்மம்
Monograph	தனிக்கட்டுரை
Multiple fruit	கூட்டுக்கனி
Mycobank	பூஞ்சை வங்கி
Necrosis	நைவுப் புண்கள்
Nitrate Assimilation	நைட்ரேட் தன்மயமாதல்
Nitrogen metabolism	நைட்ரஜன் வளர்சிதை மாற்றம்
Non-porous wood	துளைகளற்ற கட்டை
Nuclear envelope	நியூக்ளியர் உறை
Nuclear organizer	நியுக்ளியோலார் அமைப்பான்கள்
Nucleoid	உட்கரு ஒத்த அமைப்பு
Nutation	சுழலசைவு
Obligate parasite	கட்டாய ஒட்டுண்ணி
Oogamy	முட்டை கருவுறுதல்
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
Pendulous	தொங்குகின்ற
Pericarp	கனி உறை
Petrification	கல்லாதல்
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	ஒளிச்சேர்க்கையின் கார்பன் ஒடுக்க சுழற்சி
Photosynthetic unit (Quantasome)	ஒளிச்சேர்க்கை அலகு (குவாண்டோசோம்)
Photosystem	நிறமி அமைப்பு / ஒளி அமைப்பு
Pili or Fimbriae	நுண் சிலும்புகள்
Pistillode	மலட்டு சூலகம்
Plant antitranspirants	நீராவிப்போக்குத் தடுப்பான்கள்
Plasmogamy	சைட்டோபிளாச இணைவு
Plasmolysis	பிளாஸ்மா சிதைவு
Plasticity	உருமாறும் தன்மை
Plumule	முளைக்குருத்து
Plurilocular	பல்லறை சூற்பை
Polymorphism	பலபடிவுடமை
Porous woods	துளைக்கட்டை
Preparatory phase	ஆயத்த நிலை
Pressure potential	அழுத்தயியல் திறன்
Primary adapter	முதன்மை மாற்றி
Primary growth	முதல்நிலை வளர்ச்சி
Probe	ஆய்வி
Programmed cell death	திட்டமிடப்பட்ட செல் இறப்பு
Prokaryote	தொல்லுட்கரு உயிரி
Prophage	ஃபாஜ் முன்னோடி
Proton gradient	புரோட்டான் சரிவு
Pumps	உந்திகள்
Quiescent centre concept	உறக்க மையக் கொள்கை
Rachilla	சிறுகதிரின் மையஅச்சு
Radial vascular bundles	ஆரப்போக்கமைந்த வாஸ்குலக் கற்றைகள்
Radicle	முளை வேர்
Ray parenchyma	கதிர் பாரங்கைமா
Reaction Centre	வினை மையம்
Red drop	சிவப்பு வீழ்ச்சி
Redox reaction	ஆக்ஸிஜனேற்ற ஒடுக்கவினை
Reducing power	ஒடுக்கும் ஆற்றல்
Respiratory quotient	சுவாச ஈவு

Restriction site	வரையறு தளம்
Reverse osmosis	பின்னோக்கிய சவ்வூடு பரவல்
Rib meristem	வரிசை ஆக்குத்திசு
Ring Bark	வளைய பட்டை
Sap wood	சாற்றுக்கட்டை
Scale Bark	செதில் பட்டை
Seed	விதை
Seed coat	விதை உறை
Seed dormancy	விதை உறக்கம்
Semi autonomy	பாதி சுயசார்புதன்மை
Senescence	மூப்படைதல்
Serotaxonomy	ஊநீர் வகைப்பாட்டியல்
Sink	தேங்கிடம்
Slime bodies	ஸ்லைம் உடலங்கள்
Solute potential	கரைபொருள் திறன்
Source	தோற்றுவாய்
Sporophyte	வித்தகத்தாவரம்
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
Synaptonemal complex	சைனாப்டினிமல் தொகுதி
Systematics	முறைப்பாட்டு தாவரவியல்
Tandem repeat	ஒருசெயல நிகழும் மாறிகள்
Taxon	வகைப்பாட்டுத் தொகுதி
Telomorph	பால்நிலை
Terminal oxidation	இறுதி ஆக்ஸிஜனேற்றம்
Thallospores	உடல வித்துகள்
Thermonastic	வெப்ப தூண்டல்
Thigmotactic	தொடு உணர்வு அசைவு
Transamination	அமைனோ மாற்றம்
Transduction	மரபணு ஊடுகடத்தல்
Transformation	மரபணு மாற்றம்
True fruit	மெய்க்கனி
Tunica corpus theory	டூனிகா கார்பஸ் கொள்கை
Vernalization	தட்பப்பதனம்
Water potential	நீரியல் திறன்
Xeric Succession	வறள் தாவர படிநிலை வளர்ச்சி
Zoospore	இயங்கு வித்து
Zygospore	உறக்க கருமுட்டை

Competitive Examination Questions

Unit – 1 Diversity of Living World

1. Which of the following are found in extreme saline conditions? (NEET-2017)
   a. Archaebacteria b. Eubacteria
   c. Cyanobacteria d. Mycobacteria

2. Select the mismatch (NEET – 2017)
   a. *Frankia* *Alnus*
   b. *Rhodospirillum* *Mycorrhiza*
   c. *Anabaena* *Nitrogen fixer*
   d. *Rhizobium* *Alfalfa*

3. Which among the following are the smallest living cells, known without a definite cell wall, pathogenic to plants as well as animals and can survive without oxygen? (NEET – 2017)
   a. *Bacillus* b. *Pseudomonas*
   c. Mycoplasma d. *Nostoc*

4. Read the following statements (A to E) and select the option with all correct statements (AIPMT – 2015)
   A. Mosses and Lichens are the first organisms to colonise a bare rock.
   B. *Selaginella* is a homosporous pteridophyte.
   C. Coralloid roots in *Cycas* have VAM.
   D. Main plant body in bryophytes is gametophytic, whereas in pteridophytes it is sporophytic.
   E. In gymnosperms, male and female gametophytes are present within sporangia located on sporophyte.
   a. B, C and E b. A, C and D
   c. B, C and D **d. A, D and E**

5. An example of colonial alga is (NEET – 2017)
   a. *Chlorella* **b. *Volvox***
   c. *Ulothrix* d. *Spirogyra*

6. Five kingdom system of classification suggested by R.H. Whittaker is not based on (AIPMT – 2014)
   a. Presence or absence of a well defined nucleus
   b. Mode of reproduction
   c. Mode of nutrition
   d. Complexity of body organisation

7. Mycorrhizae are the example of (NEET – 2017)
   ` a. Fungitasis c. Amensalism
   b. Antibiosis **d. Mutualism**

8. Which of the following shows coiled RNA strand and capsomeres? (AIPMT – 2014)
   a. Polio virus **b. Tobacco mosaic virus**
   c. Measles virus d. Retrovirus

9. Viroids differ from viruses in having : (NEET – 2017)
   a. DNA molecules with protein coat
   b. DNA molecules without protein coat
   c. RNA molecules with protein coat
   d. RNA molecules without protein coat

10. Select the mismatch (NEET – 2017)
    a. *Pinus* — Dioecious
    b. Cycas — Dioecious
    c. *Salvinia* — Heterosporous
    d. *Equisetum* — Homosporous

11. Life cycle of *Ectocarpus* and *Fucus* respectively are (NEET – 2017)
    a. Haplontic, Diplontic
    b. Diplontic, Haplodiplontic
    c. Haplodiplontic, Diplontic
    d. Haplodiplontic, Halplontic

12. Zygote meiosis is characterisitic of (NEET – 2017)
    a. *Marchantia* b. *Fucus*
    c. *Funaria* **d. *Chlamydomonas***

13. Which of the following is correctly matched for the product produced by them? (NEET – 2017)
    a. *Acetobacter acetic* : Antibiotics
    b. *Methanobacterium* : Lactic acid
    c. *Penicillium notatum* : Acetic acid
    d. *Saccharomyces cerevisiae* : Ethanol

14. Which of the following components provides sticky character to the bacterial cell? (NEET – 2017)
    a. Cell wall b. Nuclear membrane
    c. Plasma membrane **d. Glycocalyx**

15. Which of the following statements is wrong for viroids? (NEET – 2016)
    a. They lack a protein coat
    b. They are smaller than viruses
    c. They causes infections
    d. Their RNA is a high molecular weight

16. In bryophytes and pteridophytes, transport of male gametes require (NEET – 2016)
    a. Wind b. Insects
    c. Birds **d. Water**

17. How many organisms in the list below are autotrophs? (AIPMT Mains 2012)

Lactobacillus, Nostoc, Chara, Nitrosomonas, Nitrobacter, Streptomyces, Saccharomyces,

Trypanosoma, Porphyra, Wolffia

a. Four b. Five

c. Six d. Three

18. Which of the following would appear as the pioneer organisms on bare rocks? (NEET – 2016)

a. Lichens b. Liverworts

c. Mosses d. Green algae

19. Monoecious plant of *Chara* shows occurrence of (NEET-2013)

a. Stamen and carpel on the same plant

b. Upper antheridium and lower oogonium on the same plant

c. Upper oogonium and lower antheridium on the same plant

d. Antheridiophore and archegoniophore on the same plant

20. Read the following five statement (A-E) and answer as asked next to them (AIPMT Prelims – 2012)

a. In *Equisetum*, the female gametophyte is retained on the parent sporophyte

b. In *Ginkgo*, male gametophyte is not independent

c. The sporophyte in *Riccia* is more developed than that in *Polytrichum*

d. Sexual reproduction in *Volvox* is isogamous

e. The spores of slime moulds lack cell walls

How many of the above statement are correct? (AIPMT Prelims – 2012)

a. Two b. Three

c. Four **d. One**

21 One of the major components of cell wall of most fungi is (NEET – 2016)

a. Chitin b. Peptidoglycan

c. Cellulose d. Hemicellulose

22. Which one of the following statements is wrong? (NEET – 2016)

a. Cyanobacteria are also called blue-green algae

b. Golden algae are also called desmids

c. Eubacteria are also called false bacteria

d. Phycomycetes are also called algal fungi

23. Flagellated male gametes are present in all the three of which one of the following sets? (AIPMT Prelims – 2007

a. *Riccia, Dryopteris* and *Cycas*

b. *Anthoceros, Funaria* and *Spirogyra*

c. *Zygnema, Saprolegnia* and *Hydrilla*

d. *Fucus, Marsilea* and *Calotropis*

24. Ectophloic siphonostele is found in (AIPMT Prelims – 2005)

a. *Adiantum* and Cucurbitaceae

b. *Osmunda* and *Equisetum*

c. *Marsilea* and *Botrychium*

d. *Dicksonia* and maiden hair fern

25. Which part of the tobacco plant is infected by *Meloidogyne incognita*? (NEET – 2016)

a. Flower b. Leaf c. Stem **d. Root**

26. Select the correct statement (NEET – 2016)

a. Gymnosperms are both homosporous and heterosporous

b *Salvinia, Ginkgo* and *Pinus* all are gymnosperms

c. *Sequoia* is one of the tallest trees

d. The leaves of gymnosperms are not well adapted to extremes of climate

27. Seed formation without fertilization in flowering plants involves the process of (NEET – 2016)

a. Sporulation b. Budding

c. Somatic hybridization **d. Apomixis**

28. Chrysophytes, Euglenoids, Dinoflagellates and Slime moulds are included in the kingdom (NEET – 2016)

a. Animalia **b, Monera** c. Protista d. Fungi

29. The primitive prokaryotes responsible for the production of biogas from the dung of ruminant animals, include the (NEET – 2016)

a. Halophiles b. Thermoacidophiles

c. Methanogens d. Eubacteria

Unit – 2 Plant Morphology and Taxonomy of Angiosperm

1. Leaves become modified into spines in [AIPMT-2015]

a. Silk Cotton **b. *Opuntia***

c. Pea d. Onion

2. Keel is the characteristic feature of flower of [AIPMT-2015]

a. Tomato b. Tulip

c. *Indigofera* d. *Aloe*

3. Perigynous flowers are found in [AIPMT-2015]

a. Rose b. Guava

c. Cucumber d. China rose

4. Which one of the following statements is correct [AIPMT-2014]
   a. The seed in grasses is not endospermic
   b. Mango is a parthenocarpic fruit
   c. A proteinaceous aleurone layer is present in maize grain
   d. A sterile pistil is called a staminode
5. An example of edible underground stem is [AIPMT-2014]
   a. Carrot b. Groundnut
   c. Sweet potato **d. Potato**
6. Placenta and pericarp are both edible portions in [AIPMT-2014]
   a. Apple b. Banana **c. Tomato** d. Potato
7. When the margins of sepals or petals overlap one another without any particular direction, the condition is termed as [AIPMT-2014]
   a. Vexillary **b. Imbricate** c. Twisted d. Valvate
8. An aggregate fruit is one which develops from [AIPMT-2014]
   a. Multicarpellary syncarpous gynoecium
   b. Multicarpellary apocarpous gynoecium
   c. Complete inflorescence
   d. Multicarpellary superior ovary
9. Non-albuminous seed is produced in [AIPMT-2014]
   a. Maize b. Castor c. Wheat **d. Pea**
10. Seed coat is not thin, membranous in [NEET-2013]
    a. Coconut b. Groundnut c. Gram d. Maize
11. In china rose the flower are [NEET-2013]
    a. Actinomorphic. Epigynous with valvate aestivation
    b. Zygomorphic, hypogynous with imbricate aestivation
    c. Zygomorphic, epigynous with twisted aestivation
    d. Actinomorphic, hypogynous with twisted aestivation
12. Placentation in tomato and lemon is [AIPMT Prelims-2012]
    a. Marginal **b. Axile**
    c. Parietal d. Free central
13. Vexillary aestivation is characteristic of the family [AIPMT Prelims-2012]
    a. Solanaceae b. Brassicaceae
    c. Fabaceae d. Asteraceae
14. Phyllode is present in [AIPMT Prelims-2012]
    a. Australian Acacia b. *Opuntia*
    c. *Asparagus* d. *Euphorbia*
15. How many plants in the list given below have composite fruits that develop from an inflorescence? Walnut, poppy, radish, pineapple, apple, tomato. [AIPMT Prelims-2012]
    a. Two **b. Three** c. Four d. Five
16. Cymose inflorescence is present in [AIPMT Prelims-2012]
    a. *Trifolium* b. *Brassica*
    c. Solanum d. *Sesbania*
17. Which one of the following organism is correctly matched with its three characteristics? [AIPMT Mains -2012]
    a. Pea : C3 pathway, Endospermic seed, Vexillary aestivation
    b. Tomato : Twisted aestivation, Axile placentation, Berry
    c. Onion: Bulb, Imbricate aestivation, Axile placentation
    d. Maize : C3 pathway, Closed vascular bundles, scutellum
18. How many plants in the list given below have marginal placentation?
    Mustard, Gram, Tulip, *Asparagus*, Arhar, sun hemp, Chilli, *Colchicine*, Onion, Moong, Pea, Tobacco, Lupin [AIPMT Mains -2012]
    a. Four b. Five **c. Six** d. Three
19. The Eyes of the potato tuber are [AIPMT Prelims-2011]
    a. Axillary buds b. Root buds
    c. Flower buds d. Shoot buds
20. Which one of the following statements is correct? [AIPMT Prelims-2011]
    a. Flower of tulip is a modified shoot
    b. In tomato, fruit is a capsule
    c. Seeds of orchids have oil – rich endosperm
    d. Placentation in primrose is basal
21. A drup develops in [AIPMT Prelims-2011]
    a. Tomato **b. Mango** c. Wheat d. Pea

Unit 3 Cell biology and Biomolecules

1. Who invented electron microscope? (2010 AIIMS, 2008 JIPMER)
   a. Janssen b. Edison
   c. Knoll and Ruska d. Landsteiner
2. Specific proteins responsible for the flow of materials and information into the cell are called (2009 AIIMS)
   a. Membrane receptors
   b. carrier proteins
   c. integeral proteins
   d. none of these

3. Omnis-cellula-e-cellula was given by (2007 AIIMS)
   a. Virchow b. Hooke
   c. Leeuwenhoek d. Robert Brown
4. Which of the following is responsible for the mechanical support, protein synthesis and enzyme transport (2007 AIIMS)
   a. cell membrane
   b. mitochondria
   c. dictyosomes
   d. endoplasmic reticulum
5. Genes present in the cytoplasm of eukaryotic cells are found in (2006 AIIMS)
   a. mitochondria and inherited via egg cytoplasm
   b. lysosomes and peroxisomes
   c. Golgi bodies and smooth endoplasmic reticulum
   d. Plastids inherited via male gametes
6. In which one the following would you expect to find glyoxysomes(2005 AIIMS)
   a. Endosperm of wheat
   b. endosperm of castor
   c. Palisade cells in leaf
   d. Root hairs
7. A quantosome is present in (JIPMER 2012)
   a. Mitochondria **b. Chloroplast**
   c. Golgi bodies d. ER
8. In mitochondria the enzyme cytochrome oxidase is present in (2012 JIPMER)
   a. Outer mitochondrial membrane
   b. inner mitochondrial membrane
   c. Stroma d. Grana
9. Which organelle is present in higher number in secretory cell (2008 JIPMER)
   a. Mitochondria b. Chloroplast
   c. Nucleus **d. Dictyosomes**
10. Major site for the synthesis of lipids (2013 NEET)
   a. Rough ER **b. smooth ER**
   c. Centriole d. Lysosome
11. Golgi complex plays a major role in. (2013 NEET)
   a. post translational modification of proteins and glycosidation of lipids
   b. translation of proteins
   c. Transcription of proteins
   d. Synthesis of lipid
12. Main arena of various types of activities of a cell is (2010 AIPMT)
   a. Nucleus b. Mitochondria
   c. Cytoplasm d. Chloroplast
13. The thylakoids in chloroplast are arranged in (2005 JIPMER)
   a. regular rings b. linear array
   c. diagonal direction **d. stacked discs**
14. Sequences of which of the following is used to know the phylogeny (2002 JIPMER)
   a. mRNA **b. rRNA** c. tRNA d. Hn RNA
15. Structures between two adjacent cells which is an effective transport pathway- (2010 AIPMT)
   a. Plasmodesmata
   b. Middle lamella
   c. Secondary wall layer
   d. Primary wall layer
16. In active transport carrier proteins are used, which use energy in the form of ATP to
   a. transport molecules against concentration gradient of cell wall
   b. transport molecules along concentration gradient of cell membrane
   c. transport molecules against concentration gradient of cell membrane
   d. transport molecules along concentration gradient of cell wall
17. The main organelle involved in modification and routing of newly synthesised protein to their destinations is (AIPMT 2005)
   a. Mitochondria b. Glyoxysomes
   c. Spherosomes **d. Endoplasmic reticulum**
18. Algae have cell wall made up of (AIPMT 2010)
   a. Cellulose, galactans and mannans
   b. Cellulose, chitin and glucan
   c. Cellulose, Mannan and peptidoglycan
   d. Muramic acid and galactans

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 (PMT-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 → 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

Biology - Botany - Class XI
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