GOVERNMENT OF TAMIL NADU

BOTANY

HIGHER SECONDARY FIRST YEAR

VOLUME - I

Untouchability is Inhuman and a Crime

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HOW TO USE THE BOOK

Learning Objectives:	Learning objectives are brief statements that describe what students will be expected to learn by the end of school year, course, unit, lesson or class period.
Chapter Outline	Illustrate the complete overview of chapter
DO YOU KNOW?	Amazing facts, Rhetorical questions to lead students to biological inquiry
List of Botanical terms	Tamil terminology for Botanical terms given for easy understanding
Activity	Directions are provided to students to conduct activities in order to explore, enrich the concept.
Infographics	Visual representation of the lesson to enrich learning .
Evaluation	Assess students to pause, think and check their understanding
5CU7G6	To motivate the students to further explore the content digitally and take them in to virtual world
ICT	To enhance digital Science skills among students
Concept Map	Conceptual diagram that depicts relationships between concepts to enable students to learn the content schematically
Career corner	List of professions related to the subject
References	List of related books for further details of the topic
Web links	List of digital resources
Glossary	Explanation of scientific terms
Competitive Exam questions	Model questions to face various competitive exams

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

- B.Sc.(N)- Bachelor of Science in Nursing
- 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

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

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

Research Institutions in various areas of Botany

Name of the Institution	Research Areas	Website
National Research Center on Plant Biotechnology, New Delhi	Genetic engineering for biotic resistance.	www.nrcpb.org
Indian Institute of Soil Sciences (IISS), Bhopal	Study of organic and inorganic nutrient sources affect soil biological activity.	www.iiss.nic.in
National Institute of Plant Genome Research (NIPGR), New Delhi	Structural and Functional Genomics in Plants; Computational biology; Genome analysis and molecular mapping.	www.nipgr.res.in
Sugarcane Breeding Institute, ICAR, Coimbatore.	Breeding of superior sugarcane varieties/ genotypes;	www.sugarcane.res.in
National Centre for Agricultural Economics and Policy Research (NCAP), New Delhi	Agricultural technology policy.	www.ncap.res.in
National Institute of Abiotic Stress Management., Pune	Basic and strategic research on management of abiotic stresses of crop plants.	www.niam.res.in
Central Research Institute for Dryland Agriculture, Hyderabad	Dryland, Agrometerology and Crop sciences	crida.in
Central Research Institute for Jute & Allied Fibres, Kolkata, West Bengal	Crop improvement, Crop production, Crop protection, Agricultural research.	www.crijaf.org.in
Indian Institute of Pulses Research (IIPR), Kanpur	Genetics & Plant Breeding and Seed Science	www.iipr.res.in
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
Indian Institutes of Science Education and Research(IISER) - Berhampur, Bhopal, Kolkata, Mohali, Pune, Thiruvananthapuram, and Tirupati.	Microbial Ecology; Marine Molecular Ecology; Marine Biology.	www.iiserkol.ac.in www.issertvm.ac.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.*
- *Outline the classification of fungi.*
- *Describe the structure and reproduction in Rhizopus and Agaricus.*
- *Discuss the structure and uses of Mycorrhizae and Lichens.*

Chapter Outline

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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 harbors 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

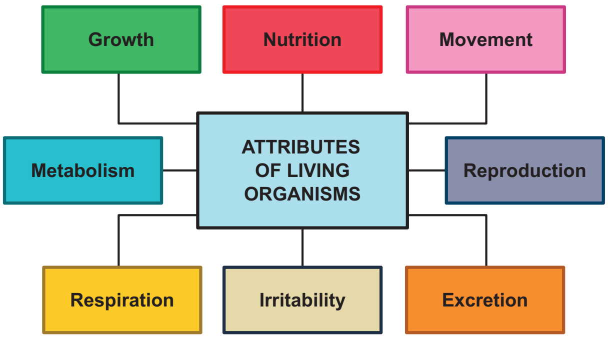

Figure 1.1: Attributes of living organisms

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. However, cell division occurs in living organisms to repair and heal the worn out tissues. 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). 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.

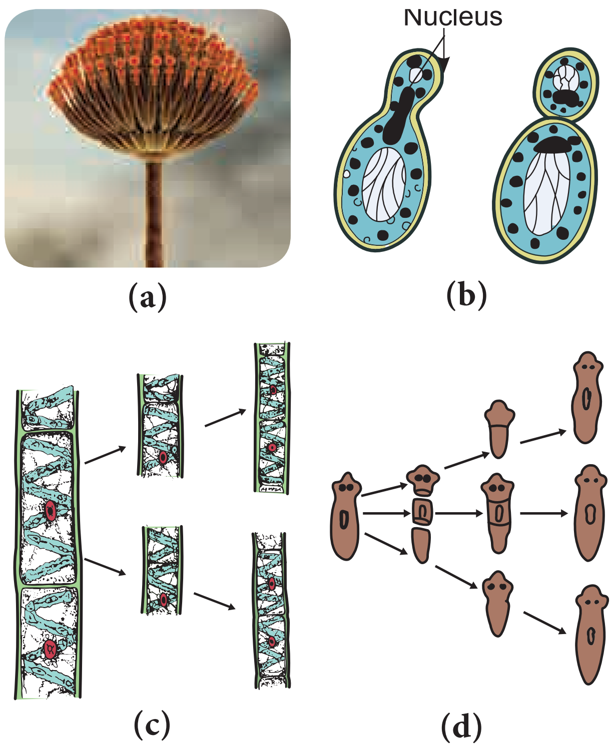

Figure 1.2: Types of Asexual Reproduction
(a) Conidia formation-*Penicillium*,
(b) Budding-Yeast, (c) Fragmentation-*Spirogyra*, (d) Regeneration-*Planaria*

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.

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.

Metabolism

The sum total 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

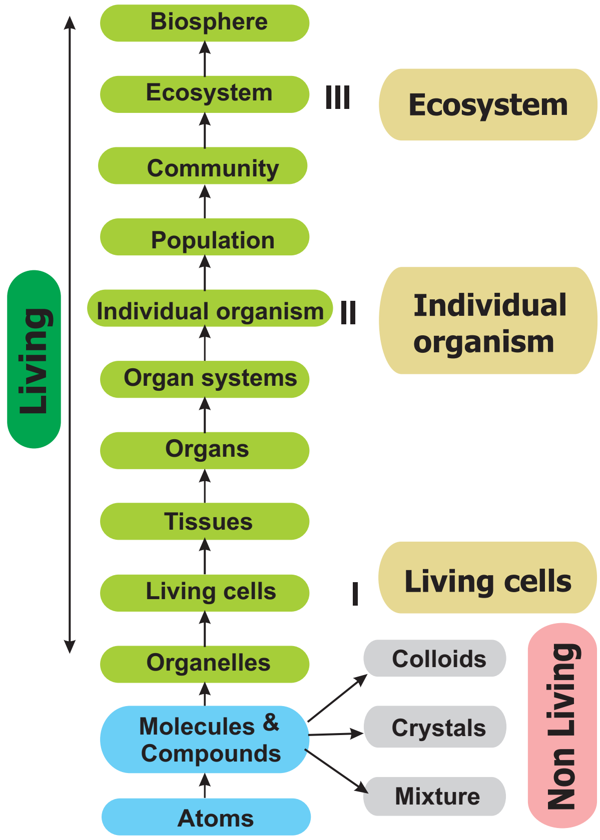

Figure 1.3: The levels of organization and integration in living organism

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**.

W.M. Stanley
(1904-1971)

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.

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.

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

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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

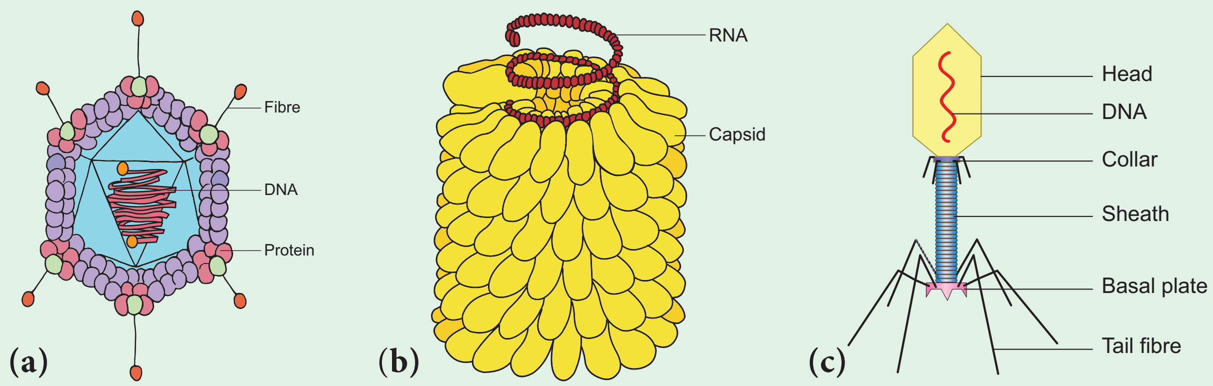


Figure 1.4: Shapes of Viruses

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

Table 1.2: Different Classes of viruses	
Class	**Example**
Class 1 - Viruses with dsDNA	Adenoviruses
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 ss RNA –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

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 (Parvoviruses), dsDNA (Bacteriophages), ssRNA (TMV) and dsRNA(wound tumour virus).

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 280x150μm with a molecular weight of 39×10^6 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

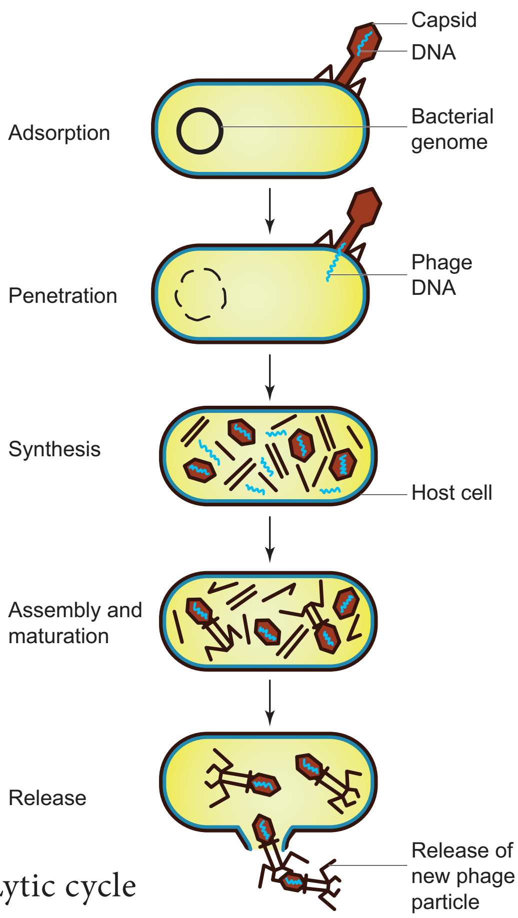
The penetration process involves mechanical and enzymatic digestion of the cell wall of the host. At the recognition site phage digests certain cell wall structure by viral enzyme (lysozyme). After pinning the tail sheath contracts (using ATP) and appears shorter and thicker. After contraction of the 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

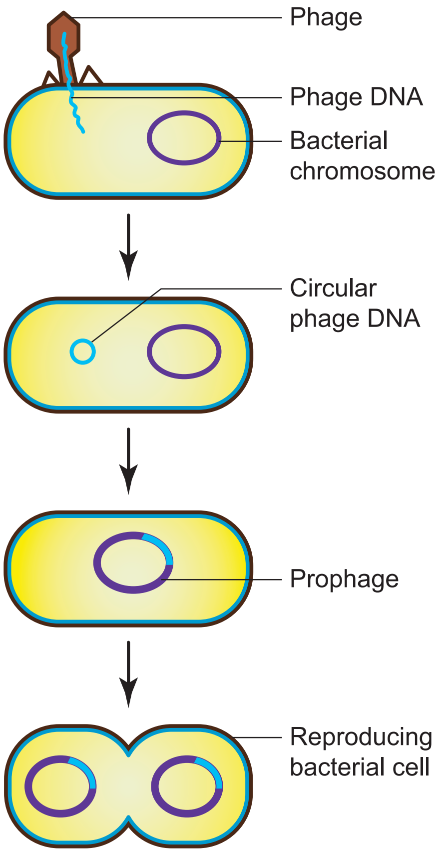
This step involves the degradation of bacterial chromosome, protein synthesis and DNA replication. The phage nucleic acid takes over the host biosynthetic machinery. Host DNA gets inactivated and breaks down. Phage DNA suppresses the synthesis of bacterial protein and directs the metabolism of the cell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



(a) Lytic cycle



(b) Lysogenic cycle

Figure 1.5: Multiplication cycle of phage,

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.

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 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.

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.**

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

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

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.

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 came 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 animal 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.

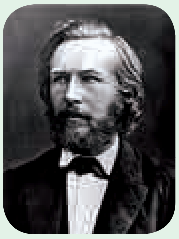
1.3.1 Need of Classification

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

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

1.3.3 Five Kingdom Classification

R.H.Whittaker, an American taxonomist proposed five Kingdom classification in the year 1969. The Kingdoms include **Monera, 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 Ruggerio *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 SuperKingdoms (**Prokaryota** and **Eukaryota**) **Prokaryota** include

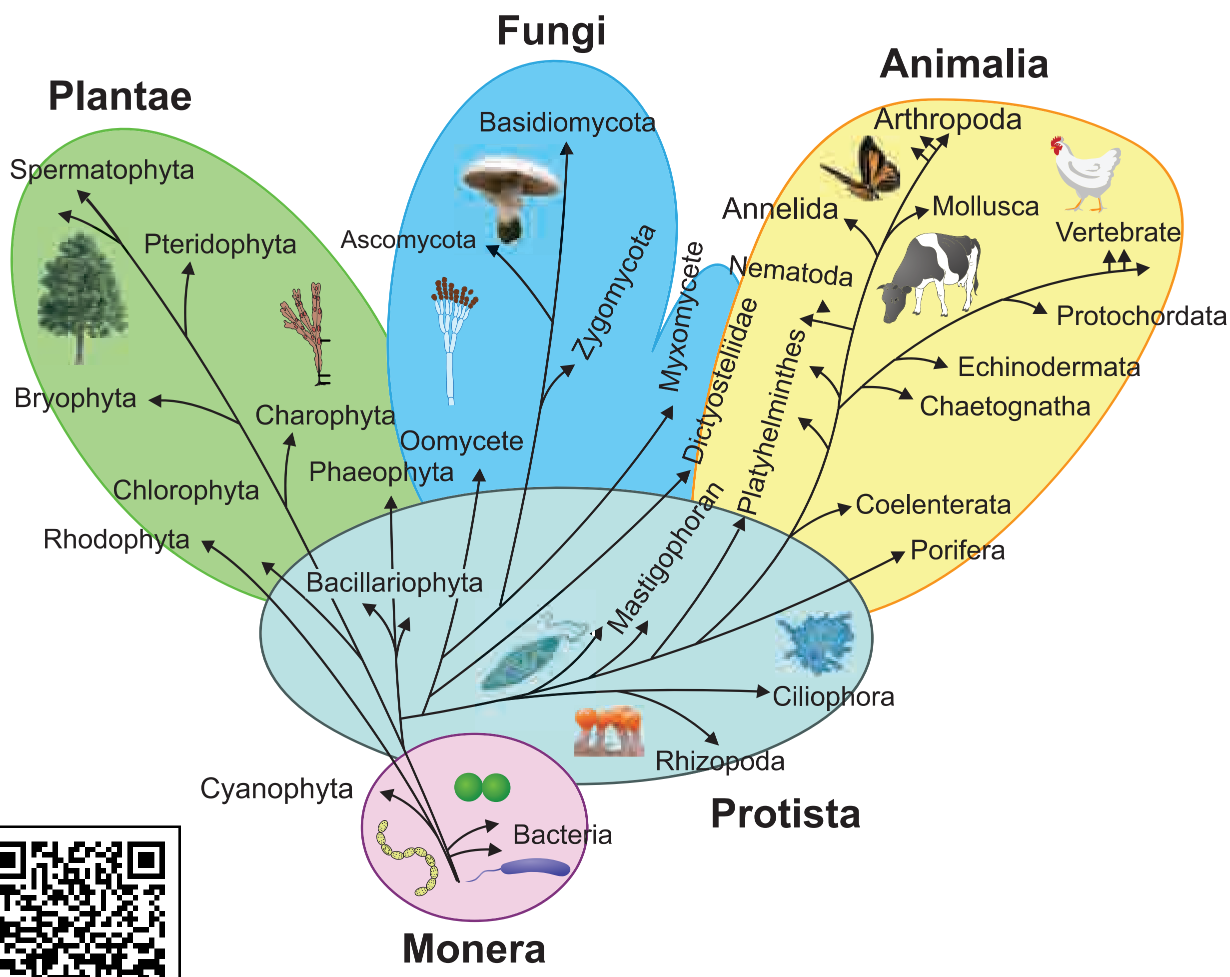


Figure 1.7: Five Kingdom classification

two Kingdoms namely **Archaebacteria** and **Eubacteria.** Eukaryota include 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 colorless 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.

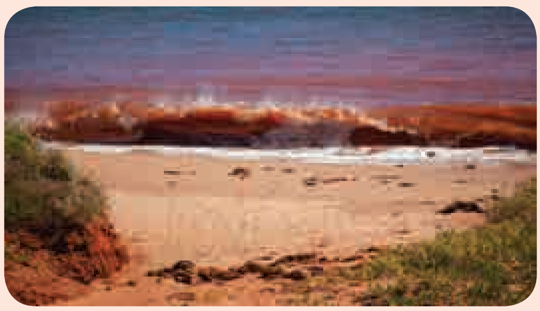


Table 1.5: Comparison of Five Kingdoms

Criteria	Kingdom				
	Monera	**Protista**	**Fungi**	**Plantae**	**Animalia**
Cell type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Level of organization	Unicellular	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

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

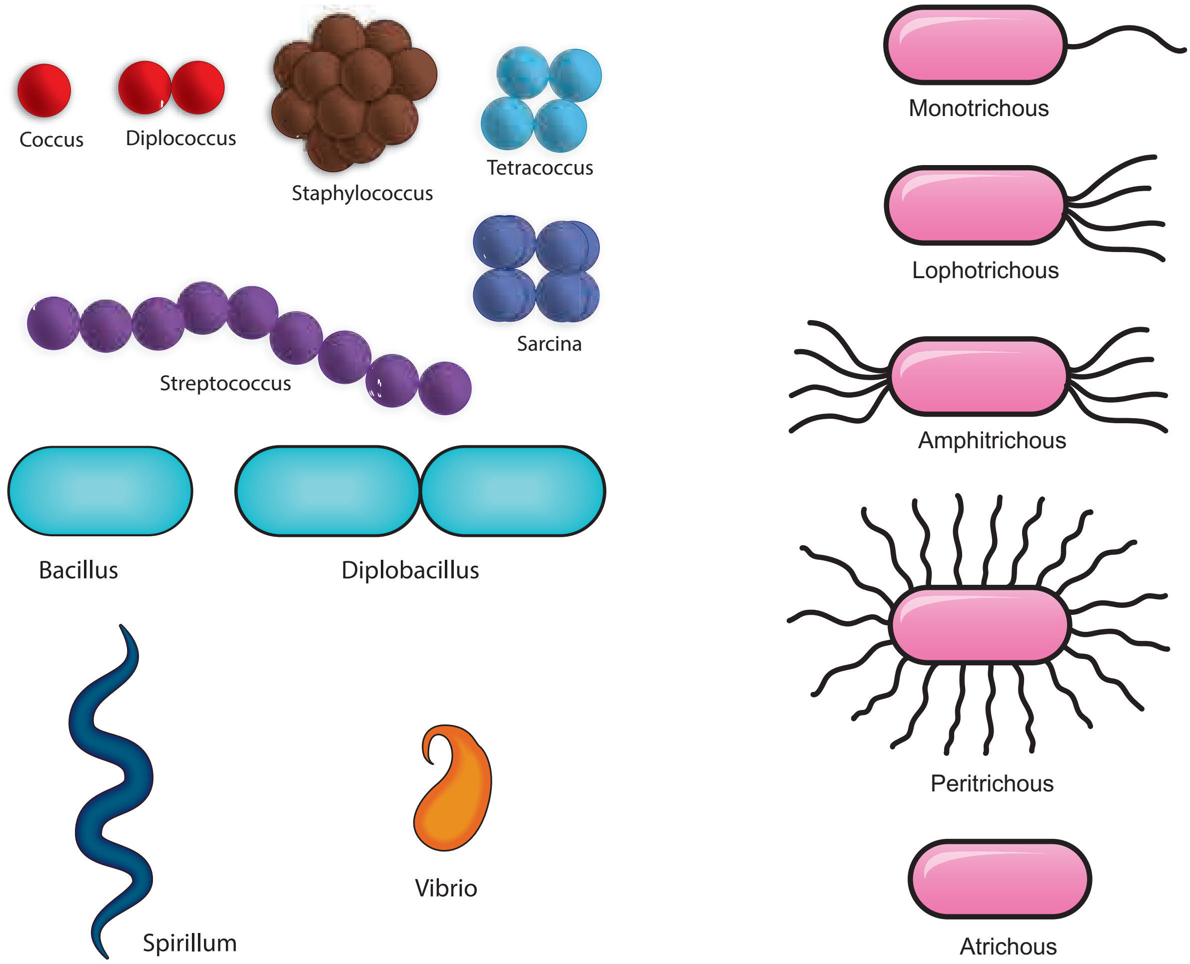


Figure 1.8: Shape and flagellation in bacteria

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)

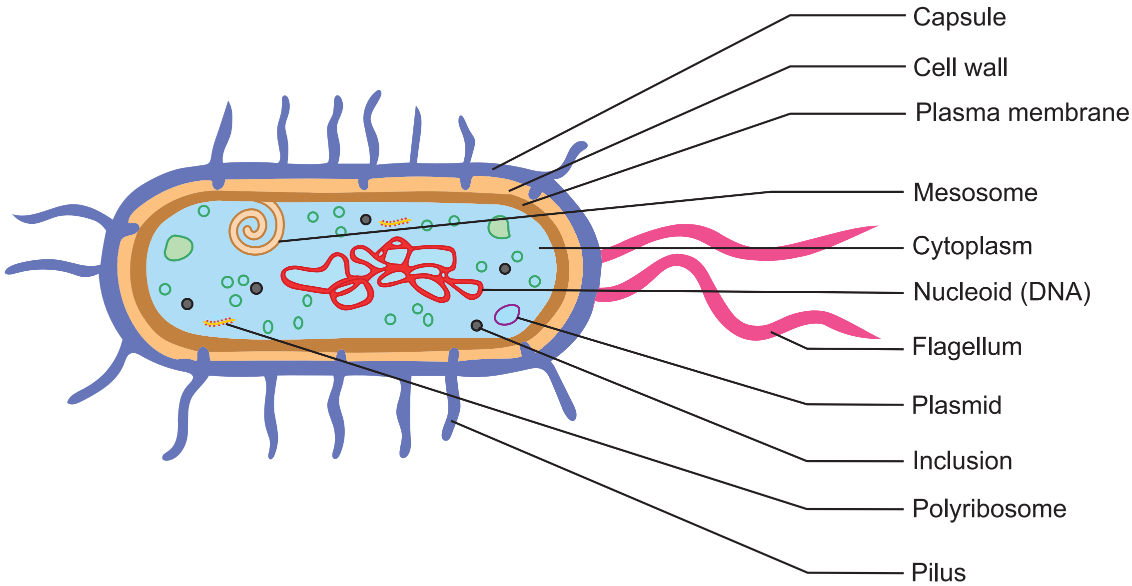


Figure 1.9: Ultrastructure of a bacterial cell

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).

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 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.

Cell wall

The bacterial cell wall is granular and is rigid. It provide 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. 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 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. 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 processes 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.

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

Most of the gram positive cell wall contain considerable amount of teichoic acid and teichuronic acid. In addition, they may contain 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 are due to differences in the structure and composition of the cell wall (Figure 1.11). The difference between Gram Positive and Gram negative bacteria is given in Table 1.6.

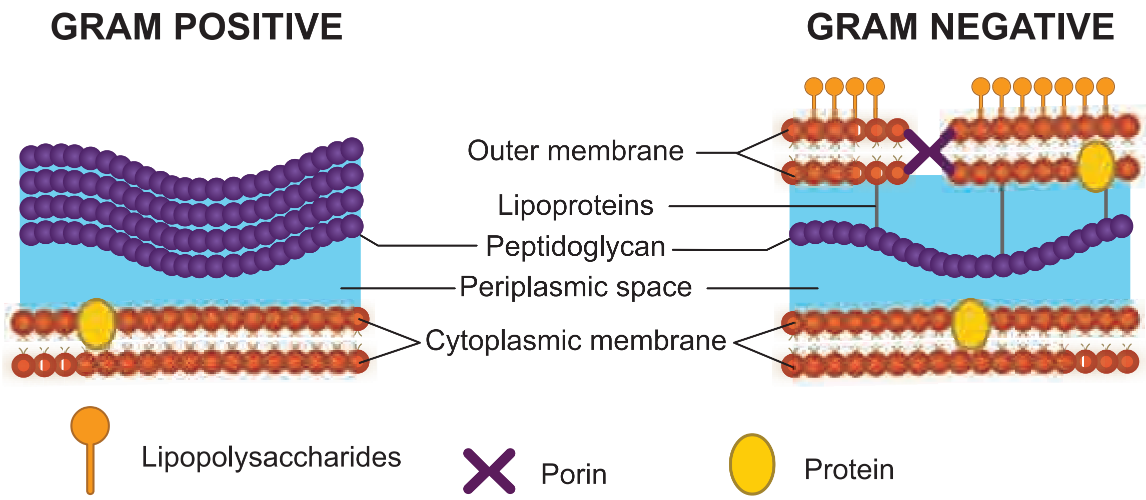


Figure 1.11: Difference between Gram positive and Gram negative bacteria

Table 1.6: Difference between Gram Positive and Gram Negative Bacteria

S.No	Characteristics	Gram positive Bacteria	Gram negative Bacteria
1.	Cell wall	Single layered with 0.015µm-0.02µm	Triple layered with 0.0075µm–0.012µm thick
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

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 is 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 synthesis 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 (*Clostridium, 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 1.12). 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.

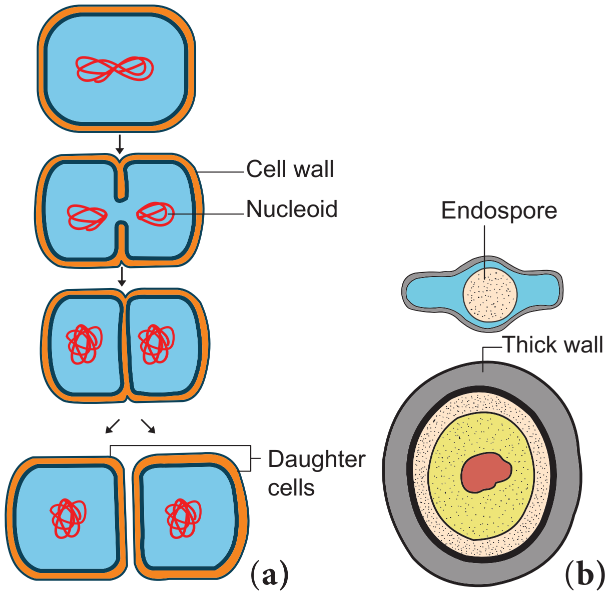


Figure 1.12: Asexual Reproduction in Bacteria (a) Binary fission, (b) Endospore

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 1.13).

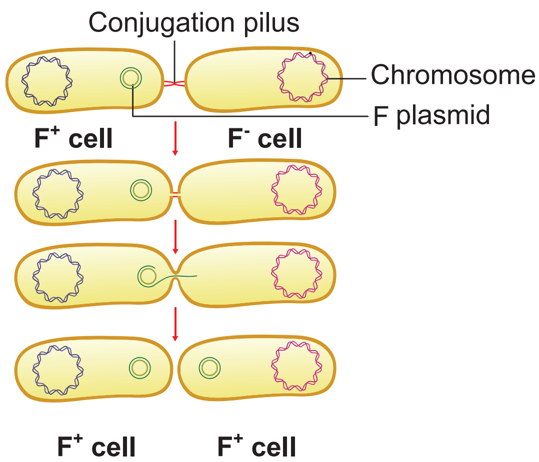


Figure 1.13: Conjugation

2. Transformation

Transfer of DNA from one bacterium to another is called transformation (Figure 1.14). 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

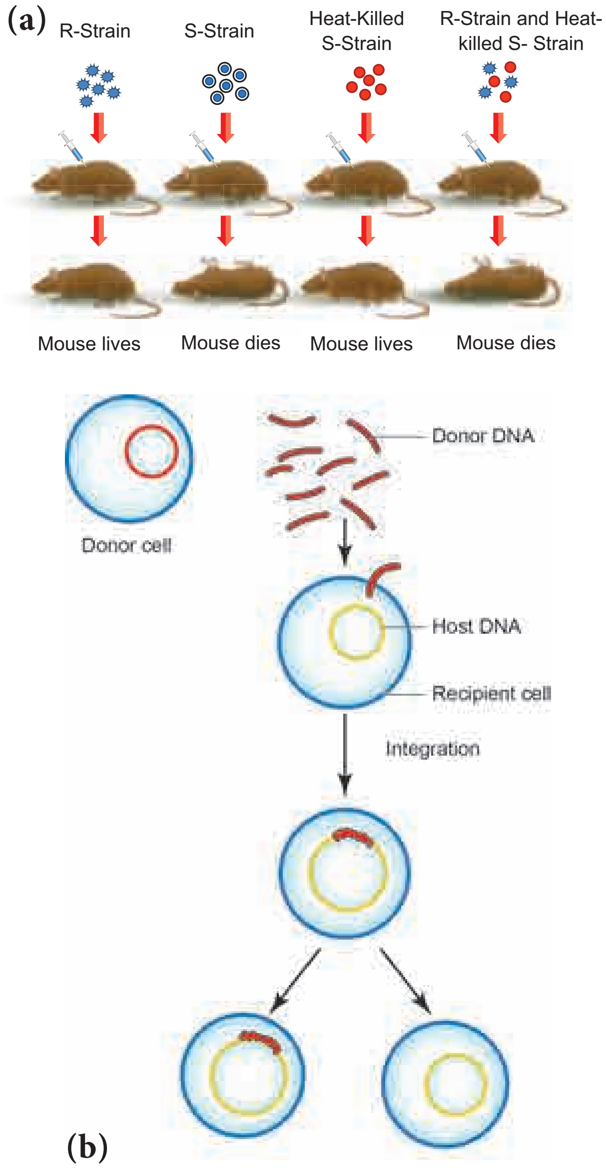


Figure 1.14: Transformation in Bacteria
(a) Griffith's experiment on Transformation
(b) Mechanism of Transformation

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.

3. Transduction

Zinder and Lederberg (1952) discovered Transduction in *Salmonella typhimurum*. Phage mediated DNA transfer is called Transduction (Figure 1.15).

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.

1.4.7 Economic importance of Bacteria

Bacteria are both beneficial and Harmful. The beneficial activities of bacteria are given in Table 1.7.

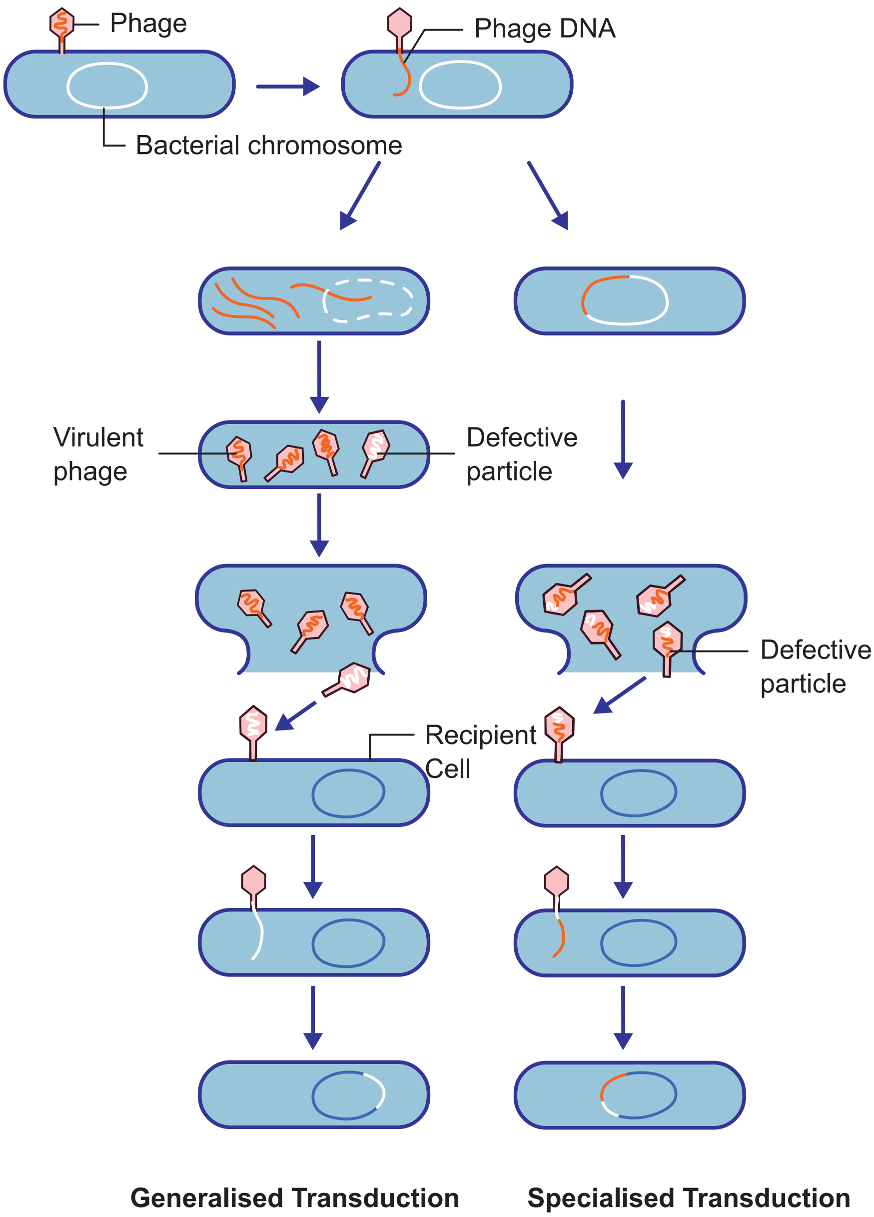


Figure 1.15: Transduction in Bacteria

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	*Streptococcus lactis* and *Lactobacillus bulgaricus*	Convert milk sugar lactose into lactic acid
2. Butter	*Streptococcus lactis,* *Leuconostoc citrovorum*	Convert milk into butter, cheese, curd and yoghurt
3. cheese	*Lactobacillus acidophobus,* *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)

(Continued)

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	*Mycococcus candisans, 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 1.16.

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

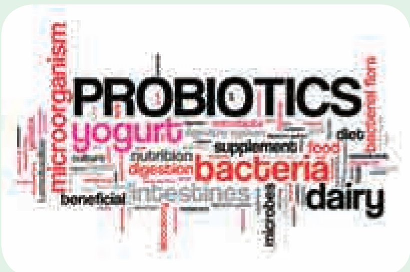
S. No	Name of the Animal	Name of the disease	Name of the pathogen
1.	Sheep	Anthrax	*Bacillus anthracis*
2.	Cattle	Brucellosis	*Brucella abortus*
3.	Cattle	Bovine tuberculosis	*Mycobacterium bovis*
4.	Cattle	Black leg	*Clostridium chanvei*

Table 1.10: Human diseases caused by Bacteria		
S.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 1.16: Plant diseases caused by bacteria (a) Citrus canker (b) Potato scab

Have you heard about the word "Probiotics"



Probiotic milk products, tooth paste are available in the Market. *Lactobacillus, 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*.

DO YOU KNOW?

- *Pseudomonas putida* is a superbug genetically engineered which breakdown hydrocarbons.
- "Pruteen" is a single cell protein derived from *Methylophilus* and *Methylotropus*.
- *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.

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.

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 sea (Red sea). Species of *Nostoc*, *Anabaena* lead an endophytic life in the coralloid root of *Cycas*, leaves of aquatic fern *Azolla* and thallus of hornworts like *Anthoceros* 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-phyocyanin 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, 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 1.17

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

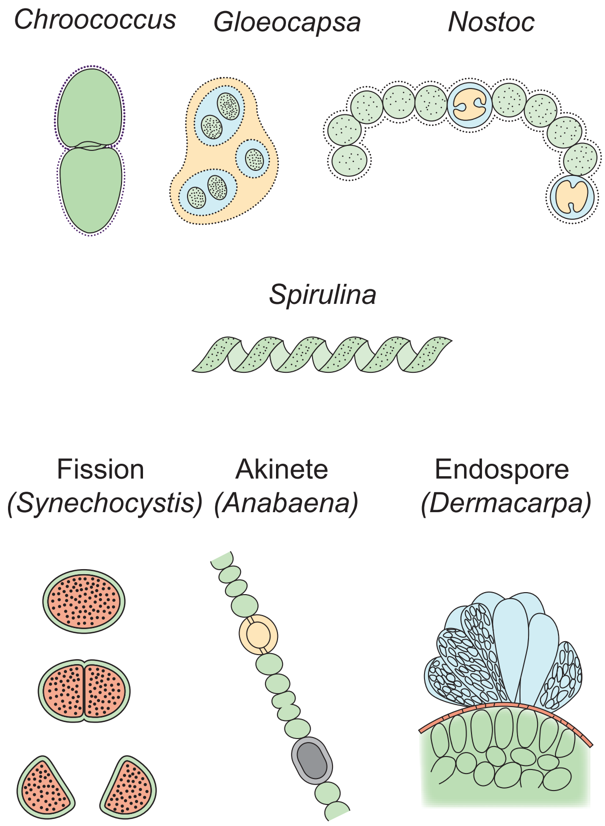


Figure 1.17: Structure and reproduction in cyanophyceae

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 appears 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 1.18.

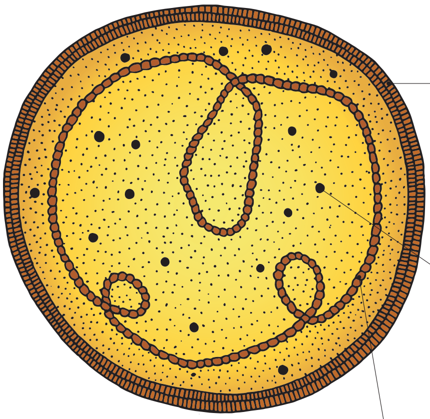


Figure 1.18: Structure of *Mycoplasma*

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 contain 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 odor" 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

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 was awarded Nobel Prize in Medicine in the year 1945.

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
1906	A.F.Blakeslee reported heterothallism in fungi
1952	Pontecarvo and Raper 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 (1874-1943)

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) 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).
- The fungal mycelium is categorised into two types based on the presence or absence of septa (Figure 1.19). 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*.

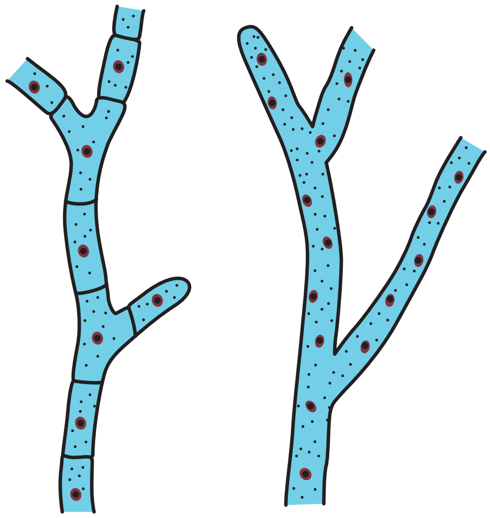


Figure 1.19: Types of mycelium

- 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**.

In 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 1.20.

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*)

3. Oidia/Thallospores/Arthrospores: The hypha divide and develop in to spores called oidia (Example: *Erysiphe*).

4. Fission: The vegetative cell divide into 2 daughter cells. (Example: *Schizosaccharomyces*-yeast).

5. Budding: A small outgrowth is developed on parent cell, which gets detached and become 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*).

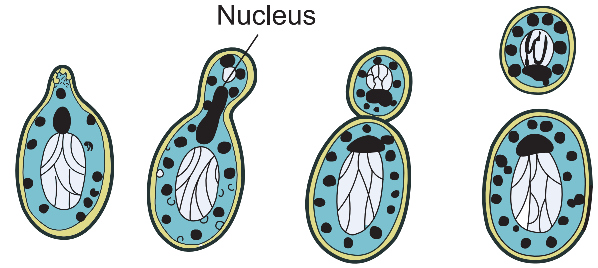
c. Oogamy – Fusion of both morphologically and physiologically dissimilar gametes. (Example: *Monoblepharis*)

2. Gametangial contact: During sexual reproduction a contact is established between antheridium and Oogonium (Example: *Albugo*)

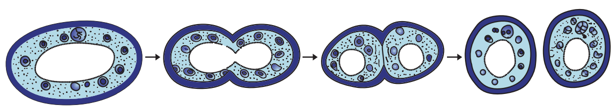
3. Gametangial copulation: Fusion of gametangia to form zygospore (Example: *Mucor, Rhizopus*).

4. Spermatization: In this method a uninucleate pycniospore/microconidium is transferred to receptive hyphal cell (Example: *Puccinia/Neurospora*)

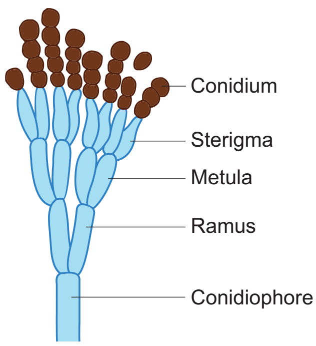
5. Somatogamy: Fusion of two somatic cells of the hyphae (Example: *Agaricus*)



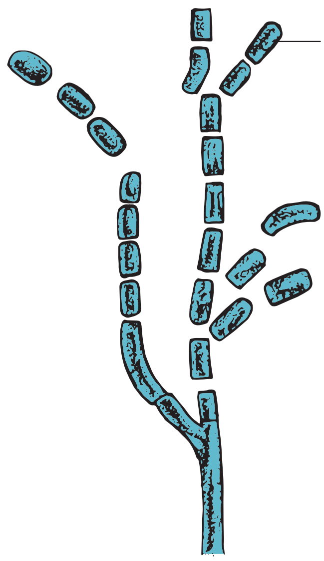
(a) Budding - Yeast



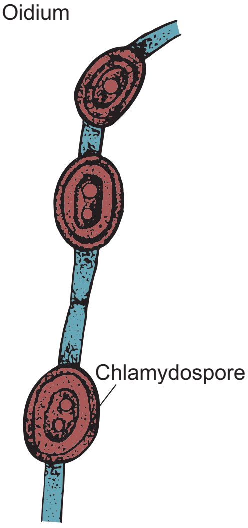
(b) Fission - Yeast



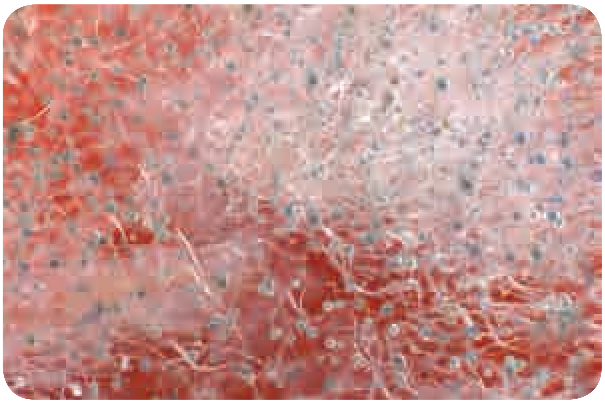
(c) Conidia formation - *Penicillium*



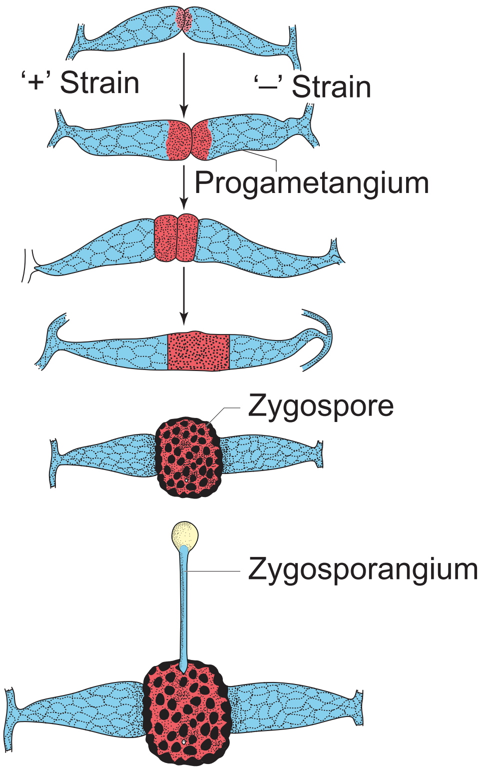
(d) Thallospore - *Erysiphe*



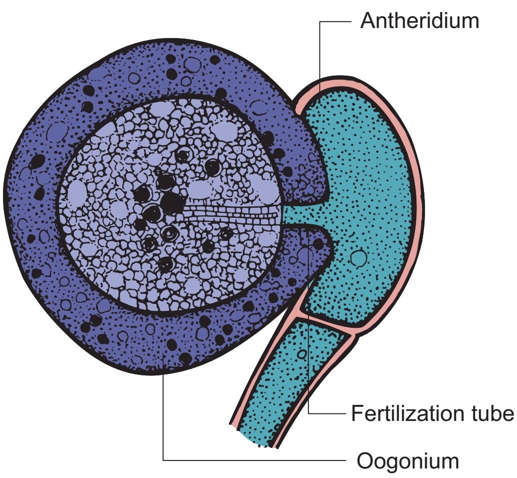
(e) Chlamydospore - *Fusarium*



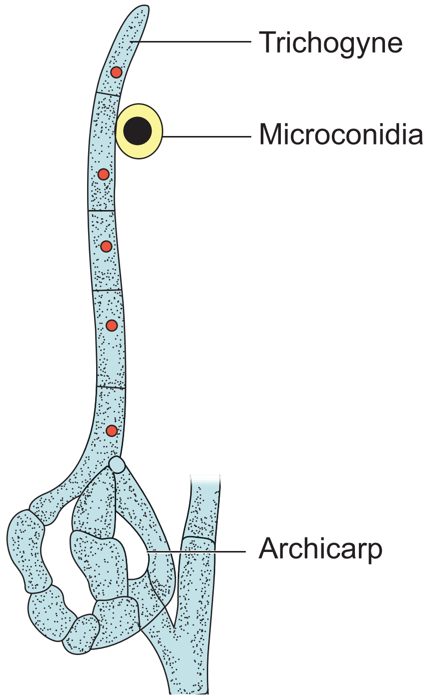
(f) Sporangia - *Mucor*



(g) Gametangial copulation - *Rhizopus*



(h) Gametangial contact - *Albugo*



(i) Spermatisation - *Neurospora*

Figure 1.20: 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 outline of the classification is given below:

KINGDOM - MYCETEAE

DIVISION – GYMNOMYCOTA

SUBDIVISION – 1
ACRASIOGYMNOMYCOTINA
CLASS – Acrasiomycetes

SUBDIVISION – 2
PLASMODIOGYMNOMY-
COTINA
CLASS – Protosteliomycetes
CLASS- Myxomycetes

DIVISION - MASTIGOMYCOTA

SUBDIVISION – 1
HAPLOMASTIGOMYCOTINA
CLASS – Chytridiomycetes
CLASS – Hyphochytridiomycetes
CLASS – Plasmodiophoromycetes

SUBDIVISION – 2
DIPLOMASTIGOMYCOTINA
CLASS - Oomycetes

DIVISION – AMASTIGOMYCOTA

SUBDIVISION -1
ZYGOMYCOTINA
Class – Zygomycetes
Class- Trichomycetes

SUBDIVISION -2
ASCOMYCOTINA
CLASS – Ascomycetes

SUBDIVISION -3
BASIDIOMYCOTINA
CLASS – Basidiomycetes

SUBDIVISION -4
DEUTEROMYCOTINA
CLASS - Deuteromycetes

1.5.5 Kingdom : Myceteae (Fungi)

Include achlorophyllous, saprophytic or parasitic organisms with Unicellular or multicellular (Mycelium) thallus surrounded by chitinous cell wall. Nutrition is absorptive except slime molds.Reproduction is through asexual and Sexual methods.

Division : I Gymnomycota

Nutrition Phagotrophic, members of this group lack cell wall. Example. *Dictyostelium*

Division :II Mastigomycota

Flagellate cells are present(Gamete/ Zoospore). Nutrition absorptive, mycelium coenocytic. Example : *Albugo*

Division : III Amastigomycota

Unicellular to multicellular forms are included. The mycelium is septate. Asexual reproduction occurs by budding, fragmentation, sporangiospores, conidia etc., Meiosis is zygotic. Example : *Peziza*

Recently, with the advent of molecular methods myxomycetes and oomycetes were reclassified and treated under chromista.

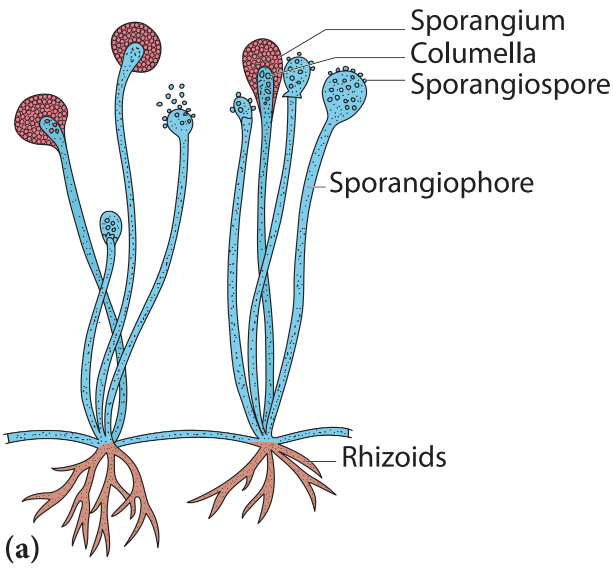
The salient features of some of the classes – Oomycetes, Zygomycetes, Ascomycetes, Basidiomycetes and Form class Deuteromycetes are discussed below.

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 1.21).



(a)

(b)

Figure 1.21: Zygomycetes (a) *Rhizopus* (b) *Pilobolus*

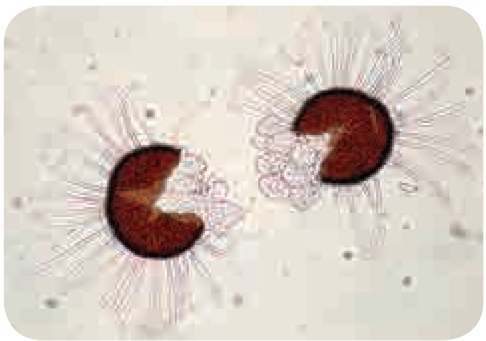
- The mycelium is branched and coenocytic.
- Asexual reproduction by means of spores produced in sporangia.
- Sexual reproduction is by the fusion of the gametangia which results in thick walled zygospore. It remains dormant for long periods. The zygospore undergoes meiosis and produce spores.

Ascomycetes

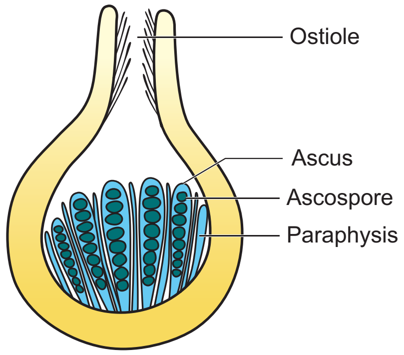
- Ascomycetes include a wide range of fungi such as yeasts, powdery mildews, cup fungi, morels and so on (Figure 1.22).

(a) *Morchella*

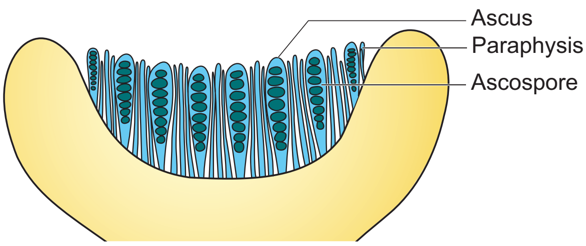
(b) *Peziza*



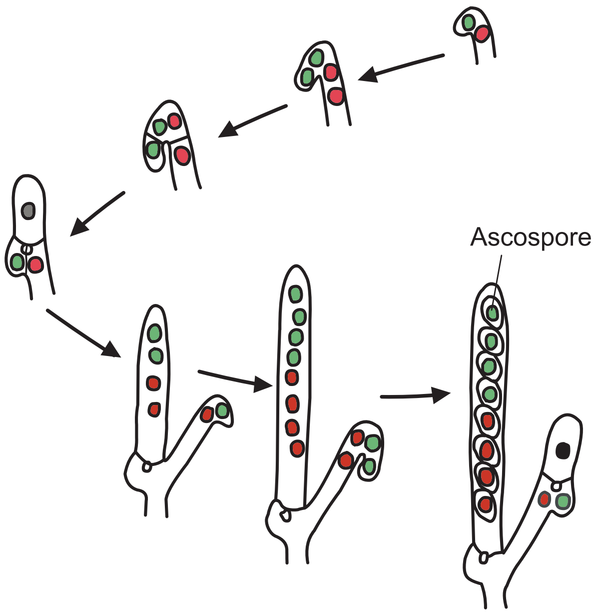
(c) Cleistothecium



(d) V.S. of Perithecium



(e) V.S. of Apothecium



(f) Steps involved in the development of Ascus

Figure 1.22: Structure and reproduction in Ascomycetes

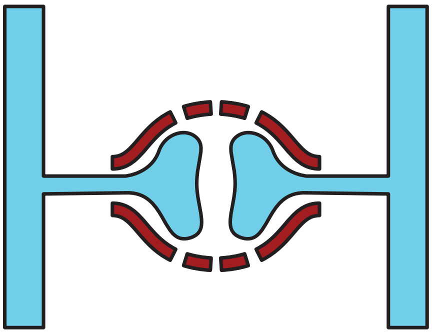
- Although majority of the species live in terrestrial environment, some live in aquatic environments both fresh water and marine.
- The mycelium is well developed, branched with simple septum.
- Majority of them are saprophytes but few parasites are also known (Powdery mildew – *Erysiphe*).
- Asexual reproduction takes place by fission, budding, oidia, conidia, 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 form 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

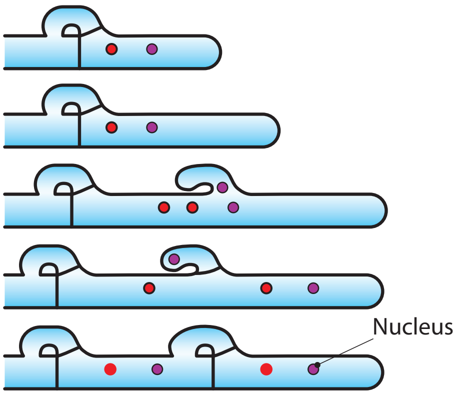
- Basidiomycetes include puff balls, toad stools, Bird's nest fungi, Bracket fungi, stink horns, rusts and smuts (Figure 1.23).

(a) *Agaricus*

(b) *Geaster*



(c) Dolipore septum



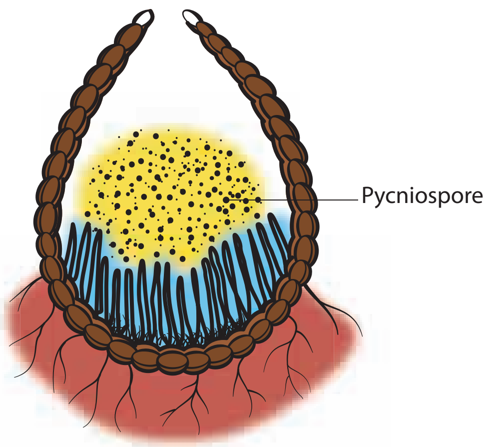
(d) Clamp connection

Figure 1.23: Structure and Reproduction in Basidiomycetes

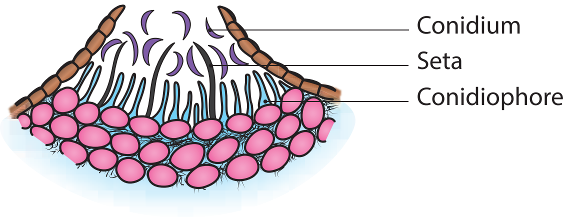
- The members are terrestrial and lead a saprophytic and parasitic mode of life.
- The mycelium is well developed, septate with dolipore septum(bracket like). Three types of mycelium namely Primary (Monokaryotic), Secondary (Dikaryotic) and tertiary are found.
- Clamp connections are formed to maintain 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

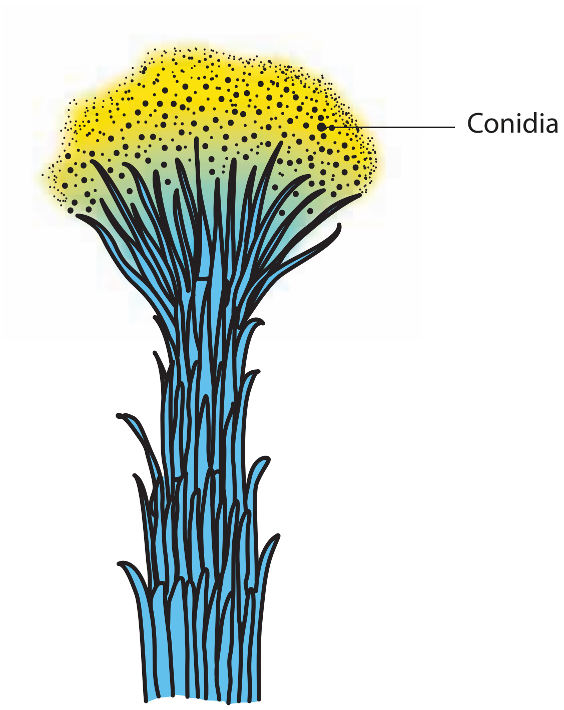
The fungi belonging to this group lack sexual reproduction and are called imperfect fungi. A large number of species live as saprophytes in soil and many are plant and animal parasites. Asexual reproduction takes place by the production of conidia, chlamydospores, budding, oidia etc., Conidia are also produced in special structures called pycnidium, Acervulus, sporodochium and Synnema



(a) Pycnidium - *Phoma*



(b) Acervulus - *Colletotrichum*



(c) Synnema - *Graphium*

Figure 1.24: Reproduction in Deuteromycetes

(Figure 1.24). Parasexual cycle operates in this group of fungi. This brings genetic variation among the species.

1.5.6. 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 and Figure 1.25)

(a) Rust of wheat

(b) Anthracnose of beans

Figure 1.25: Fungal disease in plants.

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 1.4

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

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.

1.5.7 *Rhizopus*

Class - Zygomycetes
Order - Mucorales
Family - Mucoraceae
Genus - *Rhizopus*

Rhizopus is a saprophytic fungus and grows on substrates like bread, jelly, leather, decaying vegetables and fruits. It is commonly called 'Bread mold'. *Rhizopus stolonifer* causes leak and soft rot of vegetables

Vegetative structure

The mycelium consists of aseptate, multinucleate (coenocyte) and profusely branched hyphae. There are horizontally growing aerial hyphae called **stolons**. The stolons produce rhizoids which are branched and penetrate the substratum and help in absorbing water and nutrients. Sporangiophores are borne exactly opposite to the rhizoids. The cell wall is made up of chitin and chitosan. The cell wall is followed by plasma membrane. The protoplast is granular containing many nuclei. Cell organelles like mitochondria, ribosomes and endoplasmic reticulum are present. The cell inclusions like glycogen and oil droplets are also found.

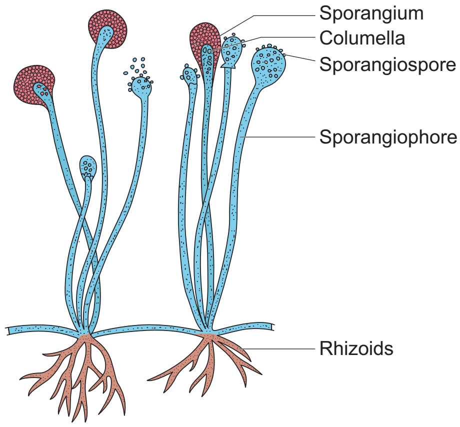


Figure 1.26: *Rhizopus*

Reproduction

Rhizopus reproduces by asexual and sexual methods.

Asexual reproduction

During favorable conditions, erect sporangiophores are produced exactly opposite to the region of formation of rhizoids of the mycelium. The sporangiophores are unicellular, unbranched and multinucleate structures which bear bag like structure called sporangia. Each sporangiophore bears a single sporangium.

Sporangium possesses a sterile region in the centre called **Columella**. Spores are produced around the columella. When the sporangial wall breaks, the columella collapses and the spores are dispersed. When the spores fall on a suitable substratum they germinate and produce new mycelia (Figure 1.26).

Sexual reproduction

Sexual reproduction is present and takes place through gametangial copulation. Most of the species are heterothallic but *Rhizopus sexualis* is homothallic. There is no morphological distinction between the two sexual hyphae although physiologically they are dissimilar. Since physiologically dissimilar thalli (hyphae) are involved in sexual reproduction, this phenomenon is called **heterothallism**. Mycelia which produce gametangia are of opposite strains (+) or (-). The first step is the formation of special hyphae called zygophores. The tips of the two zygophores swell to form progametangia. Further, a septum is formed near the tip of each progametangium and results in the formation of a terminal gametangium and a suspensor cell. The two gametangia fuse, and this is followed by plasmogamy and karyogamy. The fusion of nuclei results in the formation of a diploid zygospore. Many nuclei belonging to opposite strains (+ or –) pair and fuse to form many diploid nuclei. The zygospore enlarges and develops an outer thick dark and warty layer called exine and inner thin layer called intine. After the resting period the nuclei of zygospore undergo meiosis. The zygospore germinates to form sporangiophores and the zygosporangium contain mixture of (+) and (–) spores. When the spores fall on a suitable substratum, they germinate to produce mycelium (Figure 1.20). The life cycle of *Rhizopus* is given in figure 1.27.

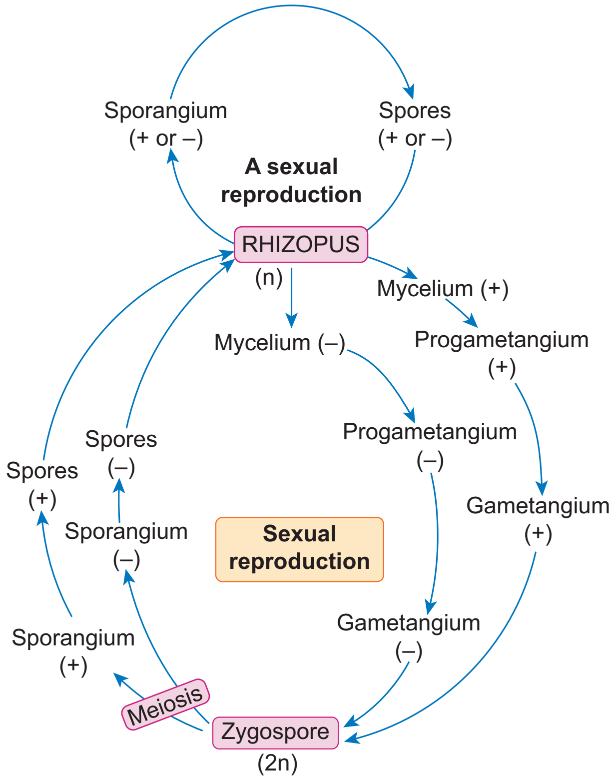


Figure 1.27: Life cycle of *Rhizopus*

1.5.8 Agaricus

Class - Basidiomycetes
Order - Agaricales
Family - Agaricaceae
Genus - *Agaricus*

It is a saprophytic fungus found on wood logs, manure piles, fresh litter, pastures etc., The fruit bodies are the visible part of the fungi. They are found in rings in some species like *Agaricus arvensis*, *Agaricus tabularis* and hence popularly called 'Fairy rings". *Agaricus campestris* is the most common 'field mushroom'.

Vegetative structure

The thallus is made up of branched structures called hyphae. A large number of hyphae constitute the mycelium.

Three types of mycelia are seen namely primary mycelium, secondary mycelium and tertiary mycelium, The primary mycelium develops from the germination of basidiospore. It is septate, uninucleate and haploid. It is also called **monokaryotic mycelium**. Fusion of two primary mycelium of opposite strains give rise to secondary mycelium or **dikaryotic mycelium**. The dikaryotic mycelium develops into hyphal cords called **Rhizomorphs**,. and perennates the soil for a long period. The tertiary mycelium is found in the fruit body called **basidiocarp**. Each cell of the hyphae posssess a cell wall made up of chitin and cell organelles like mitochondria, golgibodies, Endoplasmic reticulum etc., are also present.

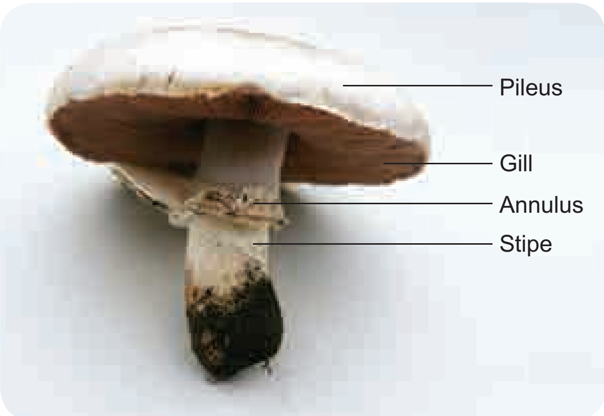


Figure 1.28: *Agaricus*-Basidiocarp

Asexual reproduction.

Agaricus produces chlamydospores during asexual reproduction. During favourable condition the chlamydospores germinate and produce mycelium.

Sexual reproduction

Agaricus reproduces by sexual method but sex organs are absent.Majority of the species are heterothallic. *Agaricus bisporus* is a homothallic species. The opposite strains of mycelium fuse(somatogamy) and results in the formation of dikaryotic or secondary mycelium. Karyogamy takes place in basidium and it is immediately followed by meiosis giving rise to four haploid basidiospores. The basidiospores are borne on sterigmata. The subterranean mycelial strands called rhizomorphs posssess dense knots of dikaryotic hyphae. These knots develop into Basidiocarps.

Basidiocarp

The mature basidiocarp is umbrella shaped and is divided into 3 parts namely stipe, pileus and gill. The stipe is thick, fleshy and cylindrical in structure. The upper part of the stipe possess a membranous structure called **annulus**. The upper convex surface is called **Pileus** which is white or cream in colour (Figure 1.28). The inner surface of pileus shows radially arranged **gills** or lamellae. The gills vary in length. On both the sides of the gills a fertile layer called **hymenium** is present. The stipe is hollow from the centre and the central part is made up of loosely arranged hyphae whereas the periphery is made up of compactly arranged hyphae forming **pseudoparenchymatous** tissue. The gill region is divided into 3 regions. The central part of gill between two hymenial layers is called **Trama** (Figure 1.29). The subhymenial layers have closely compact tissue . The **hymenium** is the fertile layer and possess club shaped basidia. The basidium is interspersed with sterile hyphae called paraphysis. Each basidium bears 4 basidiospores , of these two basidiospore belong to (+) strain and other two of them will be (–) strain. The basidiospores are borne on stalk like structures called **Sterigmata**. The basidiospore on germination produces

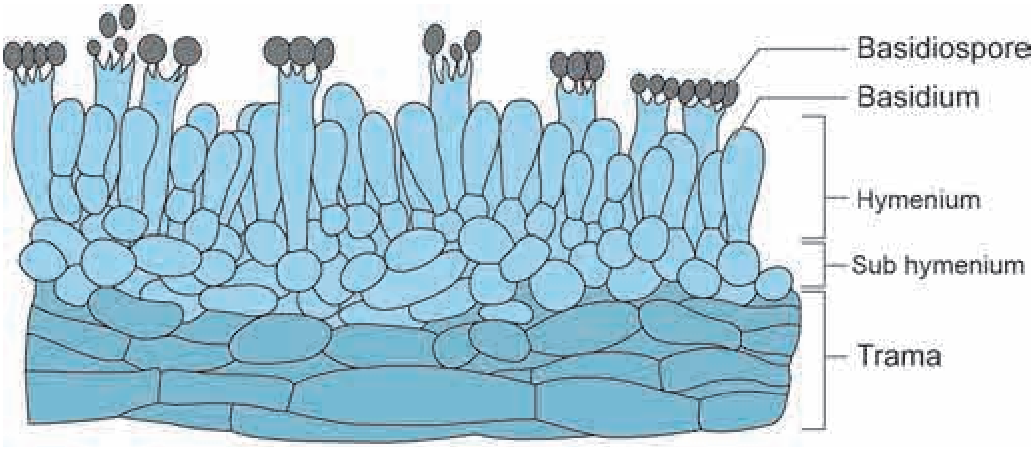


Figure 1.29: V.S. of *Agaricus* gill

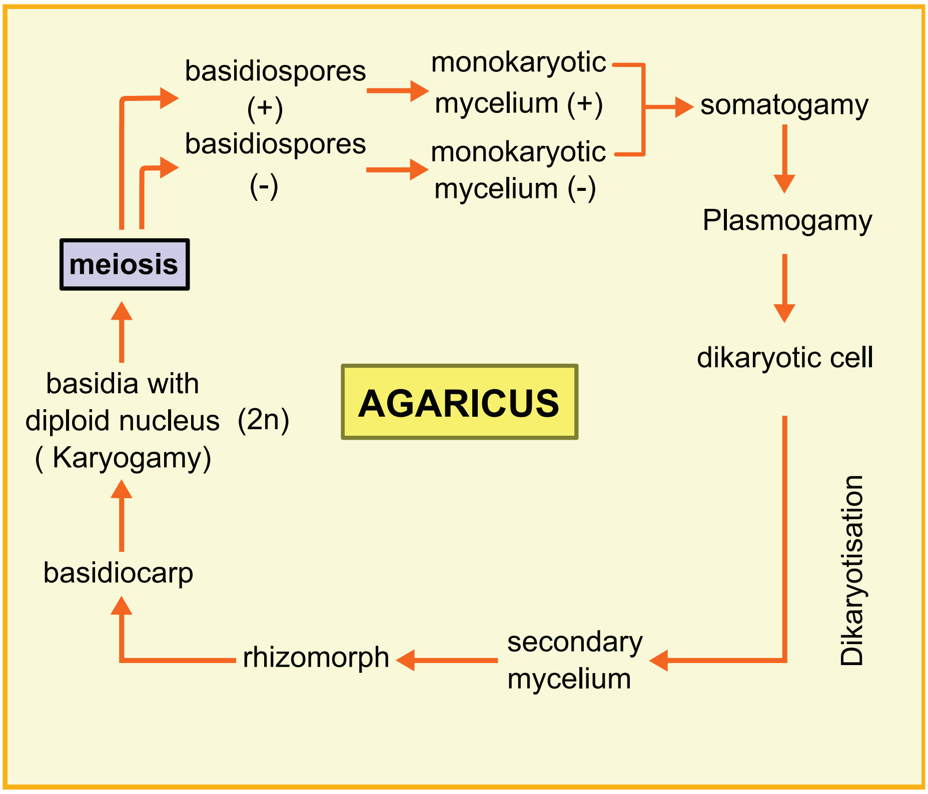


Figure 1.30: Life Cycle of *Agaricus*

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the haploid primary mycelium.

Thus the life cycle of *Agaricus* shows a very short diploid phase, haploid phase and a prolonged dikaryotic phase (Figure 1.30).

1.5.9 Mycorrhizae

The symbiotic association between fungal mycelium and roots of plants is called as mycorrhizae. In this relationship fungi absorbs 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 1.31) Mycorrhizae are classified into three types

Importance of Mycorrhizae

- Helps to derive nutrition in *Monotropa*, a saprophytic angiosperm,
- Improves the availability of minerals

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 Hartignet. 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(VAM) Example: *Gigaspora* 2. Ericoid mycorrhizae -Example: *Oidiodendron* 3. Orchid mycorrhizae -Example: *Rhizoctonia*	The fungi form both mantle and also penetrates the cortical cells.

and water to the plants.

- Provides drought resistance to the plants
- Protects roots of higher plants from the attack of plant pathogens

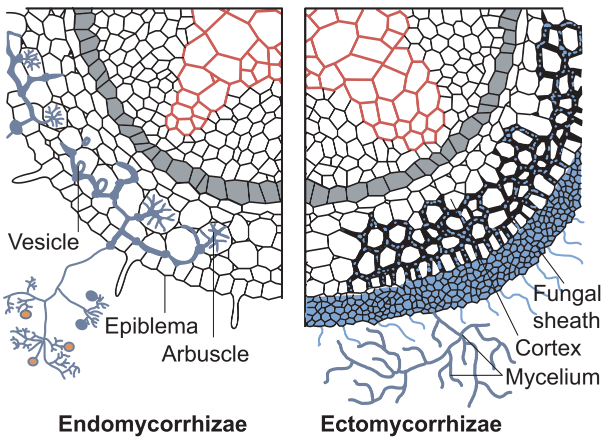


Figure 1.31: T.S. of root showing mycorrhizae

1.5.10 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**(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 1.32).
- 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**.

(a) Crustose lichen

(b) Foliose Lichen

(c) Fruticose Lichen

Figure 1.32: Types of Lichens

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 moss) 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.

Rhizopus is commonly called' Bread mold fungi'. It belongs to the class Zygomycetes. Asexual reproduction occurs by the production of sporangiospores. During sexual reproduction gametangial copulation occurs and zygospore is formed. *Agaricus* belongs to the class Basidiomycetes.It is a saprophytic fungus. Three types of mycelium , primary, secondary and tertiary mycelium are produced. Sexual reproduction is present .Basidiocarps are produced after the sexual reproduction. It bears basidia on which four basidiospores are produced.

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

5E5LPE

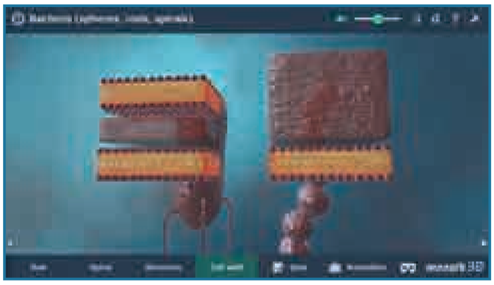
1. Which one of the following statement about virus is correct
   a. Possess their own metabolic system
   b. They are facultative parasites
   c. They contain DNA or RNA
   d. Enzymes are present
2. Identify the incorrect statement about the Gram positive bacteria
   a. Teichoic acid absent
   b. High 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.
11. Explain the asexual reproduction in *Rhizopus*.
12. Mention the steps involved in the sexual reproduction of *Rhizopus*.
13. Write outline the life cycle of *Agaricus*.
14. What is Sterigma?
15. Name the types of mycelium found in *Agaricus*.
16. Differentiate oidium and Chlamydospore.
17. Name the fungal group which possess dolipore septum.
18. Mention the diseases caused by fungi in plants.
19. Give two examples for mycorrhizae forming fungi.
20. Differentiate Gram positive and Gram negative bacteria.

ICT Corner

Bacteria

Let’s explore the structure and shapes of **Bacteria.** →

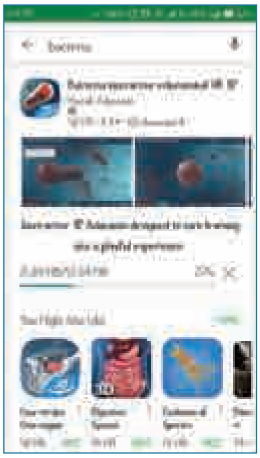


Steps

- 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

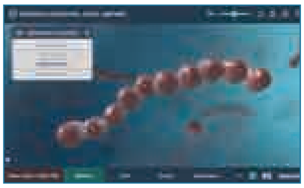
- Select structure tap and note the internal structure of bacteria
- Click cell wall and note the difference between different shapes



Step 1

Step 2

Step 3



Step 4

Step 5

URL:

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

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* Pictures are indicative only

Chapter 2

Plant Kingdom

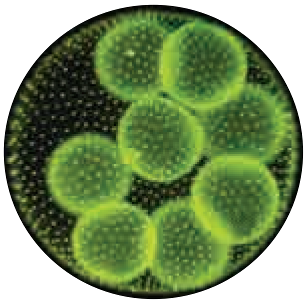
Learning Objectives

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*
- *Describe the structure, reproduction of Oedogonium and Chara*
- *Recognize the general characteristic features of Bryophytes*
- *Describe the structure, reproduction of Marchantia and Funaria*
- *Recognize the general characteristic features of Pteridophytes*
- *Describe the structure, reproduction of Selaginella and Adiantum*
- *Describe the general characteristic features of Gymnosperms*
- *Explain the structure, reproduction of Cycas and Pinus*
- *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 the 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).

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.

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

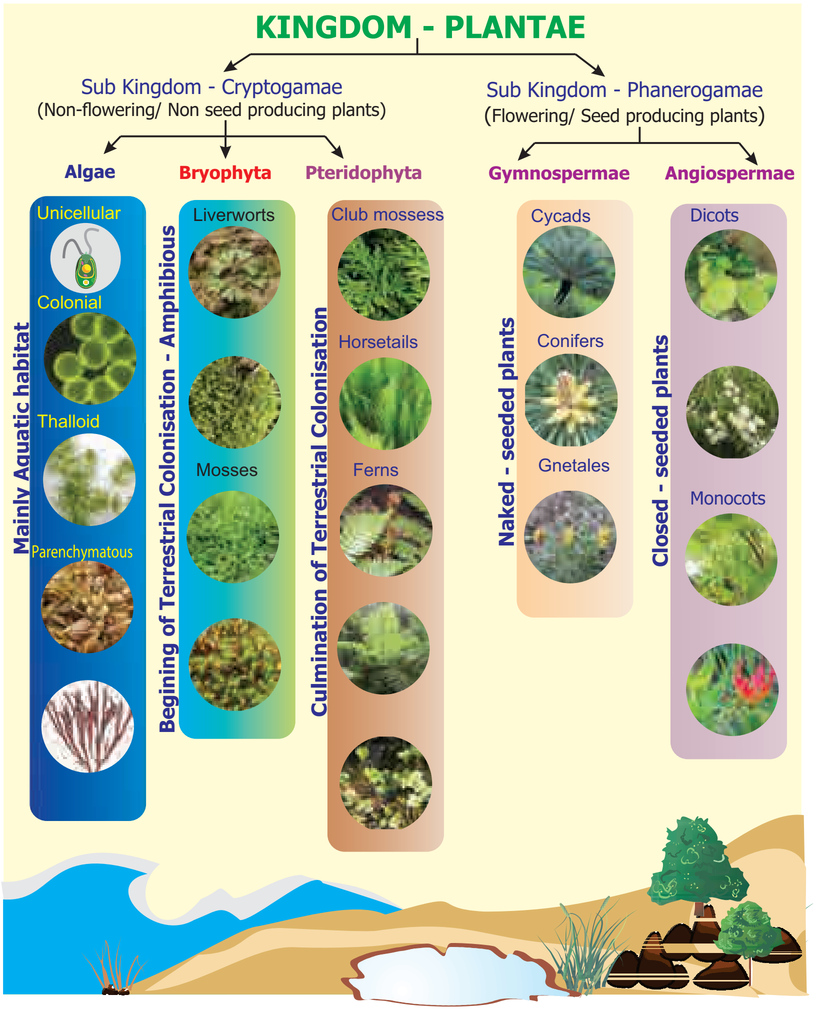


Figure 2.1: Classification of Plant Kingdom

2.2 Life Cycle Patterns in Plants

Alternation of Generation

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

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.

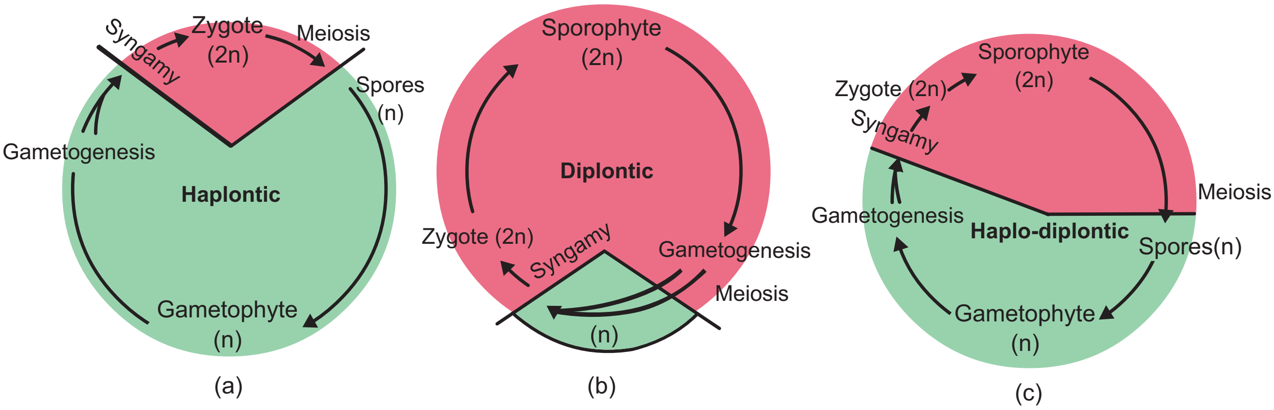


Figure 2.2: Life cycle patterns in plants a) Haplontic, b) Diplontic, c) Haplo-diplontic

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

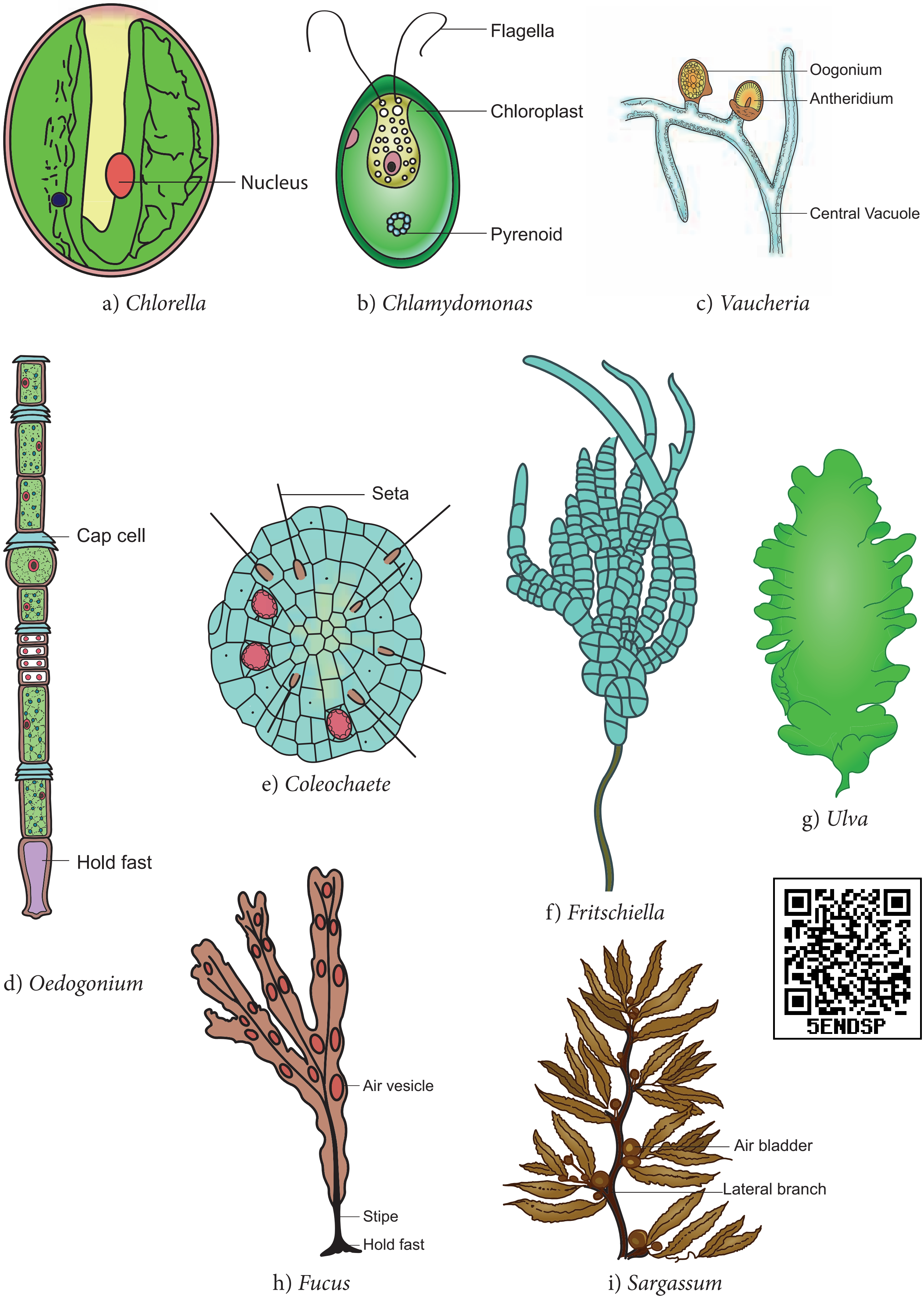
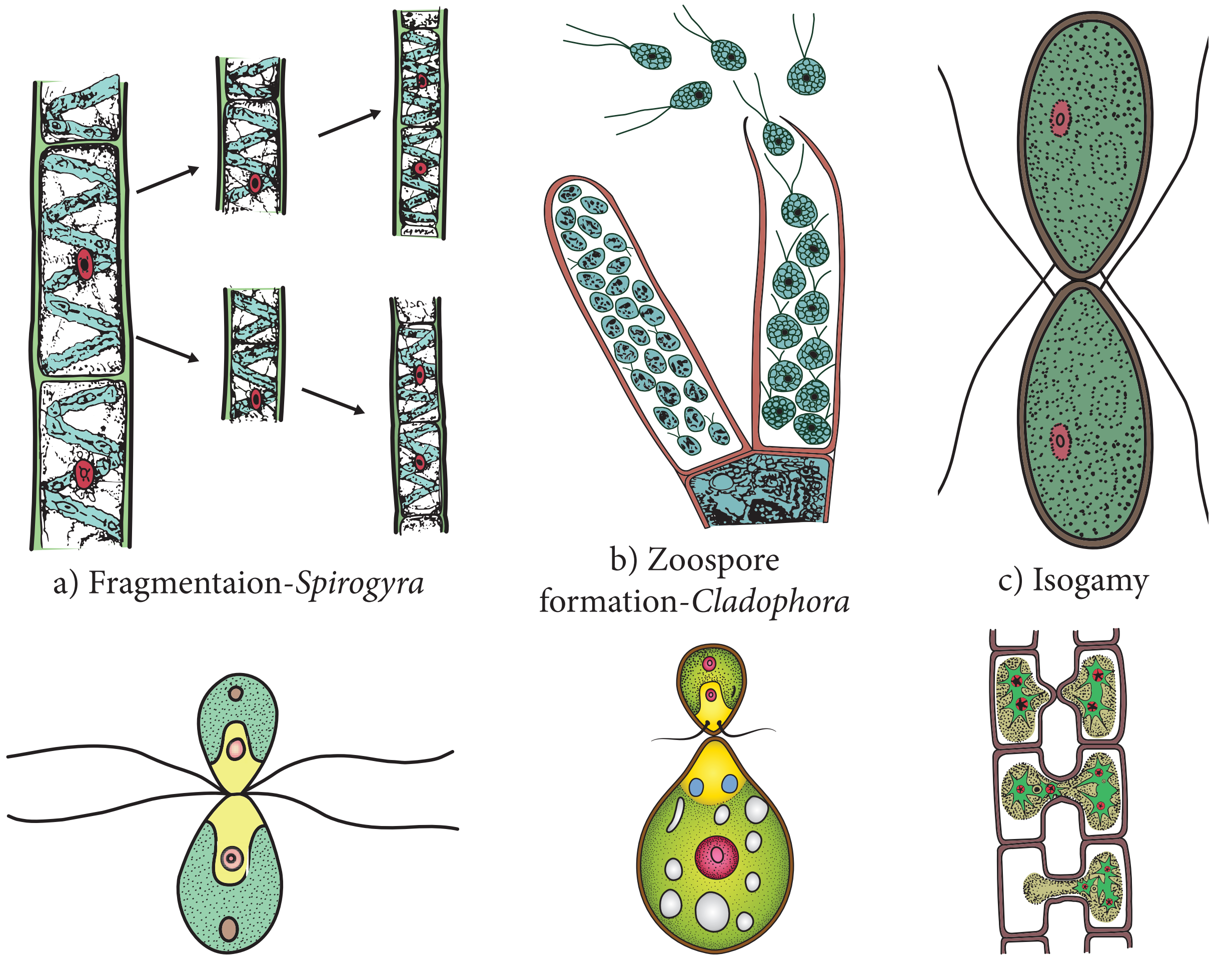


Figure 2.3: Thallus organization in Algae

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 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*). Tubers (Structures found on the rhizoids and the lower nodes of *Chara* which store food materials).

Asexual reproduction takesplace by the production of zoospores(*Ulothrix, Oedogonium*) aplanospore(thin walled non motile spores Example: *Vaucheria*);



a) Fragmentaion-*Spirogyra*

b) Zoospore formation-*Cladophora*

c) Isogamy

d) Anisogamy

e) Oogamy

f) Scalariform conjugation-*Zygnema*

Figure 2.4: Reproduction in Algae

Autospores (spores which look similar to parent cell Example: *Chlorella*); Hypnospore (thick walled aplanospore – Example: *Chlamydomonas nivalis*); Tetraspores (Diploid thallus of *Polysiphonia* produce haploid spores after meiosis).

Sexual reproduction in algae are 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.

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

Table 2.2 Classification of Algae

Class	Pigments	Flagella	Reserve food
Chlorophyceae	Chlorophyll a and b Carotenoids, Xathophyll	1,2,4 or more equal anterior whiplash flagella	Starch
Xanthophyceae	Chlorophyll a and b Carotenoids Xathophyll	2, unequal anterior 1 tinsel and 1 whiplash	Fats and leucosin
Chrysophyceae	Chlorophyll a and b Carotenoids,	1 or 2 unequal or equal anterior both whiplash or 1 whiplash and 1 tinsel	Oils and leucosin
Bacillariophyceae	Chlorophyll a and c Carotenoids,	1 anterior (only in male gametes) tinsel	Leucosin and Fats
Cryptophyceae	Chlorophyll a and c carotenoids and xanthophyll	unequal anterior both tinsel flagella	Starch
Dinophyceae	Chlorophyll a and c carotenoids and xanthophyll	Two unequal (whiplash) lateral flagella in different plane	Starch and oil
Chloromonadineae	Chlorophyll a and b Carotenoids, Xathophyll	2 equal flagella	oil
Euglenophyceae	Chlorophyll a and b	One or two anterior tinsel flagella	Fats and paramylon
Phaeophyceae	Chlorophyll a and c, Xanthophyll	Two unequal whiplash and tinsel lateral flagella	Laminarin starch and fats
Rhodophyceae	Chlorophyll a, r-Phycoerthythrin	absent	Floridean starch
Cyanophyceae	Chlorophyll a, carotenoids, c-Phycocyanin,Allophycocyanin	absent	Cyanophycean starch

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 (Table 2.2).

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*), 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*

DO YOU KNOW?

A green alga *Botryococcus braunii* is employed in Biofuel 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.

2.3.3 Economic Importance

The Economic importance of Algae is given in Table 2.3

Table 2.3: 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

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.

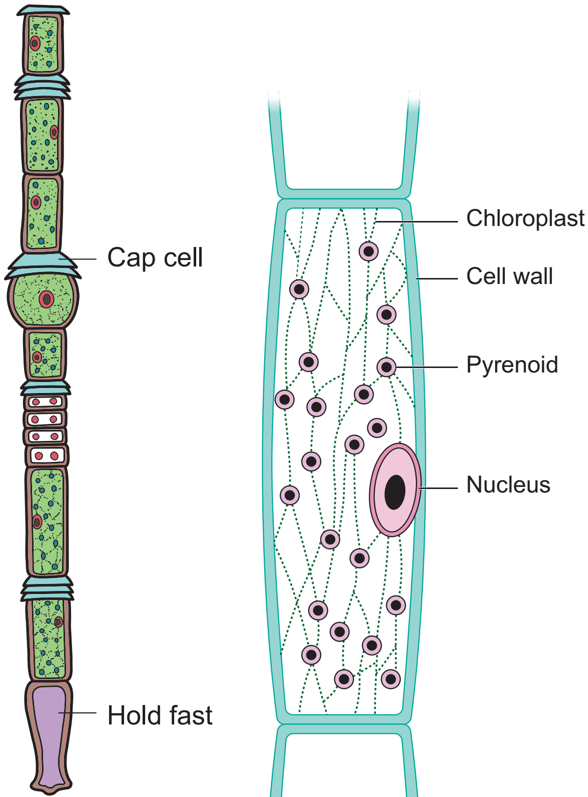
2.3.4 Oedogonium

Class – Chlorophyceae
Order - Oedogoniales
Family -Oedogoniaceae
Genus – *Oedogonium*

Oedogonium is a freshwater , filamentous alga and occurs in ponds, lakes and stagnant water. The filaments are attached to rocks. Some are epiphytic on aquatic plants. *Oedogonium terrestre* is a terrestrial form and grow in moist soils. The young filaments are attached but older ones are free floating.

Thallus structure

The thallus is filamentous ,multicellular and unbranched. All the cells of the filament are cylindrical except the basal and apical cell. The basal cell is colourless and forms hold fast. The proximal end of the hold fast extends to produce finger like projections which help the filament to attach on the substratum. The apical cell is rounded or elongated in shape. Each vegetative cell is cylindrical and possesses a thick cell wall. The inner layer is cellulosic and the outer layer is made up of pectin. A thin layer of chitin is present above the pectin layer. Next to the cell wall a plasma membrane is present. A large vacuole is present. The protoplasm contains reticulate chloroplast and it extends from one end of the cell to the other. A single nucleus and many pyrenoids are present. The distal end of some cells possess ring like markings called apical caps. Such cells are called cap cells. The presence of cap cell is characteristic feature of *Oedogonium* (Figure 2.5).

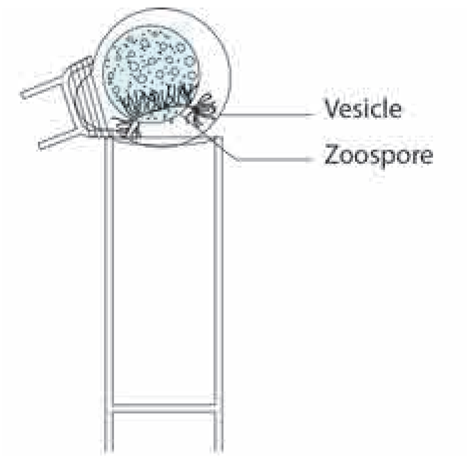


a) A single filament b) A cell enlarged

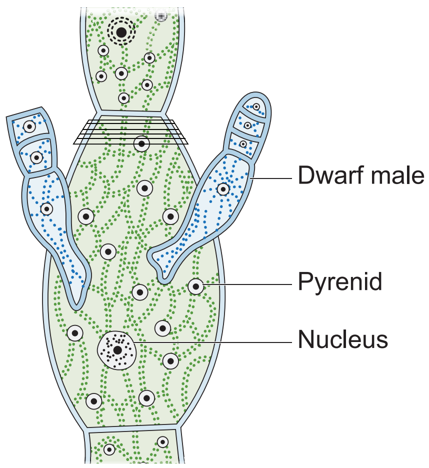
Figure 2.5: *Oedogonium*

Reproduction

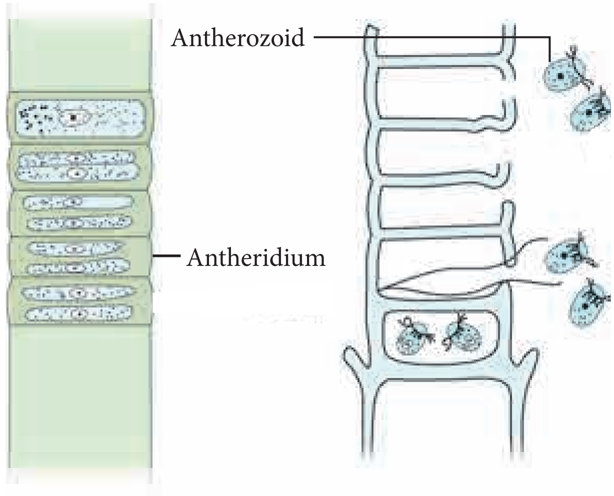
Oedogonium reproduces by vegetative, asexual and sexual methods. Vegetative reproduction takes place by fragmentation and akinete formation. During asexual reproduction zoospores are formed. During favourable conditions, some of the vegetative cells function as zoosporangia. Usually a single zoospore is produced per zoosporangium. A ring of short flagella is found at the base of colourless, beak like anterior end of the zoospore. This kind of flagellation is called stephanokont. The zoospore is released from the zoosporangium and swims in water (Figure 2.6). If it reaches a suitable substratum, it divides into two cells. The lower cell forms holdfast. The green upper cell divides and produces the filament.



a) Zoospore formation



b) Dwarf male



c) Filament showing antheridium

Figure 2.6: Reproduction in *Oedogonium*

Sexual reproduction is Oogamous. The male gametangium is antheridium and female gametangium is called Oogonium. Based on the distribution of sex organs there are two types of species namely Macrandrous and Nannandrous.

Macrandrous monoecious – Antheridia and Oogonia occur on same filament – *Oedogonium fragile*.

Macrandrous dioecious – Antheridia and Oogonia occur on separate filaments – *Oedogonium crassum*

In nannadrous species antheridia are produced on reduced male filaments called dwarf male plants(*O.cancatenatum*).

In nannandrous species antheridia develop on specialised 2–4 celled filaments called dwarf males. The dwarf male is developed from androspores released from the androsporangium.. If the androsporangia and oogonia develop on same filament, it is called **gynandrosporous** (*O. concatenatum*). If they are borne on different filaments it is called **idioandrosporous** (*O. conferatum*). The antheridium produces multiflagellate antherozoids. They are released by transverse splitting of the wall of antheridium. Antherozoids are attracted chemotactically towards the mature oogonium. A single antherozoid enters the oogonium through the opening present on the wall of the oogonium. The male nucleus fuses with the egg to form a diploid zygote. After fertilization the zygote separates from the oogonial wall and a thick wall is secreted around it. The diploid zygote undergoes meiosis to produce 4 haploid multiflagellate zoospores. The wall of the zygote ruptures to release the zoospores.The germination of the zoospore produces haploid filaments of *Oedogonium* (Figure 2.6).

In the life cycle of *Oedogonium* the diploid phase is short lived and is represented by zygote. The haploid phase is predominant and life cycle is of Haplontic type (Figure 2.7).

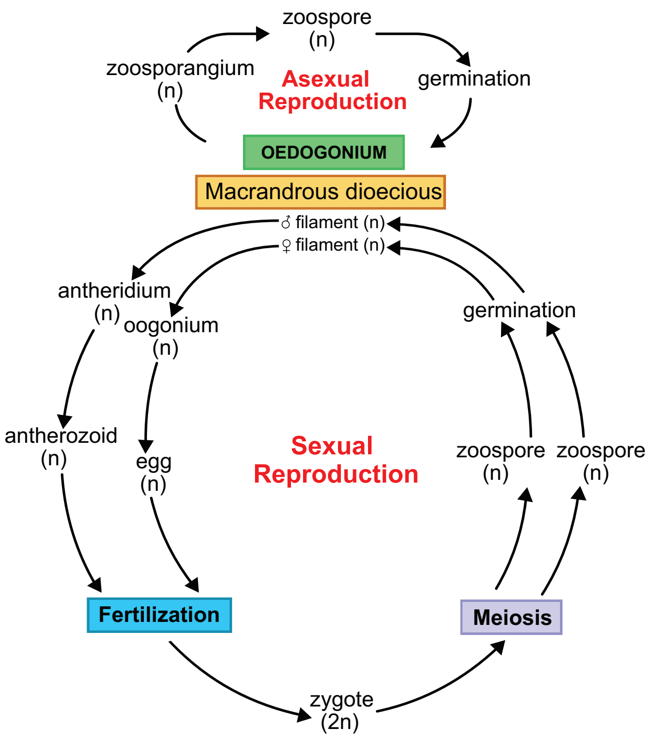


Figure 2.7: Life cycle of *Oedogonium*

2.3.5 Chara

Class – Chlorophyceae
Order – Charales
Family – Characeae
Genus – *Chara*

Chara is commonly called as ‘ stone wort’ It is a submerged aquatic freshwater alga growing attached to the mud of the lakes and slow running streams. *Chara baltica* grows in saline water. The thallus is often encrusted with calcium and magnesium carbonate.

Thallus structure

The plant body is multicellular, macroscopic and is differentiated into main axis and rhizoids. The rhizoids are thread-like, multicellular structures arise from the lower part of the thallus or peripheral cells of the lower node.They are characterised by the presence of oblique septa. The rhizoids fix the main axis on the substratum and helps in the absorption of salts and solutes (Figure 2.8).

The main axis is branched, long and is differentiated into nodes and internodes. The internode is made up of an elongated cell in the centre called axial cell or internodal cell. The axial cell is surrounded by vertically elongated small cells which originate from the node. They are called cortical cells. In *C. wallichii* and *C. corallina* the cortical cells are absent. Three types of appendages arise from the node. They are 1. Branches of limited growth 2. Branches of unlimited growth 3. Stipuloides. The growth of the main axis and its branching takes place by the apical cell.

The nodal cells are uninucleate with few ellipsoidal chloroplasts. The internodal cells are elongated and possesses a large central vacuole, many nuclei and numerous discoidal chloroplasts.

The cytoplasm is divided into outer ectoplasm and inner endoplasm. The endoplasm shows cytoplasmic streaming.

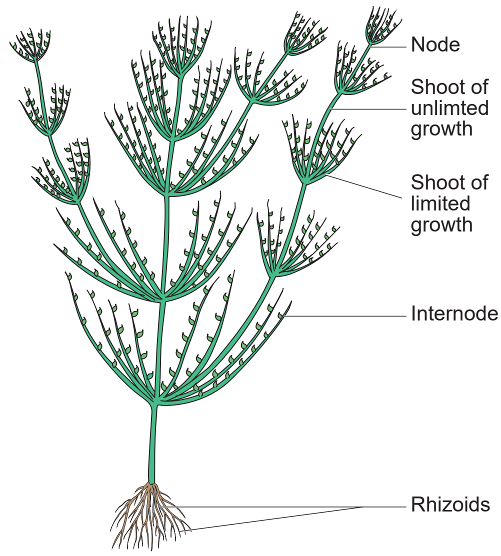


Figure 2.8: *Chara* Habit

Reproduction

Chara reproduces by vegetative and sexual methods. Vegetative reproduction takes place by Amylum stars, Root bulbils, Amorphous bulbils and secondary protonema.

Sexual reproduction - Sexual reproduction is Oogamous. Sex organs are macroscopic and are produced on the branches of limited growth. The male sex organ is called Antheridium or Globule and the female sex organ is called Oogonium or Nucule (Figure 2.9). The Nucule is located above the Globule. The antheridium is spherical, macroscopic and its wall is made up of eight cells called shield cells. The antheridium has spermatogenous filaments. These filaments produce antherozoids. The nucule is covered by five spirally twisted tube cells and five coronal cells are present at the top of the nucule (Figure 2.9). The centre of the nucule

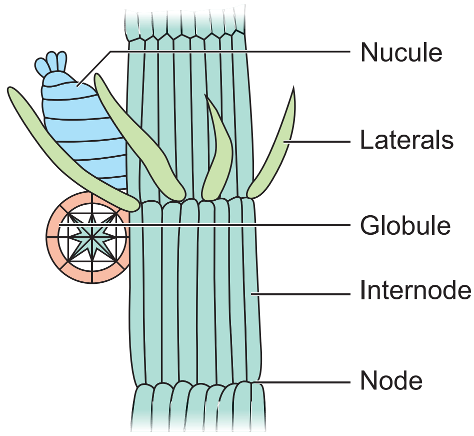


Figure 2.9: *Chara* sex organs

possesses a single egg. At maturity the tube cells separate and a narrow slit is formed. The antherozoids penetrate the oogonium and one of them fuses with the egg to form a diploid oospore. The oospore secretes a thick wall around and germinates after the resting period. The nucleus of the oospore divides to form 4 haploid daughter nuclei of which, three degenerate. The oospore or zygote germinates to produce haploid protonema. The plant body of *Chara* is

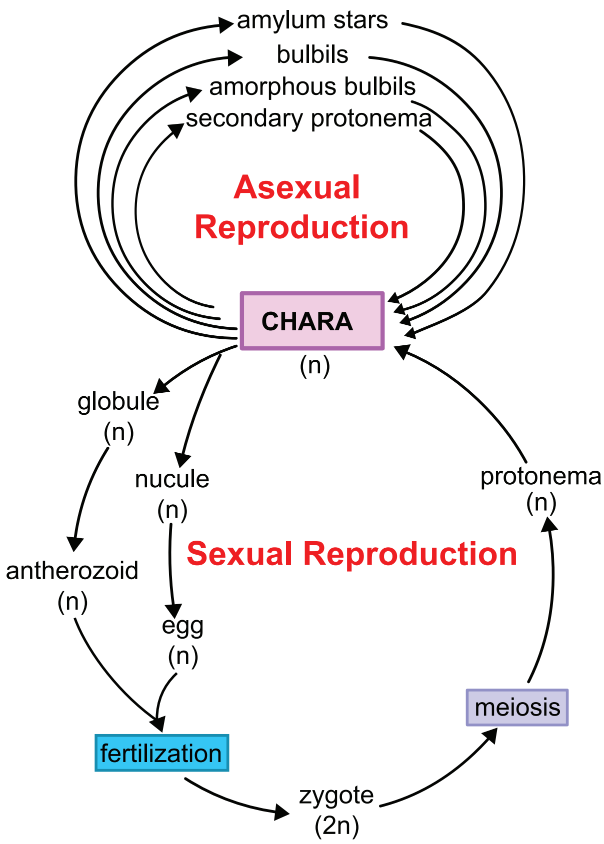


Figure 2.10: Life cycle of *Chara*

haploid and The oospore is the only diploid phase in the life cycle. Therefore, the life cycle is of haplontic type. Alternation of generations is present (Figure 2.10).

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, 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.

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.*

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.

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. 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 2.11
- 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 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:

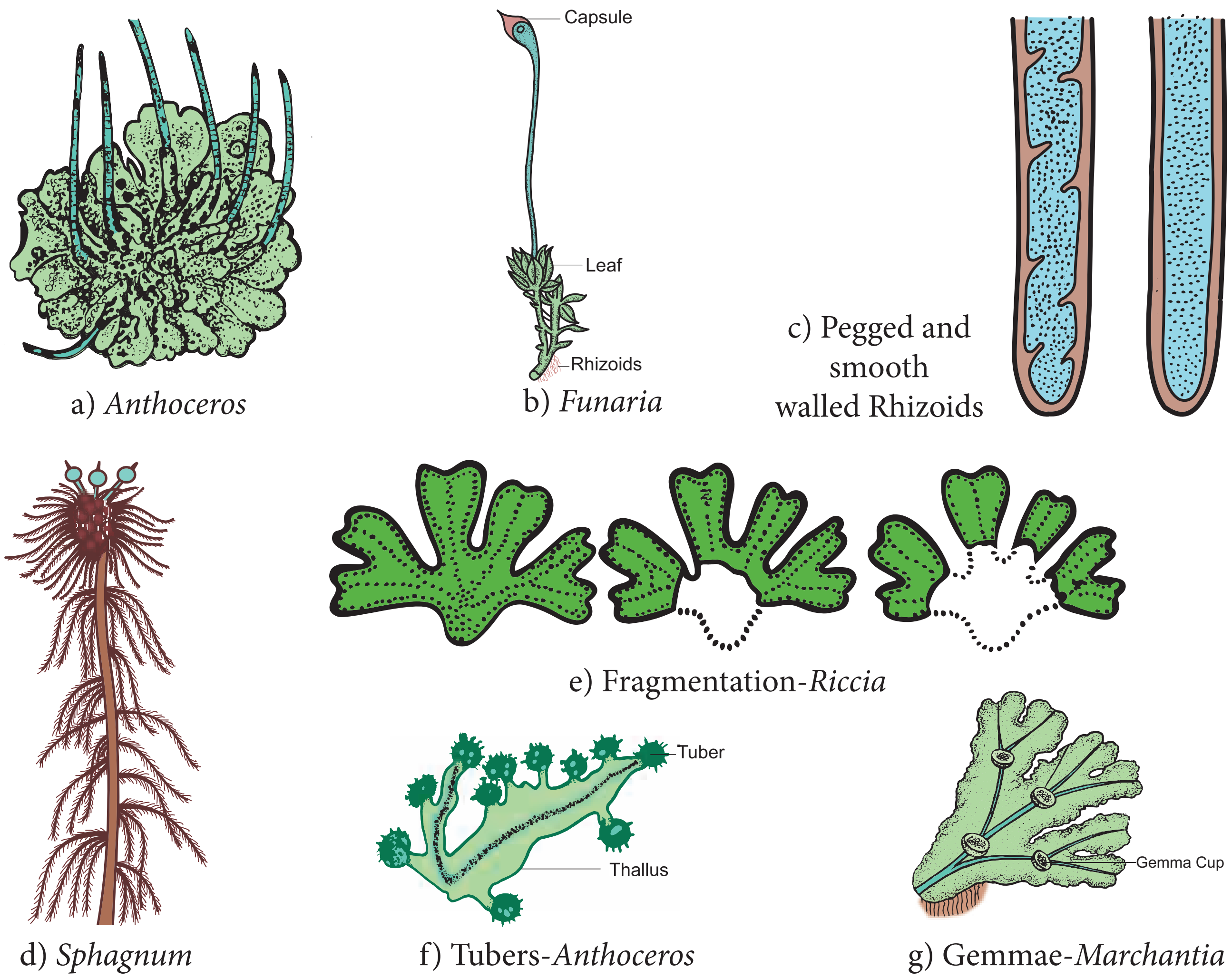


Figure 2.11: Structure and reproduction in Bryophytes

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.

2.4.2 Classification of Bryophytes

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*).

The outline of the classification is given below

Bryophyta

Hepaticopsida (Liverworts)	Anthocerotopsida (Hornworts)	Bryopsida (Mosses)

Class: Hepaticopsida

They are lower forms of Bryophytes. They are more simple in structure than mosses and more confined to damp and shady places. They have an undifferentiated thallus. Protonernal stage is absent. Sporophyte is very simple and short lived. In some the foot and seta are absent. Example *Riccia*.

Class: Anthocerotopsida

Gametophyte is undifferentiated thallus. Rhizoids are unicellular and unbranched. Protonemal stage is absent. Sporophyte is differentiated into foot and capsule and seta is absent Example: *Anthoceros*.

Class: Bryopsida

These are higher forms in which the gametophyte is differentiated into 'stem' like and'leaf' like parts and the former showing radial symmetry. Rhizoids are multi-cellular and branched. Protonemal stage is present. Sporophyte is differentiated into foot, seta and capsule. They have a more differentiated structure than liverworts. They often form dense cushions. Example: *Funaria*.

2.4.3 Economic importance

A large amount of dead thallus of *Sphagnum* gets accumulated and compressed, hardened to form peat. In northern Europe peat is used as fuel in commercial scale (Netherlands). 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

2.4.4 Marchantia

Class - Hepaticopsida
Order – Marchantiales
Family - Marchantiaceae
Genus - *Marchantia*

Marchantia grows in cool moist shady places. *Marchantia polymorpha* is the common species.

Gametophyte

The plant body of *Marchantia* is a gametophyte. It is prostrate,dorsiventral and dichotomously branched. The thallus on the dorsal surface possess conspicuous median midrib which is marked by a shallow groove on dorsal surface. The dorsal surface appears to have rhomboidal or polygonal diamond shaped areas which indicate the outline of the underlying air chambers of the thallus (Figure 2.12).

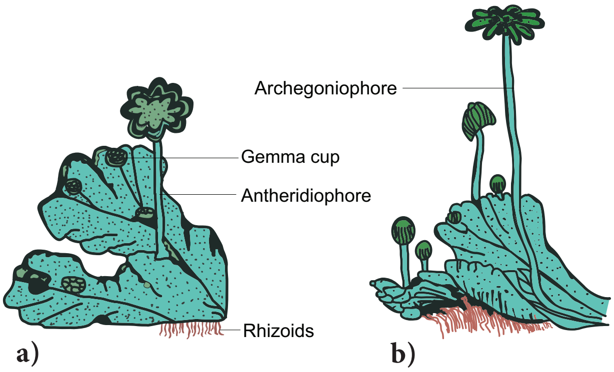


Figure 2.12: *Marchantia*

a) Thallus with antheridiophore

b) Thallus with archegoniophore

The dorsal surface also shows crescent shaped structures called gemma cups which contain vegetative reproductive structures called gemmae. The apical notch bears an apical cell which helps in the growth of the thallus.The ventral surface the thallus bears multicellular scales and rhizoids which help in fixation and absorption of water and minerals. The rhizoids are of two types namely smooth walled or pegged (tuberculate) type. On maturation the thallus bears erect antheriophores and archegoniophores.

Internal structure of Thallus

In transverse section the *Marchantia* thallus shows three parts namely: Epidermis, Photosynthetic region and storage region (Figure 2.13).

The epidermis has the upper and lower layers. The upper epidermis is single layered with thin walled parenchymatous cells. The cells possess chloroplasts. The upper epidermis is interrupted by many barrel shaped air pores which communicate with the air chambers. The pore is surrounded by 4 to 8 superimposed tiers of cells. Below the upper epidermis a number of air chambers are present in a single horizontal layer.The air chambers are separated from one another by partitions which extend from the epidermis to the floor of the air chambers. The floor of the chambers bears simple or branched green filaments. The cells of the filaments are involved in photosynthesis. The photosynthetic region is followed by storage region. It is made up of several parenchymatous cells arranged without intercellular spaces. The cells of this region contain starch grains and protein granules. The lower epidermis possesses rhizoids and multicellular scales.

Reproduction

Marchantia reproduces by vegetative and sexual methods.

1.Vegetative Reproduction takes place by progressive death and decay of thallus, formation of adventitious branches and by germination of gemmae. Death and decay of the thallus starts from posterior end .When it reach the point of dichotomy , two apical parts of the thallus get separated. Each one develops into an independent thallus. Adventitious branches are produced on the ventral surface of the gametophyte. The branches get separated from the parent thallus and grow into independent gametophytes. Gemmae are specialized multicellular asexual reproductive bodies. They are formed in small cupules known as gemma cups, present on the dorsal surface of the thallus. Usually

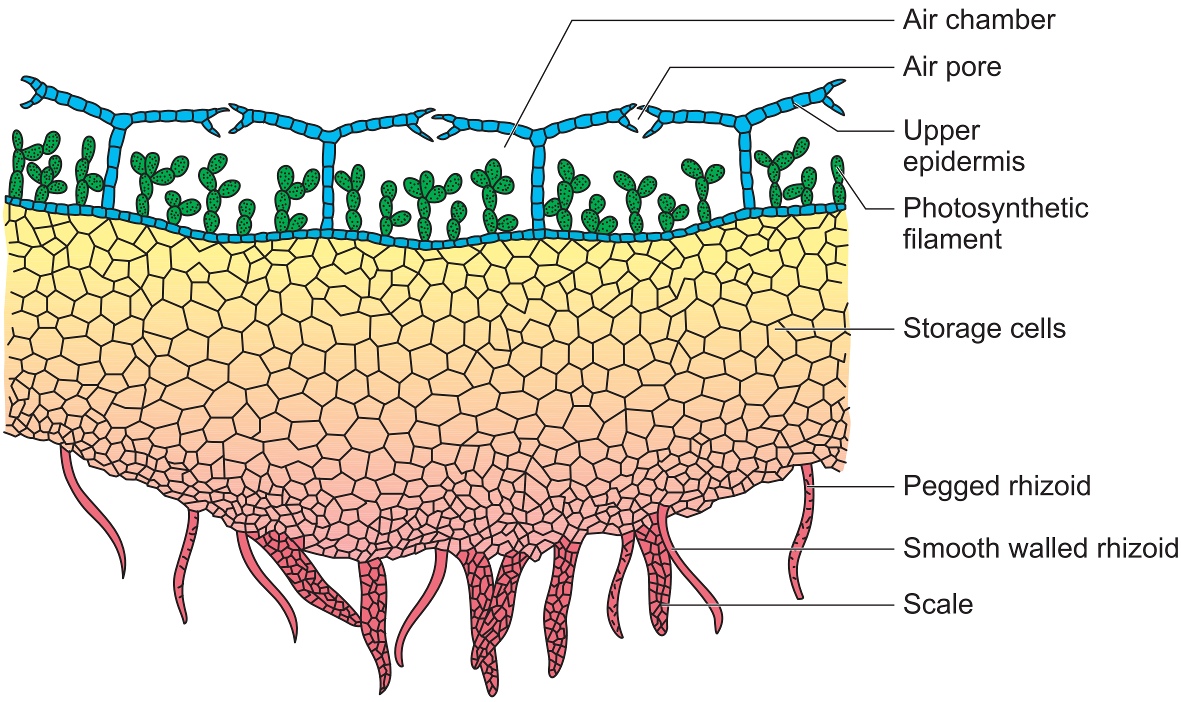
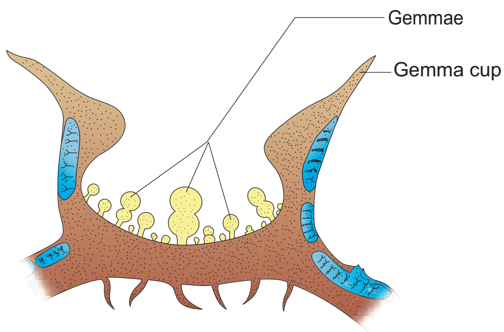
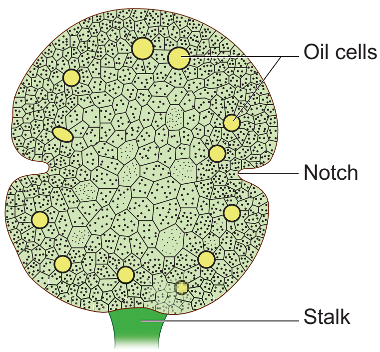


Figure 2.13: T.S. of Thallus

the gemmae present on the male thallus form male plants and those on the female thallus give rise to female plants (Figure 2.14).



a) V.S. of Gemma cup



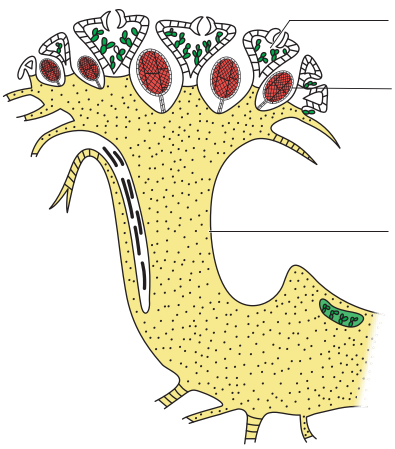
b) A gemma enlarged

Figure 2.14: Vegetative reproduction in *Marchantia*

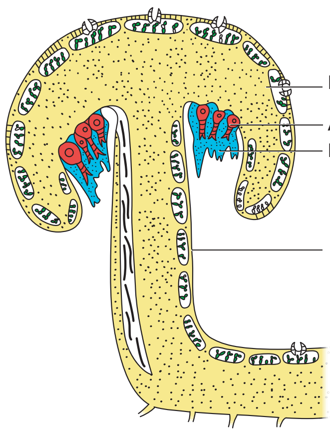
1. Sexual reproduction:

In *Marchantia*, sex organs are borne on special stalked receptacles called the gametophores. Those bearing antheridia are called antheridiophores and archegonia bearing structures are called archegoniophores (Figure 2.15). *Marchantia* is heterothallic or dioecious. i.e., male and female receptacles are present on different thalli. The sex organs in bryophytes are multicellular. The male sex organ is called antheridium. It produce biflagellate antherozoids. The female sex organ is flask shaped called archegonium and produces a single egg. Water is essential for fertilization. The antherozoids are released into water and are attracted towards archegonium through chemotaxis. Although many antherozoids enter the archegonium, only one fuses with the egg to form zygote. The zygote represent the first cell of the sporophytic generation. Zygote develops in to a multicellular structure called sporophyte. (Figure 2.16).

The sporophyte is not free-living but attached to the photosynthetic gametophyte and derives nutrition from it. Sporophyte is differentiated into foot, seta and capsule. The foot is bulbous and is embedded in the gametophyte. It derives nutrition from the gametophyte and transfers to the sporophyte. Seta is short and connects foot and capsule. The capsule consists of single layered jacket layer and encloses numerous haploid spores and elaters. The capsule is covered by protective covering called calyptra. On maturation the capsule dehisces and spores are released. Elaters helps in the dispersal of spores. The spores under favourable conditions germinate and develop into new gametophyte. The haploid gametophytic phase alternates with diploid sporophytic phase, thus the life cycle of *Marchantia* shows alternation of generation (Figure 2.17).



a) L.S. of Antheridiophore



b) L.S. of Archegoniophore

Figure 2.15: *Marchantia* - Sex organs

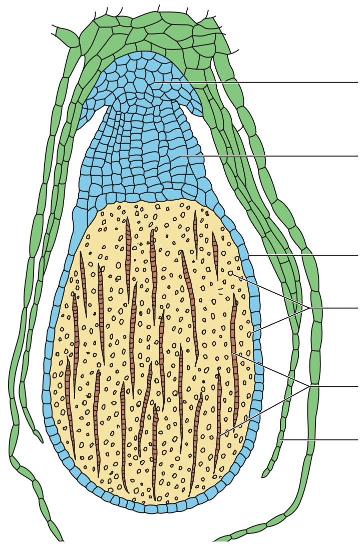


Figure 2.16: *Marchantia* - V.S. of Sporophyte

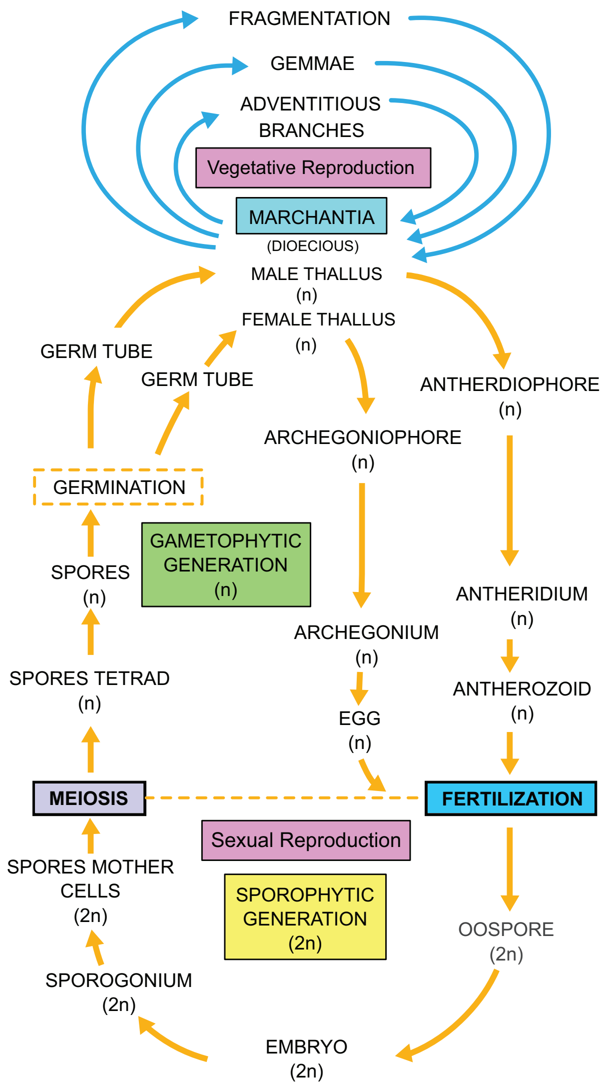


Figure 2.17: Life cycle of *Marchantia*

2.4.5 Funaria

Class – Bryopsida
Order- Funariales
Family – Funariaceae
Genus - *Funaria*

Funaria is commonly called 'cord moss'. It is distributed throughout the world. *Funaria hygrometrica* is the common species. It grows in close tufts on rocks, trunks of trees, damp walls and damp soils. They help in the process of soil formation (Pedogenesis).

External features

The plant body is a gametophyte . It is small, 1 to 3 cm high and consists of slender erect radial stem covered with small, simple leaf like structures arranged in a spiral manner. The gametophyte is attached to the substratum by means of multicellular rhizoids. They are characterized by the presence of oblique septa. The leaves are simple, sessile ovate and have broad membranous base and pointed apex.

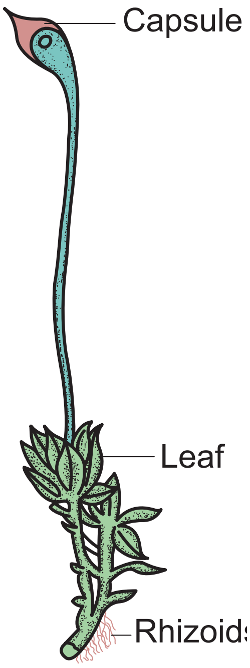


Figure 2.18: *Funaria* Habit

Internal structure

T.S. of axis

The T.S. of axis shows the presence of epidermis, cortex and central cylinder. The epidermis is the outermost layer and contain chloroplast bearing cells. The cortex is made up of parenchymatous tissue. The cells of the young axis bear chloroplasts. In mature stems the outermost cells become reddish brown colour and become thick walled. Small leaf traces are also noticed. The central cylinder is made up of long, narrow, thin walled, colourless cells which lack protoplasts. They help in the conduction of water and minerals.

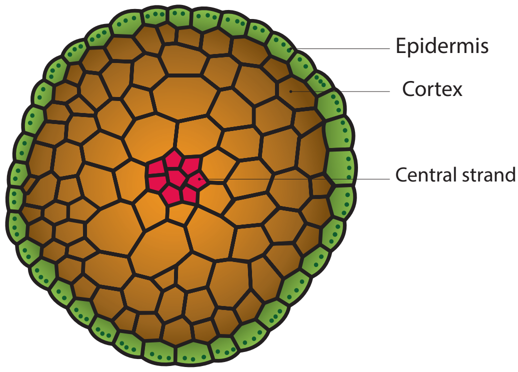


Figure 2.19: T.S. of axis

T.S. of leaf

A well defined midrib is present. It consists of several layers of cells but the lateral 'wing' or lamina is made up of single layer of thin walled cells which are rich in chloroplasts. Midrib contains small strands of slightly thickened narrow cells which help in conduction.

Reproduction

Funaria reproduces by vegetative and sexual methods.

Vegetative reproduction

Vegetative reproduction takes place by the following methods (Figure 2.20):

1. Fragmentation of primary protonema,
2. Formation of secondary protonema from any part of the gametophyte
3. Formation of gemmae on terminal cells of the protonema.

4. Development of Bulbils on the rhizoids.

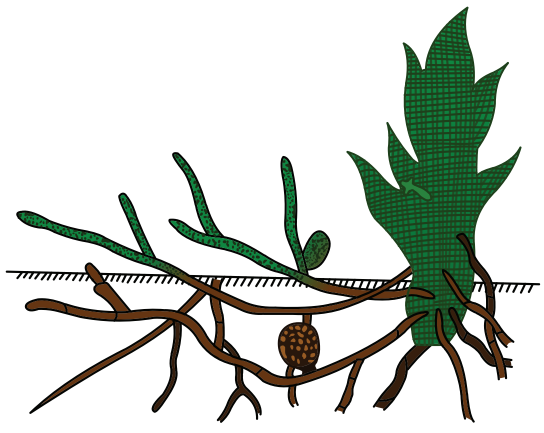
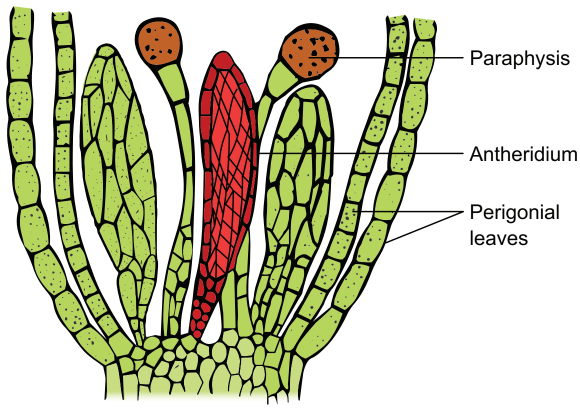


Figure 2.20: Vegetative reproduction (Protonema)

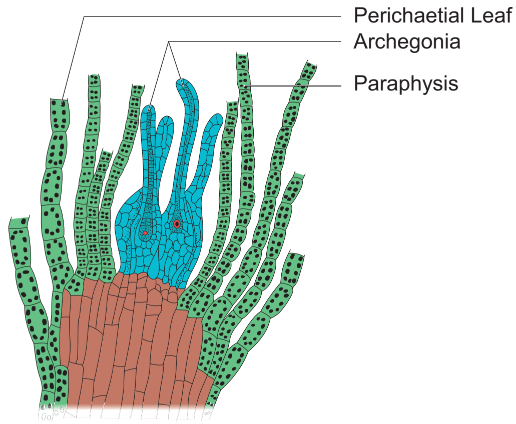
Sexual reproduction

Funaria is monoecious the male and female reproductive sex organs are borne on different branches of the same gametophyte. Male sex organ is antheridium and it is formed in groups on the antheridial branch.They are enclosed by special leaves called **perigonial leaves**. A large number of long multicellular hairs interspersed with antherdia called **paraphysis** are also present. They contain chloroplast and are involved in photosynthesis. They protect antheridial head from by minimizing transpiration, hold water between them through capillary action and secrete mucilage which helps in the liberation of antherozoids. Each antheridium is protected by single layer of jacket. It encloses a large mass of androcytes. The androcytes transform in to biflagellate antherozoids (Figure 2.21).

The female sex organ are the archegonia and are borne in clusters on the archegonial branch. Archegonial branches arise laterally at the base of the male branch. They are surrounded by **perichaetial leaves**. Paraphyses are also present. Each archegonium is flask shaped and is distinguished into a large venter and long neck region. The venter contains venter canal cell and egg. The neck contain neck canal cells (Figure 2.21). Water is essential for fertilization. Rain drops help in the transfer of antherozoids from antheridial head to archegonial head. The antherozoids are attracted to the archegonium through **chemotaxis**. A large number of antherozoids enter the neck of the archegonium but only one fuses with the egg to form a diploid zygote. The diploid zygote represents the first cell of sporophytic generation and divides to form a sporophyte.



a) Antheridial head



b) Archegonial head

Figure 2.21: *Funaria* - Sexual reproduction

Structure of Sporophyte or capsule

The structure of mature sporophyte of *Funaria* is complex. The sporophyte is differentiated into foot, seta and capsule (Figure 2.22). The foot is small, conical and is embedded in the gametophyte. The seta

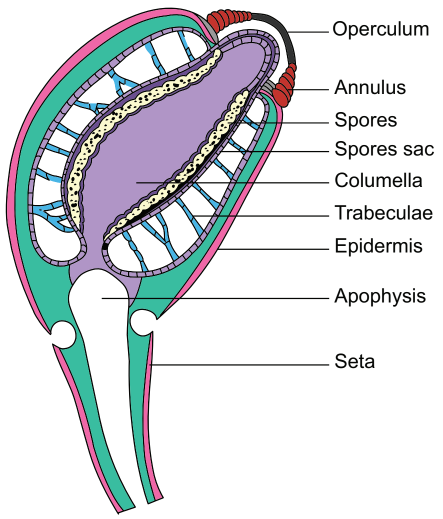


Figure 2.22: L.S. of capsule

is long, slender and conducts water and nutrients to the capsule . The capsule is differentiated into apophysis, theca proper and operculum. The cells constituting the wall of the capsule contain chloroplasts in them. The apophysis is the lowermost sterile region and connects the capsule with seta. The epidermis contains stomata which help in exchange of gases. The cells of the apophysis are photosynthetic, hence the sporophyte of *Funaria* partially depends on the gametophyte. The theca proper is the middle part and is fertile region of the capsule. It consists of a central columella surrounded by spore sac. The spore sac is surrounded by a single cylindrical air sac traversed by delicate filaments made up of parenchyma cells called **trabeculae**. The trabeculae extend from the outer wall of the spore sac to the innermost layer of the capsule wall. The spore sac contains spore mother cells which undergo meiotic division to produce haploid spores. The apical region consists of the operculum and peristome. The operculum is the lid of the capsule and comes out as a circular cup shaped lid after the dehiscence of the capsule. The peristome has one or two rows of thickened, tooth like projections found on the top of the capsule. They are hygroscopic and help in the dispersal of the spores. During favourble conditions the spores germinate to produce thread like green branched structure called protonema. It produces rhizoids and number of lateral buds which develop into new plants. In the life cycle of *Funaria* the haploid gametophytic phase (n)alternates with diploid sporophytic phase (2n) and shows alternation of generation (Figure 2.23).

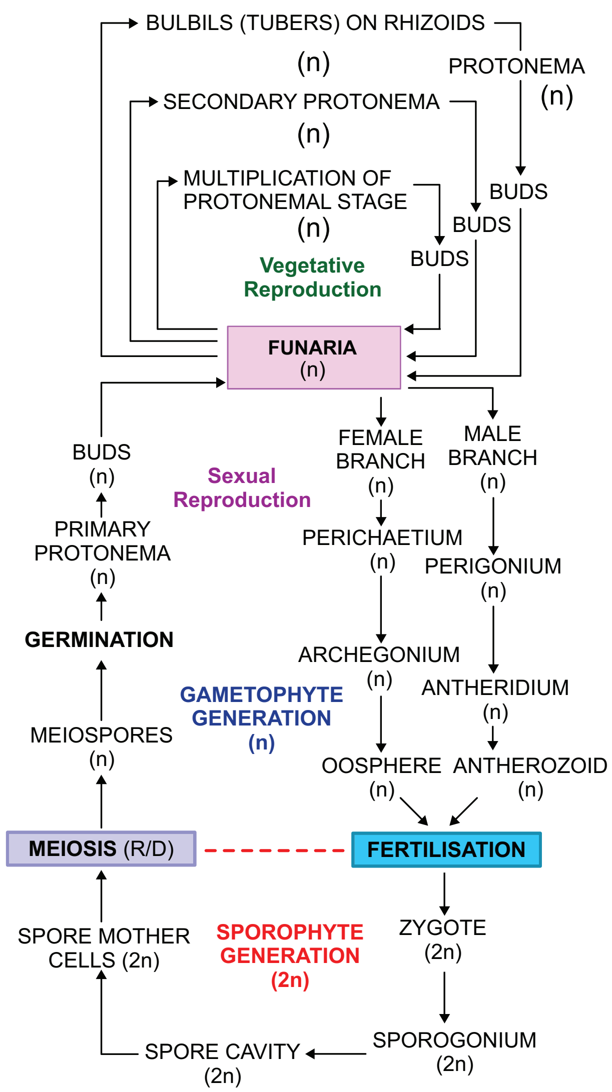


Figure 2.23: Life cycle of *Funaria*

2.5 Pteridophytes

Seedless Vascular Cryptogams

From the previous chapter 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 2.24.

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 gets 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.**

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

Figure 2.24: Pteridophytes

2.5.2 Classification of Pteridophytes

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.

2.5.3 Economic Importance

The Economic importance of Pteridophyte is given in Table 2.4

Table 2.4: 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

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.

Division- PTERIDOPHYTA

Sub division

Psilophytopsida	Psilotopsida	Lycopsida	Sphenopsida	Pteropsida
All are extinct plants. Plant body had only stem and rhizome. Roots and leaves were absent. Homosporous Spore tetrads were borne at the terminal sporangia. Example: *Rhynia*.	The plant body is rootless and have fungal association. Small, scaly appendages represent the leaves. Gametophyte is colourless and have fungal association. They are homosporous and spores are produced in sporangia or synangia. Example: *Psilotum*.	The plant body is differentiated into root, stem and leaves. Leaves are small, univeined, spirally arranged. Ligules are present. Sporophylls are arranged in the form of strobilus. Both homospory (*Lycopodium*) and heterospory (*Selaginella*) are found. Example: *Selaginella*.	The plant body is differentiated into root, stem and leaves. Stem shows jointed nodes and internodes. Small, scaly leaves are arranged at nodes in whorls. Peltate disc of sporangiophore possess compact strobilus. Homosporous but incipient heterospory is found in *Equisetum arvense*.	The plant body is differentiated into root, stem and leaves. Includes all the megaphyllous pteridophytes. leaf gap is present sporangia are organized into sorus. Both homosporus and heterosporus forms are present. Example: *Marsilea*

2.5.4 Selaginella

Division – Lycophyta
Class – Ligulopsida
Order – Selaginellales
Family –Selaginellaceae
Genus – *Selaginella*

Selaginella is commonly called 'spike moss'. They are distributed in humid temperate and tropical rain forests. *Selaginella rupestris* and *Selaginella lepidophylla* are Xerophytic. *Selaginella kraussiana*, *Selaginella chrysocaulos, Selaginella megaphylla* are some common species. In few *Selaginella* species during dry season the entire plant body gets curled and become fresh, green when moisture is available. Due to this they are called **Resurrection plants**. Example *S. lepidophylla*

External morphology

Habit

The plant body of *Selaginella* is sporophyte (2n) and it is differentiated into root, stem, and leaves (Figure 2.25). There exist variations in the habit of *Selaginella*. Some species possess prostrate creeping system (*S. kraussiana*); suberect (*S. rupestris*); erect (*Selaginella erythropus*); Climbing (*Selaginella alligans*). *S. oregana* is an epiphyte. Most of the species are perennials. on the basis of structure of stem and arrangement of leaves, *Selaginella* is divided into two sub genera namely Homoeophyllum and Heterophyllum.

Homeophyllum include species with erect stem and spirally arranged leaves. (Example: *S. upestris* and *S. oregana*). Heterophyllum include species with prosrate stem with short erect branches and dimorphic leaves (Example: *S. kraussiana* and *S. lepidophylla*).

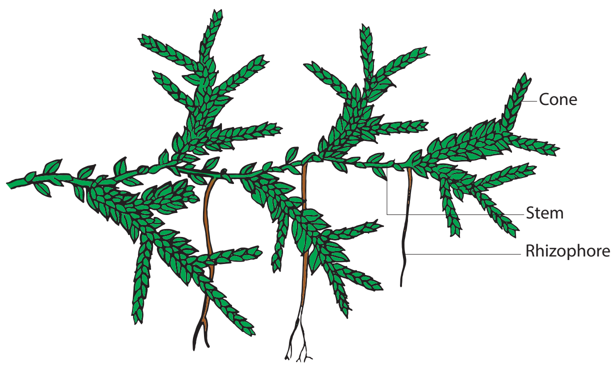


Figure 2.25: *Selaginella* Habit

Root

Primary roots are short lived and the adult plant has adventitious roots. The root may arise at the point of dichotomous branching or knot like swelling present at the basal portion of the stem. Roots are endogenous in origin.

Rhizophore

In many species long, cylindrical, unbranched and leafless structures arise from the lower side of the stem at the point of dichotomy called rhizophores. They grow vertically downwards and produce tufts of adventitious roots.

Stem

The stem may be erect, dichotomously branched or prostrate with lateral branching. The prostrate stem is dorsiventral.

Leaves

The leaves are microphyllous, sessile and simple. A single midvein is present in the leaves. The vegetative leaf as well as the sporophyll bears a small membranous tongue like structure on adaxial surface called **ligule**. The basal part of the ligule possess a hemispherical mass of thin walled cells called **glossopodium**. The function of ligule is not known, but it is viewed to be associated with water absorption, secretion and prevent dessication of shoot. The members belonging to Homeophyllum type possess same type of leaves spirally arranged on the stem whereas the Heterophyllum type have two types of leaves- two dorsal rows of small leaves(Microphylls) and two ventral rows of large leaves(Megaphylls).

Internal structure

Root

The transverse section of the root reveals an outermost layer called epidermis. It is made up of tangentially elongated cells. The cortex is homogeneous made up of thin walled parenchyma . The innermost layer of cortex is called endodermis. The stele is a protostele, monarch and xylem is exarch (Figure 2.26).

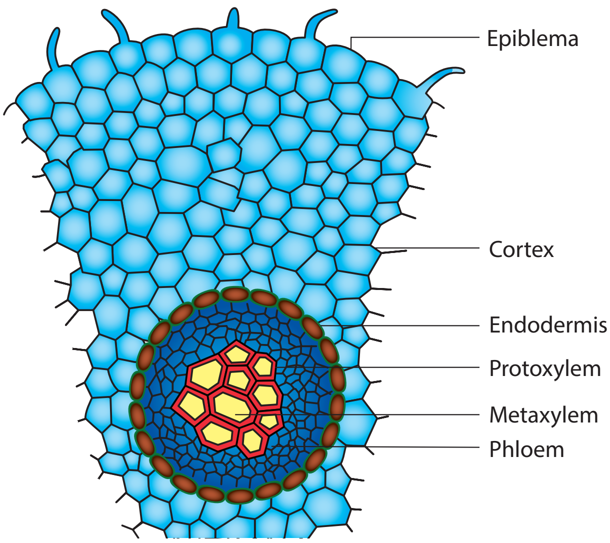


Figure 2.26: T.S. of root

Rhizophore

The outermost layer of Rhizophore is the epidermis. It is single layered and is covered with a thick cuticle. The cortex is differentiated into outer scelrenchymatous and inner parenchymatous layers. The innermost layer of cortex forms endodermis. The stele is a protostele Figure 2.37. It is monarch and exarch but it is centrifugal in *S. kraussiana* and crescent shaped in *S. atroviridis*.

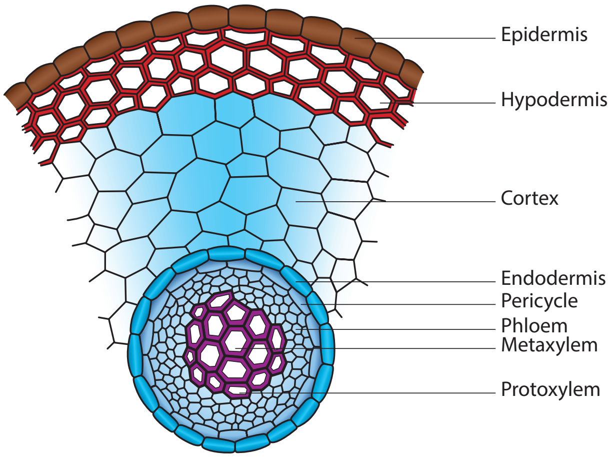


Figure 2.27: T.S. of Rhizophore

Stem

The anatomy of the stem reveals the presence of epidermis, cortex and stelar region (Figure 2.28).

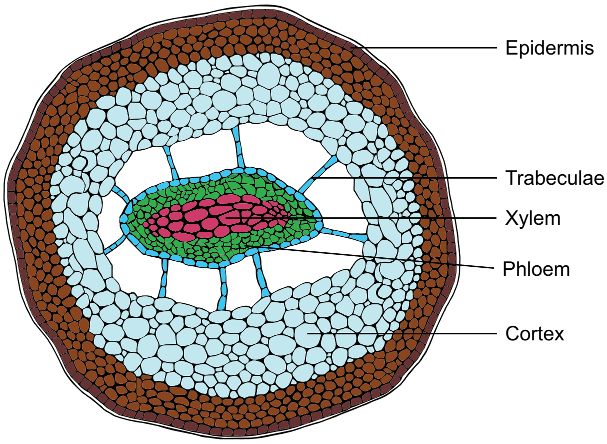


Figure 2.28: T.S. of Stem

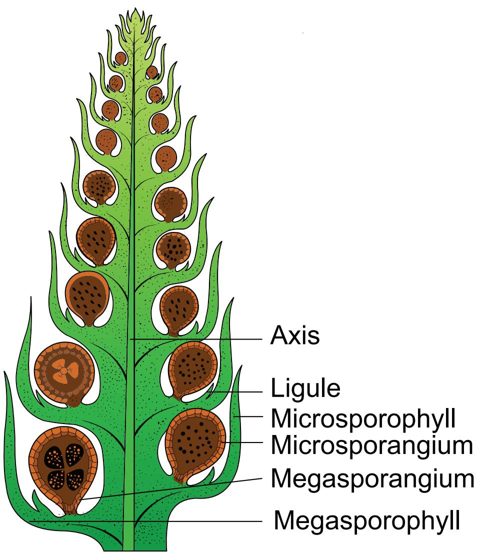
The epidermis is parenchymatous and is covered with a thick cuticle. The cortex is parenchymatous with cells arranged without intercellular spaces. A sclerenchymatous hypodermis is noticed in *Selaginella lepidophylla*. The presence of radially elongated endodermal cells called **trabeculae** is the characteristic feature of *Selaginella*. The casparian strips are found on the lateral walls. The rapid stretching of the innermost cortical cells in comparison with stele results in air spaces and stele appears to be suspended in air space with the help of trabeculae. The stele is a protostele and exarch. A variation in number of steles is found. It may be monostelic (*S. spinulosa*); distelic (*S. kraussiana*)or polystelic (*S. laevigata*). The xylem is monarch(*S. kraussiana*) or diarch (*S. oregana*). Tracheids are present but vessels are also noticed in *S. densa* and *S. rupestris*.

Leaf

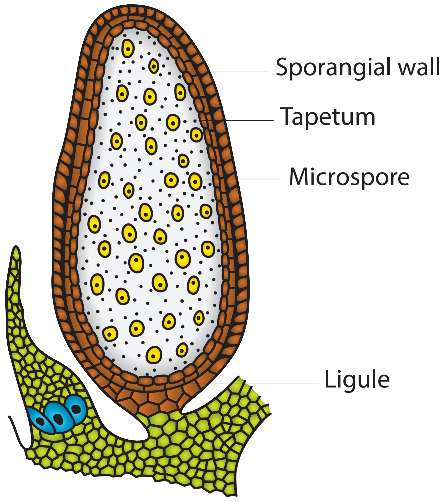
The leaf shows upper and lower epidermis. The epidermal cells have chloroplast. Stomata occur on both surfaces. The mesophyll is made up of loosely arranged thin walled cells with intercellular spaces. There is a median vascular bundle surrounded by a bundle sheath. In vascular bundle xylem is surrounded by phloem.

Reproduction

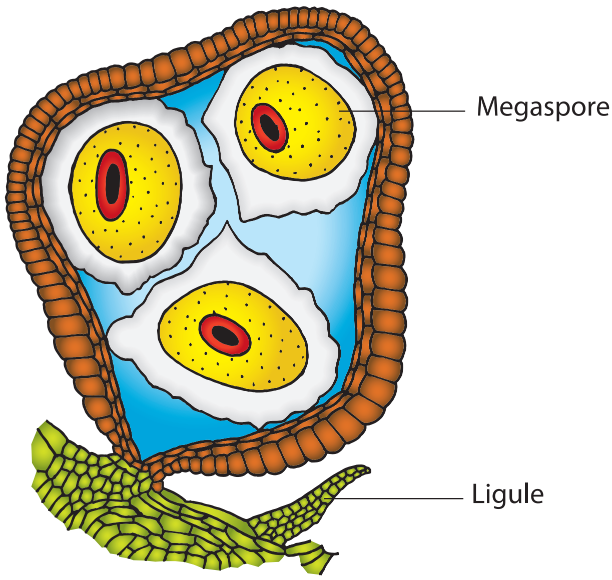
Selaginella shows both vegetative and asexual modes of reproduction.



a) L.S. of cone



b) A microsporangium enlarged



c) A megasporangium enlarged

Figure 2.29: Reproduction in *Selaginella*

Vegetative reproduction

Selaginella reproduces vegetatively by fragmentation, bulbil formation, tuber formation and resting buds.

Sexual reproduction

During sexual reproduction spores are produced (Figure 2.29). *Selaginella* is heterosporous and produces two types of spores namely microspores in microsporangium and megaspores in megasporangium. The sporangia are borne singly in the axils of microsporophyll and megasporophyll respectively. The sporophylls are arranged spirally around a central axis and aggregate to form strobili or cones. Variations in the distribution of microsporangia and megasporangia among the species are seen. In S. *selaginoides* and *S. rupestris* megasporangia are present in the basal part of the cone. *S. kraussiana* possesses a single megasporangium at the base of the strobilus. In *S. inaequifolia* one side of the strobilus bear only megasporangia and other microsporangia. Separate strobili for microsporangia and megasporangia are present in *S. gracilis*. and *S. atro-viridis*.

The development of sporangium is of eusporangiate type. The sporangial initial divides periclinally to form outer jacket initials and inner archesporial initials. The archesporial initials by repeated anticlinal and periclinal divisions form sporogenous cells. Microspore mother cells of microsporangium undergo reduction division to produce halpoid microspores. Similarly the megaspore mother cell undergoes reduction division to produce 4 haploid megaspores. The microspore and megaspore represent the male and female gametophyte and germinate inside the sporangium. The microspores produce biflagellate antherozoids. Archegonia develop in the megaspore. The antherozoids swim in water and reach the archegonium. Fertilization brings the fusion of male and female nucleus which result in the formation of a diploid zygote. The diploid zygote represents the first cell of sporophyte.

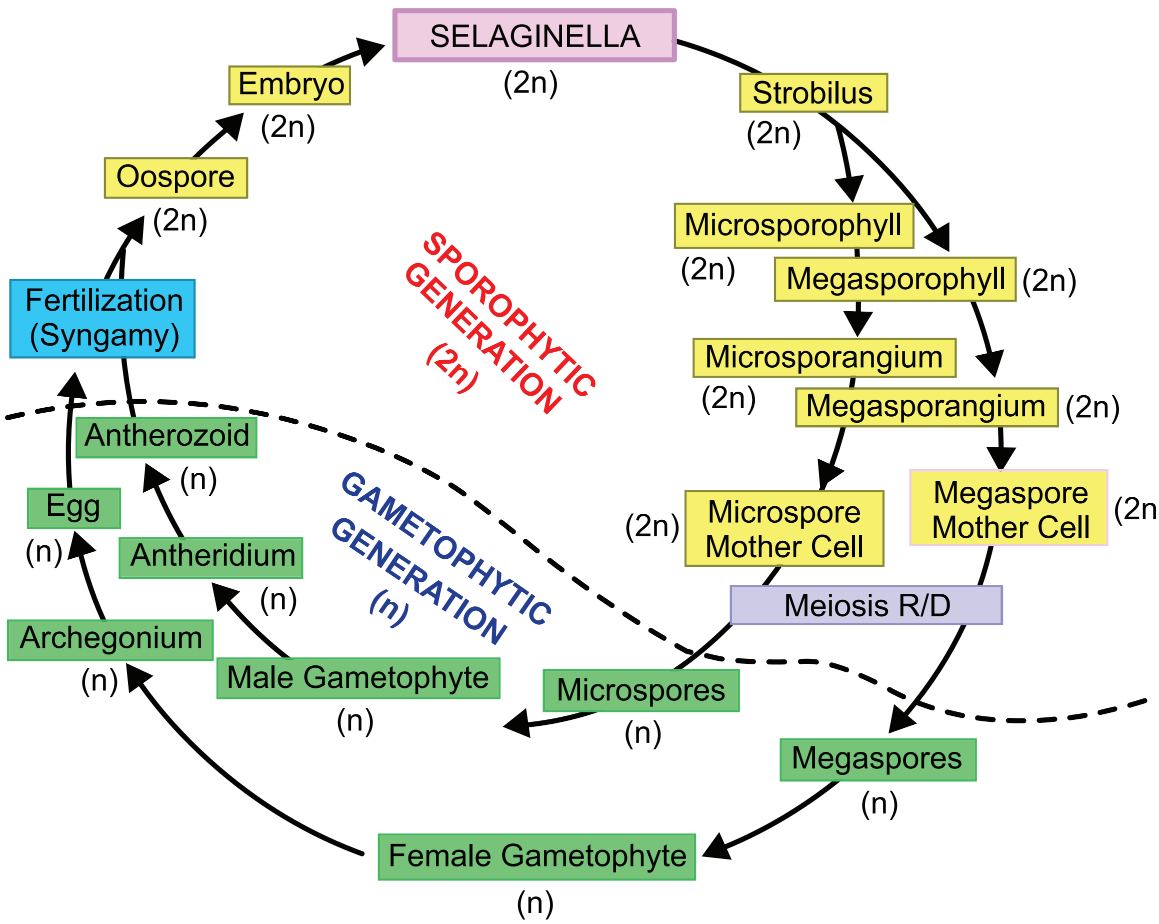


Figure 2.30: Life cycle of *Selaginella*

It undergoes several mitotic division to form embryo. The embryo develops into a mature sporophytic plant.

In the life cycle of *Selaginella* alternation of sporophytic and gametophytic generation is present (Figure 2.30).

2. 5.5 Adiantum

Division – Pteropsida
Class - Leptosporangiopsida
Order – Filicales
Family – Polypodiaceae
Genus – *Adiantum*

Adiantum is commonly known as 'Maiden hair fern' or 'Walking fern'. They are distributed in the tropical and temperate regions of the world. Some of the Indian species include *Adiantum capillus-veneris, Adiantum pedatum, Adiantum caudatum* and *Adiantum venustum*. The sporophyte is differentiated into rhizome, roots and leaves Figure 2.31.

External features

Rhizome

The rhizome is a perennial, subterranean dichotomously branched structure and is creeping in *A. capillus-veneris* or may be erect as in *A. caudatum*. It is covered with persistent leaf bases and hairy outgrowths called **ramenta**.

Root

The roots are adventitious and arise from the rhizome.

Leaf

The leaves are also called fronds and are pinnately compound (unipinnate- *A. caudatum*, bipinnate- *A. capillus-veneris*) the young leaves are circinately coiled. The petiole is long, black and shiny. The venation is free and dichotomous in all the species. The vein spread in a fan-like manner in the lamina. The leaves bear marginal sori which are covered by a **false indusium.**

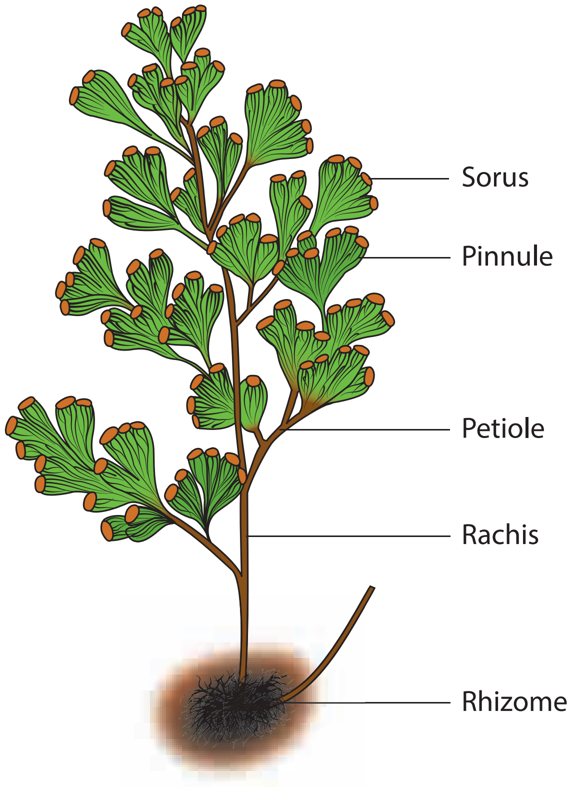


Figure 2.31: Adiantum Habit

Internal structure

Root

The root is differentiated into epidermis, cortex and central vascular cylinder.

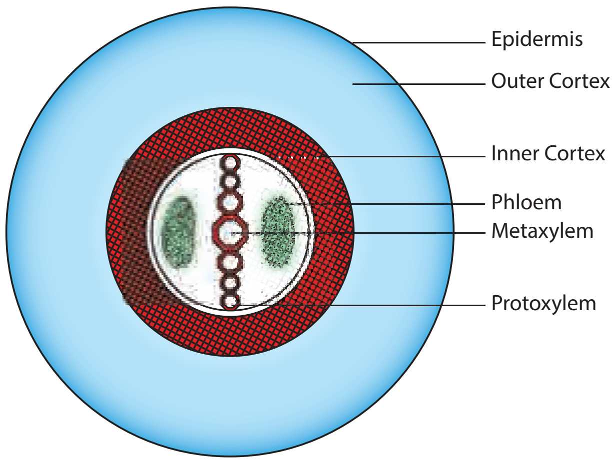


Figure 2.32: T.S. of root

The epidermis is the outermost layer and bears unicellular root hairs. The cortex is divided into outer wide parenchymatous and inner narrow sclerenchymatous layer. The stele is simple and possesses a central core of xylem in diarch condition with phloem on either side of it (Figure 2.32).

Rhizome

The rhizome in transverse section shows a single layered epidermis covered by cuticle. Some epidermal cells bear multicellular hairs. The Epidermis is followed by two to three layered hypodermis made up of sclerenchyma tissue. A parenchymatous ground tissue is present. The young rhizomes have amphiphloic siphonostele. The older rhizomes have solenostele or dictyostele (Figure 2.33).

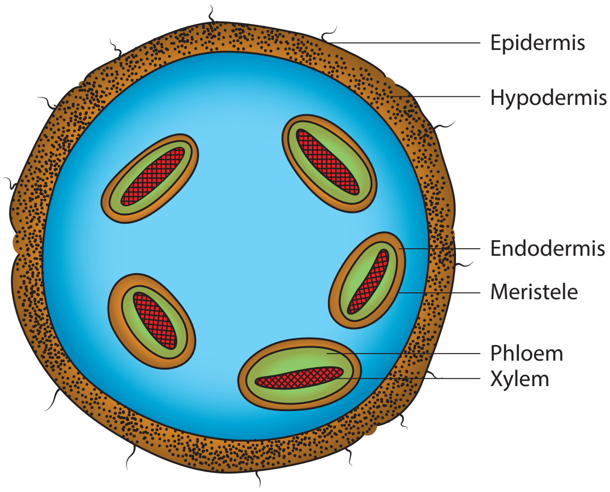


Figure 2.33: T.S. of Rhizome

Petiole

The petiole in T.S. shows a single layered epidermis with thick cuticle. Epidermis is followed by a sclerenchymatous hypodermis which provides mechanical support. There is an extensive parenchymatous ground tissue. The central region possesses a single large horse shoe shaped stele. Xylem forms central core surrounded by phloem (Figure 2.34).

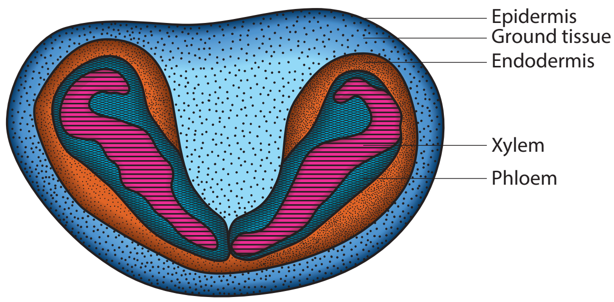


Figure 2.34: T.S. of Petiole

Pinnule

The Pinnule shows upper and lower epidermis. The cells contain chloroplasts. Stomata are confined to lower epidermis. The mesophyll is not differentiated into palisade and spongy parenchyma. The vascular bundle is surrounded by sclerenchymatous bundle sheath.

Reproduction

Adiantum is homosporous. The reproduction takes place by the production of spores. The spores are produced in sporangia. A group of sporangia forms sori. The sori are marginal but the reflex margins of the pinna form a protective membranous structure called *false indusium* (Figure 2.35). The development of sporangium is of leptosporangiate type.

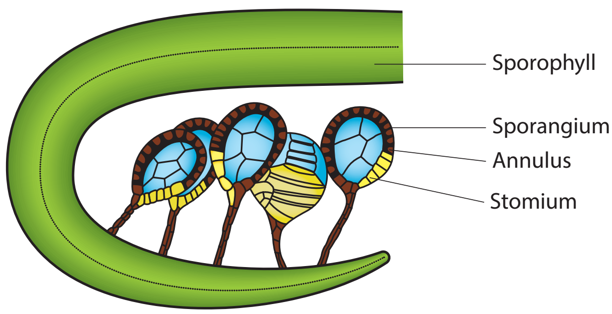


Figure 2.35: V.S. of Sporophyll

The sorus does not show any definite sequence hence fall under mixed type.

A mature sporangium bears a multicellular stalk and a spherical or elliptical single layered structure called **capsule**. The capsule contains haploid spores. The wall of the capsule is differentiated into thick walled annulus and thin walled **stomium**. On maturity the sporangium bursts and spores are released. The spores germinate and undergo repeated division to produce a **prothallus**. The prothallus is flat, green and heart shaped. It is monoecious and represents the gametophytic phase. Sex organs called **antheridia** and **archegonia** develop on the prothallus. Antheridia release multiflagellate antherozoids which swim in water and reach the egg of the archegonium to accomplish fertilization. The fertilization results in zygote(2n) and it represents the first cell of sporophytic generation. The zygote develops into embryo which further differentiates into sporophyte. Thus *Adiantum* shows alternation of generation (Figure 2.36).

2.5.6 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 2.37).

There are two types of steles

1. Protostele
2. Siphonostele

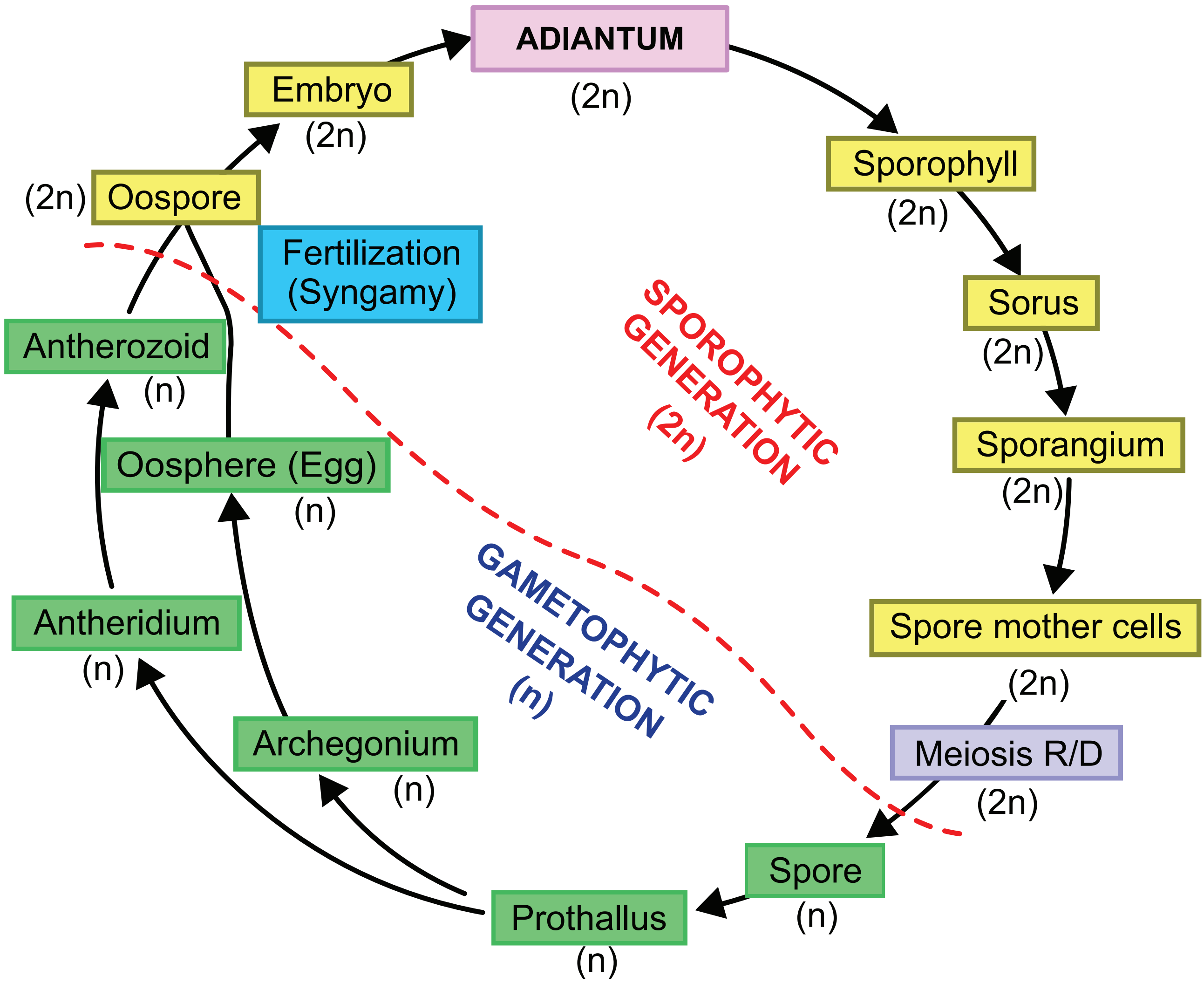


Figure 2.36: Life cycle of *Adiantum*

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*.

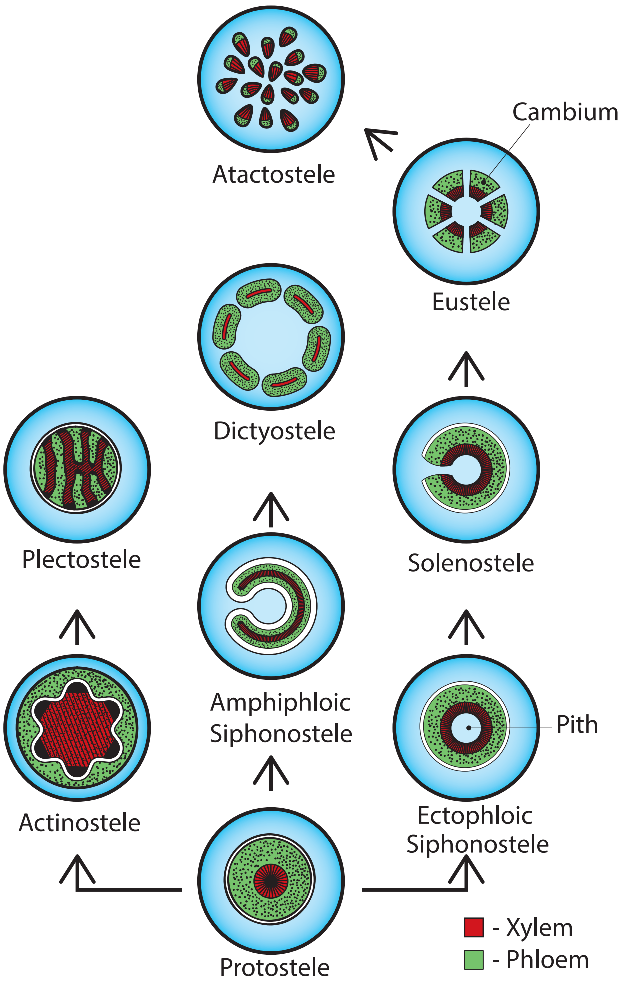


Figure 2.37: Types of Stele

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.

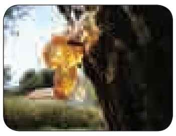
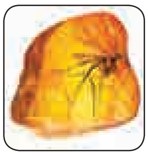
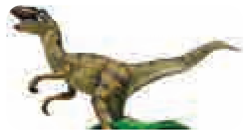
(v) **Atactostele**: The stele is split into distinct collateral vascular bundles and are scattered in the ground tissue Example: Monocot stem.

(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 in 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 that is a 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 2.38

a) *Cycas* b) *Thuja* c) *Taxus* d) *Ginkgo*

Figure 2.38: Gymnosperms

2.6.2 Classification of Gymnosperms

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

GYMNOSPERMS		
Class-I	Class-II	Class-III
Cycadopsida	**Coniferopsida**	**Gnetopsida**
Orders: 1. Pteridosper-males 2. Bennettitales 3. Pentoxylales 4. Cycadales	Orders: 1. Cordaitales 2. Coniferales 3. Taxales 4. Ginkgoales	Order: 1. Gnetales

General Characters of Main classes:

Class I – Cycadopsida

- Plants are palm-like or fern-like.
- Compound, frond-like pinnate leaves.
- Manoxylic wood.
- Sperms are motile.
- Flower like structures are absent. Strobili are simple.

  Example: *Cycas, Zamia*.

Class II – Coniferopsida

- Tall trees with simple leaves of varied shape.
- Wood is pycnoxylic.
- Cone like strobili are present.
- Motile sperms are absent (except *Ginkgo biloba*). Example: *Pinus*.

Class III – Gnetopsida

- Shrubs, trees and lianas.
- Leaves are elliptical or strap-shaped, simple, opposite or whorled.
- Motile sperms are absent.
- Wood contains vessels.
- Strobili is called as inflorescence.
- Flower like structure with perianth is present. Example: *Gnetum, Ephedra*.

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 to the angiosperm male flower. 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 2.5

Table 2.5: 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 2.6: 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

2.6.4 Cycas

Class – Cycadopsida
Order – Cycadales
Family- Cycadaceae
Genus - *Cycas*

It is widely distributed in tropical and sub tropical region of eastern hemisphere of the world. *Cycas revoluta*, *Cycas beddomei*, *Cycas circinalis, Cycas rumphii* are some of the common species. The plant body is sporophyte and resemble a small palm. The growth is very slow. It is evergreen and xerophytic in nature.

Sporophyte:-

The sporophyte is differentiated into root, stem and leaves. The stem is columnar bearing a crown of spirally arranged pinnately compound leaves (Figure 2.39).

External features

Figure 2.39: *Cycas* Habit

Root

Two types of roots are found in *Cycas*. They are the tap root and coralloid root.

The primary root persists and forms the tap root. Some of the lateral roots give rise to branches which grow vertically upward below the ground level. They branch repeatedly to form dichotomously branched coral- like roots called coralloid roots. The cortical region of the coralloid root contains the Blue green alga – *Anabaena* sp. which helps in nitrogen fixation (Figure 2.40).

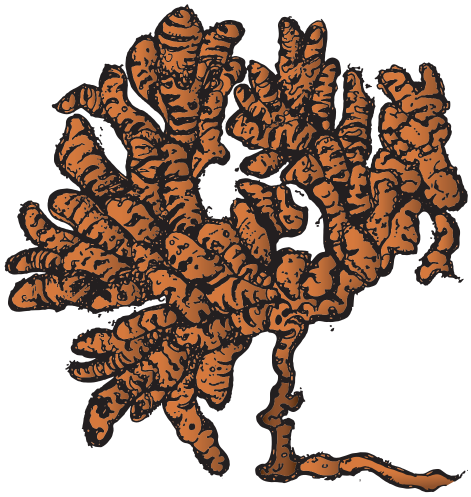


Figure 2.40: Coralloid root

Stem

The stem is columnar, unbranched and woody. It is covered with persistent woody leaf bases. The stem also bears adventitious buds at the base.

Leaves

Cycas has two types of leaves

(i) Foliage or assimilatory leaves
(ii) Scale leaves

(i) Foliage or assimilatory leaves

Foliage leaves are large, pinnately compound and form a crown at the top of the stem. Each leaf has 80-100 pairs of sessile leaflets. The apex is acute or spiny. The leaflet has a single midvein. Lateral veins are absent. Circinate vernation is present and young leaves are covered with **ramenta**.

(ii) Scale leaves

Scale leaves are brown, small, triangular and persistent which are protective in function. They are covered with ramenta.

Internal structure

T.S. of Root

The internal organization of the primary root reveals the following parts. 1. Epiblema, 2. Cortex 3. Vascular region (Figure 2.41). Epiblema is the outermost layer and is made up of single layered parenchyma. It is followed by thin walled parenchymatous cortex. The cortex is delimited by single layered endodermis. A multilayered parenchymatous pericycle is present and it surrounds the vascular tissue. The xylem is diarch in young root and tetrarch in older ones. Secondary growth is present. Coralloid root also shows similar structure but the middle cortex is characterized by the presence of Algal zone. Blue green alga called, *Anabaena* is found in this zone. The xylem is triarch and exarch.

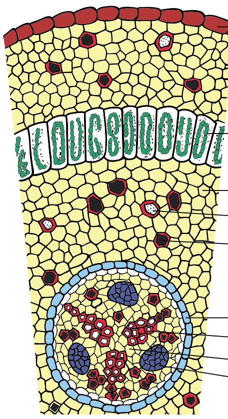


Figure 2.41: T.S. of Coralloid root

T.S. of Stem

The cross section of young stem is irregular in outline due to the presence of persistent leaf bases. It is differentiated into epidermis, cortex and vascular cylinder. It resembles the structure of a dicot stem (Figure 2.42).

The epidermis is the outermost layer and is covered with thick cuticle. It is discontinuous due to the presence of leaf bases. The cortex constitutes the major part and is made up of thin walled parenchymatous cells. The cells are filled with starch grains. Cortex also possesses several mucilage ducts and tannin cells. In young stem the vascular bundles are arranged in the form of a ring. A broad medullary ray is present. The vascular bundles are conjoint, collateral, endarch and open. Xylem is made up of tracheids and phloem consists of sieve tubes and phloem parenchyma. Companion cells are absent. The cambium present in the vascular bundle is active for short period. The secondary cambium is formed from the pericycle or cortex and helps in secondary growth of the stem. The cortical region shows a large number of leaf traces. The presence of direct leaf traces and girdling leaf trace is the unique feature of *Cycas* stem. Secondary growth results in polyxylic condition. Phellogen and cork are formed and replace the epidermis.The wood formed belongs to manoxylic type.

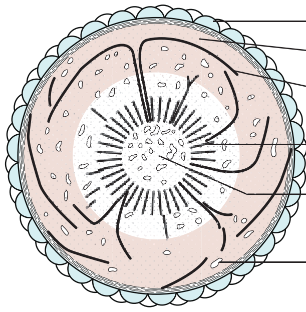


Figure 2.42: T.S. of stem

T.S. of Rachis

The outermost layer is epidermis and is covered by thick cuticle. The hypodermis is made up of two layers of sclerenchyma on the adaxial side and many layered on the abaxial side. The ground tissue is parenchymatous. The peculiar feature of the rachis is the arrangement of vascular bundle i.e., in an inverted Omega shape pattern (Figure 2.43). Each vascular bundle is covered by a single layered sclerenchymatous bundle sheath. Vascular bundles are collateral, endarch and open. A single layered endodermis and few layered pericycle surrounds the bundle. A diplopxylic condition is present in the vascular bundles.(presence of both centripetal and centrifugal xylem).

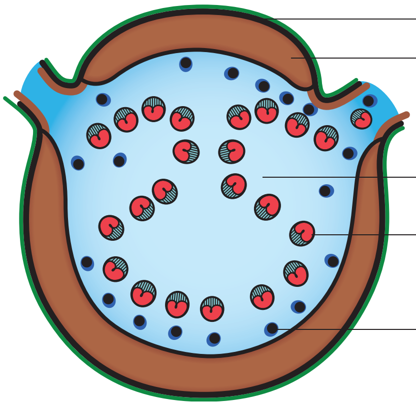


Figure 2.43: T.S. of Rachis

T.S. of Leaflet

The leaflet of *Cycas* in transverse section shows the presence of upper and lower epidermis. The epidermal cells are thick walled and are covered with thick cuticle. The lower epidermis is not continuous and is interrupted by sunken stomata. The hypodermis consists of sclerenchyma cells to prevent transpiration. The mesophyll is differentiated into palisade and spongy parenchyma. The cells of this layer are involved in photosynthesis. The spongy parenchyma present in close proximity to the lower epidermis bear large intercellular spaces which help in gaseous exchange.

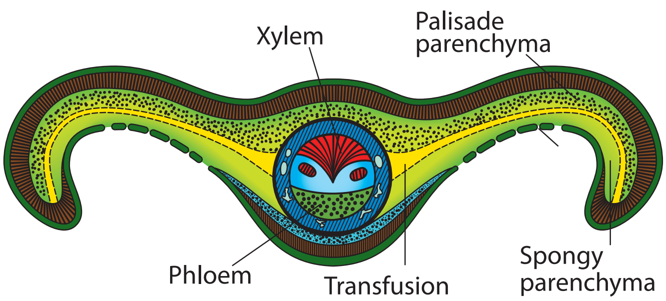


Figure 2.44: T.S. of leaflet

Layers of colourless, elongated cells which run parallel to the leaf surface from the midrib to the margin of the leaflet are seen. These constitute the **Transfusion tissue** that helps in the lateral conduction of water. The vascular bundle has xylem facing upper epidermis and phloem facing lower epidermis. The protoxylem occupies the centre, hence the bundle is mesarch. The vascular bundle has a sclerenchymatous bundle sheath (Figure 2.44).

Reproduction

Cycas reproduces by both vegetative and sexual methods

Vegetative reproduction

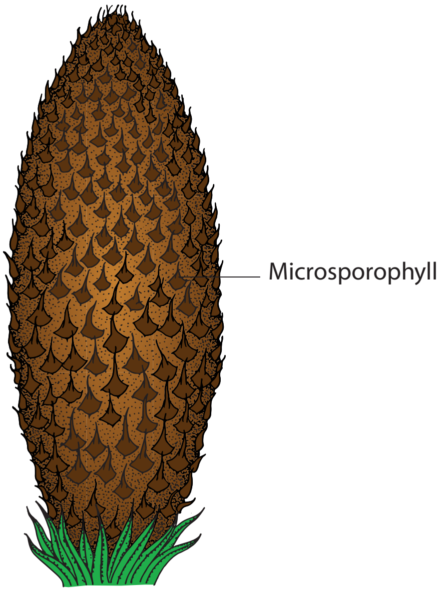
It takes place by adventitious buds or bulbils. They develop in the basal part of the stem. The bulbils on germination produce new plants.

Sexual reproduction

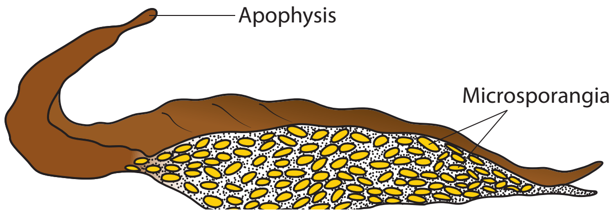
Cycas is dioecious i.e., male and female cones are produced in separate plants. It is heterosporous and produces two types of spores (Figure 2.45).

Male cone

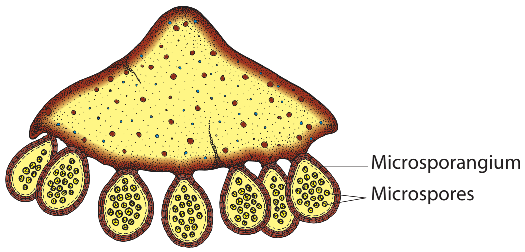
The male cone or staminate cone are borne singly on the terminal part of the stem. The growth of the stem is continued by the formation of axillary buds at the base of the cone. The male cone is displaced to one side showing sympodial growth in the stem. Male cones are stalked, compact, oval or conical and woody in structure. It consists of several microphylls which are arranged spirally around a central cone axis.



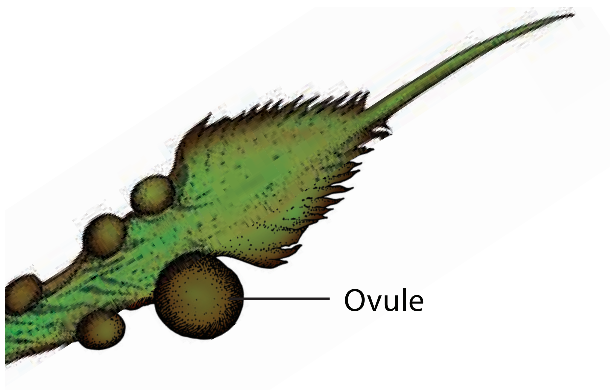
a) Male cone entire



b) A microsporophyll enlarged



c) T.S. of Microsporophyll



d) Megasporophyll

Figure 2.45: Reproduction in *Cycas*

Microsporophylls

Microsporophylls are flat, leaf-like and woody structures with narrow base and expanded upper portion. The upper expanded portion becomes pointed and is called apophysis. The narrow base is attached to the cone axis. Each microsporophyll contains thousands of microsporangia in groups called sori on abaxial (lower) surface. Development of sporangium is of Eusporangiate type. The spore mother cell undergoes meiosis to produce halpoid microspores. Each Microsporangium bears large number of microspores or pollen grains. Each sporangium is provided with a radial line of dehiscence, which helps in the dispersal of spores. Each microspore (Pollen grain) is a rounded, unicellular and uninucleate structure surrounded by outer thick exine and an inner thin intine. The microspore represents the male gametophyte.

Megasporophylls

The megasporophylls of *Cycas* are not organised into cones. They occur in close spirals around the tip of the stem of female plant. The megasporophylls are flat and measuring 15-30 cm in length. Each megasporophyll is differentiated into a basal stalk and an upper leaf like portion. The ovules are attached to the lateral side of the sporophyll. The ovules contain megaspore and it represent the female gametophyte.

Structure of Ovule

Cycas produces the largest ovule of the plant kingdom. The ovules are orthotropous, unitegmic and possess a short stalk. The single integument is very thick and covers the ovule leaving a small opening called *micropyle*. The integument consists of 3 layers, the outer and inner are fleshy (**sarcotesta**), the middle layer is stony called **sclerotesta**. The inner layer remains fused with the nucellus. The nucellus grows out into a beak-like structure and the upper part dissolves and forms a cavity-like structure called **pollen chamber**. A single megaspore mother cell undergoes meiosis to form four haploid megaspores. The lowermost becomes functional and others get degenerated. The nucellus gets reduced in the form of a thin papery layer in mature seeds and encloses the female gametophyte An enlarged megaspore or the embryo-sac is present within the nucellus. An archegonial chamber with 3-6 archegonia are present in the archegonial chamber below the pollen chamber (Figure 2.46).

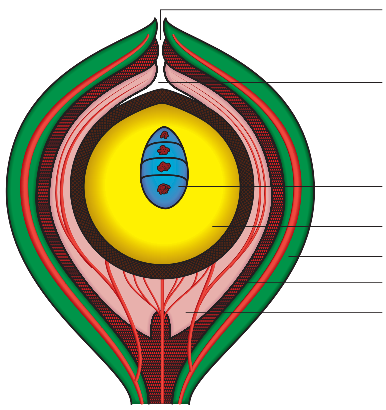


Figure 2.46: L.S. of Ovule

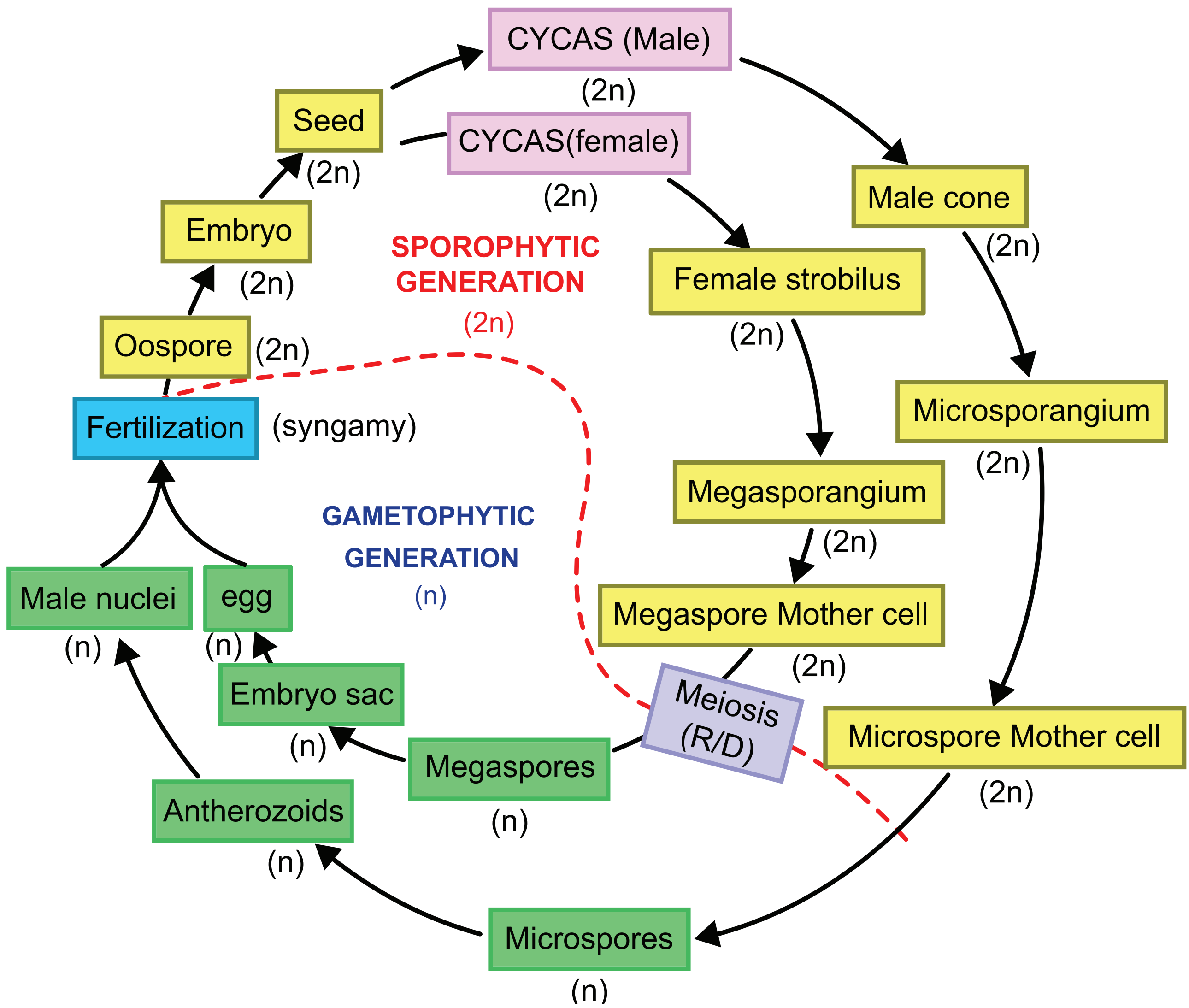


Figure 2.47: Life cycle of *Cycas*

Pollination and Fertilization.

Pollination is carried out by wind and occurs at 3 celled stage(a prothallial cell, a large tube cell and a small generative cell). Pollen grains gets lodged in the pollen chamber after pollination. The generative cell divides into a stalk and a body cell. The body cell divides to produce two large multiciliated antherozoids or sperms. During fertilization, one of the male gamete or multiciliated antherozoid fuses with the egg of the archegonium to form a diploid zygote (2n). The endosperm is haploid. The interval between pollination and fertilization is 4- 6 months. The zygote undergoes mitotic division and develops into embryo. The ovule is transformed into seed. The seed has two unequal cotyledons. Germination is hypogeal. The life cycle shows alternation of generations (Figure 2.47).

2.6.5 Pinus

Class – Coniferopsida
Order – Coniferales
Family –Pinaceae
Genus - *Pinus*

Pinus is a tall tree, looks conical in appearance and forms dense evergreen forest in the North temperate and sub-alpine regions of the world. They mostly grow in high altitudes (ranging from 1,200 to 3,000 metres). Some species of this genus include, *Pinus roxburghii, P. wallichiana, P. gerardiana* and *P. insularis.*

External features

The plant body is sporophyte and is differentiated into root, stem and leaves. The main stem is branched. The branches are dimorphic with long and short branches (Figure 2.48).

Figure 2.48: *Pinus* Habit

Root

Tap root system is found in *Pinus*. The root hairs are not well developed and the roots are covered with fungal hyphae called mycorrhizae.

Stem

The stem is cylindrical, erect, woody and branched. The branches are monopodial. The branches are of two types.

(i) Long shoots or branches of unlimited growth, (ii) Dwarf shoot or branches of limited growth

(i) Long shoots or branches of unlimited growth

The long shoot is present on the main trunk the apical buds grow indefinitely, They shorten gradually towards the tip, thus providing a pyramidal appearance to the tree. These branches bear scale leaves only.

(ii) Dwarf shoot or branches of limited growth

These branches do not have apical buds and hence show only limited growth. They develop in the axils of scale leaves and bear both scale and foliage leaves.

Leaves

There are two types of leaves 1. scale leaves, 2. foliage leaves

1. Scale leaves:

They are dark, brown, membranous, thin and small. They are present on both long and dwarf shoots. Their function is to protect young buds. The scale leaves on the dwarf shoots have a distinct midrib and are called "**Cataphylls**".

2. Foliage leaves:

The foliage leaves are green angular and needle like structures. They are borne on the dwarf shoot. A dwarf shoot with a group of needle like foliage leaves is known as **foliar spur**. The number of needles per dwarf shoot varies among the species. It may be one (*Pinus monophylla*), two (*P. sylvestris*), three (*P. gerardiana*), four (*P. quadrifolia*) and five (*P. excelsa*).

Internal Structure

T.S. of root

The internal structure of root reveals the presence of epiblema, cortex and stele.

The epiblema is made up of single layer of parenchymatous cells. Cortex is the wide zone and consists of parenchyma. Some of the cells have resin ducts. A single layered endodermis with suberised wall is present and is impregnated with tannins.A multilayered pericycle made up of parenchyma is present. Vascular tissue is radial, diarch with exarch xylem. The protoxylem bifurcates to form a 'Y' shaped structure and a resin duct lies in between the two arms of protoxylem. Secondary growth is present (Figure 2.49).

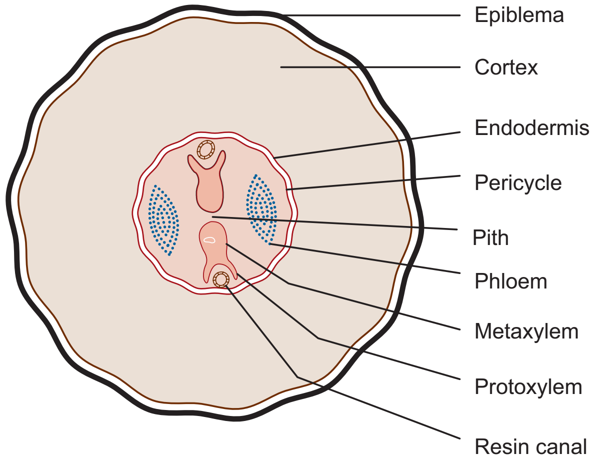


Figure 2.49: T.S. of *Pinus* root

T.S. of Stem

The internal organization of the stem shows three regions namely epidermis, Cortex and vascular tissue (Figure 2.50).

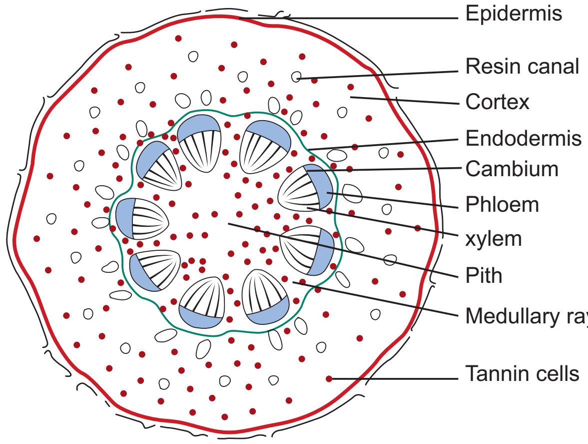


Figure 2.50: T.S. of *Pinus* stem

Epidermis is the outermost layer composed of compactly arranged and heavily cutinized cells. Epidermis is followed by few layers of sclerenchymatous hypodermis. The cortex consists of thin walled parenchyma cells. Resin canals and tannin filled cells are present in this region. Endodermis is indistinguishable from cortical cells. Vascular region is surrounded by pericycle. A ring consists of five or six vascular bundles are present. Vascular bundles are conjoint, collateral, open and endarch. Pith and medullary rays are present. Secondary growth is present and annual rings are formed.

T.S. of needle or foliage leaf

The internal structure of needle shows xerophytic adaptations. In cross section the outline appears more or less triangular and is divided into epidermis, mesophyll and vascular bundles. The epidermis is single layered and possesses thick cuticle and sunken stomata.Epidermis is followed by a few layers of sclerenchymatous hypodermis. It is interrupted by sub-stomatal cavities (Figure 2.51).

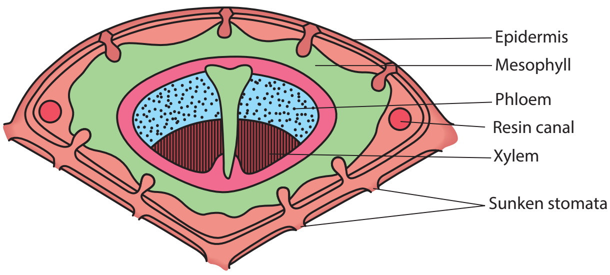


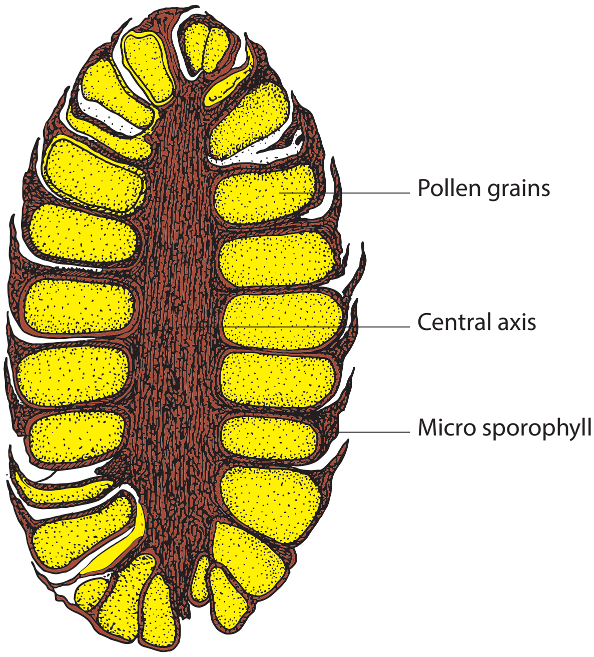
Figure 2.51: T.S. of *Pinus* needle leaf

Mesophyll is not differentiated into palisade and spongy parenchyma. Thin walled cells with chloroplasts are present. The cells are peculiar with numerous small infoldings which project into the cavities. The infoldings increase the photosynthetic area of the needle leaves Resin canal is present in the mesophyll. A single layered endodermis separates the vascular region from the cortex. A multilayered pericycle containing starch is present. Two types of specialised cells called **albuminous cells** and **tracheidal cells** are present. The former helps to pass substances from the mesophyll to the phloem while the latter helps in water conduction and constitutes transfusion tissue. Two vascular bundles are present. They are separated by sclerenchyma tissue. The Vascular bundles are conjoint, collateral and open.

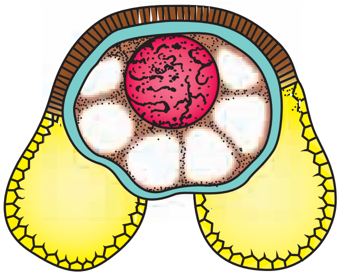
Reproduction

Pinus is heterosporous and produces two types of spores called. microspores and megaspores. The plants are monoecious. Both male and female cones or strobili develop on the different branches of the same plant (Figure 2.52).

a) *Pinus* - A twig with male cones

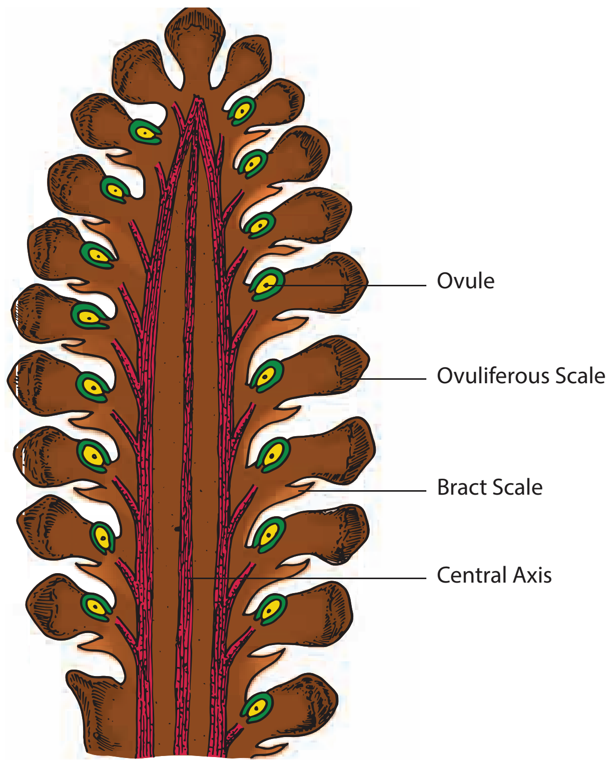


b) L.S. of male cone



c) A mature pollen grain

d) *Pinus* - A twig with female cone



e) L.S. of female cone

Figure 2.52: Reproduction in *Pinus*

Male cone

Male cones are produced in clusters on branches of unlimited growth. Each cone develops on the axil of scale leaf . The male cone consists of a centrally located cone axis surrounded by numerous spirally arranged microsporophyll. It bears two microsporangia at the base of the abaxial side of the microsporophyll. Each sporangium bears numerous winged microspores (n) or pollen grains. The microspores represent the male gametophyte

Female cone:-

Female cones are formed in the groups of 1 to 4 in the axils of the scale leaves. The female cone takes about three years to mature. It has the central axis around which megasporophylls are arranged spirally. The megasporophyll is the compound structure consisting of two types of scales. 1. Bract scale (sterile), and 2. Ovuliferous scales (fertile). The dorsal surface of each ovuliferous scale bears two ovules. Ovules bear megaspores which represent the female gametophyte.

Pollination and fertilization

In *Pinus* wind pollination takes place (Anemophilous). The microspore or pollen grain is released in the 4 celled stage(two prothallial cell, 1 generative and 1 tube cell). At the time of pollination a secretion oozes out from the micropyle of the ovule which entangles pollen grains which helps to lodge them in the pollen chamber. The tube cell protrudes to form pollen tube. The generative cell divides to produce stalk cell and body cell. The body cell divides into unequal male cells. Fertilization takes place after about a year of pollination. The pollen tube containing two male nuclei penetrates through the micropyle and reaches the egg. One of the male nuclei fuses with the egg forming diploid zygote and the remaning one gets degenerated. The fertilized egg

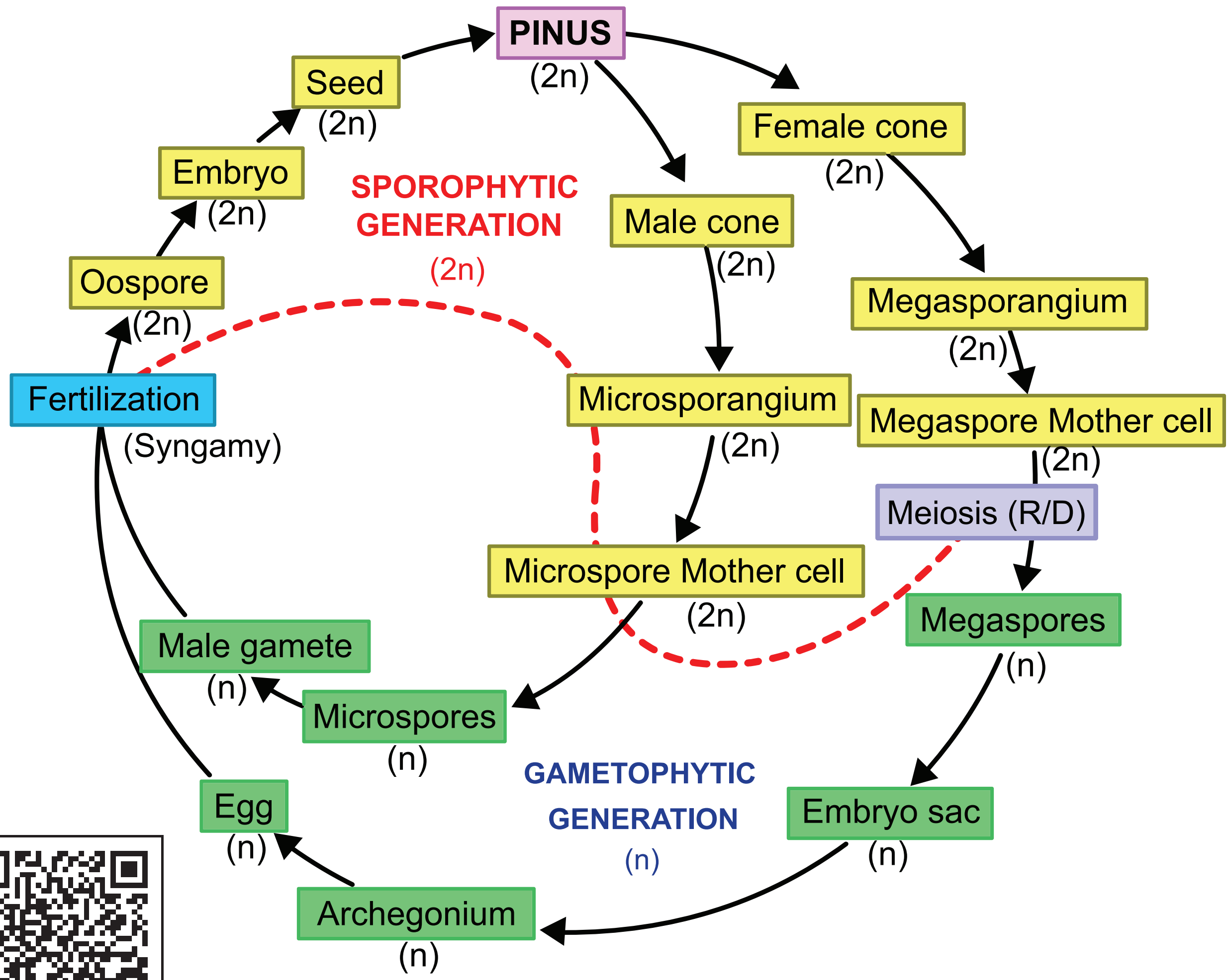


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Figure 2.53: Life cycle of *Pinus*

(zygote) undergoes mitotic division and develops into an embryo. Polyembryony is present. The embryo undergoes several changes and finally becomes a winged seed. The seed germination is epigeal. Life cycle of *Pinus* shows alternation of generation (Figure 2.53).

Know about Fossil plants

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

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 Palaebotany is located in Lucknow 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, Lepidocarpon, Williamsonia, Lepidodendron*

Fossil Angiosperms – *Archaeanthus, Furcula*

2.7 Angiosperms

In the previous lesson 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 world 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 embryosac (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.

Oedogonium is a fresh water, filamentous, multicellular alga. The presence of cap cell is the prominent characteristic feature in addition reticulate chloroplast is present. Asexual reproduction takes place through Zoospores. The sexual reproduction is Oogamous.

Chara is a fresh water alga and is popularly called "Stone worts". The plant body is multicellular, macroscopic and is differentiated into main axis and rhizoids. Sexual reproduction is Oogamous.

Bryophytes are 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.

Marchantia belongs to the class Hepaticopsida. The thallus is dorsiventral and is attached to the substratum by means of rhizoids. The internal structure of the thallus reveals the presence of photosynthetic region and a storage region. Vegetative reproduction takes place through fragmentation and formation of Gemmae. The sexual reproduction is Oogamous. Sporophyte bears spores. Alternation of generation is present.

Funaria belongs to the class Bryopsida. The gametophyte is differentiated into leaf-like, stem-like structures with rhizoids. Gemmae, Protonema and bulbils help in asexual reproduction. Sexual reproduction is Oogamous. Alternation of generation is present.

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.

Selaginella belongs to the class Lycopsida. The plant body is sporophyte. It is differentiated into stem, leaf, rhizophore and roots. Heterospory is found and two types of spores namely microspores and megaspores are produced in sporangia. The microsporangia and megasporania are borne on sporophylls. The sporophylls are organized to form cone. Sexual reproduction is oogamous. Alternation of generation is present.

Adiantum belongs to Pteropsida. The sporophyte is differentiated into root, rhizome and leaves. The spores are produced in sporangia and is covered by false indusium. The sexual reproduction is oogamous and sex organs (antheridum and archegonium) are produced on prothallus. Alternation of generation is present.

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

Cycas belongs to Cycadopsida. The plant body is sporophyte and looks like a small palm tree. Apart from Taproot Coralloid roots are present. It is dioecious, Microsporophylls are organized into male cone. Ovules are borne on megasporophylls which are not organized into cone. Fertilization results in zygote and it develops into embryo. Alternation of generation is present.

Pinus belongs to Coniferopsida.. The plant body is sporophyte and is differentiated into root, stem and leaves. The main stem is branched. The branches are dimorphic with long and short branches. It is monoecious, heterosporous and produces two types of spores called microspores and megaspores. 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

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1. Which of the plant group has gametophyte as a dominant phase?
   a. Pteridophytes
   b. Bryophytes
   c. Gymnosperm
   d. Angiosperm
2. Which of following represent 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.
11. List the classes of algae.
12. Mention the pigments and storage food of Dinophyceae.
13. What are cap cells?
14. Name the flagellation found in the zoospore of *Oedogonium*
15. What is Nucule?
16. Differentiate nodal and internodal cells of *Chara*.
17. What are elaters?
18. What is protonema?
19. Where do we find false indusium?
20. Explain the internal structure of *Cycas* rachis.
21. Differentiate long and dwarf shoot.

ICT Corner

Different forms of plants

Is all the **plants** are same? →

Steps

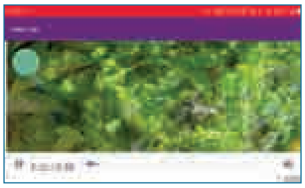
- Scan the QR code or go to google play store
- Type online labs and install it.
- Select biology and select Characteristics of plants
- Click theory to know the basic about Characteristics of plants
- Register yourself with mail-id and create password to access online lab simulations

Activity

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

Step 1

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.phschool.com/atschool/phbio/active_art/plant_life_cycle/plantlifecycle.swf

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* Pictures are indicative only

Chapter 3

Unit II: Plant Morphology and Taxonomy of Angiosperm

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 of leaf and functions of leaf*

Chapter Outline

5FG1XM

The study of various external features of the organism is known as **morphology. Plant morphology** also known as **external morphology** 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 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 to 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. 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: *Phyllanthus amarus, Cleome viscosa.*

II. Shrubs

A shrub is a perennial, woody plant with several main stems arising from the ground level. Example: *Hibiscus*

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 major categories: I. Terrestrial and II.Aquatic.

I. Terrestrial

Plants growing on land are called **terrestrial plants.** The following table illustrate the types of terrestrial plants classified based on their environmental adaptation.

II. Aquatic

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

3.3 Life Span

Based on life span plants are classified into 3 types. They are annual, biennial and perennial

Terrestrial habitat		
Types	**Nature of environmental adaptation**	**Example**
Mesophytes	Growing in soils with sufficient water	*Azadirachta indica*
Xerophytes	Growing on dry habitats	*Opuntia*, *Euphorbia*
Psammophytes	Growing on sand	*Ipomoea pes-caprae, Spinifex littoralis*
Lithophytes	Growing on rock	Many algae and lichens, *Ficus spp*

Aquatic habitat		
Types	**Nature of environmental adaptation**	**Example**
Free Floating	Growing on water surface	*Eichhornia, Trapa, Pistia, Lemna*
Submerged	Plants growing completely under water	*Hydrilla, Vallisneria*
Emergent	Plants with roots or stems anchored to the substrate under water and aerial shoots growing above water	*Limnophyton, Typha*
Floating leaved	Anchored at bottom but with floating leaves	*Nelumbo, Nymphaea*
Mangroves	Plants growing emergent in marshy saline habitat	*Avicennia, Rhizophora*

I. Annual (Therophyte or Ephemerals)

A plant that completes its life cycle in one growing season. Example: Peas, maize, water melon, groundnut, sunflower, rice and so on.

II. Biennial

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

III. Perennial (Geophyte)

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.** 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**. Example: *Bamboo, Agave, Musa, Talipot palm.*

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.

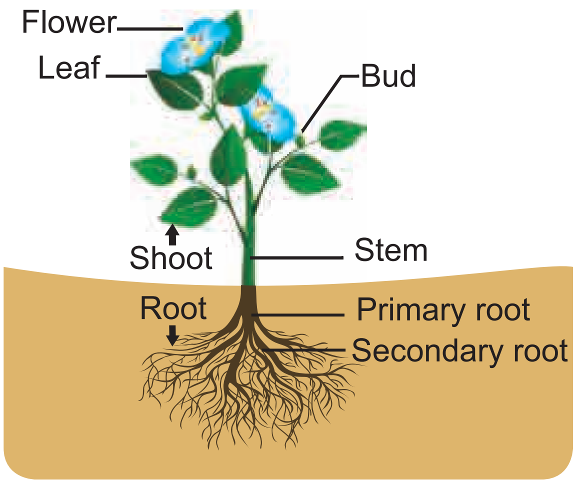


Figure: 3.1: Parts of a flowering plant

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 parenchymatous cells called **root cap.** 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

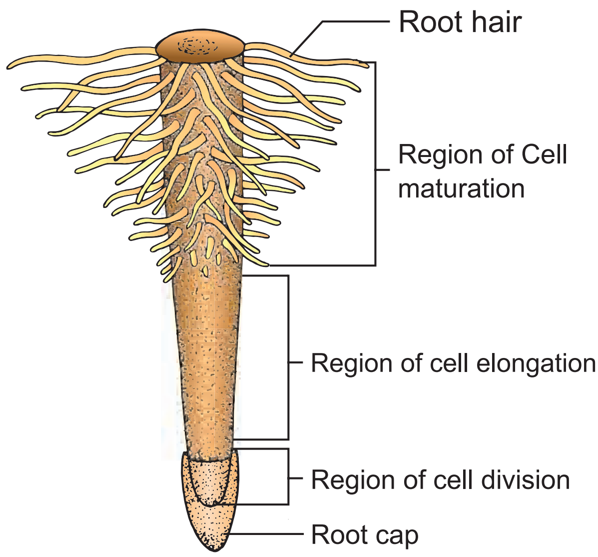


Figure 3.2: Regions of root

Table: 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

3.5.1 Types of root

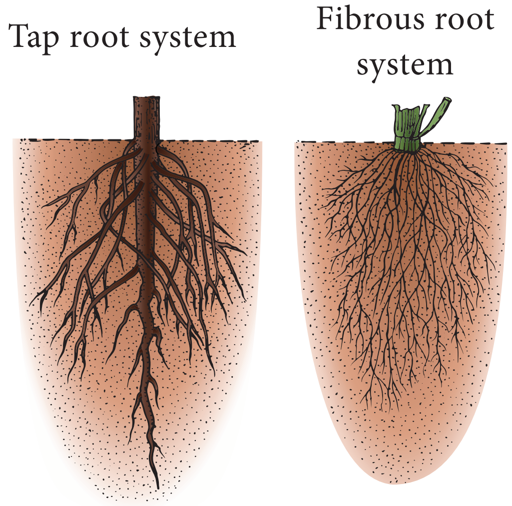


Figure 3.3: Types of root system

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 its 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, Ficus benghalensis, Piper nigrum*. In most of the monocots the primary root of the seedling is short lived and lateral roots arise from various regions of the plant body. These are bunch of thread-like roots equal in size which are collectively called **fibrous** root system generally found in grasses. Example: *Oryza sativa, Eleusine coracana, Pennisetum americanum*.

III. Functions of root

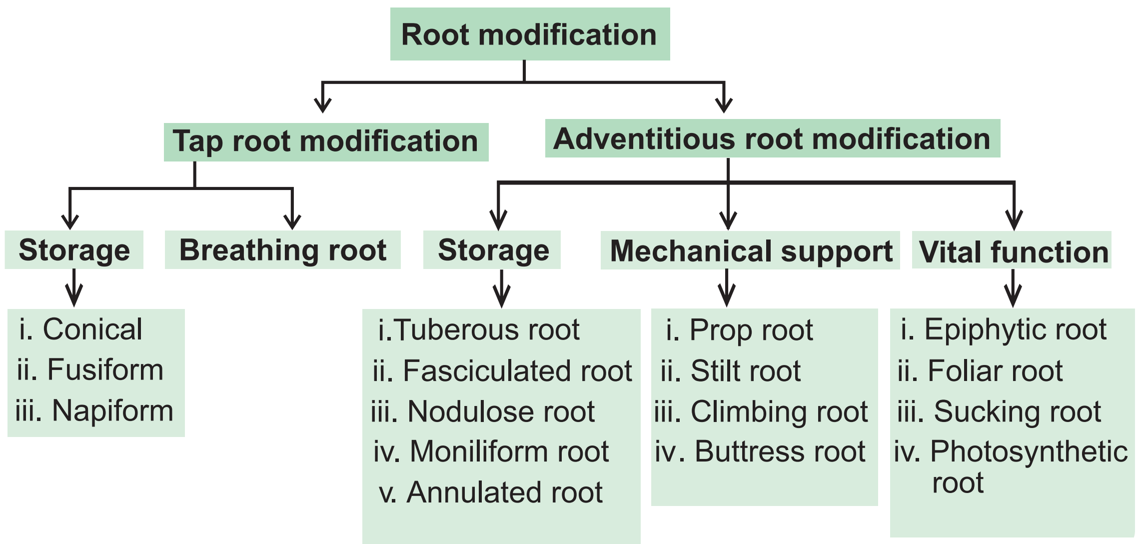
Root performs two kinds of functions namely primary and secondary functions.

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, these roots are modified in their structure.



3.5.2 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 and suddenly tapers like a tail at the apex. Example: *Beta vulgaris*

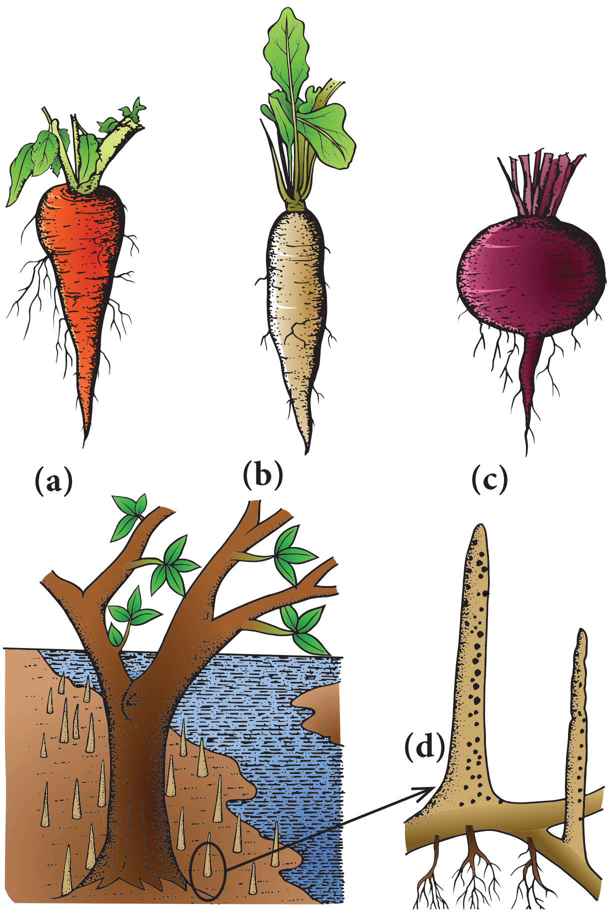


Figure 3.4: Tap root modification
(a) *Daucus carota* **(b)** *Raphanus sativus*
(c) *Beta vulgaris* **(d)** *Avicennia - pneumatophores*

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 large number of breathing pores or 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, Ruellia*.

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, Basella* (Indian spinach).

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.


Ipomoea batatas


Dahlia


Maranta


Psychotria

Figure 3.5: Adventitious Root Modification for Storage

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, Zeamays, Pandanus, Rhizophora*.

3. Climbing (clasping or 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: *Epipremnum pinnatum, Piper betel, Ficus pumila*.

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), *Terminalia arjuna, Delonix regia, Pterygota alata*.

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, Aerides*.

2. Foliar root

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


Ficus benghalensis


Saccharum officinarum


Epipremnum pinnatum


Bombax

Figure 3.6: Adventitious root modification for mechanical support

3. Sucking or Haustorial roots

These roots are found in parasitic plants. Parasites develop adventitious roots from stem which penetrate into the tissue of the 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 usually the aerial portion of the plant
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. Provides support and bears leaves, flowers and fruits.
2. It transports water and mineral nutrients to the other parts from the root.
3. It transports food prepared by leaves to other parts of the plant body.

Vanda *Bryophyllum* *Cuscuta* *Tinospora*

Figure 3.7: Adventitious Root Modification for Vital Functions

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*
5. **Photosynthesis** – Example: *Opuntia, Ruscus, Casuarina, Euphorbia, Caralluma.*
6. **Protection** – Example: *Citrus, Duranta, Bougainvillea, Acacia, Fluggea, Carissa.*
7. **Support** - Example: *Passiflora, Bougainvill*ea, *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 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 bud. 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. In *Agave* an*d Allium proliferum* floral buds get modified into bulbils. In *Lilium bulbiferum* and *Dioscorea bulbifera,* the bulbils develop in axil of leaves. In *Oxalis*, they develop just above the swollen root.

3.6.2 Types of Stem

Majority of angiosperm possess upright, vertically growing erect stem. They are (i) Excurrent, (ii) Decurrent, (iii) Caudex, (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: *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, Azadirachta indica, Tamarindus indicus, Aegle marmelos*

iii. Caudex

It's an unbranched, stout, cylindrical stem, marked with scars of fallen leaves. Example: *Cocus nucifera, Borassus flabelliformis, Areca catechu*

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 produces roots at each node. Example: *Cynodon dactylon, Oxalis, 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: *Evolvulus alsinoides, Indigofera prostrata.*

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

iii. **Diffuse:** A trailing stem with spreading branches. Example: *Boerhaavia diffusa, Merremia tridentata*

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.

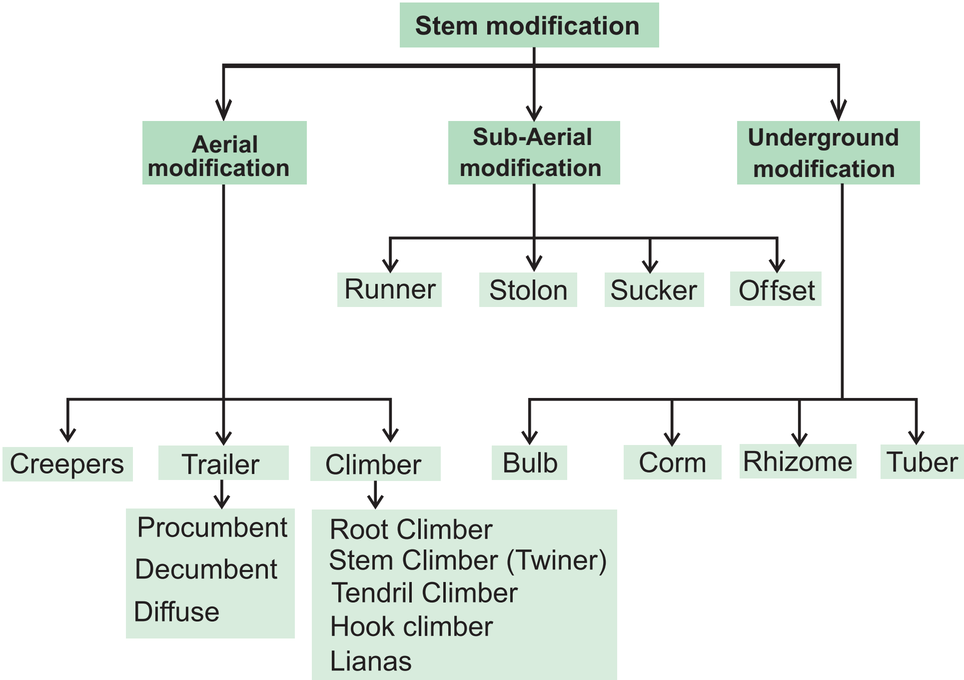
i. Root climbers

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

ii. Stem climbers (twiners)

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

Stem climbers may coil around the support 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, Entada pursaetha.*

vi. Tendril climbers

Tendrils are thread-like coiling structures which help the plants in climbing. Tendrils may be modifications of Stem – as in *Passiflora*, *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.

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).

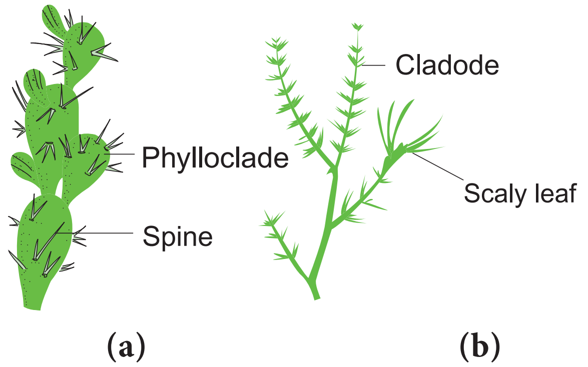


Figure 3.8: (a) Phylloclade-*Opuntia*
(b) Cladode-*Asparagus*

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).

Thorns

Thorn is a woody and sharp pointed modified stem. Either the axillary bud or the terminal bud gets modified into thorns. In *Carissa* apical bud 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: *Centella* (Indian pennywort), *Oxalis* (wood sorrel), lawn grass (*Cynodon dactylon*).

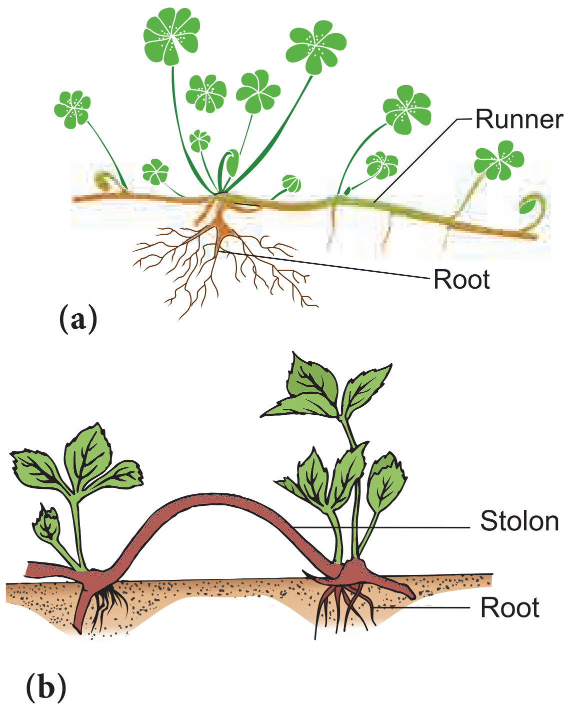


Figure 3.9: **(a)** Runner-*Oxalis*
(b) Stolon-*Fragaria*

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).

3. Sucker

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

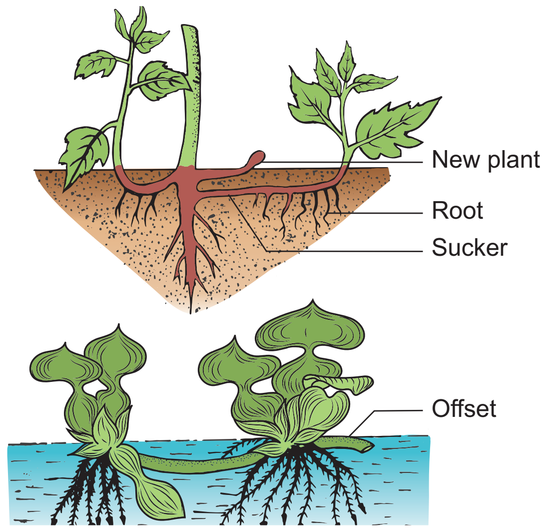


Figure 3.9: **(c)** Sucker-*Chrysanthemum*
(d) Offset-*Eichhornia*

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. These are two types (a) Simple Tunicated bulb Example: *Allium cepa* (b) Compound Tunicated bulb. Example: *Allium sativum*. 2. Scaly bulb: They are narrow, partially overlap each other by their margins only. Example: *Tulipa spp*.

Pseudobulb is a short erect aerial storage or propagating stem of certain epiphytic and terrestrial sympodial orchids. Example: *Bulbophyllum*.

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, Gladiolus, Colocasia, Crocus, Colchicum*

Bulb-
Allium cepa

Rhizome
Zingiber officinale

Corm-*Colocasia*

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 conspiquous nodes and internodes covered by scale leaves. Example: *Zingiber officinale, Canna, Curcuma longa, Maranta arundinacea, Nymphaea, Nelumbo.*

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, Antiaris.*
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, Kalanchoe, Sedum, Brassica oleracea.*
2. Protection – Example: *Berberis, Opuntia, Argemone mexicana.*
3. Support – Example: *Gloriosa, Nepenthes*
4. Reproduction - Example: *Bryophyllum, Begonia, Zamioculcas.*

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 growing buds at its axil.

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

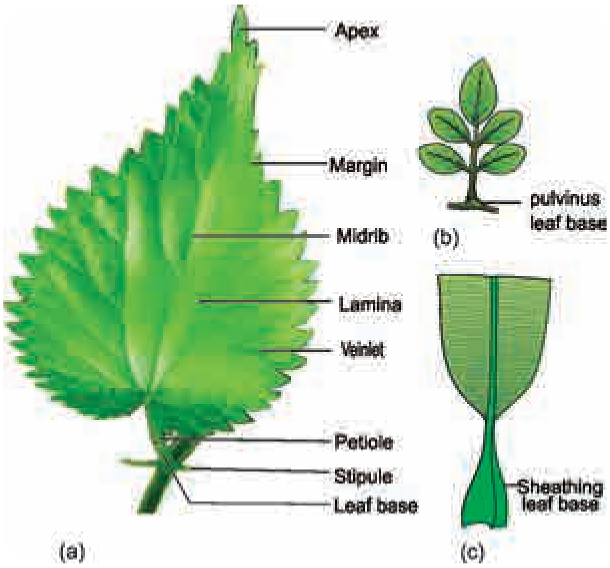


Figure 3.11: (a) Parts of the leaf **(b)** Pulvinus leaf base **(c)** Sheathing leaf base

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 is said to be **petiolate.** Example: *Ficus, Hibiscus, Mangifera, Psidium*. Leaves that do not possess petiole is said to be **sessile**. Example: *Calotropis, Gloriosa.*

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

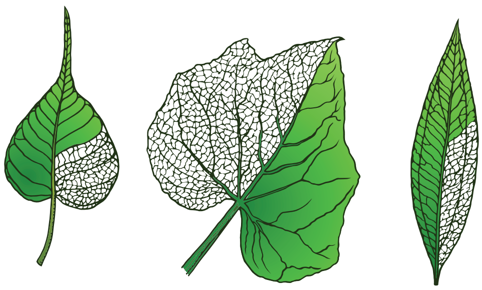
In this type of venation leaf contain a prominent midrib from which several secondary veins arise that branch and anastomose like a network. This type of venation is common in all dicot leaves. It is of two types.

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, Ficus religiosa, Nerium.*

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

   i. **Divergent type:** When all principal veins originate from the base and diverge from one another towards the margin of the leaf as in *Cucurbita, Luffa, Carica papaya*, etc.,

   ii. **Convergent:** When the veins converge to the apex of the leaf, as in Indian plum (*Zizyphus*), bay leaf (*Cinnamomum*)



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

Figure 3.12: Types of reticulate venation

(a) Pinnately reticulate
(b) Palmately reticulate (Divergent)
(c) Palmately reticulate (Convergent)

II. Parallel venation

Veins run parallel to each other 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)

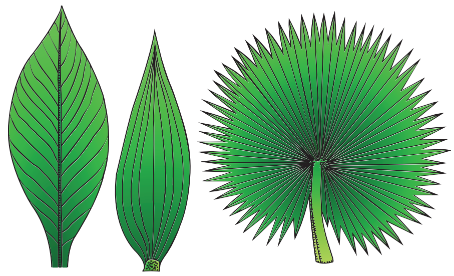
When there is a prominent midrib in the center, from which arise many veins perpendicularly and run parallel to each other. Example: *Musa*, Zinger, *Curcuma, Canna*.

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.

5FPWZA

1. Alternate phyllotaxy

In this type there is only

DO YOU KNOW?

Modern morphologist Hickey (1973) and Hickey and Wolf (1975) classified the venation into following major types based on the pattern of primary, secondary and tertiary venation.

- Craspedodromous – In which secondary veins terminate at the leaf margin. (sub types are simplecraspedodromous, semicraspedodromous, mixed craspedodromous).
- Camptodromous – In which secondary veins do not terminate at the margin. (sub types are brochidodromous, eucamptodromous, cladodromous, reticulodromous).
- Hyphodromous – With only the primary midrib vein present or evident and secondary veins either absent, very reduced or hidden with the leaf mesophyll.
- Parallellodromous – Venation is equivalent to parallel in which two or more primary or secondary veins run parallel to one another, converging at the apex.
- Actinodromous – If three or more primary veins diverge from one point.
- Palinoactinodromous – Similar to actinodromous, but the primary veins have additional branch in above the main point of divergence of the primaries.
- Flabellate – Venation is that in which several equal, fine veins branch toward the apex of the leaf.
- Campylodromous – Venation is that in which several primary veins run in prominent, recurved arches at the base, curving upward to converge at the leaf apex.
- Acrodromous – If two or more primary veins run in convergent arches toward the leaf apex.

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 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), *Eugenia jambolana* (Jamun), *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, Zinnia, Ocimum*

3. Ternate phyllotaxy

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

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

Figure 3.14: Phyllotaxy

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, Alstonia scholaris.*

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 decreasing length petioles. Example: *Acalypha, Begonia.*

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 (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 tamarind, *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*, *Abrus, Sesbania, Saraca, Cassia*.
   b. when the leaflets are odd in number, the leaf is said to be **imparipinnate.** Example: *Rosa*, *Azadirachta* (Neem), (*Murraya* Chinese box).

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*, *Mimosa*, *Acacia nilotica, Caesalpinia*.

- **Foliage leaves** — are ordinary green, flat, lateral appendages of the stem or the branch borne at the node.
- **Cotyledons or seed leaves** — are attached to the axis of the embryo of the seed. As the seed germinates, they usually turn green and become leaf-like.
- **Cataphylls or scale leaves** — are reduced forms of leaves, stalkless and often brownish. They are the bud-scales, scales on the rhizome (underground stems), and also on other parts of the plant body (Bamboo).
- **Prophylls** — the first formed leaves are called prophylls.
- **Floral leaves** — are members of a flower, forming into two accessory whorls (calyx and corolla), two essential whorls(androecium and gynoecium).
- **Hypsophylls or bract leaves** — these leaves cover the flower or an inflorescence in their axil. The main function of these leaves is to protect the flower buds.

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, Oroxylum*.

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

2. Palmately compound leaf

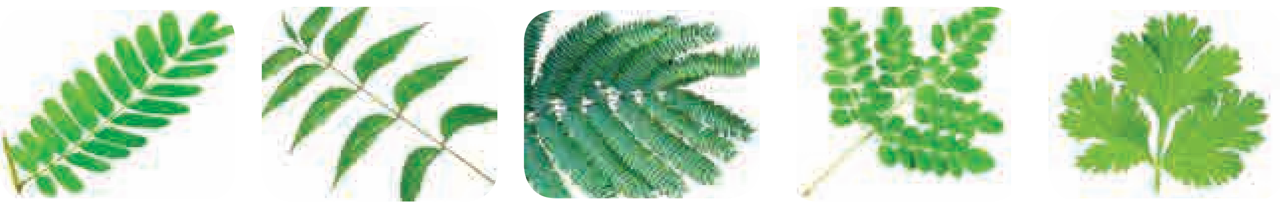
A palmately compound leaf is defined as one in which the petiole bears terminally, one or more leaflets which seem to be radiating from a common point like fingers from the palm.

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

ii. **Bifoliolate:** When there are two leaflets articulated to the petiole it is said to be bifoliolate. Example: *Balanites roxburghii, Hardwickia binata, 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*), *Lablab, Oxalis*

iv. **Quadrifoliolate:** There are four leaflets articulated to the petiole it is



(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*

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 *Ceiba pentandra, Cleome pentaphylla, Bombax ceiba*

3.7.6 Modification of Leaf

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

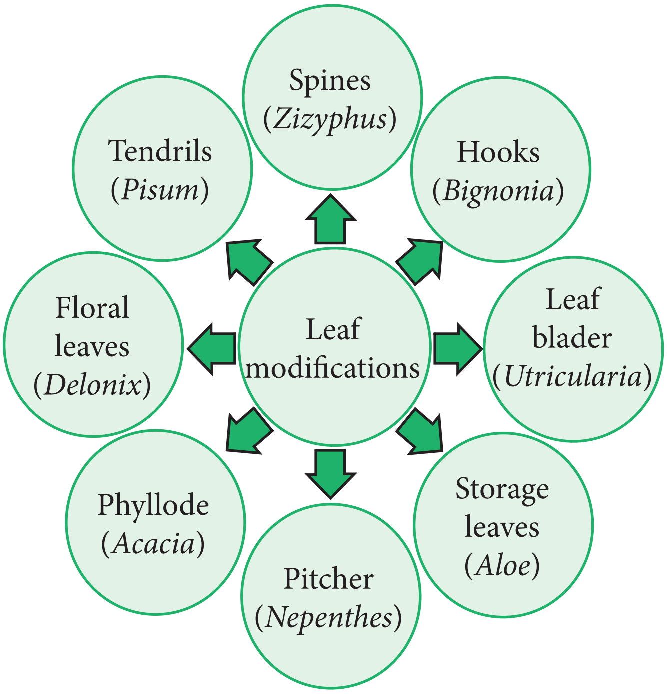
I. Leaf tendrils

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: *Argemone mexicana* (Prickly poppy), *Solanum trilobatum, Solanum virginianum*. 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, Rubus 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, Kalanchoe*, *Sedum, Sueada*, *Brassica oleracea* (cabbage-variety *capitata*).

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.*

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 as 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 Ptyxis

Rolling or folding of individual leaves may be as follows:

1. **Reclinate** - when the upper half of the leaf blade is bent upon the lower half as in loquat (*Eriobotrya japonica*).
2. **Conduplicate** - when the leaf is folded lengthwise along the mid-rib, as in guava, sweet potato and camel's foot tree (*Bauhinia*).

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

Figure 3.17: Leaf Modification

3. **Plicate or plaited** – when the leaf is repeatedly folded longitudinally along ribs in a zig-zag manner, as in *Borassus flabellifer*.
4. **Circinate** - when the leaf is rolled from the apex towards the base like the tail of a dog, as in ferns.
5. **Convolute** - when the leaf is rolled from one margin to the other, as in banana, aroids and Indian pennywort. *Musa* and members of Araceae.
6. **Involute** - when the two margins are rolled on the upper surface of the leaf towards the midrib or the centre of the leaf, as in water lily, lotus, Sandwich Island Climber (*Antigonon*) and *Plumbago*.
7. **Crumpled** - when the leaf is irregularly folded as in cabbage.

3.7.8 Leaf duration

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

Cauducuous (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.

3.7.9 Leaf symmetry

1. Dorsiventral leaf

When the leaf is flat, with the blade placed horizontally, showing a distinct upper surface and a lower surface, as in most dicotyledons, it is said to be dorsiventral. Example: *Tridax.*

2. Isobilateral leaf

When the leaf is directed vertically upwards, as in many monocotyledons, it is said to be isobilateral leaf. Example: *Grass.*

3. Centric leaf

When the leaf is more or less cylindrical and directed upwards or downwards, as in pine, onion, etc., the leaf is said to be centric.

4. Heterophylly

Occurrence of two different kinds of leaves in the same plant is called **heterophylly.** Heterophylly is found in many aquatic plants. Here, the floating or aerial leaves and the submerged leaves are of different kinds. The former are generally broad, often fully expanded, and undivided or merely lobed, while the latter are narrow, ribbon-shaped, linear or much dissected. Heterophylly in water plants is, thus, an adaptation to two different conditions of the environment. Example: water crowfoot (*Ranunculus aquatilis*), water plantain (*Alisma plantago*), arrowhead (*Sagittaria*), *Limnophila heterophylla.*

Terrestrial (land) plants also exhibit this phenomenon. Among them *Sterculia villosa*, jack (in early stages), *Ficus heterophylla* show leaves varying from entire to variously lobed structures during different developmental stages. Young leaves are usually lobed or dissected and the mature leaves are entire. Such type is known as **developmental heterophylly.** Example: *Eucalyptus, Artocarpus heterophyllus.*

Summary

Flowering plants consist of two major organ systems: Underground root system and aerial root 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 radical which further branches into secondary roots. Adventitious roots arise from different parts of the plant other than radical. 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

5FYT1X

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 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. *Sagittaria* - Heterophylly
   b. *Lablab* - Trifoliolate
   c. *Begonia* - 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

Climbers

Root climber - *Piper betel*

Stem climber - *Clitoria*

Thorn climber - *Bougainvillea*

Lianas - *Entada*

Tendril climber - *Cissus quadrangularis*

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

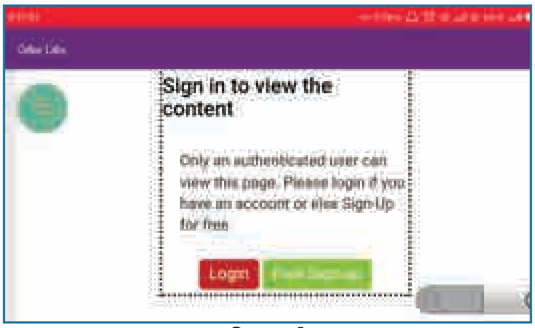
Activity

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

Step 1

Step 2

Step 3



Step 4

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* Pictures are indicative only

Chapter 4

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*

Chapter Outline

5G8P3K

Flowers of five types of land in tamil literature.

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

a. Kurinji (*Strobilanthus kunthianus*),
b. Mullai (*Jasminum auriculatum*),
c. Marutham (*Lagerstroemia speciosa*),
d. Neithal (*Nymphaea pubescens*),
e. Palai (*Wrightia tinctoria*)

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 present in the axile of the nearest vegetative leaf. Example: *Hibiscus rosa-sinensis*

Cauliflorous: Inflorescence developed directly from a woody trunk. Example: *Theobroma cocoa, Couroupita guianensis*

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

Figure 4.1: Cauliflorous inflorescence

4.1.2 Based on branching pattern and other characters

Inflorescences may also have 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 confined to these patterns

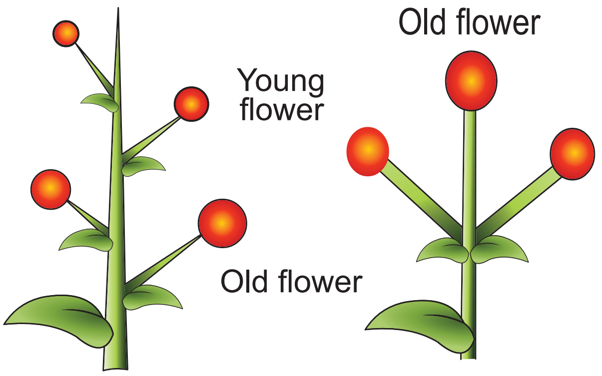


Figure 4.2: (a) Racemose **Figure 4.2: (b)** Cymose inflorescence

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.

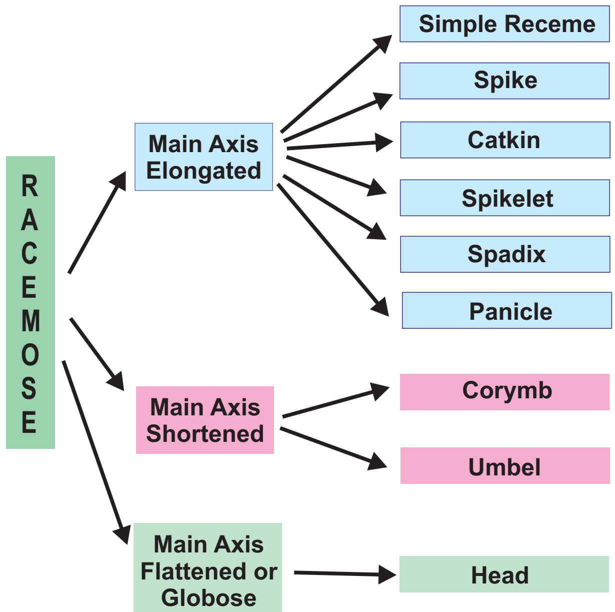


Figure 4.3: Racemose

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 and radish.

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

c. Spikelet: Literally it is a small spike. The Inflorescence is with

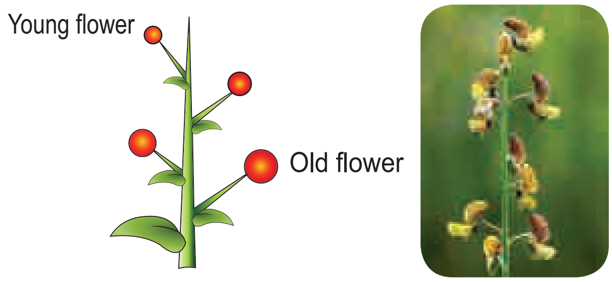


Figure 4.4: (a) diagrammatic, **(b)** Simple raceme

Figure 4.4: (c) diagrammatic, **(d)** Spike

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, Barley, *Sorghum*.

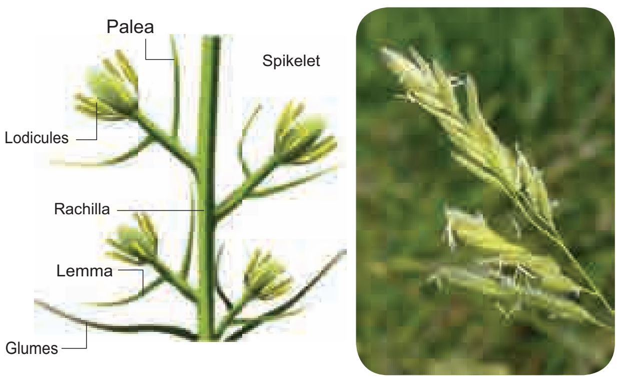


Figure 4.4: (e) diagrammatic, **(f)** Spikelet

d. Catkin: **Pendulous spikes** with a long and drooping axis bearing small unisexual or bisexual flowers. It is also

Figure 4.4: (g) diagrammatic, **(h)** Catkin

called **ament**. Example: *Acalypha hispida, Prosopis juliflora, Piper nigrum.*

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

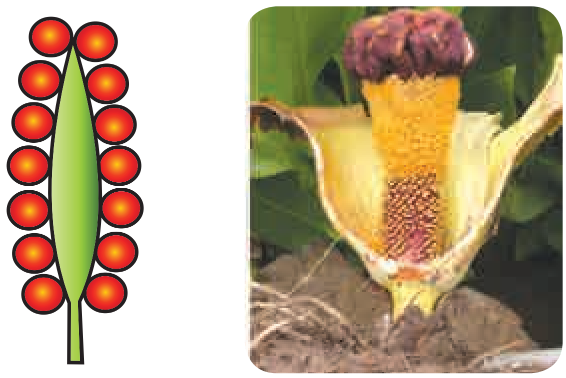


Figure 4.4: (i) diagrammatic, **(j)** Spadix

inflorescence is covered by a brightly coloured or hard bract called a **spathe**. Example: *Amorphophallus, Colocasia, Phoenix, Cocos.*

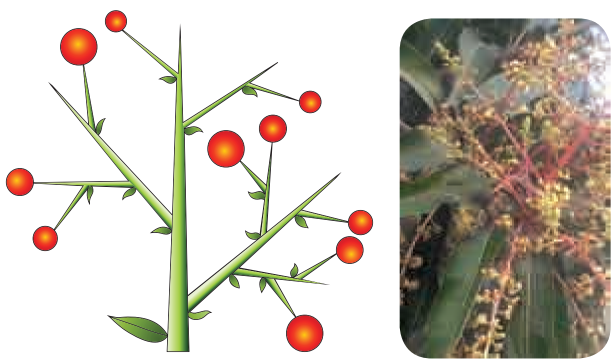


Figure 4.4: (k) diagrammatic, **(l)** Panicle

f. Panicle: A branched raceme is called **panicle**. Example: *Mangifera*, neem, *Delonix regia*. 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 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.

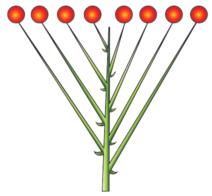


Figure 4.4: (m)
Corymb diagrammatic

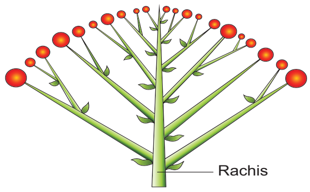


Figure 4.4: (n)
Compound corymb diagrammatic

Figure 4.4: (o)
Corymb

Figure 4.4: (p)
Compound corymb

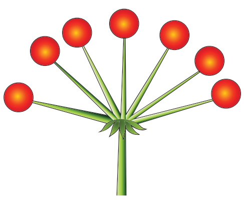


Figure 4.4: (q)
Umbel diagrammatic

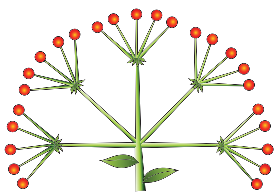


Figure 4.4: (r)
Compound umbel diagrammatic

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

Figure 4.4: (s)
Umbel

Figure 4.4: (t)
Compound umbel

3. Main axis flattened:

The main axis of inflorescence is mostly flattened (convex or concave) or globose. A **head** or **capitulum** is a 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.

Figure 4.4: (u)
Neolamarkia cadamba head

Example: *Neolamarkia cadamba*, *Mitragyna parvifolia* and in some members of Fabaceae-Mimosoideae. Example:

Acacia nilotica, *Albizia lebbeck*, *Mimosa pudica* (sensitive plant).

Torus contains two types of florets: 1. Disc floret or tubular floret. 2. Ray floret or ligulate floret.

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 Involucel.

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, Ageratum* or Ray florets alone. Example: *Launaea, Sonchus.*

Figure 4.4: Homogamous head
(v) disc floret, **(w)** ray floret

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 pistilate (unisexual).

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

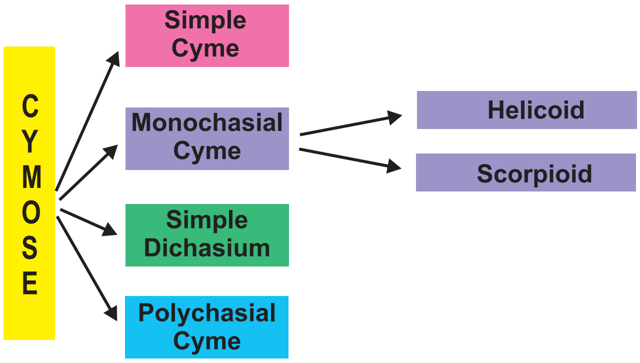


Figure 4.5: Cyme

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.*

Figure 4.6: (a) Simple cyme

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

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

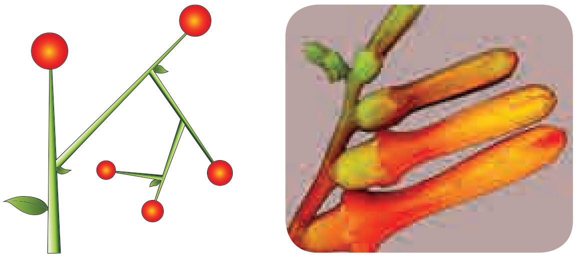


Figure 4.6: (b) diagrammatic,
(c) Monochasial Helicoid

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

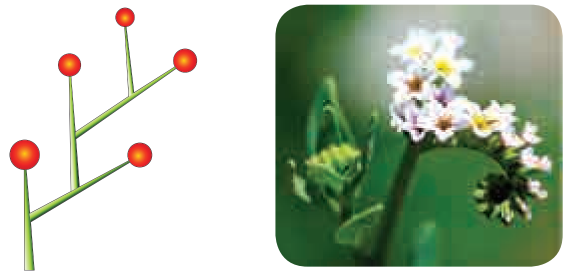


Figure 4.6: (d) diagrammatic,
(e) Monochasial Scorpioid

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*.

Figure 4.6: (f) diagrammatic,
(g) Simple dichasium

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**

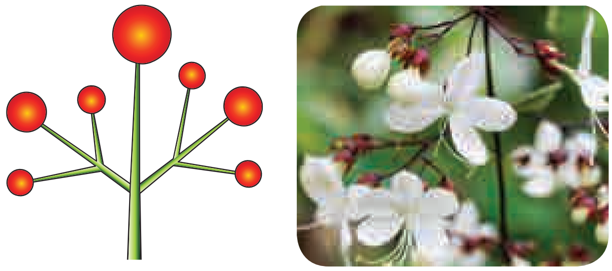


Figure 4.6: (h) diagrammatic,
(i) Compound dichasium

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

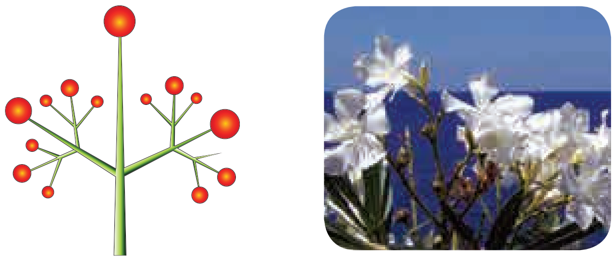
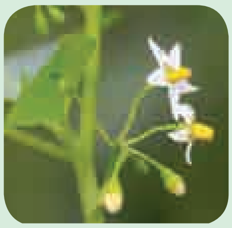


Figure 4.6: (j) diagrammatic,
(k) Polychasial cyme



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

III. Mixed Inflorescence

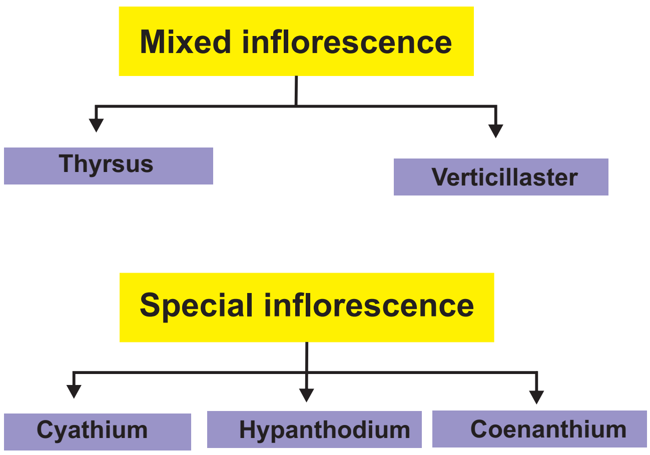


Figure 4.7: Mixed and special inflorescence

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*, *Anisomeles*.

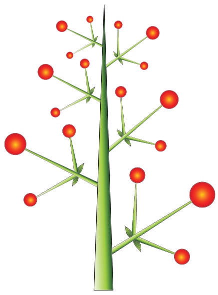



Figure 4.8: (a) diagrammatic, **(b)** Thyrsus

2. Verticil or 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: *Leonotis, Leucas*.

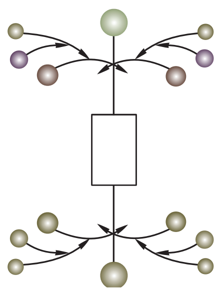



Figure 4.8: (c) diagrammatic, **(d)** Verticillaster

IV. Special Inflorescence

The inflorescences 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 pistil. Cyathium may be actinomorphic (Example: *Euphorbia*) or zygomorphic (Example: *Pedilanthus*.). Nectar is present in involucre.

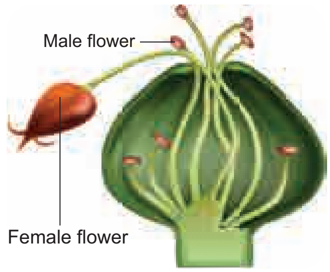


Figure 4.9: (a) diagrammatic, **(b)** Cyathium

2. Hypanthodium: Receptacle is a hollow, globose structure consisting unisexual flowers present on the inner wall of the receptacle. Receptacle is closed except 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 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*

Figure 4.9: (c) Hypanthodium

Figure 4.9: (d) Coenanthium

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.

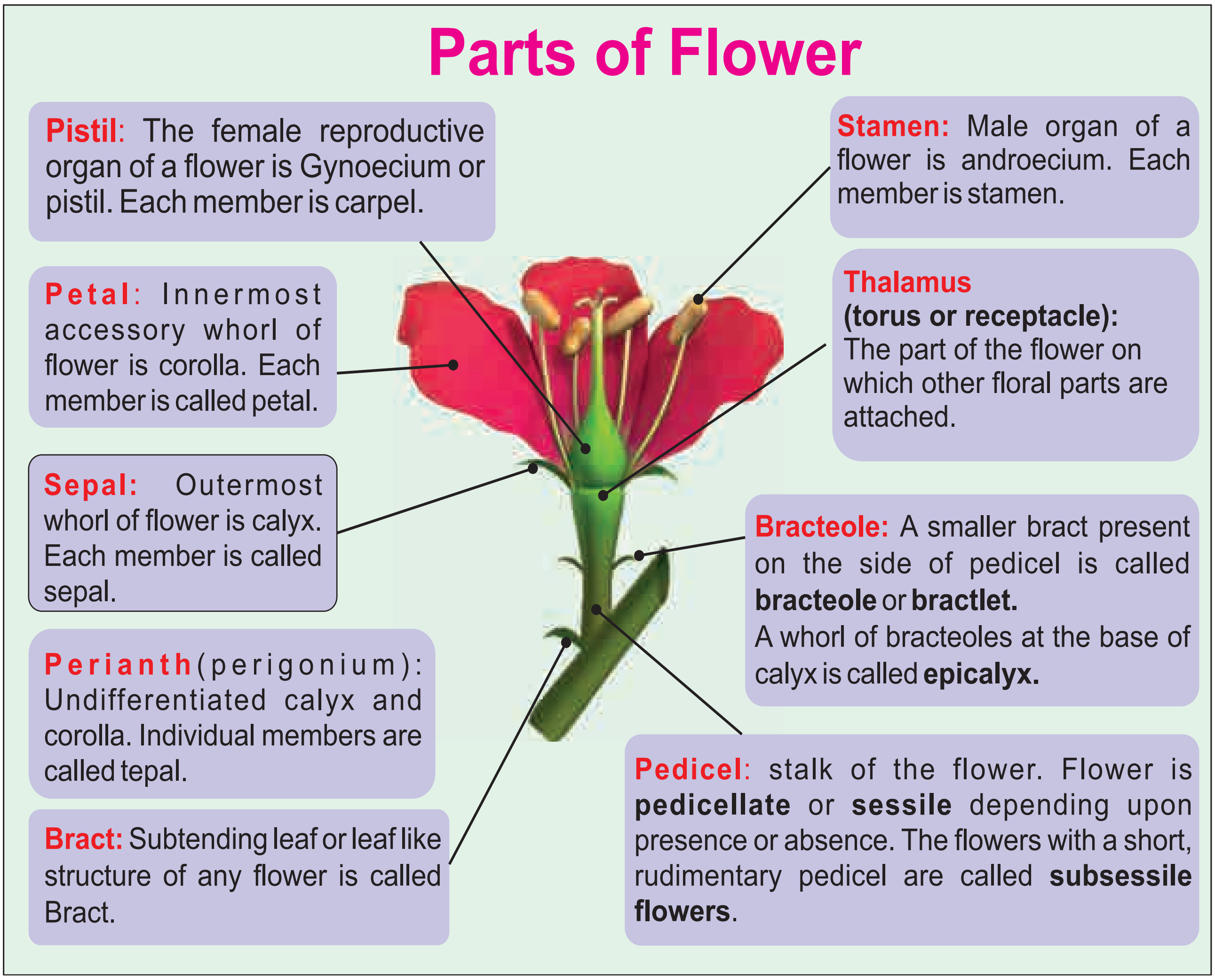


Figure 4.10: Parts of flower

4.2.2 Flower sex

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

1. Perfect or bisexual(monoclinous): When a flower contains both androecium and gynoecium is called **perfect flower**.

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

i) **Staminate flowers**: Flowers only with androecium alone are called **staminate flowers**.

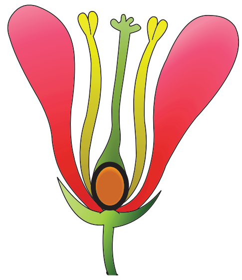


Figure 4.11: (a)
Bisexual flower

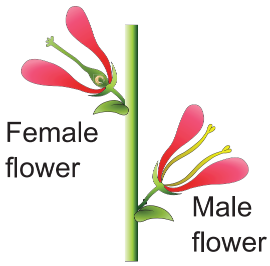


Figure 4.12: (a)
Monoecious

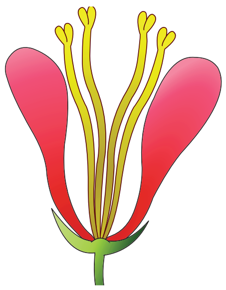


Figure 4.11: (b)
Male flower

Figure 4.12: (b)
Dioecious

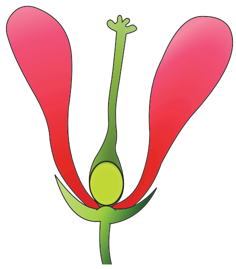


Figure 4.11: (c)
Female flower

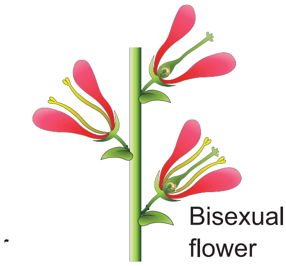


Figure 4.12: (c)
Polygamous

ii) Pistillate flowers: Flowers with only gynoecium are called **pistillate flowers**.

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** (*mono*-**one;** *oikos*-**house**): Both male and female flowers are present in the same plant Example: Coconut.

3. **Dioecious** (*di*-**two:** *oikos*-**house**): Male and Female flowers are present on separate plants. Example: Papaya, Palmyra.

Types of Polygamous:

Andromonoecious: A plant with both male flowers and bisexual flowers.

Gynomonoecious: A plant with both pistillate and bisexual flowers.

Polygamomonoecious: A plant with pistillate, staminate and bisexual flowers. It is also called trimonoecious.

Androdioecious: A plant with staminate flowers on one individual and bisexual flower on other individual

Gynodioecious: A plant with pistillate flowers on one individual and bisexual flowers on other individual.

Polygamodioecious: A plant with staminate flowers and bisexual in one individual and pistillate flowers and bisexual flowers in other individual.

Trioecious: A plant with staminate,pistillate and bisexual flowers on different individuals

4. **Polygamous**: The condition in which bisexual and unisexual (staminate/ pistillate) flowers occur in a same plant is called **polygamous**. It is of several types. See box. 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

Figure 4.13: (a) Actinomorphic

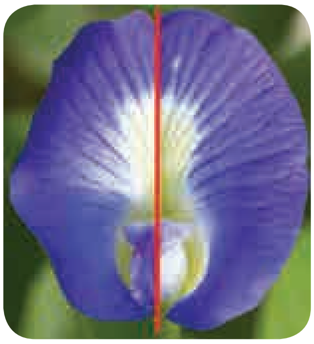


Figure 4.13: (b) Zygomorphic

Figure 4.13: (c) Asymmetric

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*, water lily.

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

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,Solanum.*

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: *Nymphaea, Annona, Polyalthia*

4.3.2 Cycly

It explains the number of whorls of floral parts. Perianth cycly is the number of whorls of perianth (sepals, petals) parts.

Figure 4.14: (a) Cyclic

Figure 4.14: (b) Acyclic

Figure 4.14: (c) Spirocyclic

1. Uniseriate: It is a single whorl of accessory(non-essential) floral part. It is less common.Example: *Sterculia.*

2. Biseriate (dicyclic): It is with two whorls of accessory floral parts. (outer=lower,inner=upper)It is the most common type of perianth cycly. Example: *Hibiscus.*

3. Multiseriate: (**triseriate,tetraseriate**) More than two whorls of non–essential floral parts.Example: *Chrysanthemum.*

4. Dichlamydeous: A flower is composed of distinct outer calyx and inner corolla.

5. Homochlamydeous: Perianth is un-differentiated into calyx and corolla and com-posed of similar parts called **tepals**. Most monocots have a homochlamydeous perianth.

6. Achlamydeous: Perianth is absent altogether.Flowers without petals are called **apetalous** and flowers without sepals are called **asepalous.**

Figure 4.15: (a)
Uniseriate

Figure 4.15: (b)
Biseriate

Figure 4.15: (c)
Multiseriate

Figure 4.16: (a)
Dichlamydeous

Figure 4.16: (b)
Homochlamydeous

4.3.3 Merosity

Number of floral parts per whorl is called **merosity**. Perianth merosity is the number of perianth parts per whorl.

1. Isomerous: Presence of same number of perianth parts in different whorls of a flower. (five sepals, five petals). Example: *Hibiscus.*

2. Anisomerous: Each whorl of flower contains different number of members. Example: *Annona*.

3. Bimerous: Floral parts in two or multiples of two. Example: *Ixora*

4. Trimerous: Floral parts in three or multiples of three. Example: *Allium*, Monocots.

5. Tetramerous: Floral parts in four or multiples of four. Example: *Brassica juncea.*

6. Pentamerous: Floral parts in five or multiples of five. Example: *Hibiscus*, Dicots.

4.3.4 Calyx

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

Figure 4.17: (a)
Trimerous

Figure 4.17: (b)
Tetramerous

Figure 4.17: (c)
Pentamerous

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

Figure 4.18 (a): Aposepalous

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

Figure 4.18: (b) Synsepalous

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 during the early development stage of flower. Example: *Papaver.*

Figure 4.19: (a)
Caducous bud with sepal

Figure 4.19: (b)
Caducous flower without sepal

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

Figure 4.19: (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*, Palmyra.

Figure 4.19: (d)
Persistant calyx

Figure 4.19: (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*, *Sterculia*. Calyx is distinctly leafy,large and often yellow or orange coloured sometimes white as in *Mussaenda*. It is modified into hair like structure or scaly called **pappus** as in *Tridax* of Compositae.

Figure 4.20: (c)
Mussaenda

Figure 4.20: (a)
Companulate

Figure 4.20: (b)
Pappus

What is the use of pappus ?

4.3.5 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, choripetalous)**: Petals are distinct. Example: *Hibiscus*.

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

2. Shapes of corolla

I. Apopetalous Actinomorphic

1. Cruciform: Four petals arranged in the form of a cross. Example: *Brassica*, mustard, radish, cauliflower.

2. Caryophyllaceous: Five petals with long claws with limb at right angles to the claw. Example: Caryophyllaceae. *Dianthus*.

3. Rosaceous: Five to many sessile or minutely clawed petals with radiating limbs. Example: Rose, Tea.

Figure 4.21: (a)
Cruciform

Figure 4.21: (b)
Caryophyllaceous

II. Apopetalous Zygomorphic

1. Papilionaceous:

Made up of five distinct petals organized in a butterfly shape. Corolla has three types of petals. One usually large posterior petal called **vexillum**(standard)two lateral petals-wings **(alae)** and two anterior sympetalous petals called **carina**. Example: *Clitoria ternatea*, Pea, Bean.

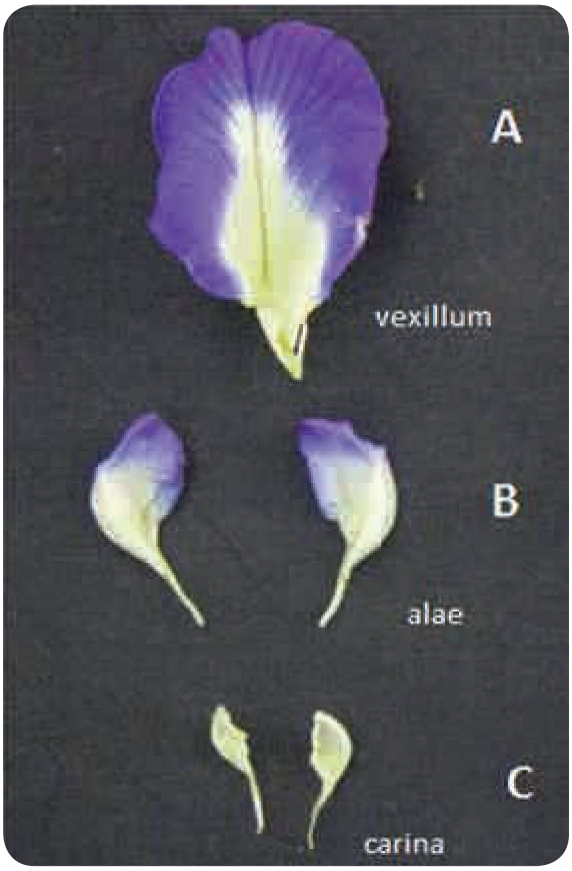


Figure 4.21: (c) Papilionaceous

Figure 4.21: (d) Campanulate

Figure 4.21: (e) Infundibuliform

Figure 4.21: (f) Rotate

Figure 4.21: (g) Salvershaped

Apopetalous		Sympetalous	
Actinomorphic	Zygomorphic	Actinomorphic	Zygomorphic

III. Sympetalous Actinomorphic

1. Tubular:

Petals united to form a narrow tubular structure with very short limbs. Example: Disc floret of sunflower.

2. Campanulate:

Petals fused to form a bell-shaped corolla. Example: *Physalis*,*Cucurbita maxima*, *Campanula*.

3. Infundibuliform:

Petals fused to form funnel-shaped corolla. Tube gradually widens into limbs. Example: *Datura, Ipomoea.*

4. Rotate:

Petals fused to form a wheel shaped corolla with very short tube and a spreading circular limb. Example: brinjal, *Evolvulus*

5. Salver shaped or **Hypocrateriform**;

Petals fused to form a long narrow tube with spreading limbs. Example: *Catharanthus*, *Ixora*, *Tabernaemontana*

6. Urceolate:

Petals fused to form urn-shaped or pot-shaped corolla.Example: *Bryophyllum calycinum*, *Diospyros.*

Figure 4.21: (h) Urceolate

IV. Sympetalous Zygomorphic

1. Bilabiate:

Corolla with two lips. Example: *Ocimum,Leucas,Adhatoda*.

Tubular corolla with a single strap-shaped limb. Example: Ray floret of *Helianthus*

2. Personate:

Corolla made up of two lips with the upper arched and the lower protruding into the corolla throat. Example: *Antirrhinum,Linaria*.

3. Ligulate:

Tubular corolla with a single strap-shaped limb. Example: Ray floret of *Helianthus*.

Figure 4.21: (i) Bilabiate

Figure 4.21: (j) Personate

4.3.6 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*.

Aestivation

Arrangement of sepals and petals in the flower bud.

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

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 the 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.

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

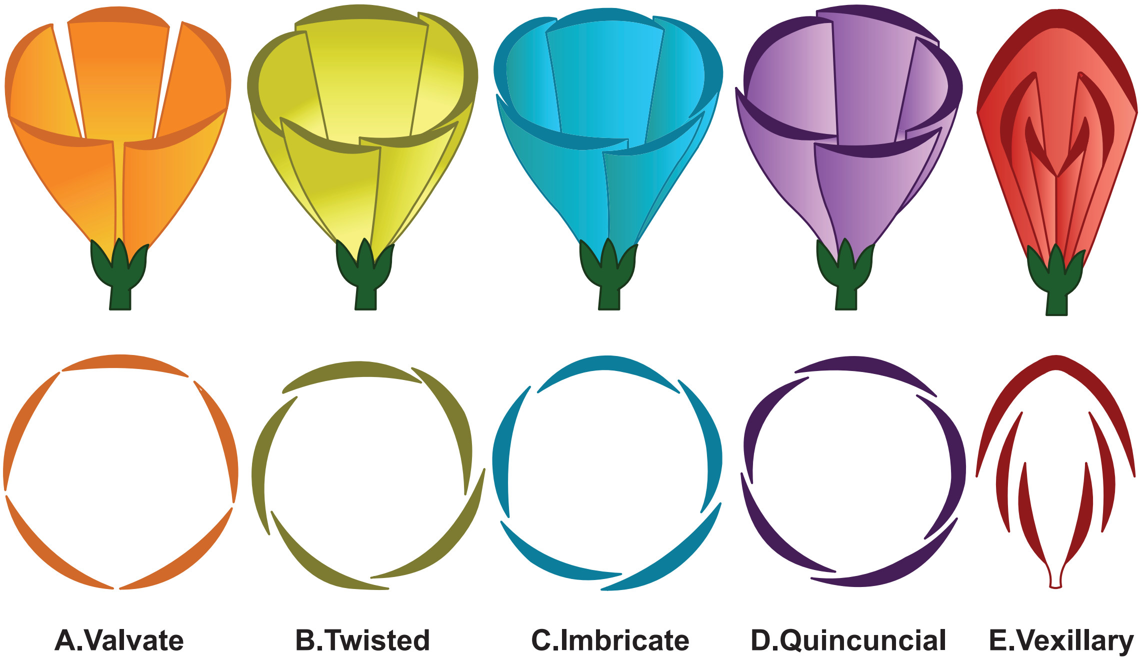


Figure 4.22: Aestivation

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

Ikebana

A creative mind can earn more money in floral art industry. Ikebana is a Japanese form of floral art. Ikebana is all about flowers arranged in angles. Floral art is not just an arrangement of flowers, but it is also about coordinating colours and texture. Ikebana experts are needed for marriages, other functions and in star hotels.

Essential Parts of Flower

4.4 Androecium

5GHK58

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

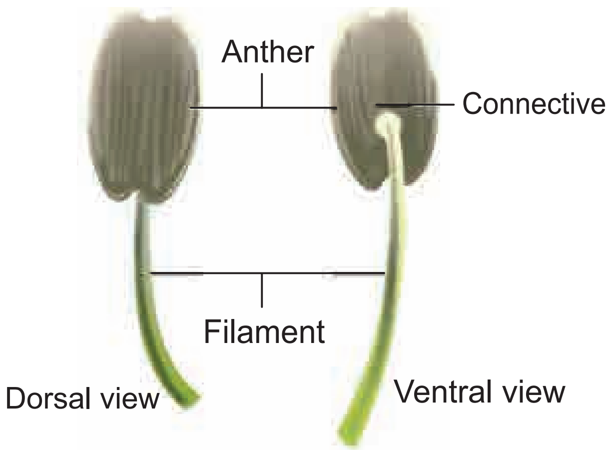


Figure 4.23: Stamen

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:

Refers to the stamens fusing among themselves or with other parts of flower. 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).

Figure 4.24: (a)
Monadelphous

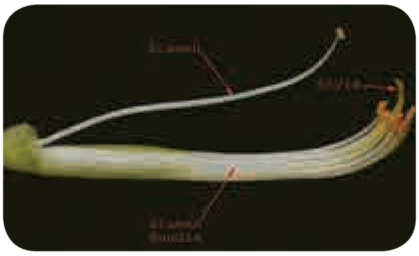


Figure 4.24: (b)
Diadelphous

Figure 4.24: (c)
Polyadelphous

2. Diadelphous: Filaments of stamens connate into two bundles. Example: Fabaceae, pea.

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*.

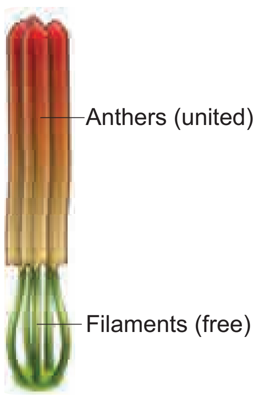


Figure 4.24: (d)
Syngenesious

Figure 4.24: (e)
Synandrous

2. Adnation: Refers to the fusion of stamens with other floral parts. **Epipetalous** (petalostemonous): 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: *Asphodelus*, *Asparagus*.

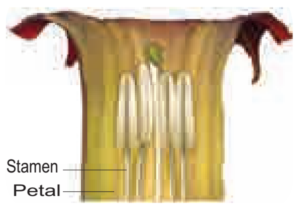


Figure 4.25: (a)
Epipetalous

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

Figure 4.25: (b)
Gynostegium

Figure 4.25: (c)
Pollinium

4.4.2 Arrangement of stamens relate to length of stamens:

1. **Didynamous (di-two, dynamis-strength)**: Four stamens in which two with long filaments and two with short filaments. Example: Lamiaceae, *Ocimum*. If all four stamens are in two equal pairs then the condition is called **didynamous.**

Figure 4.26: (a)
Didynamous

2. **Tetradynamous(tetra-four)**: Six stamens of which four with long filaments and two with short filaments. Example: Brassicaceae, (*Brassica*).

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

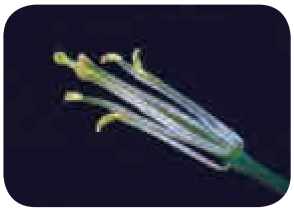


Figure 4.26: (b)
Tetradynamous

Figure 4.26: (c)
Heterostemonous

4.4.3 Stamen insertion

1.Inserted: Shorter than the corolla tube and included within. Example: *Datura*.

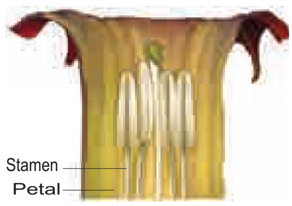


Figure 4.27: (a)
Inserted

Figure 4.27: (b)
Exserted

2.Exserted:Longer than the corolla tube and project out.Example: *Mimosa, Acacia arabica*

The number of whorls of stamens present in a flower is called **stamen** cycly. Two major types are 1.**uniseriate**,a single whorl of stamens and 2.**biseriate,**two whorls of stamens.

4.4.4 Anther types

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

Figure 4.28: (a)
Monothecal

Figure 4.28: (b)
Dithecal

Some other types: **a) Haplostemonous**: stamens are uniseriate and equal in number to the petals and opposite the sepals (antisepalous)

b) Obhaplostemonous: Stamens are uniseriate, number equal to petals and opposite the petals (antipetalous)

c) Diplostemonous: Stamens are biseriate, outer antisepalous, inner antipetalous. Example: *Murraya*.

d) Obdiplostemonous: Stamens are biseriate, outer antipetalous, inner antisepalous. Example: Caryophyllaceae.

e) Polystemonous: Numerous stamens are normally many more than the number of petals.

ⓒ ⓓ ⓔ

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

4.4.5 Anther attachment

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

2. Dorsifixed: Apex of filament is attached to the dorsal side of the anther. Example: *Citrus, 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: *Verbena, Ranunculus, Nelumbo*

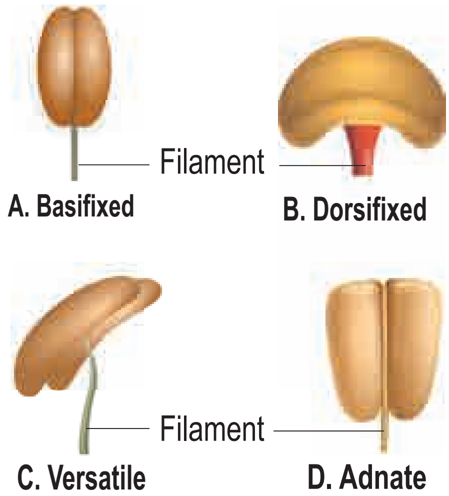


Figure 4.29: Anther attachment

4.4.6 Anther dehiscence

It refers to opening of anther to disperse pollen grains.

1. Longitudinal: Anther dehisces along a suture parallel to long axis of each anther lobe. Example: *Datura*, chinarose, cotton.

2. Transverse: Anther dehisces at right angles to the long axis of anther lobe. Example: Malvaceae.

3. Poricidal: Anther dehisces through pores at one end of the thecae. Example: Ericaceae, *Solanum*, potato, brinjal, *Cassia*.

4. Valvular: Anther dehisces through a pore covered by a flap of tissue. Example: Lauraceae, *Cinnamomum*.

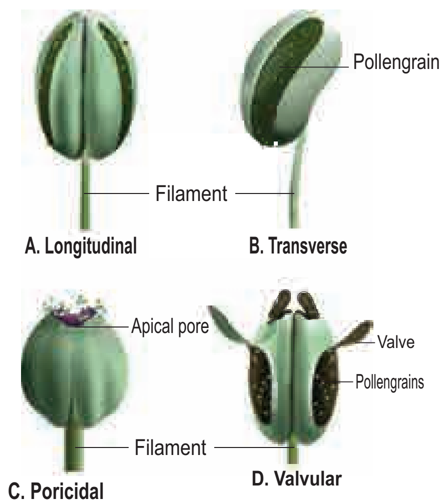


Figure 4.30: Anther dehiscence

4.4.7 Anther dehiscing direction

It shows the position of anther opening relative to the anther of the flower.

1.Introrse: Anther dehisces towards the center of the flower. Example: *Dianthus*.

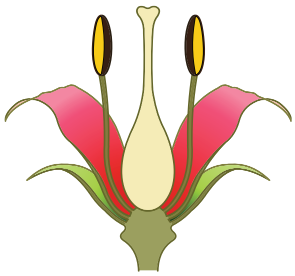


Figure 4.31: (a) Introrse

Figure 4.31: (b) Extrorse

2. Extrorse: Anther dehisces towards periphery of the flower. Example: *Argemone*.

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.**

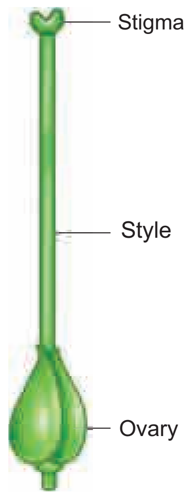


Figure 4.32: Pistil

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	Bicarpellary	Tricarpellary	Tetracarpellary	Multicarpellary
(monocarpellary) Single carpel Example: Fabaceae	Two carpels Example: Rubiaceae	Three carpels Example: Cucurbitaceae	Four carpels Example: Lamiaceae.	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	Syncarpous
A pistil contains two or more distinct carpels. Example: *Annona*.	A pistil contains two or more carpels which are connate. Example: Citrus, tomato.

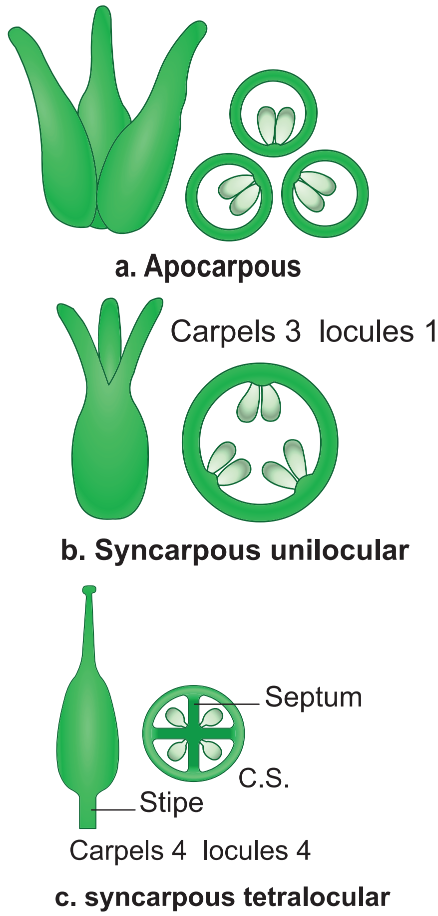


Figure 4.33: Fusion of carpels

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**.

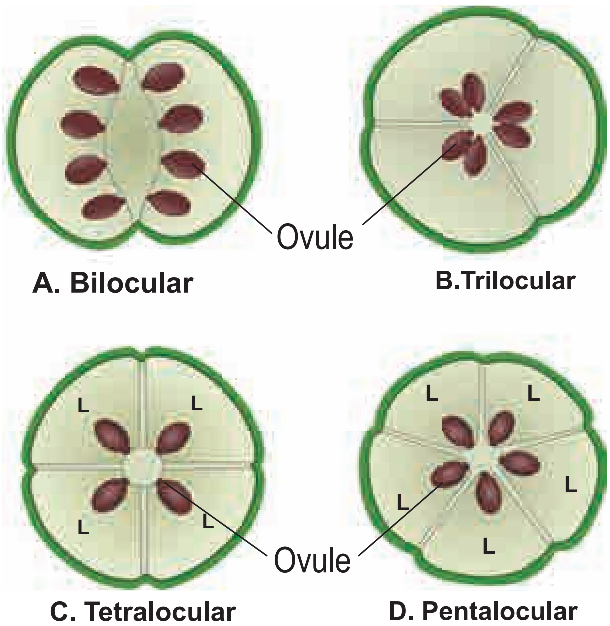


Figure 4.34: Locules

Number of locules

Unilocular Ovary with one chamber Example: pea, groundnut.	**Bilocular** Ovary with two chambers Example: mustard, *Crossandra*.	**Trilocular** Ovary with three chambers Example: banana, *Euphorbia*.

Like that tetralocular and pentalocular ovaries are present according to the locule numbers four and five. More than one locule ovaries are called **plurilocular.**

4.5.4 Style and stigma

1. Style is a stalk like structure of a pistil connecting ovary and stigma.

a. Simple: Single unbranched style. Example: *Hibiscus*.

b. Bifid: A style branched into two. Example: Asteraceae

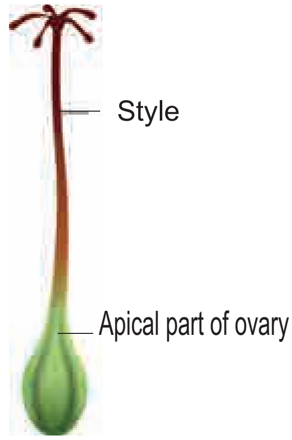


Figure 4.35: (a) Simple style

Figure 4.35: (b) Bifid style

c. Gynobasic style: arising from base of the ovary. Example: Lamiaceae (*Ocimum*), characteristic of Boraginaceae.

d. Lateral style: Style arises from the side of ovary. Example: *Mangifera*.

Figure 4.35: (c) Gynobasic style, **(d)** Lateral style

2. Stigma: A stigma is a structure present at the tip of a pistil which receives the pollen grains.

a. Discoid: A disk-shaped stigma is called **discoid**.

b. Capitate: Stigma appearing like a head. Example: *Alchemilla*

c. Globose: Stigma is spherical in shape is called **globose**.

d. Plumose stigma: Stigma feathery which is unbranched or branched as in Asteraceae, Poaceae.

3. Pistillode: A reduced sterile pistil. Example: ray floret of head infloresence in *Helianthus*.

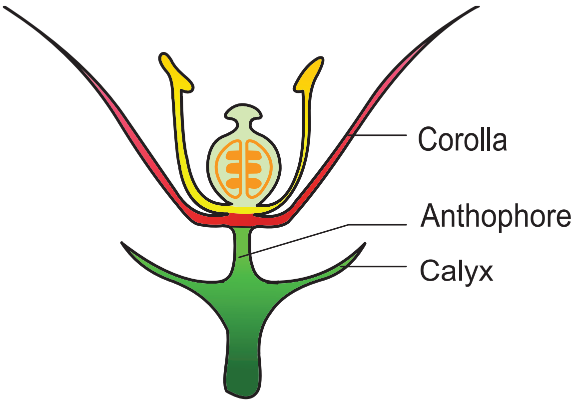


Figure 4.36: (a) Anthophore

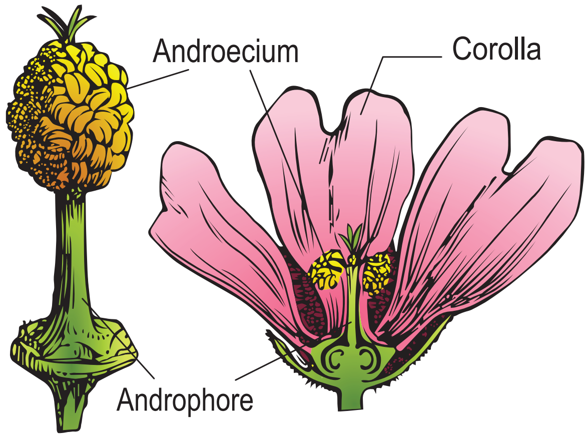


Figure 4.36: (b) Androphore

Saffron flower stigma is costly. One gram of saffron is around Rs.300. In traditional texts ascribe a few medicinal properties to saffron stigma.It is also used as a flavoring substance.

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

Figure 4.36: (d) Androgynophore

4.5.5 Extension of the condensed internode of the receptacle

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

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

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

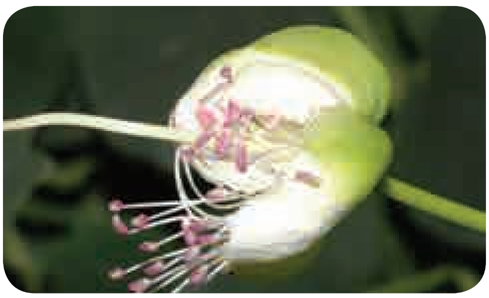


Figure 4.36: (c) Gynophore

4.5.6 Ovary position

Hypanthium: (staminal disk); a fleshy, elevated often nectariferous cup like thalamus.

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.

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.
5GRG6V	**Perigynous:** The term is used for a hypanthium attached at the base of a superior ovary.	**Epiperigynous:** The term is used for hypanthium attached at the apex of an inferior ovary.

4.5.7 Perianth / androecial position on thalamus:

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

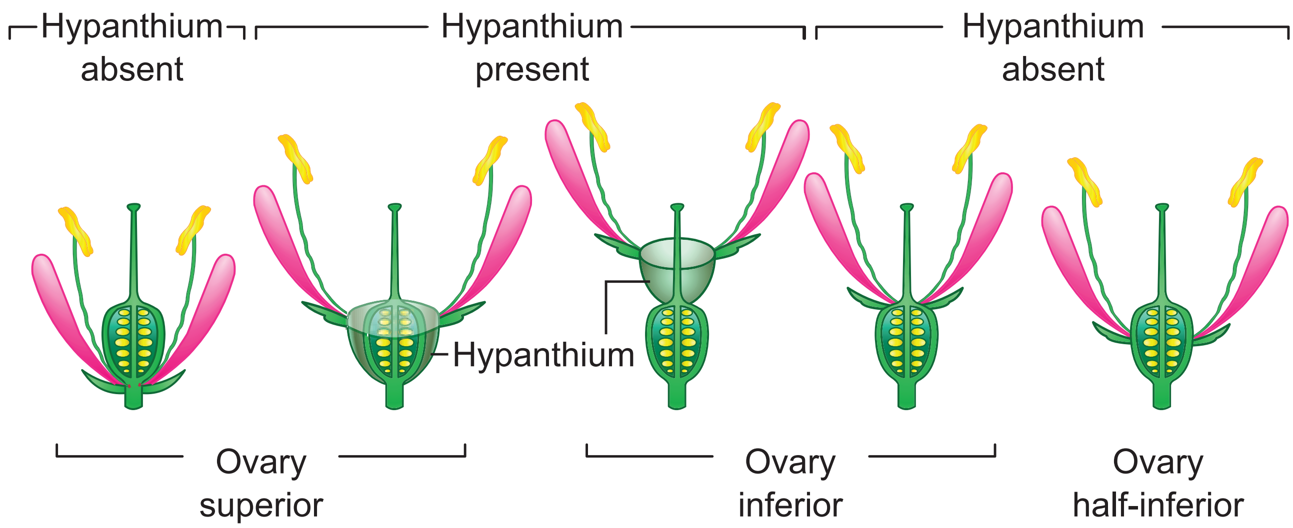


Figure 4.37: Perianth / androecial position on thalamus

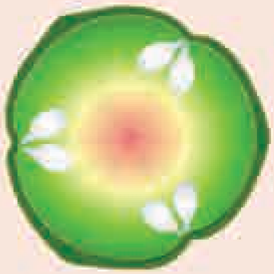
Parietal axile: It is with the placentae at the junction of the septum and ovary wall of a two or more locular ovary. Example: Brassicaceae.	**Apical pendulous** It is with placenta at the top of ovary. Ovules hanging down.
Parietal septate: It is with placentae on the inner ovary walls but within septate locules as in Aizoaceae.	**Apical axile** It is with two or more placentae at the top of a septate ovary. Example: Apiaceae.

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.

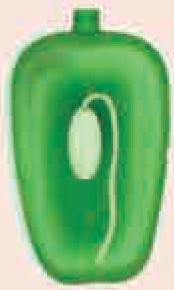
Axile
The placentae arises from the column in a compound ovary with septa.
Example:
Hibiscus,tomato
lemon

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



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

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



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

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.

Floral formula and floral diagram of

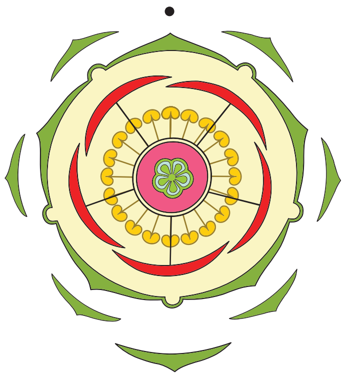


Figure 4.38: (a) *Hibiscus rosa-sinensis*

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

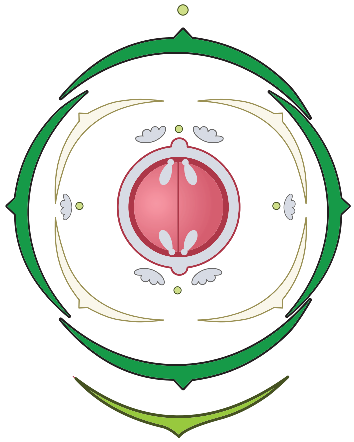


Figure 4.38: (b) *Brassica compestris*

Br Brl $\oplus$ ⚥ $K_{2+2}\ C_{2+2}\ A_{2+4}\ \underline{G}_{(2)}$

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

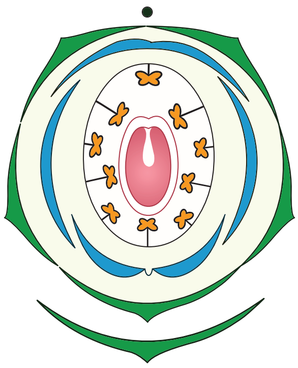


Figure 4.38: (c) *Crotalaria juncea*

Br Ebrl % ⚥ $K_{(5)}\ C_{1+2+(2)}\ A_{5+5}\ G^{-}_{(1)}$

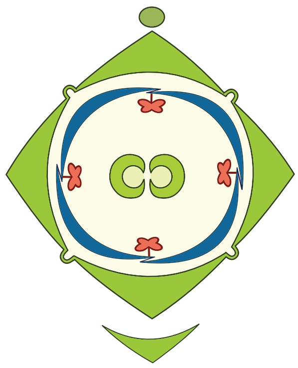


Figure 4.38: (d) *Ixora coccinea*

Br Brl $\oplus$ ⚥ $K_{(4)}\ \widehat{C_{(4)}\ A_4}\ \underline{G}_{(2)}$

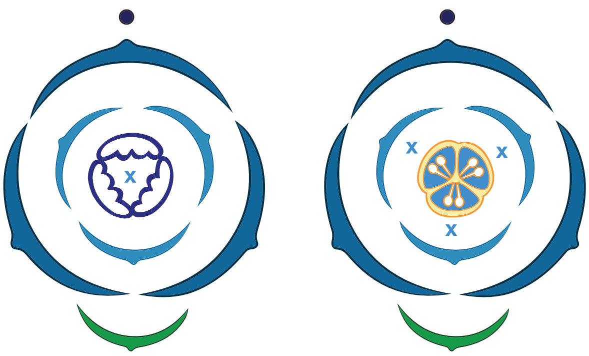


Figure 4.38: (e) *Phyllanthus amarus*

Br Ebrl $\oplus$ ♂ $P_{3+3}\ A_{(3)}\ G_0$

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

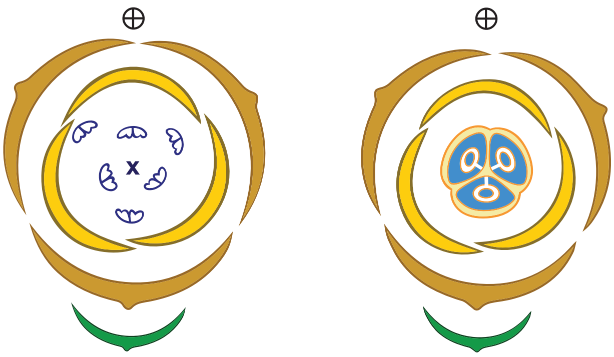


Figure 4.38: (f) *Cocos nucifera*

Br Brl $\oplus$ ♂ $P_{(3)+3}\ A_{3+3}\ G_0$

Br Brl $\oplus$ ♀ $P_{(3)+3}\ A_0\ \underline{G}_{(3)}$

Br : Bracteate.

Ebr : Ebracteate

Brl : Bracteolate

Ebrl : Ebracteolate

⊕ : Actinomorphic flower or polysymmetric

% : Zygomorphic or monosymmetric

♂ : 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 one bundle,1 another bundle.

$\overset{\frown}{C_5A_5}$—Epipetalous represents 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, the line under G

$\overline{G}$ inferior ovary, the line above G

G– – semi-inferior ovary, the line before middle of G.

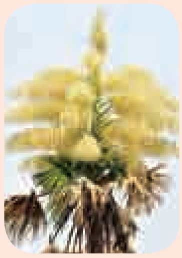
∞ – Indefinite number of units

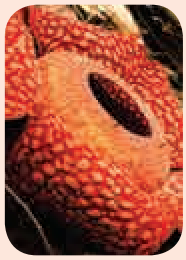
DO YOU KNOW?

Can you imagine a man sized inflorescence? The largest unbranched inflorescence is a spadix of titan arum(*Amorphophallus titanium*).It can grow upto 6 feet.Though the male and female flowers are very small,they combine to form a huge spadix surrounded by a huge modified leaf and appear like a single flower.The largest inflorescence of any flowering plant is *Corypha umbraculifera*.It grows upto 6 to 8 feet.

Do you accept a flower weigh as much as 11 kg.The largest single flower of giant refflesia(*Refflesia arnoldi*)grows up to 3 feet and weighs as much.


Titan arum


Corypha


Refflesia

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 perpective 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 various 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 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, Date Palm, 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 terns leathery or woody which encloses, fleshy mesocarp and smooth endocarp. Example: Cucumber, Watermelon, Bottle gourd, Pumpkin.

d) **Hesperidium**: Fruit develops from multicarpellary, multilocular, syncarpous,

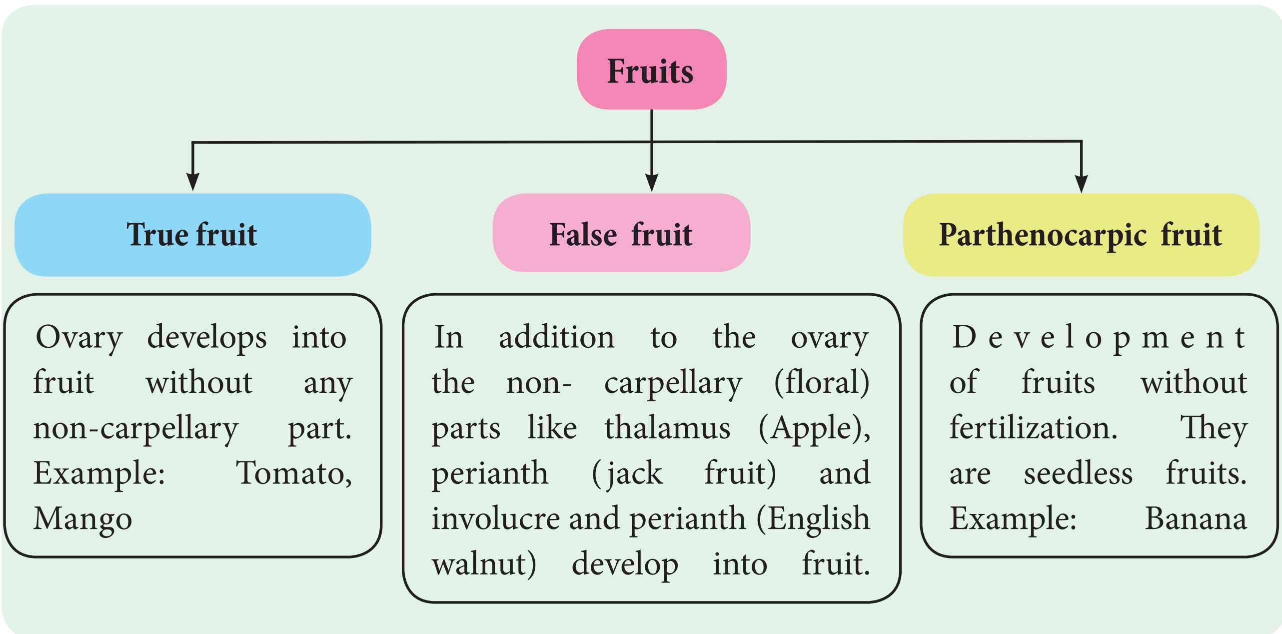
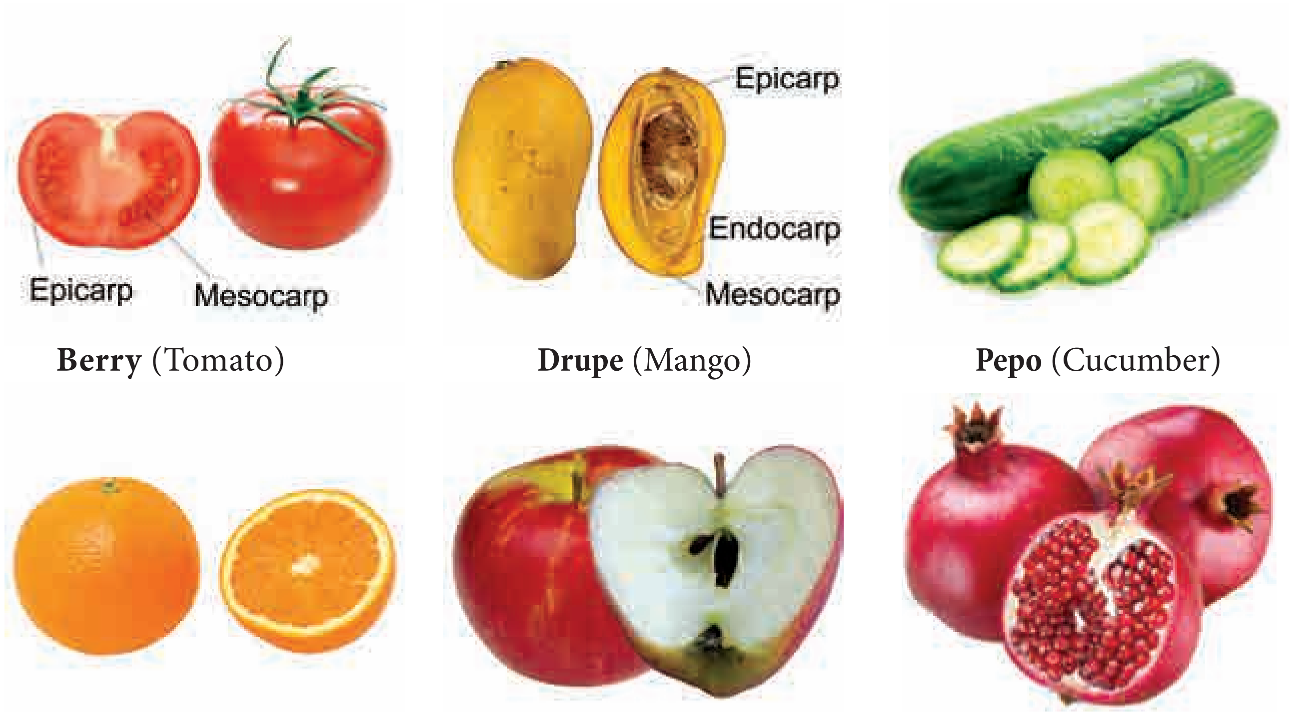


Figure 4.39: Classification of fruits based on formation



Berry (Tomato) **Drupe** (Mango) **Pepo** (Cucumber)

Hesperidium (Orange) **Pome** (Apple) **Balausta** (Pomegranate)

Figure 4.40: Simple fleshy fruits

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 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 develops 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

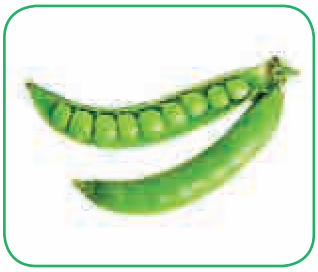
Pericarp is dry and splits open along the sutures to liberate seeds. They can be classified into following types.

a) Follicle: Fruit develops from monocarpellary, 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*.

Follicle (*Calotropis*)



Legume (*Pisum*)

Siliqua (*Brassica*)

Silicula (*Capsella*)

Loculicidal (Lady's finger)

Septifragal (*Datura*)

Figure 4.41: Dry dehiscent fruit

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

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

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

ii) Loculicidal: Capsule splitting along locules and values remaining attached to septa. Example: Lady's finger.

iii) Septifragal: Capsule splitting so that valves fall off leaving seeds attached to the central axis. Example: *Datura.*

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

v) Denticidal: Capsule opening at top exposing a number of teeth. Example: *Primula, Cerastium.*

vi) Circumscissile: (pyxidium) Dehisces transversely so that top comes off as a lid or operculum. Example: *Anagallis arvensis, Portulaca, Operculina.*

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

Achene (*Clematis*)

Cypsela (*Tridax*)

Caryopsis (*Oryza*)

Nut (*Anacardium*)

Samara (*Acer*)

Utricle (*Chenopodium*)

Figure 4.42: Dry indehiscent fruit

is free from seed coat. Example: *Clematis, Delphinium,* Strawberry.

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

c) Caryopsis: It is a one seeded fruit which develops from a monocarpellary, superior ovary. Pericarp is inseparably fused with seed. Example: *Oryza, Triticum.*

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

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

f) Utricle: They develops 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 rather 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, Carrot.

b) Carcerulus: Fruit develops from bicarpellary, syncarpous, superior ovary and splitting into four one seeded

Cremocarp (Coriander)

Carcerulus (*Abutilon*)

Lomentum (Mimosa)

Regma (Castor)

Figure 4.43: Schizocarpic Fruit

segments known as **nutlets**. Example: *Leucas, Ocimum, Abutilon*

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: *Desmodium, Mimosa*

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

Aggregate Fruits

Aggregate fruits develop from a single flower having an apocarpous pistil. each of the free carpel is 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: *Magnolia*, Raspberry, *Annona, Polyalthia*

Annona *Polyalthia*

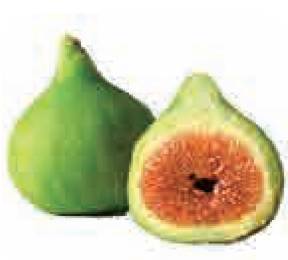
Figure 4.44: Aggregate Fruits

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: Pineapple, Jack fruit, Mulberry

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*



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

Figure 4.45: Multiple or composite fruit

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*.

4.7.3 Functions of Fruit

1. Edible part of the fruit is a source of food, 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 humans.

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.

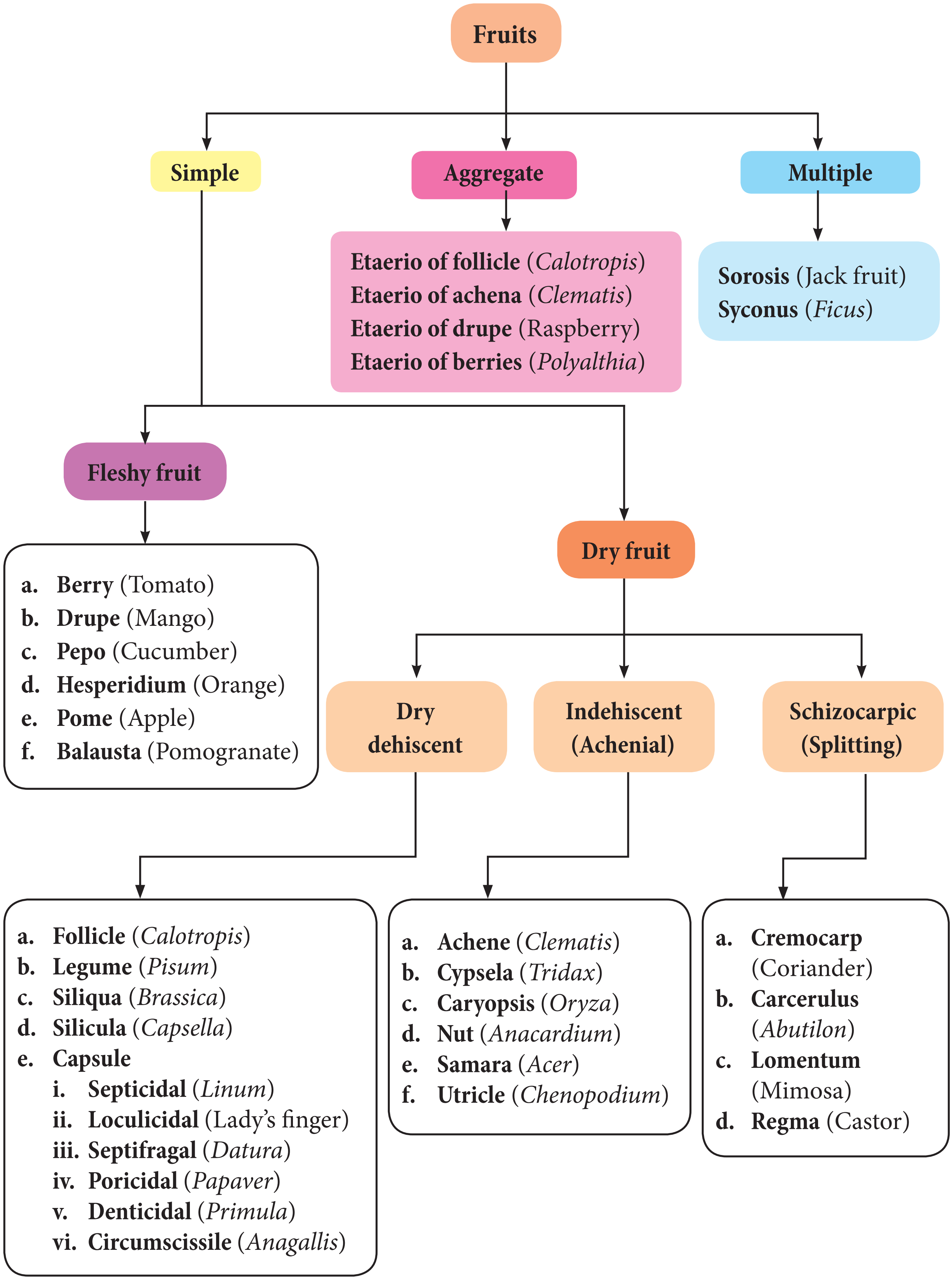


Figure 4.46: Types of fruits

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
	Date	*Phoenix dactylifera*	Pericarp
Drupe	Mango	*Mangifera indica*	Mesocarp
	Coconut	*Cocos nucifera*	Endosperm (both cellular and liquid)
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 var.*	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

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

Do seeds germinate as soon as they are dispersed

I. Based on the number of cotyledons present 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 variations 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, symmetry and arrangement of whorls, merosity. 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 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

5H1C8I

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. Overy, 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. Differenciate between aggregate fruit with multiple fruit.
10. Explain the different types of fleshy fruit with suitable example.

ICT Corner

Floral diagram and floral formula

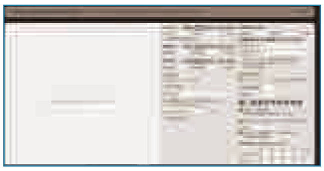
Let's generate
Floral diagram and
Floral formula.

Steps

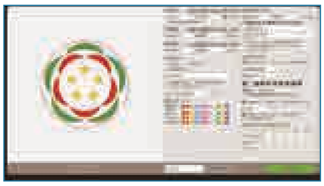
- Scan the QR code
- Enter sepal, petal, androecium & Gynoecium
- Select enable colour
- Select shape of sepal & petal, fused (if so)
- Enter carpel number & position submit the from
- Click formula to generate floral formula

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

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* Pictures are indicative only

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, Apocynaceae, Solanaceae, Euphorbiaceae, Musaceae 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 Type concept
5.6 Taxonomic Aids
5.7 Botanical Gardens
5.8 Herbarium – Preparation and uses
5.9 Classification of Plants
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 16th 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). **Davis** and **Heywood** (1963) defined taxonomy as "the science dealing with the study of classification including the bases, principles, rules and procedures".

Though there were earlier usages of the term 'systematics', only during the latter half of 20th century 'Systematics' was recognized as a formal field of study. **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.

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

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.

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 consist 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. Greek philosopher **Plato** proposed concept of *"eidos"* or species and believed that all objects are shadows of the *"eidos"*. According to **Stebbins** (1977) species is the basic unit of evolutionary process. 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.
4. In asexually reproducing organisms, they are identified by their morphological resemblance.
5. In case of fossil organisms, they are identified by the morphological and anatomical resemblance.

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.** These species are defined and categorized with no knowledge of phylogenetic history, gene flow or detailed reproductive mechanisms.

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

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 1737 and 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, the earliest that is in accordance with the rules except in specified cases.

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 telomorph (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.
>
> **Telomorph** – 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 did not hold good as it was cumbersome to remember and use. 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 Type concept

ICN's second principle states that a specimen must be associated with the scientific name known as **nomenclatural type.** A nomenclatural type is either a specimen or may be an illustration. Example: Herbarium sheet for vascular plants.

There are different nomenclatural types.

Holotype: A specimen or illustration originally cited by the author in protologue. It is a definitive reference source for identity. Citation of holotype and submission of it is one of the criteria for valid publication of a botanical name.

Isotype: Duplicate specimen of the holotype collected from same population by same person on same date with same field number. They are the reliable duplicates of holotype and may be distributed to various herbaria of various regions.

Lectotype: Specimen selected from original material serves as a type, when no holotype was designated at the time of publications or if holotype is missing or destroyed.

Syntype: When more than one specimen cited by the author in the protologue without designating holotype.

Neotype: Specimen derived from non-original collection selected as the type, when original specimen is missing or destroyed.

Paratype: Specimen cited in the protologue is other than holotype, isotype or syntype.

Epitype: Specimen or illustration serves as an interpretive type, when holotype, neotype or lectotype is ambiguous.

5.6 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.

1. 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.

2. Flora

Flora is the document of all plant species in a given geographic area. Flora consists of total number of plant species in an area and gives information about flowering season, fruiting season and distribution for the given geographic area. It also provides details on rare and endemic species of that area. Example: Flora of Tamil Nadu Carnatic by K.M.Matthew. Floras are categorized based on the scope and area covered.

Local Flora

It covers the limited areas, usually state, country, city or mountain range. Example: 'Flora of Thiruvannamalai District' by R. Vijaysankar, K. Ravikumar and P. Ravichandran.

Regional Flora

It includes large geographical area or a botanical region. Example: 'Flora of Tamil Nadu' Carnatic by **K.M.Matthew** (1983), 'Flora of Madras Presidency' by **J.S. Gamble** and **Fischer**.

Continental Flora

This flora covers the entire continent. Example: 'Flora of Europaea' by D.A.Web.

Electronic Floras (e - floras)

It is nothing but the digitized form of a flora published online. Example: 'e – Flora China'. This provides the information and also functions as an identification tool.

3. Monograph

A Monograph is a complete global account of a taxon of any rank – family, genus or species at a given time. This includes the existing taxonomic knowledge and all relevant information about the group concerned such as Anatomy, Biochemistry, Palynology, Chromosome Number and Phylogeny. It also includes extensive literature review, all nomenclatural information, identification key to all taxa, citation of specimens examined and distribution map.

Example: The Family *Lentibulariaceae* by Peter Tylor.

Revisions

Taxonomic revision is carried out for a family or genus. Usually taxonomic revision is less comprehensive than a monograph for a given geographical area. Revisions normally incorporate keys to identify the taxa, short descriptions, often confined to diagnostic characters, distribution maps and a classification. Illustrations mostly in the form of line drawings are included both in monographs and revisions. There are difficulties in identifying various members within a taxon. If there is inconsistency of the characters within the taxon's geographic range then a revision is needed. Taxonomic revisions are primarily based on original research work. Example: Malvaceae of India by T.K.Paul, Venu. P. 2006 Strobilanthes (Acanthaceae) in Peninsular India.

Catalogues

Catalogues are the books of libraries rich in botanical titles. They have special value in taxonomic studies. To refer a catalogue, one should know full name of the author, exact title of the book, exact date of publication the particulars of edition.

Example: Catalogue of the Library of British Museum (of Natural History) Catalogue of the Library of the Massachusetts Horticultural Society.

5.7 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.

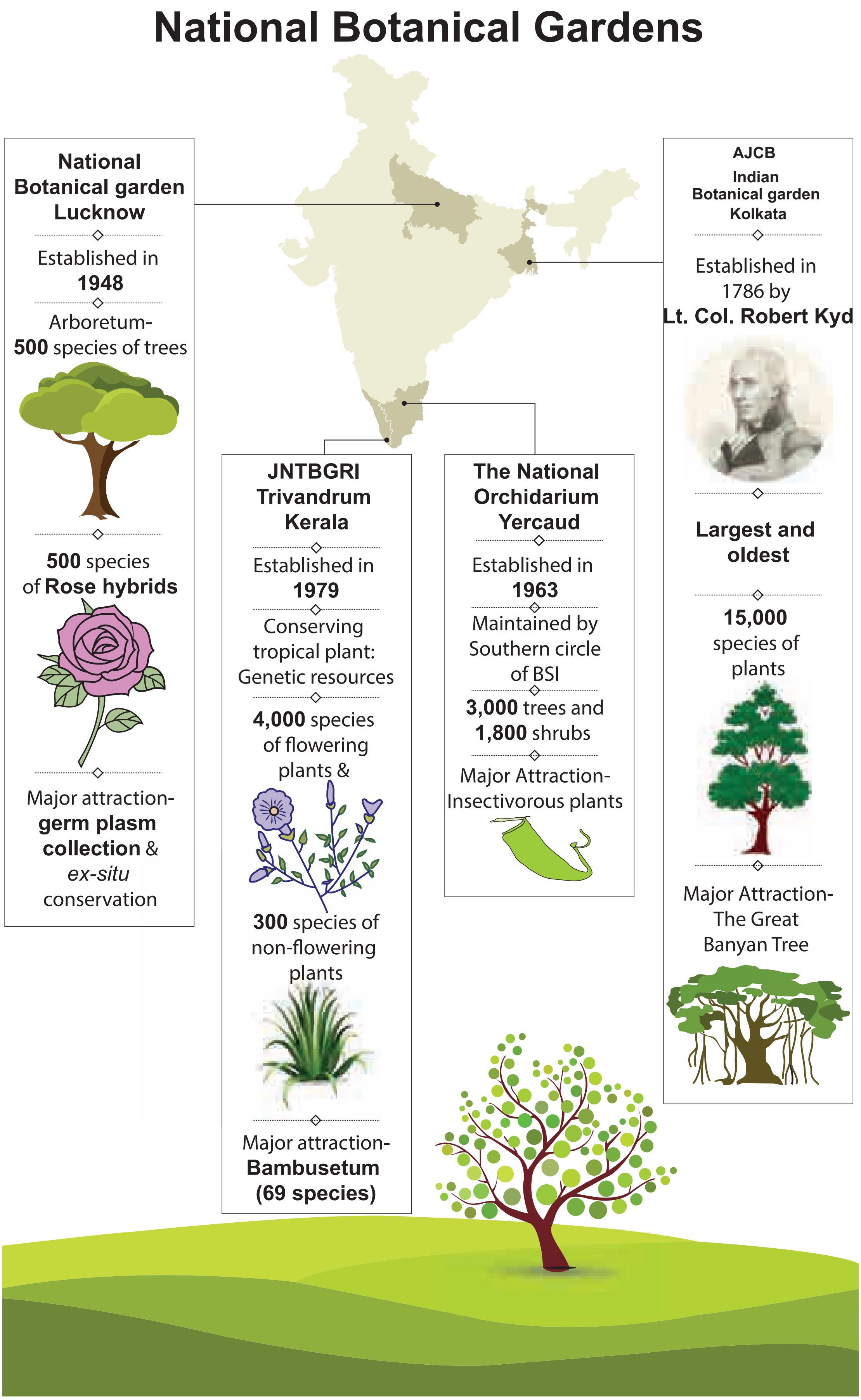


Figure 5.1: National Botanical Garden

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 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, Phytochemistry, 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

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.

Figure 5.2: Royal Botanic garden, Kew - England

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

5.8 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**

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.

↓

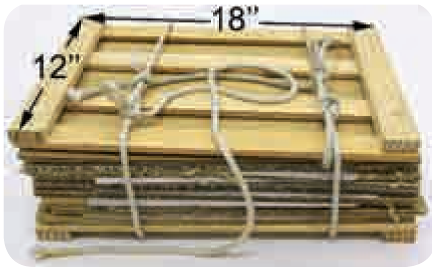
Mounting herbarium specimen
The standard size of herbarium sheet is used for mounting the specimen (29cm x 41cm). specimens are affixed to herbarium sheet with standard white glue or solution of Methyl cellulose.

↓

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
Applycation of 2% Mercuric chloride, Naphthalene, DDT, carbon disulphide. Fumigation using formaldehyde. Presently deep freezing(**-20°C**) 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	TBGT	30,500
4.	Presidency College Herbarium, Chennai.	1844	PCM	15,000

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 illustrations and also a collection of more than 1,75,000 prints, books, photographs, letters, manuscripts, periodicals, maps and botanical illustrations.

International Botanic Garden

New York Botanic garden, USA.

Royal Botanic Garden, Kew - England.

Botanical Gardens of the New South Wales, Sydney.

Rio- de jenerio Botanic Garden, Brazil.

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

Activity

Prepare herbarium of 5 common weed plants found inside your school campus /nearby garden /waste land.

5.9 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 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.

5.9.1 Need for Classification

- Understanding the classification of organisms can gives an insight in to 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

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

Figure 5.4: Carolus Linnaeus

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
6	Hexandria	stamens six
7	Heptandria	stamens seven
8	Octandria	stamens eight
9	Ennandria	stamens nine
10	Decandria	stamens ten
11	Dodecandria	stamens 11-19
12	Icosandria	stamens 20 or more, on the calyx
13	Polyandria	stamens 20 or more, on the receptacle
14	Didynamia	stamens didynamous; 2 short, 2 long
15	Tetradynamia	stamens tetradyna-mous; 4 long, 2 short
16	Monadelphia	stamens monadelphous; united in 1 group
17	Diadelphia	stamens diadelphous; united in 2 groups
18	Polyadelphia	stamens polyadelphous; united in 3 or more groups
19	Syngenesia	stamens syngenesious; united by anthers only
20	Gynandria	stamens united with the gynoecium
21	Monoecia	plants monoecious
22	Dioecia	plants dioecious
23	Polygamia	plants polygamous
24	Cryptogamia	flowerless plants

(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**.

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**.

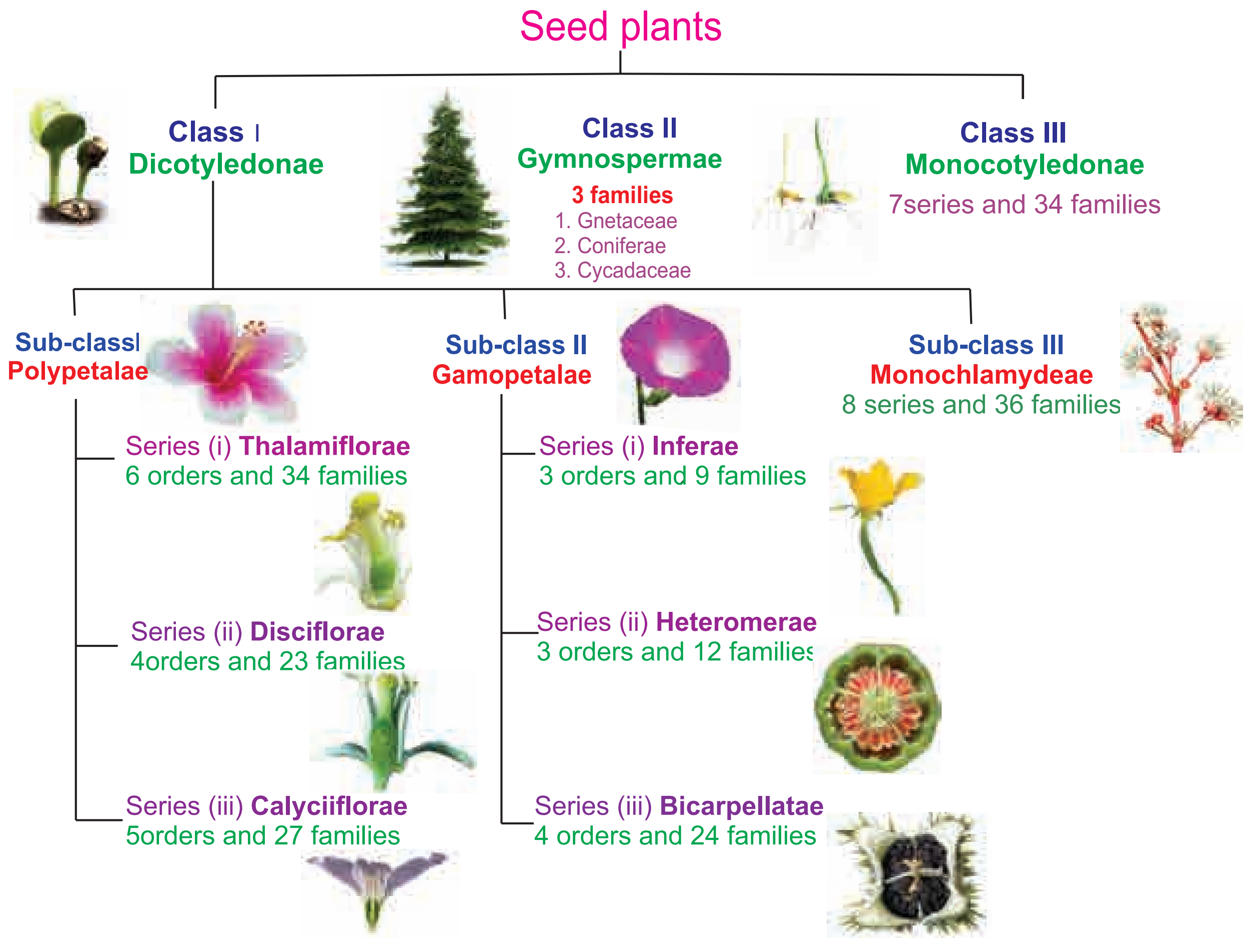


Figure 5.6: Bentham and Hooker system of classification

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.

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 undifferenciated 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

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

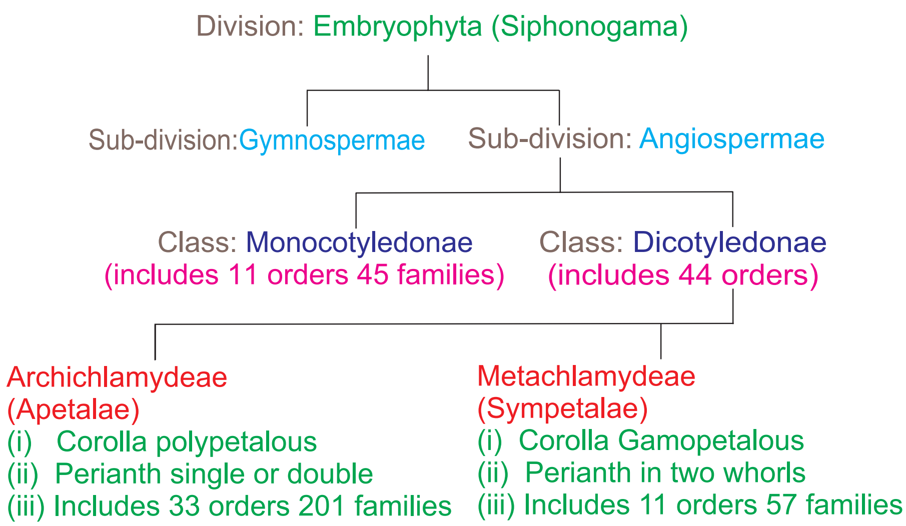


Figure 5.7: Outline of Engler and Prantl classification

Figure 5.8: Adolph Engler and Karl A Prantl

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**

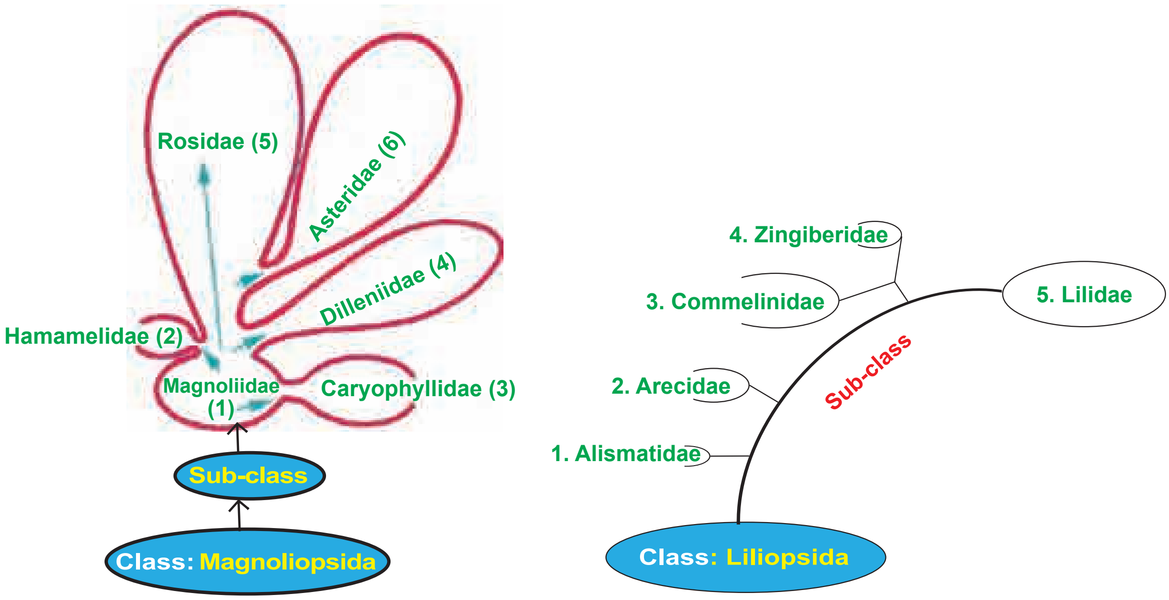


Figure 5.10: Diagramatic representation of the relationship between class Magnoliopsida and Liliopsida.

(= 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.

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 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 416families. Of these, 416 families 259 are represented in India.

The outline of APG IV classification is given below.

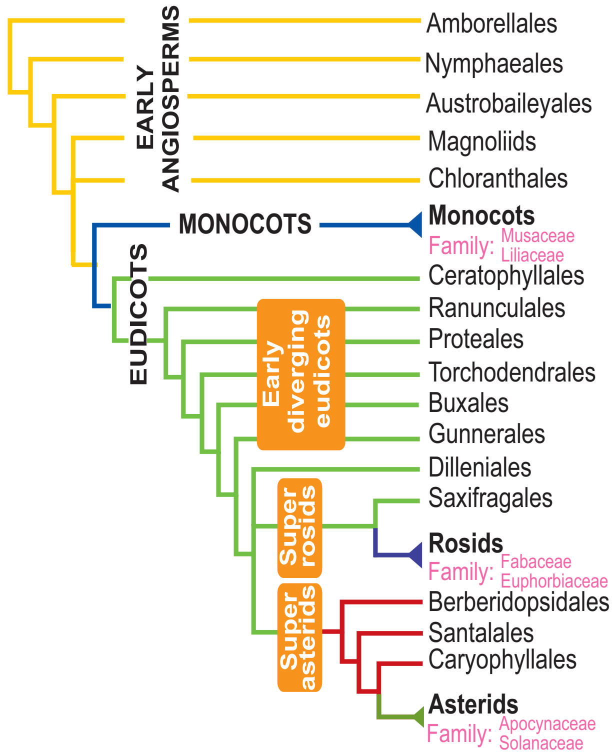


Figure 5.11: Simplified version of APG IV (Source: Plant Gateway's The Global Flora, Vol. I January 2018)

Angiosperms are classified into three clades early angiosperms, monocots and eudicots. Early angiosperms are classified into **8 orders** and **26 families** (**ANA**-grade + magnoliids + Chloranthales)

Amborellales
Nymphaeales
Austrobaileyales

- Seeds 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.

Monocots are classified into 11 orders and 77 families (basal monocots + lilioids + commelinids)

- Seeds with single cotyledon.
- Primary root short-lived.
- 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.

Changes in earlier taxonomic understanding.

The newly proposed APG classification system has brought many changes in our earlier understanding on the concept of primitive flowering plant families. Some of them are given below:

- The real Ranalean families, especially the arborescent ones are no more the primitive families. But as per APG classification system, Amborellaceae, Nymphaceae, Austrobaileyaceae, Magnoliaceae and Chloranthaceae form the early angiosperms.
- Monocots are recognised as a monophyletic group and hence terminology is retained.
- Dicots are polyphyletic group and as a result the use of the term dicotyledons as a group becomes outdated.
- Liliaceae (Sensu lato) is split into 14 families.
- Molluginaceae and Gisekiaceae are recognised separately from Aizoaceae.
- Euphorbiaceae (s.l.) is split in to Phyllanthaceae, Picrodendraceae and Putranjivaceae.
- Asclepiadaceae are merged with Apocynaceae (s.l.)
- Many genera that were conventionally treated under Verbenaceae such as *Clerodendron*, *Tectona* and *Vitex* are transferred to Lamiaceae based on the modified circumscription of these families.

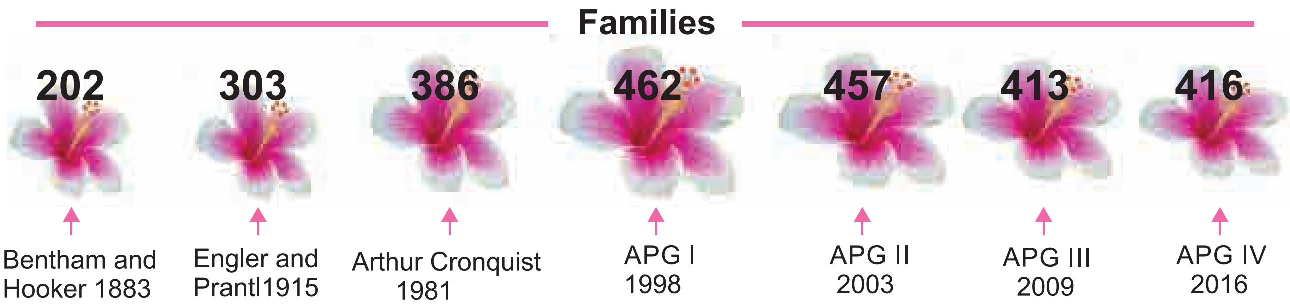


Figure 5.12: A timeline showing the history of classifying flowering plants into families. (Source: Royal Botanic Gardens Kew State of World's Plant 2017)

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

Various medicines, spices and preservatives obtained from plant have drawn the attention of Taxonomists. Study of various chemicals available in plants help to solve certain taxonomical problems. 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. Proteins, amino acids, nucleic acids, peptides etc. are the most studied chemicals in chemotaxonomy.

The chemical characters can be divided into three main categories.

1. Easily visible characters like starch grains, silica etc.
2. Characters detected by chemical tests like phenolics, oil, fats, waxes etc.
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

Molecular Markers

Allozyme electrophoresis is a method which can identify genetic variation at the level of enzymes that are directly encoded by DNA.

Mitochondrial DNA markers are non- nuclear DNA located within organelles in the cytoplasm called mitochondria. The entire genome undergoes transcription as one single unit. They are not subjected to recombination and thus they are homologous markers.

Microsatellite is a simple DNA sequence which is repeated several times across various points in the DNA of an organism. These (usually 2-5) repeats are highly variable and these loci can be used as markers. (Example: TGTGTG, in which two base pairs repeat, the region are termed **tandem repeat**.)

Single nucleotide polymorphisms arise due to single nucleotide substitutions (transitions/transversions) or single nucleotide insertions/deletions. SNPs are the most abundant polymorphisms in the genome (coding and non-coding) of any organism. These single nucleotide variants can be detected using PCR, microchip arrays or fluorescence technology.

DNA microarray or DNA chip consists of small glass microscope slides, silicon chip or nylon membranes with many immobilized DNA fragments arranged in a standard pattern. A DNA microarray can be utilized as a medium for matching a reporter probe of known sequence against the DNA isolated from the target sample which is of unknown origin. Species-specific DNA sequences could be incorporated to a DNA microarray and this could be used for identification purposes.

Arbitrary markers are sometimes used to target a segment of DNA of unknown function. The widely used methods of amplifying unknown regions are RAPD and AFLP DNA.

Specific Nuclear DNA markers: Variable Number of Tandem Repeat is a segment of DNA that is repeated tens or even hundreds to thousands of times in nuclear genome. They repeat in tandem; vary in number in different loci and differently in individuals. There are two main classes of repetitive and highly polymorphic DNA viz. **minisatellite** DNA referring to genetic loci with repeats of length 9-65 bp and microsatellite DNA with repeats of 2-8 bp (1-6) long. Microsatellites are much more numerous in the genome of vertebrates than minisatellites.

the form of a tree called **phylogenetic tree.** Different molecular markers like allozymes, mitochondrial DNA, micro satellites, 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.

List of conferences of International Barcode was held

S.No.	Year	Place
1.	2005	London, United Kingdom
2.	2007	Taipei, Taiwan
3.	2009	Mexico City, Mexico
4.	2011	Adelaide, Australia
5.	2013	Yunnan, China
6.	2015	Guelph, Canada
7.	20-24 Nov' 2017	Skukuza, South Africa

5.11.7 Differences between classical and modern taxonomy

Classical Taxonomy	Modern Taxonomy
It is called old systematics or Alpha (ἀ) 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 morpho-logical, reproduc-tive characters and phylogenetic (evolu-tionary) 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 sam-ples/individuals

5.12 Cladistics

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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).

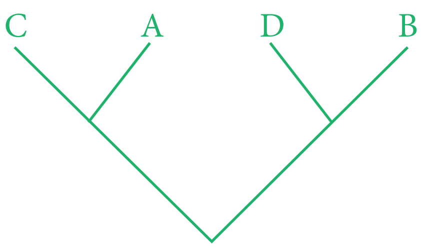
The outcome of a cladistic analysis is a **cladogram**, a tree-shaped diagram that represent the best hypothesis of phylogenetic relationships. Earlier generated cladograms were largely on the basis of morphological characters, but now genetic sequencing data and computational softwares are commonly used in phylogenetic analysis.

Cladistic analysis

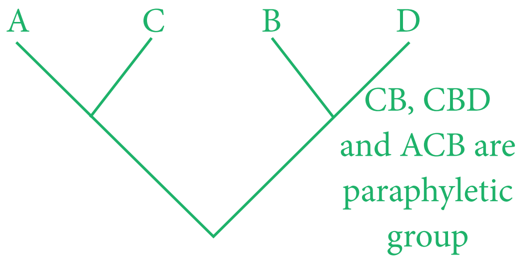
Cladistics is one of the primary methods of constructing phylogenies, or evolutionary histories. Cladistics uses shared, derived characters to group organisms into clades. These clades have atleast one shared, derived character found in their most recent common ancestor that is not found in other groups 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.

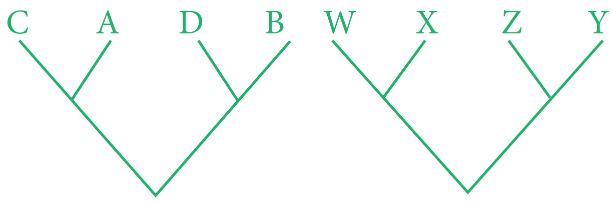
i. **Monophyletic group;** Taxa comprising all the descendants of a common ancestor.



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 morphological characteristics of organism.
3. Cladistics helps to elucidate mechanism of evolution.

5.13 Selected Families of Angiosperms

Dicot Families

Plant kingdom is so vast and varied. For the purpose of study, they have been classified into Artificial, Natural, Phylogenetic and APG system in course of time. Bentham and Hooker system of classification is followed in India till recently. Great variation occurs not only in different families, but also varies in genera and species which are included within the family. Variation occurs in number, arrangement, adhesion and cohesion of the floral parts. We study a few families for understanding the process and purpose of classification.

5.13.1 Family: Fabaceae (Pea family)

Systematic position

APG classification		Bentham and Hooker classification	
Kingdom	Plantae	Kingdom	Plantae
Clade	Angiosperms	Class	Dicotyledonae
Clade	Eudicots	Sub-class	Polypetalae
Clade	Rosids	Series	Calyciflorae
Order	Fabales	Order	Rosales
Family	Fabaceae	Family	Fabaceae

Diagnostic features

- Leaves simple or imparipinnately compound or palmate, leaf base pulvinate, leaflets stipellate.
- Flowers Zygomorphic
- Corolla: Papilionaceous, descendingly imbricate aestivation, posterior petal outermost,
- Petals clawed.
- Stamens: Monadelphous, diadelphous
- Ovary stipitate (a short stalk as the base), monocarpellary, unilocular with marginal placentation.
- Fruit a legume or lomentum.

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 (*Indigofera, Crotalaria*), prostrate (*Indigofera enneaphylla)* erect (*Crotalaria verrucosa*), shrubs (*Cajanus cajan*), small trees (*Sesbania*), climbers (*Clitoria*), large tree (*Pongamia, Dalbergia, Erythrina, Butea*), woody climber (*Mucuna*), hydrophyte (*Aeschynomene aspera*) commonly called **pith plant.**

Root: Tap root system, roots are nodulated, have tubercles containing nitrogen – fixing bacteria (*Rhizobium leguminosarum)*

Root nodule

Stem: Aerial, herbaceous, woody (*Dalbergia*) twining or climbing *Clitoria*.

Leaf: Leaf simple or unifoliate (*Desmodium gangeticum*) bifoliate (*Zornia diphylla,*), Trifoliate (*Lablab purpureus),* unipinnate or simple pinnate (*Clitoria*), alternate, stipulate, leaf base, **pulvinate**, stipulus 2, free. Leaves showing 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 (*Sesbania*), 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 from underground). 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 **reniformed**.

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

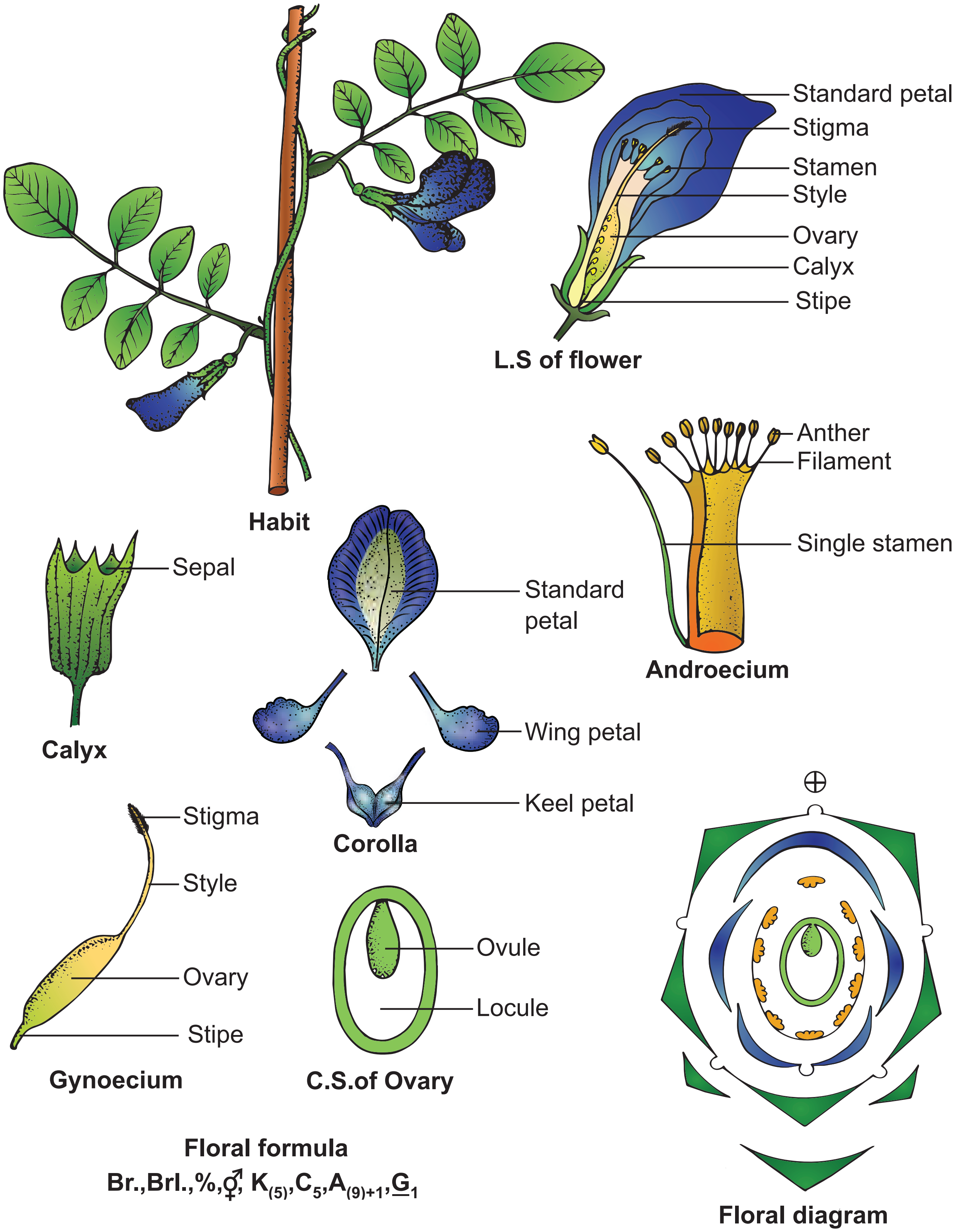


Figure 5.13: *Clitoria ternatea*

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: Br.,Brl.,%,⚥, $K_{(5)},C_5,A_{(9)+1},\underline{G}_1$

Botanical description of *Pisum sativum* (Pea Plant)

Habit: Cultivated herb, becoming shrubby.

Root: Branched tap root system, nodulated due to the presence of nitrogen fixing bacteria (*Rhizobium leguminosorum).*

Stem: Erect and climbing, one to three feet high, young stem densely pubescent, somewhat angular, herbaceous, green and branched.

Leaves: Alternate, petiolate, stipulate, stipules ¼ to ½ inch long attached near the base, compound (trifoliate), leaflets dark green, entire, acuminate, pubescent on both the sides, reticulate venation.

Inflorescence: Clustered axillary racemes.

Flower: Bracteate (small and deciduous), bracteolate (usually persistent), pedicellate, heterochlamydeous, complete, bisexual, pentamerous, zygomorphic and hypogynous.

Calyx: Sepals 5, green synsepalous, companulate, showing valvate aestivation. Odd sepal is anterior in position.

Corolla: Petals 5, apopetalous, irregular papillionaceous, consisting of a posterior standard, two lateral wings, two anterior ones forming a keel which encloses stamen and pistil, vexillary / descendingly imbricate aestivation.

Androecium: Stamens 10, diadelphous (9)+1 nine stamens fused to form a bundle and the tenth one is posterior and free. Anthers dithecous, basifixed, introse and dehisce longitudinally.

Gynoecium: Monocarpellary, ovary superior, unilocular, with many ovules on marginal placentation, style simple and curved, stigma capitate.

Fruit: Legume

Seed: non-endospermous with thick cotyledons.

Floral Formula: Br.,Brl.,%,⚥, $K_{(5)},C_5,A_{(9)+1},\underline{G}_1$

Arachis hypogea

Crotalaria verrucosa

Indigofera tinctoria

Aeschynomene aspera

Figure 5.14: Selected plants belongs to the Family Fabaceae

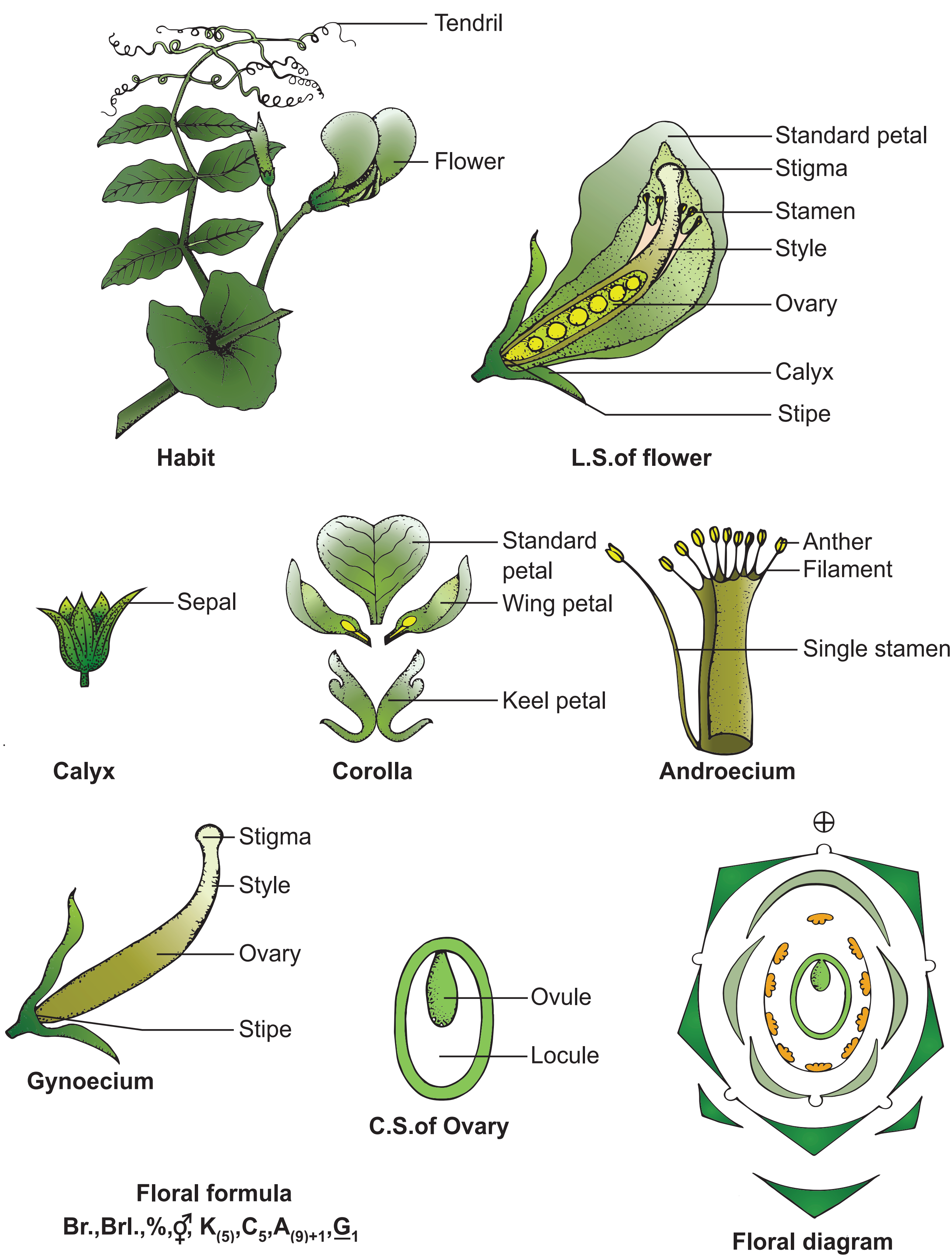


Figure 5.15: *Pisum sativum*

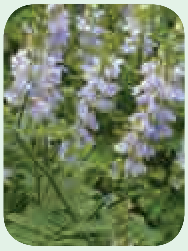
Economic Importance

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, vegetable humming bird) *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.dalbergioides* (Padauk) *P.marsupium* (வேங்கை)	Timber	Timber is used for making furniture, cabinet articles and as building materials.
Medicinal Plants	*Crotalaria albida* *Psoralea corylifolia* (கார்போக அரிசி) *Glycirrhiza 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.

Continued

Economic importance	Binomial	Useful part	Uses
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
Green Manuring	*Indigofera tinctoria* *Tephrosea purpurea* *Gliricidia sepium*	Entire plant	Used as green manure because of the presence of nitrogen fixing bacteria in the lateral roots.
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 seeds of *Abrus precatorius* are used in necklaces and rosaries, but are extremely poisonous and can be fatal if ingested.

The attractive seeds of *Adenanthera pavonina* (Family: Caesalpiniaceae) have been used as units of weight for the measures of gold throughout India.

The Food and Agriculture Organization (FAO) of the United Nations has been nominated to declare 2016 as the year for pulses, to make people more aware of the nutritional value of pulses.

5.13.2 Family: Apocynaceae (milk weed family) (including Asclepiadaceae)

Systematic position

APG classification		Bentham and Hooker classification	
Kingdom	Plantae	Kingdom	Plantae
Clade	Angiosperms	Class	Dicotyledonae
Clade	Eudicots	Sub-class	Gamopetalae
Clade	Asterides	Series	Bicarpellatae
Order	Gentianales	Order	Gentianales
Family	Apocynaceae	Family	Apocynaceae

Diagnostic features

- Plants with milky sap.
- Leaves opposite or whorled, exstipulate.
- Flowers pentamerous.
- Stamens epipetalous, connate with corona.
- Fruit a follicle.
- Stigma is thick and massive often connate to stamen to form Gynostegium
- Seeds often with coma (hair).
- Presence of nectariferous disc.

General Characters

Distribution:

This family is represented by 345 genera, 4,675 species. Mostly tropical and subtropical whereas a few species found in temperate region.

Habit: Tree (*Alstonia*), shrub, (*Nerium*), herb (*Catharanthus*), woody twiner (*Allamanda*, Succulent, *Adenium* usually twining shrubs with milky sap in laticiferous vessels.

Root: Branched tap root system

Stem: The stems are succulent in some taxa (*Stapelia, caralluma*), usually erect, branched solid, glabrous, rarely tube like and thick.

Leaves: Simple, undivided, sometimes reduced, exstipulate, opposite decusate (*Calotropis*) or sometimes alternate (*Thevetia*) or in whorls of 3 (Nerium), entire, rarely stipulate (*Tabernaemontana*).

Inflorescence: A Panicle, dichasial cyme, often umbelliform in (Asclepiadoids) or raceme, or axillary cluster of two flowers each (*Catharanthus*).

Flowers: Bracteate, bracteolate, pedicellate, complete, bisexual, actinomorphic, zygomorphic in *Ceropegia* heterochlamydeous , pentamerous, hypogynous but rarely perigynous or epigynous *(Plumeria*)

Ceropegia spp

Calyx: Sepals 5, synsepalous (at least basally) sometimes aposepalous (*Catharanthus*) deeply lobed ; valvate or quincuncial (*Thevetia*), odd sepal posterior, glandular appendages (*Squamellae*) present on the adaxial side.

Corolla: Petals 5, sympetalous united into a tube, salver or funnel shaped; twisted or rarely valvate, often hairy within or contain some corona like out growths at the mouth of the corolla tube.

Androecium: Stamens 5 , alternipetalous, often epipetalous, apostemonous to monadelphous, In *Asclepiadoids* the stamens are connate to the styles to form a **gynostegium**, pollen grains of each theca of an anther are fused into a waxy mass called **pollinium**. The right pollinium of each anther attached to the left pollinium of the adjacent anther by a hair like translator, translator arms (**retinacula**) attached together with the gland like structure called **corpusculum**. Anthers are dithecous, basifixed, often sagitate, introse; dehisce longitudinally, anthers basally awned; sometimes bear hairy appendages over the lobes (*Nerium*).

Gynoecium: Bicarpellary, carpels apically united, superior, or rarely half inferior (*Plumeria*) 1 to 2 locule with 2 to many ovules in each locule on marginal placentation. Style one and simple, stigma is characteristically thickened, massive and bilobed. A nectariferous disc is often present around or at the base of the gynoecium, (*Thevetia, Catharanthus, Allamanda* and *Rauvolfia*).

Fruit: The fruit is variable and can be a berry (*Landolphia*), drupe (*Cerbera*) follicle (*Asclepias*), capsule (*Allamanda*).

Seed: Seeds are endospermous often with crown of hairs.

Botanical description of *Catharanthus roseus*

Habit: Erect ever blooming ornamental plant with milky latex.

Root: Branched tap root system

Stem: Aerial, erect, cylindrical reddish green, glabrous and branched.

Leaves: Usually simple, opposite decussate, exstipulate, subsessile, or petiolate, elliptic – ovate, entire, mucronate, unicostate reticulate venation.

Inflorescence: cymose, axillary pairs.

Flower: Ebracteate, Ebracteolate, subsessile, complete, bisexual, heterochlamydeous, actinomorphic, hypogynous, pentamerous, rosy purple, white or pink.

Calyx: Sepals 5, slightly synsepalous, green showing valvate aestivation.

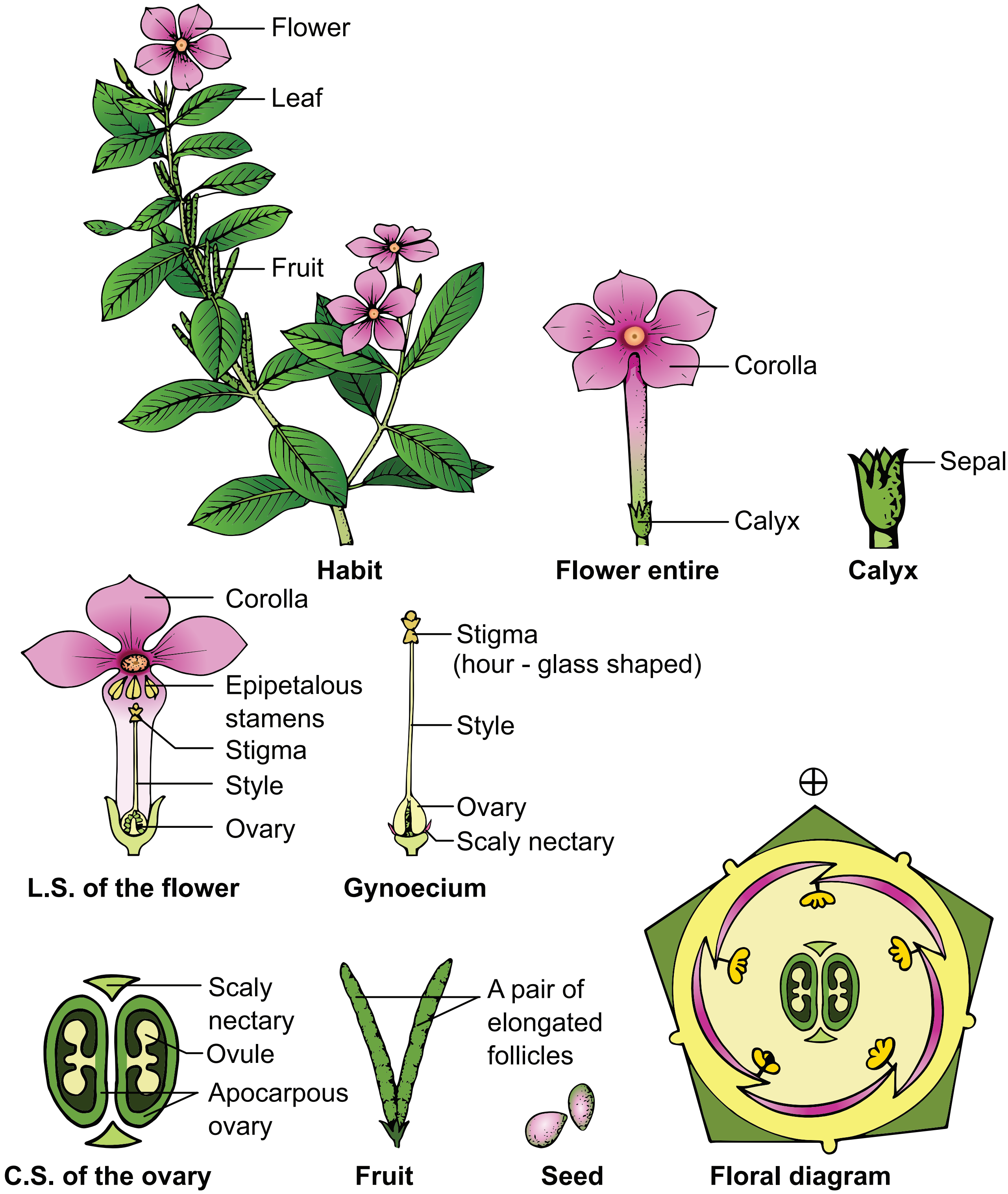
Corolla: Petals 5, sympetalous, throat of corolla tube hairy forming a corona, twisted (hypocrateriform).

Androecium: Stamens 5, apostemanous, epipetalous, inserted at the mouth of the corolla tube, filaments short, anthers sagittate, dithecous, dorsifixed, introse.

Gynoecium: Bicarpellary, apocarpous, ovaries superior, unilocular, ovules many, placentation marginal, style simple, stigma hour-glass shaped. Two scaly nectaries are present one on the anterior and another on the posterior side of the ovary.

Fruit: A pair of elongated follicles.

Floral Formula: $\mathbf{Ebr.,Ebrl.,}\oplus,⚥,\mathbf{K}_{(5)},\overset{\frown}{\mathbf{C}_{(5)},\mathbf{A}_5},\underline{\mathbf{G}}_{(2)}$



Floral formula

$\text{Ebr., Ebrl.}, \oplus, ⚥, K_{(5)}, \overset{\frown}{C_{(5)}, A_5}, \underline{G}_2$

Figure 5.16: *Catharanthus roseus*

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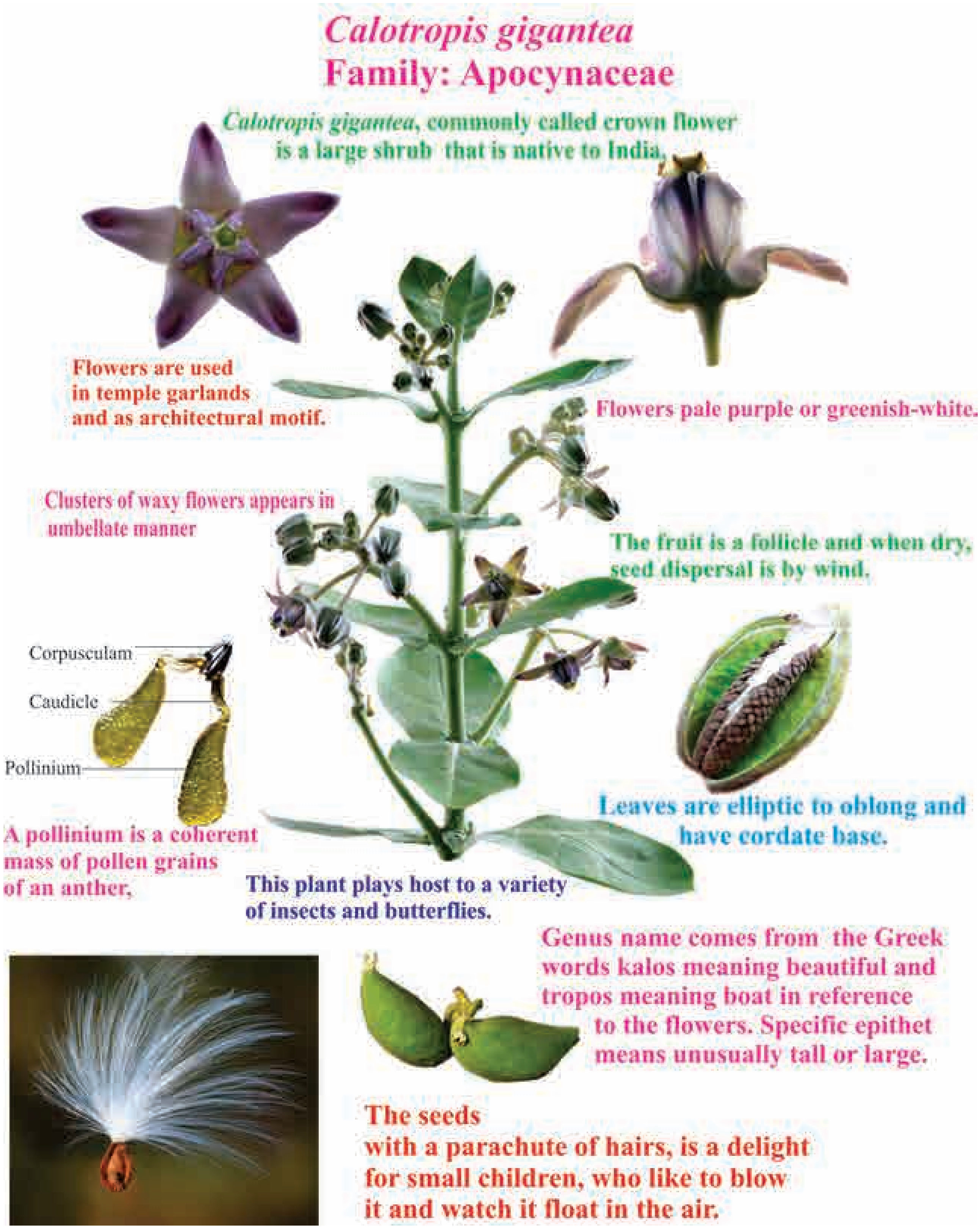


Figure 5.17: *Calotropis gigantea*

Economic importance of the family Apocynaceae

S.No	Economic importance	Binomial	Useful part	Uses
1	**Food plant**	*Carissa carandas* (பெரும்களா) *Carissa spinarum* (சிறுகளா)	Fruits	Edible and used in pickles
2	**Medicinal plant**	*Rauvolfia serpentina* (Indian snake root / sarpagandha)	Shoot	To treat hypertension and mental disorders
			Dried roots	Alkaloid (reserpine) obtained from the dried roots, of the plant can lower the blood pressure and used as sedative for patients suffering from *Schizophrenia*.
		Thevetia peruviana (lucky nut/ தங்கஅலரி)	Seeds	Used in rheumatism
		Vallaris solanacea	Latex	Useful in toothache and to treat inflated gums.
		Cerbera odollam	Latex	Used as an emetic and purgative.
		Alstonia scholaris	Bark	Used in malaria and dysentery.
		Strophanthus hispidus	Seeds	Yield the drug strophanthin
		Wrightia tomentosa (பாலை)	Bark and Roots	Used as antidote to snakebite.
		Catharanthus roseus	Aerial parts	Used to treat muscle pain, the alkaloids like vinblastine and vincristine are mainly used to treat various human cancers.
		Caralluma umbellate (களிமுளியான்)	Succulent stem	Antiobesity

3.	**Dye yielding plant**	*Wrightia tinctoria*	Seeds	An indigo- like dye is obtained from the seeds.
4.	***Ornamental plants***	*Allamanda nerifolia* (golden trumpet), *Alstonia scholaris, Beaumontia grandiflora, Catharanthus roseus,* *Nerium indicum* *Plumeria obtusa,* *Plumeria alba,* *Stapelia spp, Hoya, Asclepias, and Cryptostegia.*	plant	Grown as ornamentals plants.

Thevetia

Plumeria

Rauvolfia

Tabernaemontana

Figure 5.18: *Selected plants belongs to the family Apocynaceae*

5.13.3 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

Diagnostic Features

- Leaves alternate, exstipulate.
- Flowers actinomorphic, pentamerous.
- Calyx often persistence / accrescent.
- Stamens 5, epipetalous, poricidal in dehiscence.
- Carpels 2, ovary superior, 2 chambered, obliquely placed, falsely four chambered placenta swollen, ovule numerous.
- Fruits berry or capsule, vascular bundles with both outer and inner phloem (Bicollateral vascular bundle).

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*), many with stellate trichomes; rarely vines (*Lycium sinensis*)

Root: Branched tap root system.

Stem: Herbaceous or woody; erect or twining, or creeping; sometimes modified into tubers (*Solanum tuberosum*) often with **bicollateral** vascular bundles.

Leaves: Alternate, simple, rarely pinnately compound(*Solanum tuberosum* and *(Lycopersicon esculentum*) exstipulate, opposite or sub-opposite in upper part, unicostate reticulate venation.

Inflorescence: Generally axillary or terminal cymose (*Solanum*) or solitary flowers (*Datura stramonium*). Extra axillary scorpiod cyme called **rhiphidium** (*Solanum nigrum*) solitary and axillary (*Datura* and *Nicotiana*) umbellate cyme (*Withania somnifera*).

Flowers: Bracteate (*Petunia*), or ebracteate (*Withania*) pedicellate, bisexual, heterochlamydeous, actinomorphic or weakly zygomorphic due to oblique position of ovary pentamerous, hypogynous.

Calyx: Sepals 5, rarely 4 or 6, Synsepalous, valvale peristaent, often accrescent (enlarging to envelop the fruit) occasionally enclosing the fruit (*Physalis, Withania*)

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), 4 and didynamous in (*Salpiglossis*) 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. In *Lycopersicon esculentum, Capsicum*, the fruit is a berry and in species of *Datura* and *Petunia*, the fruit is a capsule.

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 persistant, 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 biloculear 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: $Br., Ebrl., \oplus, ⚥, K_{(5)}, \overset{\frown}{C_{(5)}, A_5}, \underline{G}_{(2)}$

Solanum trilobatum *Atropa belladonna*

Withania somnifera *Schizanthus pinnatus*

Figure 5.19: Selected plants belongs to the Family Solanace

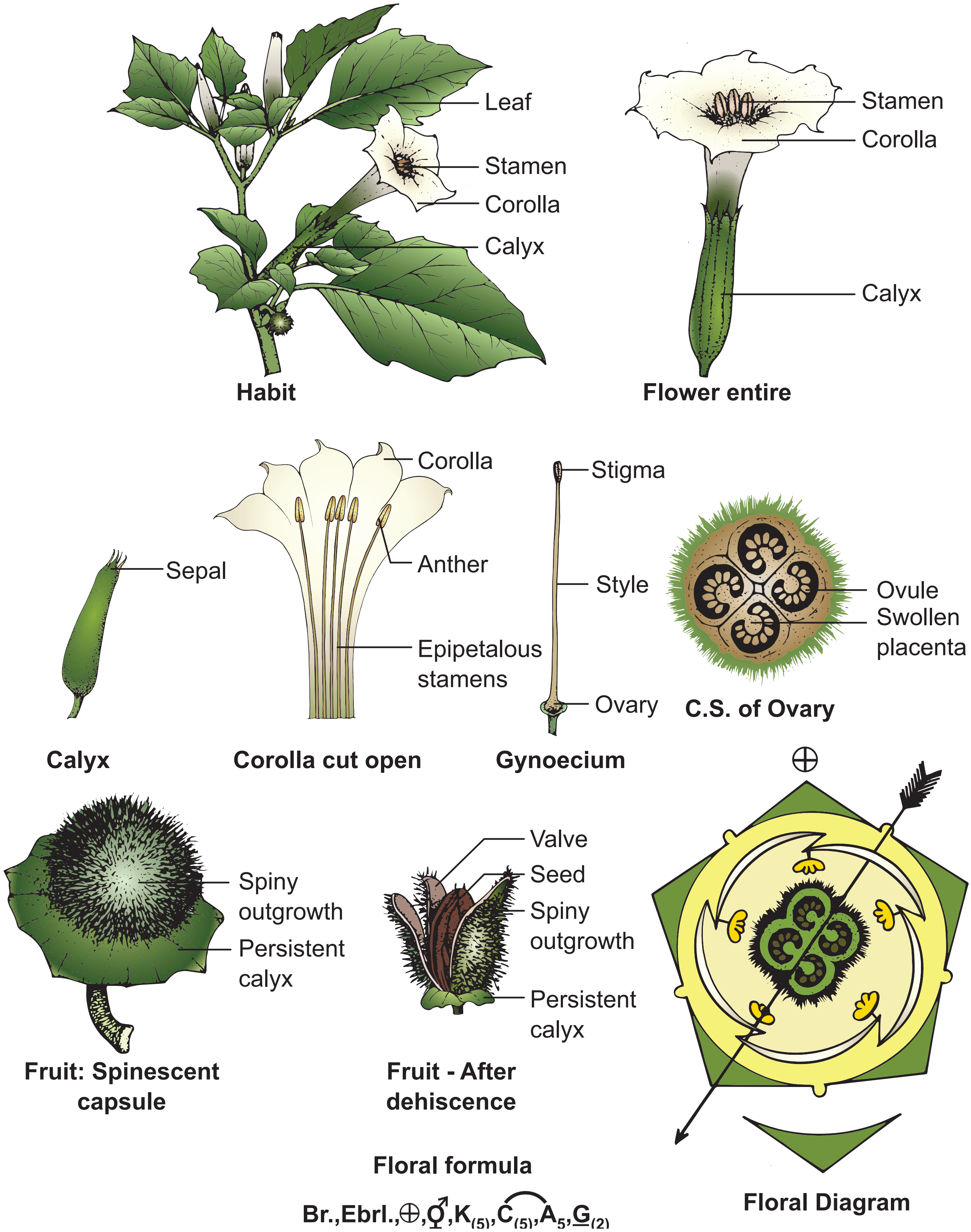


Figure 5.20: *Datura metel*

Botanical description of *Solanum americanum*

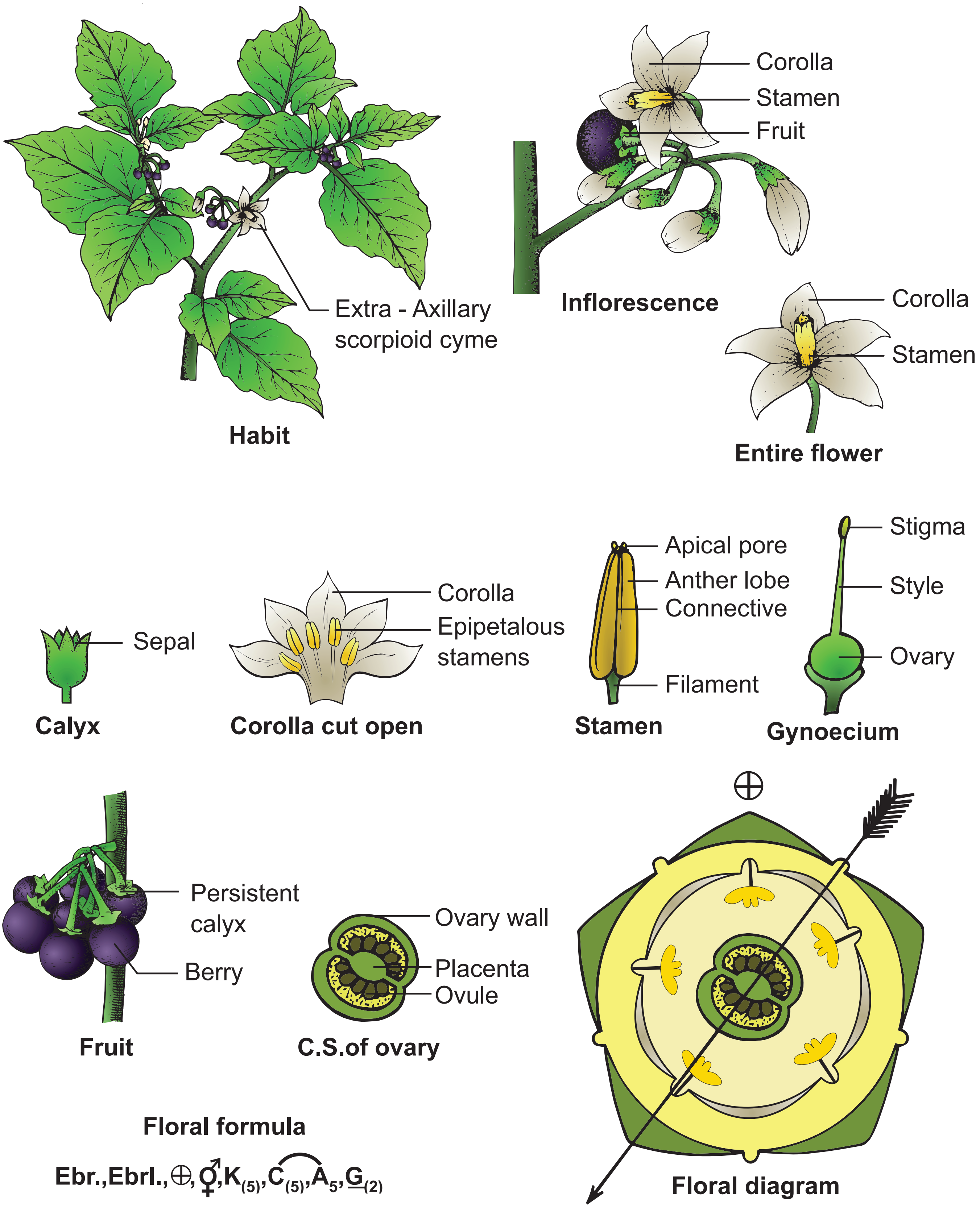


Figure 5.21: *Solanum americanum*

Habit: A small annual herb

Root: Branched tap root system.

Stem: Aerial, erect, green and herbaceous

Leaf: Simple, alternate but opposite in the floral region, petiolate, exstipulate ovate, entire or slightly lobed, acute unicostate reticulate venation.

Inflorescence: Extra-axillary (due to fusion of floral axis) scorpioid cyme called rhiphidium

Flower: Ebracteate, pedicellate, white, bisexual, actinomorphic, heterochlamydeous, pentamerous, hypogynous white.

Calyx: Sepals 5, synsepalous, green, persistent and showing valvate aestivation.

Corolla: petals 5, sympetalous, white, showing valvate aestivation.

Androecium: Stamens 5, apostamenous, epipetalous, filaments short, anthers conniving and forming an envelope around the style dithecous, basifixed with apical pores.

Gynoecium: Bicarpellary, syncarpous, superior, bilocular, many ovules in each locule on axile placentation, septum oblique, highly swollen placenta, style long and hairy at the base, stigma bifid.

Fruit: Berry

Floral Formula: $Ebr., Ebrl., \oplus, ⚥, K_{(5)}, \overparen{C_{(5)}, A_5}, \underline{G}_{(2)}$

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)	Roots	A powerful alkaloid 'atropine' obtained from root is used in belladona plasters, tinctures etc. for relieving pain and also for dialating pupils of eyes for eye –testing.
		Datura stramonium (ஊமத்தை)	Leaves and roots	Stramonium drug obtained from the leaves and roots of this is used to treat asthma and whooping cough.
		Solanum trilobatum (தூதுவளை)	Leaves, flowers and berries	Used to treat cough.
		Withania somnifera (Ashwagandha / அமுக்காரா)	Roots	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* *Brugmansia* species (Angel trumpet)	Plant	Grown in garden as ornamental plants for their aesthetic nature. Do tomatoes come from a tree?  *Solanum betaceum* (Tree tomato)

5.13.4 Family: Euphorbiaceae (Castor Family / Spurge Family)

(In APG classification Peraceae, Phyllanthaceae and Picrodendraceae are excluded from the family Euphorbiaceae)

Systematic position

APG Classification		Bentham and Hooker Classification	
Kingdom	Plantae	Kingdom	Plantae
Clade:	Angiosperms	Class:	Dicotyledonae
Clade:	Eudicots	Sub-class:	Monochlamydeae
Clade:	Rosids	Series:	Unisexuales
Order:	Malpighiales	Order:	Euphorbiales
Family:	Euphorbiaceae	Family:	Euphorbiaceae

Diagnostic features

- Latex is present either milky or watery.
- Inflorescence generally cymose, catkin in *Acalypha*, cyathium in *Euphorbia* sp.
- Flowers apetalous, unisexual.
- Ovary tricarpellary, distinctly trilobed.
- Fruit capsule or regma.

General characters

Distribution: Euphorbiaceae includes 214 genera and about 5600 species. The plants of this family are found throughout the world. Well represented in Africa and South America.

Habit: Mostly shrubs (*Ricinus communics, Jatropha gossypifolia*) or tree *Emblica officinalis*, herbs (*Phyllanthus amarus*) , twiners (*Tragia involucrata*) some are xerophytic (*Euphorbia*) with cactus – like (phylloclades) plants usually contain milky or watery sap.

Root: Well branched tap root system.

Stem: Aerial, erect or prostrate (*E.prostrata*), herbaceous or woody. Stem becomes modified into flattened, leaf-like and becomes succulent in several species of *Euphorbia*. Such modified stem is called phylloclades. Cylindrical, branched, solid or hollow, usually contain latex either milky (*E.tirucalli*) or watery (*Jatropha curcas*).

Leaf: Stipulate or exstipulate. Mostly simple, alternate, often reduced or deciduous as in several species of *Euphorbia*, palmately lobed in *Ricinus* or deeply lobed in *Manihot*. The stiplues are modified into a pair of spines (*E.splendens*) or glandular hairs (*Jatropha curcas*). The leaves around the cyathium inflorescence become beautifully coloured in *E.pulcherrima* (Paalperukki tree) with unicostate or multicostate reticulate venation.

Inflorescence: The inflorescence of Euphorbiaceae varies greatly, Terminal raceme – *Croton, Ricinus,*

Catkin – *Acalypha hispida* Cyme - *Jatropha,* solitary axillary – *Phyllanthus asperulatus,* cyathium – *Euphobia* species.

Cyathium is the an unique and special inflorescence of this family. Each cyathium contains centrally a single, naked terminal female flower, usually represented by a tricarpellary gynoecium. The female flower is surrounded by a cup-like involucre formed by 4 or 5 connate sepaloid bracts. In the axil of each bract develops a group of stamens in a scorpioid manner. Each stamen represents a naked male flower because it is a jointed structure, its upper portion is the filament bearing the anther and its lower portion represents the pedicel of the male flower bearing stamen. A nectar secreting gland is present on the rim of the involucre. Glands are oval or crescent shaped and often brightly coloured. Though cyathium appears like a single flower, it actually an inflorescence.

Flowers: Flowers are always unisexual, and are highly variable. Bracteate, ebracteolate, generally unisexual, homochlamydeous, rarely heterochlamydeous, monoecious (*Baliospermum*) or dioecious (*Bridelia*), actinomorphic, rarely zygomorphic, hypogynous, rearly perigynous (*Bridelia*).

Perianth: Tepals 0 to 5 **biseriate** (male flowers of *Croton bonplandianum*) uniseriate or aphyllous (*Euphorbia*), valvate or imbricate when present, apophyllous or synphyllous.

Androecium: The number of stamens vary from 1 to many. In *Euphorbia* a single stalked stamen represents a single male flower. In *Ricinus* usually 5 stamens are present, but each stamen is profusely branched. In *Jatropha* they are arranged in two whorls each of 5 stamens. The stamens are indefinite (*Crotons*), the filaments may be free or connate. The anthers are dithecous, dehisce either by apical or by transverse or longitudinal slits.

Gynoecium: Tricarpellary, rarely bicarpellary (*Bridelia, Mercurialis*), tetra or pentacarpellary

(*Wielandia*), syncarpous, ovary superior, rarely semi-inferior, ovules one or two in each locule on axile placentation, rarely locule splits into two forming six chambers (*Phyllanthus*). Styles 3, each split into two feathery stigma. Nectaries are usually present, gynoecium is present as a pistillode in staminate flowers.

Fruit: Fruits are capsule or schizocarp. It breaks violently and dehisce into three one seeded cocci called regma (*Ricinus*), drupe in *Emblica officinalis* and berry or samara.

Seed: Seeds are endospermous. In *Ricinus* knob-like caruncle develops from the micorpyle, that absorbs and temporarily retains water enabling germination.

Ricinus

Botanical Description Of *Ricinus communis* (Castor)

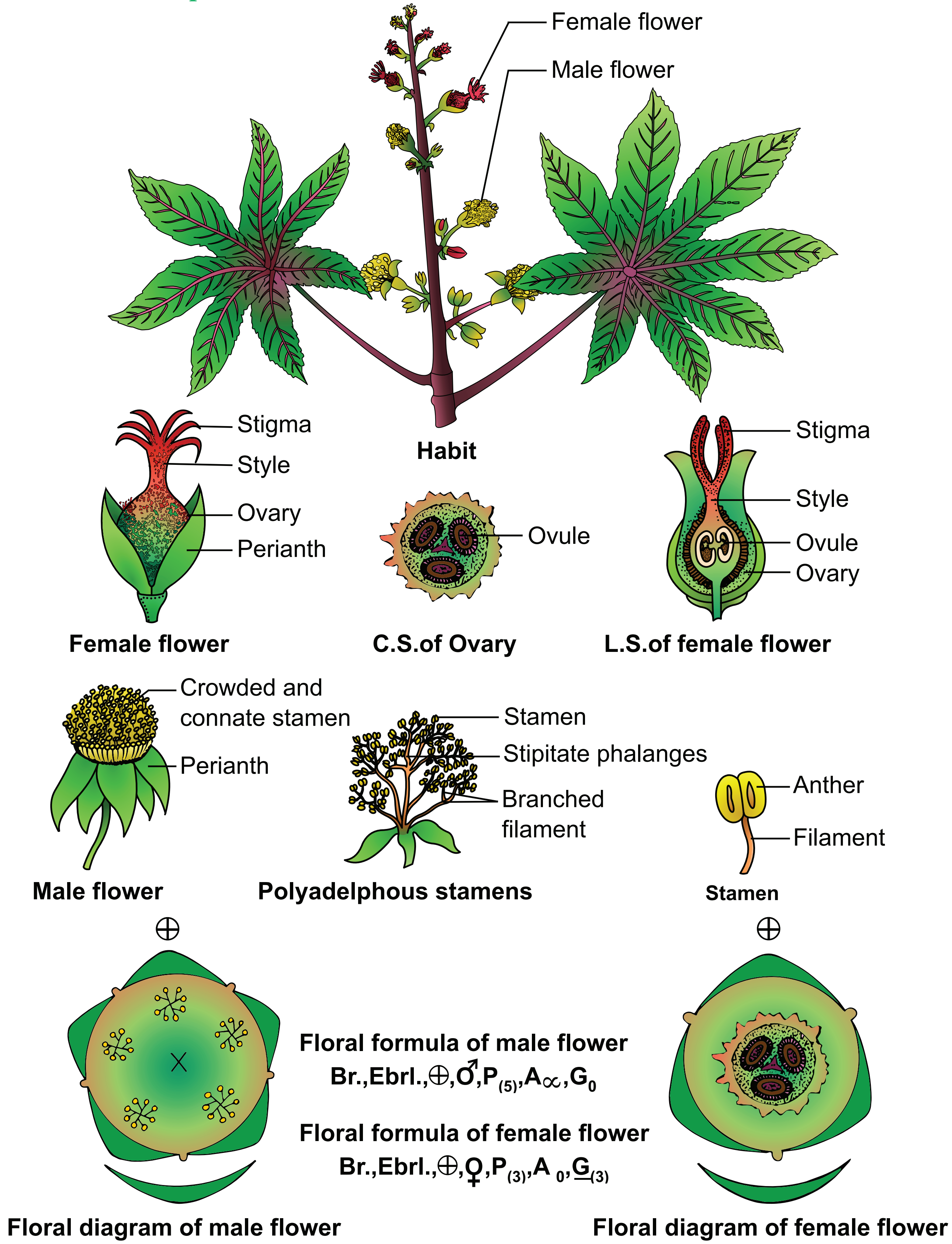


Figure 5.22: *Ricinus communis*

Habit: Tall perennial shrub

Root: Branched tap root system

Stem: Aerial, erect, cylindrical, branched and hollow, solid at the base, glabrous,

Leaf: Simple, petiolate, hollow, exstipulate, alternate, broad, palmately lobed, usually 7-9 lobes, serrate, palmately reticulate divergent venation.

Inflorescence: Terminal panicle.

Male Flower Bracteate, ebracteolate, pedicellate, male flowers (open for one day) towards lower portion of the inflorescence, actinomorphic, incomplete.

Perianth: Tepals 5, apophyllous, uniseriate, green, valvate aestivation, odd tepal posterior in position.

Androecium: Stamens numerous (upto 1000) crowded and connate into about 8mm long cluster of stipitate phalanges, each stamen profusely branded, anthers globose basifixed.

Gynocium: usually absent rarely represented by pistillode.

Female Flower Bracteate, ebracteolate, pedicellate, female flowers (open for fourteen days) found towards the apical portion of inflorescence, actinomorphic, incomplete and hypogynous.

Perianth: Tepals 3, apophyllous, green valvate.

Androecium: Absent but staminode is present.

Gynoecium: Tricarpellary, syncarpous, ovary superior, distinctly trilobed, trilocular, covered with spiny outgrowth, single large ovule in each locule on axile placentation, style three with three bifid stigma.

Fruit: A schizocarp with spiny outgrowth, splits into three one seeded cocci.

Seed: Endospermous, knob-like caruncle develops from the micorpyle, that absorbs and temporarily retains water enabling germination.

Floral Formula:

Male flower: Br.,Ebrl.,$\oplus$,♂,$P_{(5)}$,A_{∞},G_0

Female flower: Br.,Ebrl.,$\oplus$,♀,$P_{(3)}$,A_0,$\underline{G}_{(3)}$

Hevea brasiliensis

Euphorbia pulcherrima

Euphorbia splendens

Croton tiglium

Figure 5.23: Selected plants belongs to the Family Euphorbiaceae

Economic importance of the family Euphorbiaceae

Economic importance	Binomial	Useful part	Uses
Food plant	*Emblica officinalis* (Nellikai) *P. acidus* (அரைநெல்லி)	Fruits	Rich in vitamin C, which are edible and pickled.
	Manihot esculenta (Maravalli kizhanku / Tapioca)	Tuberous roots	Roots are rich in starch and used for preparing bread, biscuits, chips and other food stuffs.
	Sauropus androgynous	Leaves	Greens (multi vitamin plant)
Oil plant			
Croton oil	*Croton tiglium*	Seed	Used as a powerful purgative and also to treat skin diseases.
Castor Oil	*Ricinus communis* (Amanakku/Castor)	Seeds	Used as vegetable oil, ricinoleic acid present in this oil eliminate acne causing bacteria apart from that it acts as laxative and lubricant.
Jatropha Oil	*Jatropha curcas* (Kattamanakku)	Seeds	Used for biofuels.
Rubber:	*Hevea brasiliensis* (Para rubber) *Manihot glaziovii* (Manicoba rubber)	Coagulated latex	Latex is used in rubber products like tube and tyre.
Medicinal plants	*Euphorbia resinifera*	Latex	*Euphorbium* drug is obtained from the latex and used as a purgative.
	Euphorbia hirta (அம்மான் பச்சரிசி)	Whole plant	Lactogogue
	Mallotus philippenensis	Fruits	Used as anthelmintic.
	Phyllanthus amarus (Keezhanelli)	Entire shoot system	Used to treat Jaundice.

Economic importance	Binomial	Useful part	Uses
	Jatropha gossypifolia *Croton tiglium* (நேர்வாளம்) *Ricinus communis*	Leaves and roots Seed Seed oil	Used in the treatment of leprosy and snakebite. Purgative Purgative
Dye yielding plants **Kamela dye,** **Blue dye** **Purple dye** **Red dye**	 *Mallotus philippenensis* *Jatropha curcas* *Chrozophora tinctoria* *Phyllanthus reticulatus*	 Fruits Bark Bark Roots	 Used for dyeing wool and silk. Used for dyeing clothes and fishing nets. Used in textile Industry Used for tanning and *dyeing* fishing lines and nets
Timber plant	*Aporosa dioica,* *Bischofia javanica,* (ரோமவிருட்சம்) *Drypetes roxburghii* (வீரைமரம்)	Timber	Used for packing cases, tea boxes, veneers, plywood, match industry and several other similar purpose.
Ornamental plant	*Acalypha ciliata,* *A. hispida,* *Codiaeum varigatum* *Croton tiglium* *Euphorbia antiquorum, E.pulcherrima, E.splendens.* *E. tirucalli* *Jatropha gossypifolia*	Plants	Grown as ornamental plants.

5.13.5 Family *Musaceae* – Banana Family

Diagnostic Features

- Perennial giant herbs with pseudostems formed by leaf sheaths.
- Leaves are large with thick midrib, parallel venation.
- Flowers are zygomorphic, unisexual, inflorescence spadix covered by spathe.
- Corolla 2 lipped.
- Ovary tricarpellary, inferior.
- Fruit elongated berry.
- Septal nectaries are present.

Systematic Position

APG Classification		Bentham and Hooker Classification	
Kingdom	Plantae	Kingdom	Plantae
Clade	Angiosperms	Class:	Monocotyledonae
Clade	Monocots	Subclass	Zingiberidae
Clade	Commelinids	Series	Epigynae
Order	Zingiberales	Order	Zingiberales
Family	Musaceae	Family	Musaceae

Musa velutina

Rhizogram of the Zingiberales

Note: Earlier Musaceae was a large family with 6 genera viz. *Musa, Ensete, Ravenala, Strelitzia, Orchidantha* and *Heliconia*. In APG only Musa and Ensete are retained while *Ravenala, Strelitzia, Orchidantha* and *Heleconia* are separated.

General Characters

Distribution

Musaceae includes only 2 genera (*Musa* and *Ensete*) and 81 species. The members of this family are mainly wet tropical lowlands from West Africa to Pacific (southern Japan to Queensland). (*Musa* is the most common plant of the family found in India)

Habit: Large perennial herbs perennating by means of rhizome (*Musa paradisiaca*), raraly trees as in *Ravenala madagascariensis*.

Root: Fibrous adventitious root system.

Stem: In *Musa* the real stem is found underground called rhizomatous (dichotomously branching in atleast some spp). The apparent aerial erect, unbranched tall pseudostem is formed by the long stiff and sheathy leaf bases which are rolled around one another to form an aerial pseudostem. The central axis that is concealed at the bottom of the pseudostem in called shaft, which elongates and pierces through the pseudostem at the time of flowering and produces inflorescence terminally. **monocorpic** in *Musa*. (produces flowers and fruits once during its life time). Stem is aerial and woody in *Ravenala madagascariensis.*

Leaf: Simple with long and strong petiole the leaf blade is large and broad with sheathy leaf base. The leaf is exstipulate. Oval, obtuse or oblong with a stout midrib, entire, numerous parallel veins extending up to the margin, rolled in bud . Phyllotaxy is spiral in *Musa* and distichous i.e. leaves are arranged alternately in two opposite vertical rows in *Ravenala*.

Inflorescence: Terminal or axillary thyrse of one to many monochasial branched spadix in *Musa*, Usually the flowers are protected by large brightly coloured, spirally arranged, boat shaped bract called spathe. Compound cyme in *Ravenala.*

Flowers: Bracteate, ebracteolate, sessile, trimerours, unisexual, or bisexual or polygamous, when unisexual the flowers are monoecious. Flowers are zygyomorphic and epigynous. (In *Musa* flowers are polygamous i.e. staminate flowers, pistilate flowers and bisexual flowers are present in the same plant).

Perianth: Tepals 6, biseriate, arranged in two whorls of 3 each and homochlamydeous, 3 +3 syntepalous. In most of the species of *Musa*, the three outer tepals and two lateral tepals of the inner whorl are fused to form 5 toothed tube like structure called **abaxial lip**. The posterior inner median tepal alone is free, which is distinctly broad and membranous called **labellum**.

Androecium: Stamens 5 or 6, arranged in two whorls of 3 each opposite and adnate to the tepals. In *Musa* only 5 stamens are fertile and the inner posterior stamen is either absent or represented by a staminode. In *Ravenala* all the six stamens are fertile. Filaments free, anthers linear, dithecous dehisce by longitudinal slits, and with sticky pollen.

Gynoecium: Tricarpallary, syncarpous, the median carpel is anterior in position, trilocular ovary inferior, ovules many, placentation axile, style filiform, stigma three lobed septal nectaries are present.

Fruit: Elongated berry containing numerous seeds, fruits forming compact bunches, seeds with copious and small embryo in *Musa*. Capsule in *Ravenala.*

Seed: Starch rich endosperm and starchless perisperm. Species of *Ensete* are distinguished from those of *Musa* by their larger seeds.

Botanical Description of *Musa paradisiaca.*

Habit: Monocarpic gigantic herb.

Root: Fibrous adventitious root system.

Stem: The real stem is underground called rhizomatous. The apparent, aerial erect unbranched pseudo stem is formed by the long, stiff and sheathy leaf bases which are rolled around one another to form an aerial pseudostem. The central

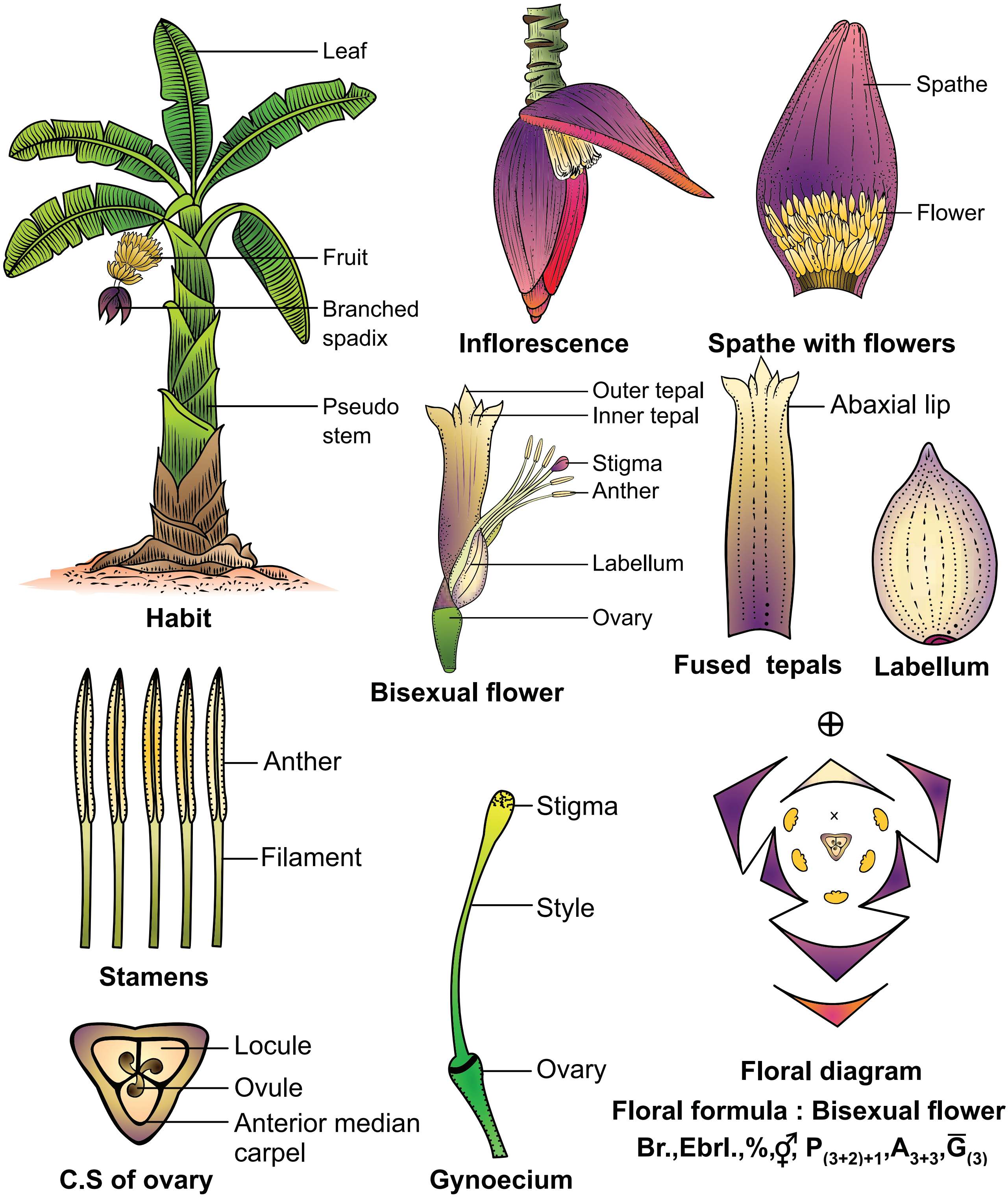


Figure 5.24: *Musa paradisiaca*

axis that is concealed at the bottom of the pseudostem is called shaft. The shaft elongates, pierces through the pseudostem and produces an inflorescence terminally.

Leaf: Simple with a long and strong petiole. The leaf blade is large and broad with sheathy leaf base. Leaf exstipulate and obtuse pinnately parallel venation which extends upto the leaf margin phyllotaxy is spiral.

Inflorescence: Terminal branched spadix. Flowers are protected by large, brightly coloured spirally arranged, boat shaped bracts called spathe. When the flowers open, spathe rolls back and falls off.

Flower: Bracteate, ebracteolate, sessile, trimerous, unisexual or bisexual, flowers are zygomorphic and epigynous.

Perianth: Tepals 6, biseriate, 3+3 syntepalous, arranged in two whorls of 3 each and homochlamydeous, the three tepals of the outer whorl and the two lateral tepals of the inner whol are fused by valvate aestivation to form 5 toothed tube like structure called abaxial lip, the posterior inner median tepal is distinctly broad membrancus and free called labellum.

Androecium: Stamens 6, arranged in two whorls of 3 each, arranged opposite to the tepals. Only five stamens are fertile and the inner posterior stamen is either absent or represented by staminode. Anthers are dithecous and they dehisce by vertical slits. Filament is simple and filiform and rudimentary ovary or pistillode is often present in the male flower.

Gynoecium: Tricarpellary, syncarpous, the median carpel anterior, trilocular, ovary inferior, numerous ovules on axile placentation. Style is simple and filiform, stigma trilobed. Septal nectaries are present.

Fruit: An elongated fleshy berry and seeds are not produced in cultivated varieties.

Floral Formula

Male flower:

$\mathbf{Br, Ebrl, \%, ♂, P_{(3+2)+1}, A_{3+3}, G_0}.$

Female flower:

$\mathbf{Br, Ebrl, \%, ♀, P_{(3+2)+1}, A_0, \overline{G}_{(3)}}.$

Bisexual flower:

$\mathbf{Br, Ebrl, \%, ⚥, P_{(3+2)+1}, A_{3+3}, \overline{G}_{(3)}}.$

Ensete ventricosum

Ravenala madagascariensis

Strelitzia reginae

Heliconia spp

Figure 5.25: Selected plants belongs to the Family Musaceae

Economic Importance of The Family Musaceae

S.No	Economic importance	Binomial	Useful part	Uses
1	**Food plant**	*Musa paradisiaca.*	The raw (tender green) bananas, the shaft and male buds. Leaves Fruit Flower stalk (Shaft)	Cooked and eaten as vegetable. Commonly used as plates on festive occasions and are widely used to wrap food items when cooking. Crunchy and salty fried plantain chips are delicious. Edible after cooking.
		Ensete ventricosa *Musa chinensis* (Chinea kela)	Fruits	Edible bananas which are sweet, rich in starch and vitamins.
2.	**Medicinal plant**	*Musa spp.*	Sap obtained from the sheathy leaf base.	Considered to be an antidote for cobra bite.
3.	**Starch**	*Ensete ventricosum* (Ethiopean banana)	The swollen basal parts of leaf sheaths	Used as a source of starch and vitamins.
4.	**Fibre yielding plant**	*Musa textilis* (Manila hemp)	Fibre	Fibre is woven and made into abaca cloth, also used for twine, bagging and wrapping paper.
5.	**Ornamental plant**	*Musa coccinea* (a wild banana species). (*M. acuminata*, *M. velutina* and *M. ornata*) *Ensete ventricosum*	Plant	Have ornamental scarlet flowers. Cultivated as ornamentals

Continued

		**Ravenala madagascariensis* (traveller's palm), **Strelitzia reginae* (bird of paradise) and **Heliconia spp.*	Plant	Grown as ornamental plants

5.13.6 Monocot Family

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

Diagnostic Features

- Perennial herbs often with bulbous stem / rhizomes.
- Radical leaves.
- Perianth showy.
- Stamens six.
- Ovary superior.

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 in *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, usually 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 intrese, 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* & *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, ebrcteolate, 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:

$\mathrm{Br., Ebrl.}, \oplus, ⚥, \overparen{P_{(3+3)} + A_{3+3}}, \underline{G}_{(3)}$

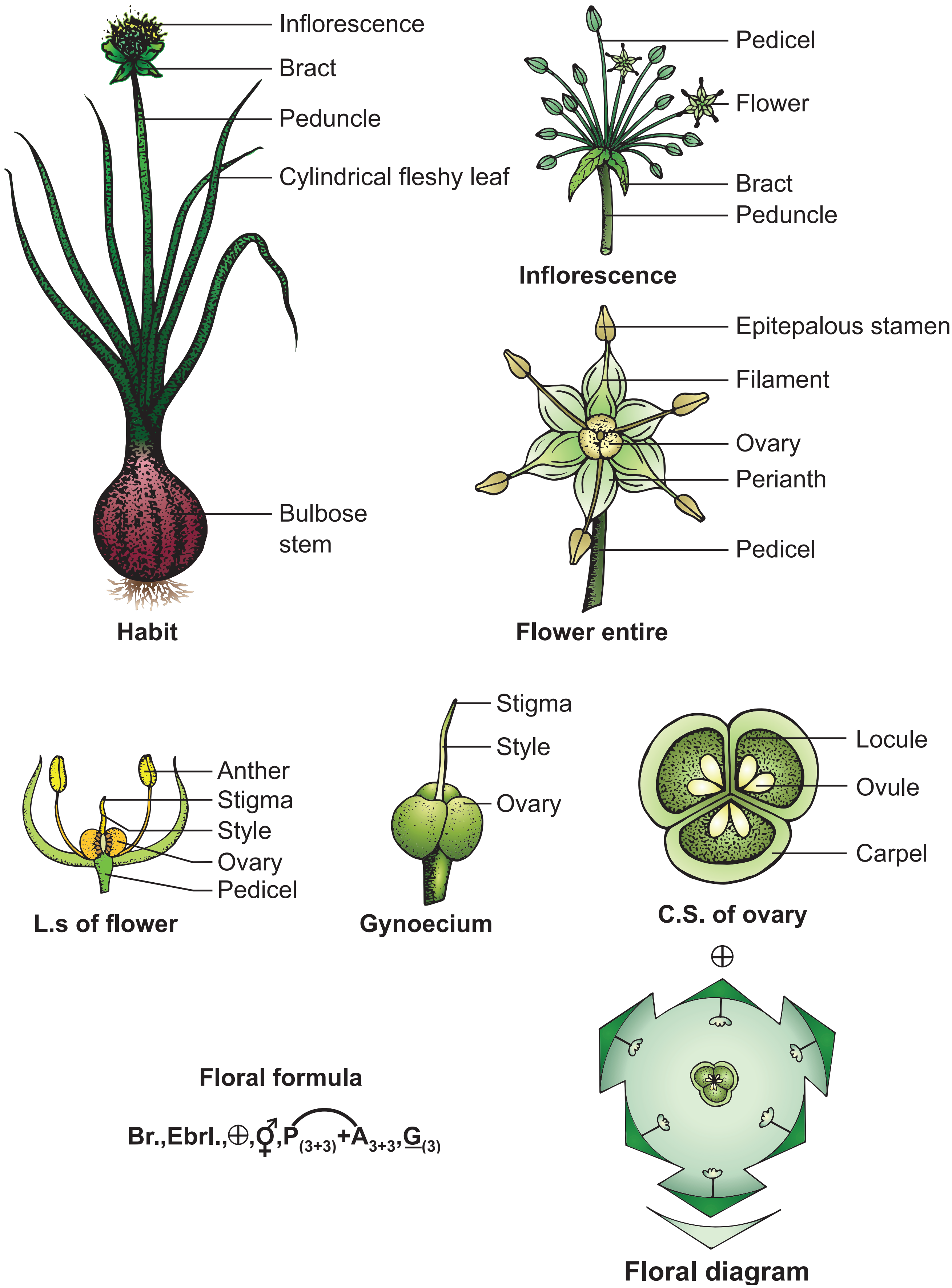


Figure 5.26: *Allium cepa*

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.
		A. racemosus	Tuberous roots	Used as vegetables.
2.	Medicinal plant	*Aloe barbadense*	Leaves	Leaves are the source of resinous drug, used as a purgative.
		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.
		Scilla hyacinthiana;	Bulbs	Used as heart stimulant.
		Smilax glabra; and *S.ovalifolia;*	Roots	Used in the treatment of venereal diseases.
4.	Fibre yielding plant	*Phormium tenax*	Fibre	Used for cordage, fishing net, mattings, twines
5.	Raticides	*Urginea indica*	Bulbs	Used for killing rats
	Insecticides	*Veratrum album*	Bulbs	Used as insecticide.

Continued

S.No	Economic importance	Binomial	Useful part	Uses
6.	Polyploidy	*Colchicum luteum*	Corm	Colchicine (alkaloid) used to induce polyploidy.
7.	Ornamental plants	*Agapanthus africanus* (African Lilly) *Hemerocallis fulva* (Orange Day Lilly) *Gloriosa superba* (Malabar glory lilly) *Lilium candidum* *Lilium giganteum* *Ruscus aculeatus* (Butchers Broom) *Tulipa suaveolens* *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.

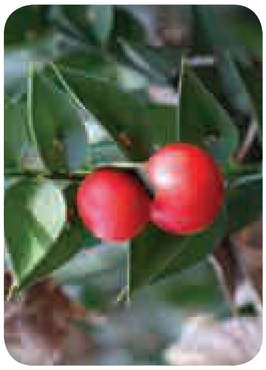
DO YOU KNOW?

In *Yucca* the cross-pollination 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*.

Lilium nilgiriensis

Smilax

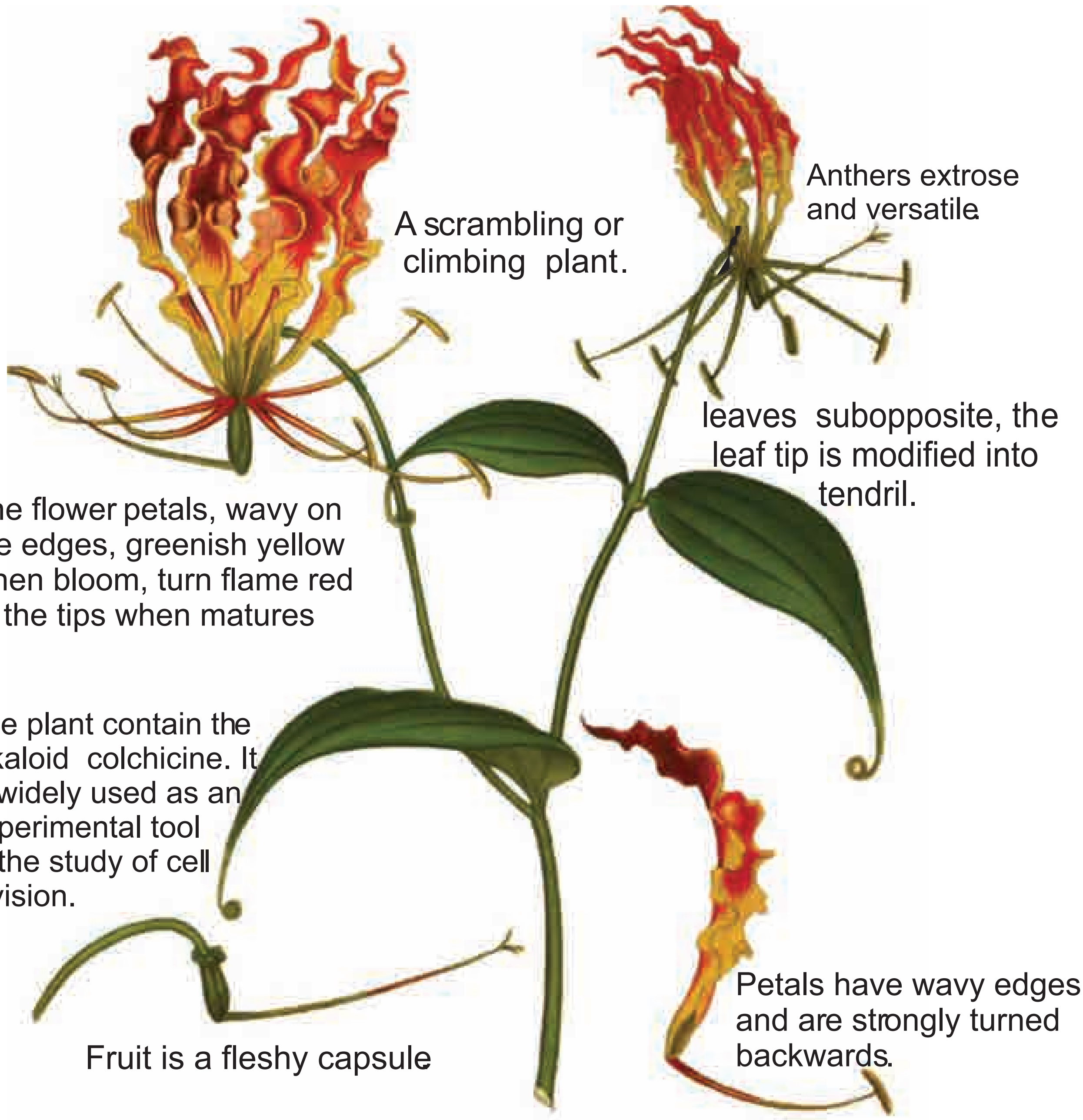
Tulipa



Ruscus

Figure 5.27: Selected plants belongs to the Family Liliaceae

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. Type concept emphasizes that a specimen must be associated with the scientific name which is known as nomenclatural type. There are different types and they are holotype, isotype, lectotype etc. 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

5QIV5Y

1. Specimen derived from non-original collection serves as the nomenclatural type, when original specimen is missing. It is known as
   a. Holotype b. Neotype
   c. Isotype d. Paratype
2. Phylogenetic classification is the most favoured classification because it reflects
   a. Comparative Anatomy
   b. Number of flowers produced
   c. Comparative cytology
   d. Evolutionary relationships
3. 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
4. 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*
5. Flowers are zygomorphic in
   a. *Ceropegia* b. *Thevetia*
   c. *Datura* d. *Solanum*
6. What is the role of national gardens in conserving biodiversity – discuss
7. Where will you place the plants which contain two cotyledons with cup shaped thalamus?
8. How does molecular markers work to unlock the evolutionary history of organisms?
9. Give the floral characters of *Clitoria ternatea*.
10. How will you distinguish Solanaceae members from Liliaceae members?

ICT Corner

Characteristics of flowers

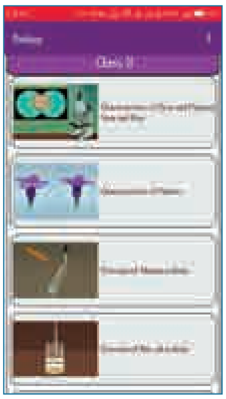
Look inside the **Flower.** →

Steps

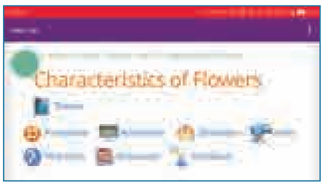
- Scan the QR code or go to google play store
- Type online labs and install it.
- Select biology and select Character of flower
- Click theory to know the basic about Character of flower
- Register yourself with mail-id and create password to access online lab simulations

Activity

- Select simulation and dissect the different flowers
- Record your observations



Step 1



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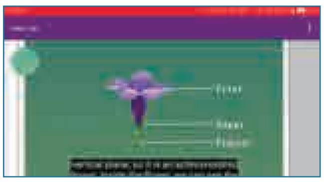

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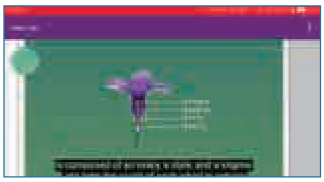

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* Pictures are indicative only

Unit III: Cell biology and Biomolecules

Chapter 6

Cell: The Unit of Life

Learning Objectives

The learner will be able to,

- *Describe the cell and contributions of early scientist towards its discovery*
- *Appreciate the use of light and electron microscopes for better understanding of the cell*
- *Understand the ideas of cell theory and the different concepts associated with it*
- *Distinguish the significant characters of various groups of life forms*
- *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*
- *Describe the flagellar structure, types and movements*
- *Get acquainted with the cytological techniques*

Chapter Outline

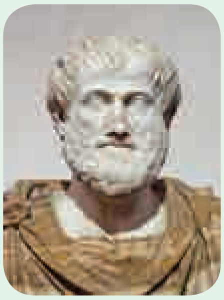
5QSR7L

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 little boxes' which was later called as '**cell**' from the cork tissue in 1665. He compiled his work as **Micrographia**. Later, **Antonie von Leeuwenhoek** observed unicellular particles which he named as '***animacules***'. **Robert Brown** (1831-39) described the spherical body in the plant

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

cells as nucleus. **H. J. Dutrochet** (1824), a French scientist, was the first to give 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'.

6.2. Microscopy

Microscope is an inevitable instrument in studying the cell and subcellular structures. It offers scope in studying

Resolution: The term resolving power or resolution refers to the ability of the 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 the size of an image is called magnification. It is calculated by the following formula

$$\text{Magnification} = \frac{\text{size of image seen with the microscope}}{\text{size of the image seen with normal eye}}$$

microscopic organisms therefore it is named as microscope (mikros – small; skipein – to see) in Greek terminology. Compound microscope was invented by **Z. Jansen**.

Microscope works on the lens system which basically relies on 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, where interaction takes place.

6.2.1 Bright field Microscope

Bright field microscope is 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 depending upon the contrast from absorption of visible light. 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 as **stage**. The light comes from the Compact Flourescent Lamp (CFL) or Light Emitting Diode (LED) light system. 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).

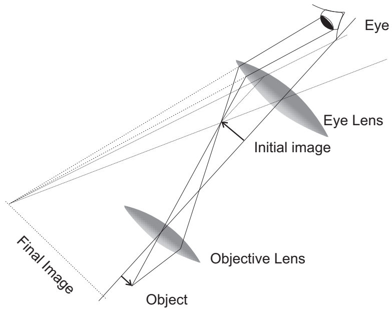
6.2.2 Dark Field Microscope

The dark field microscope was discovered by **Z. Sigmondy** (1905). Here the field will be dark but object will be glistening so the appearance will be bright. A special effect in an ordinary microscope is brought about by means of a special component called '**Patch Stop Carrier**'. It is fixed in metal ring of the condenser component. Patch stop is a small glass device which has a dark patch at centre of the disc leaving a small area along the margin through which the light passes. The light passing through the margin will travel oblique like a hollow cone and strikes the object in the periphery, therefore the specimen appears glistening in a dark background. (Figure 6.2 d and e).

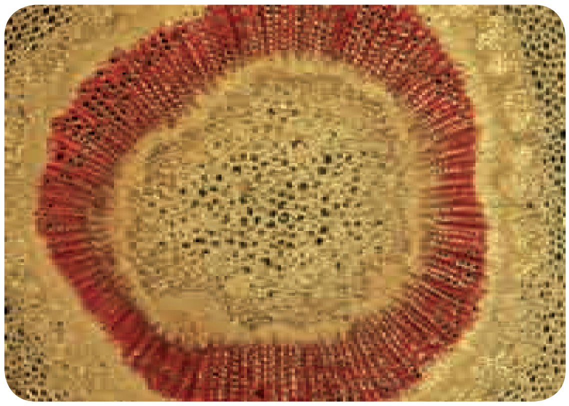
6.2.3 Phase contrast microscope

This was invented by **Zernike** (1935). It is a modification of light microscope with all its basic principle. The objects observed by increasing the contrast by bringing about change in amplitude of the light waves. The contrast can be increased by introducing the '**Phase Plate**' in the condenser lens. Phase plate is a circular component with circular annular etching.

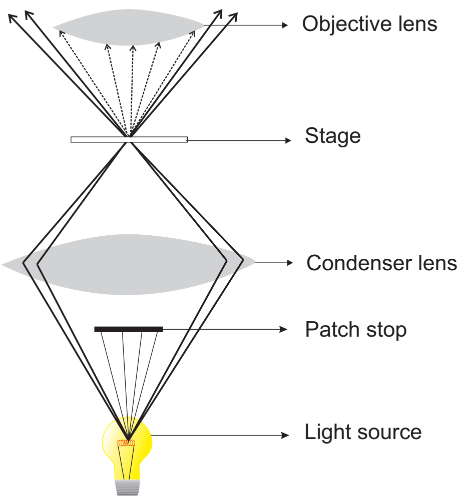
(a)



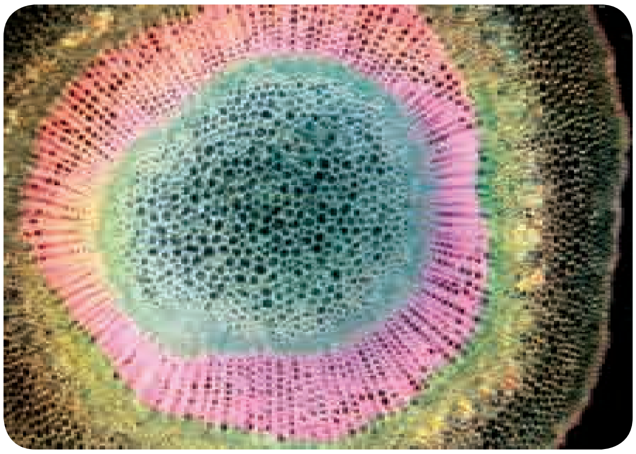
(b)



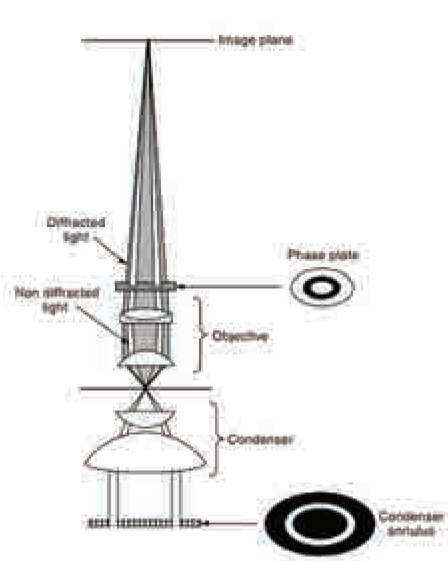
(c)



(d)



(e)



(f)

(g)

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Figure 6.2: a. Light microscope; **b.** Ray diagram - light path; c. Image taken using light microscope; **d.** Light path in dark field; **e.** Image taken using dark field microscope; **f.** Light path in phase contrast microscope; **g.** Image taken using phase contrast microscope

Microscopic measurements:

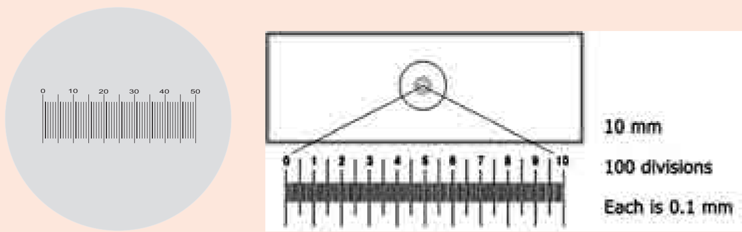
The microscope also has facility to measure microscopic objects through a technique called '**micrometry**'. There are two scales involved for measuring.

1. Ocular Micrometer
2. Stage Micrometer

Ocular Micrometer: 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 Micrometer: This is a slide with a line divided into 100 units. The line is about 1mm. The distance between two adjacent lines is 10 µm. The known value of the stage micrometer is transferred to the ocular micrometer, thereby the measurements can be made using ocular micrometer.

$$\text{The distance between two adjacent line of ocular meter} = \frac{\text{Number of stage divisions}}{\text{Number of ocular divisions}} \times 10$$



(a) (b)

Figure 6.3: a. Ocular micrometer; b. Stage micrometer

Light passes with different velocity after coming out of the thinnest and thickest areas of the phase plate thereby increasing the contrast of the specimen. A hollow cone of light passes through the condenser. Direct light pass through thin area of phase plate, whereas light passing from the specimen reaches thick area of phase plate. The light passing through thicker area travel at low speed, on the other hand the light passing through thin area reach fast therefore contrast is increased in the specimen. Phase contrast microscope is used to observe living cells, tissues and the cells cultured *invitro* during mitosis (Figure 6.2 f and g).

6.2.4 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 the 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 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.

There are two kinds of electron microscopes namely

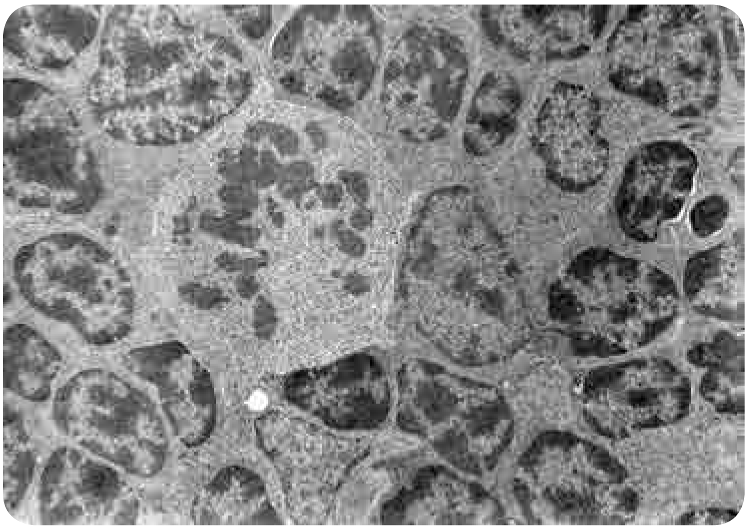
1. Transmission Electron Microscope (TEM)
2. Scanning Electron Microscope (SEM)

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

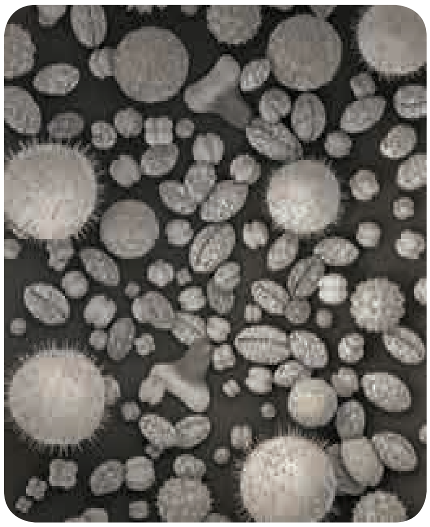
(a)



(b)

Figure 6.4: a. Transmission electron microscope; b. Image of TEM

(a)

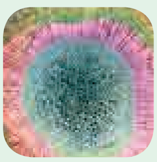
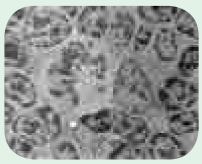
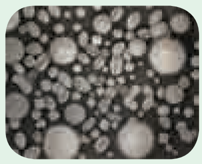


(b)

Figure 6.5: a. Scanning electron microscope; b. Image of SEM

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 6.4 a and b).

Comparison of Microscopes

Features	Light Microscope	Dark Field Microscope	Phase Contrast Microscope	Transmission Electron Microscope	Scanning Electron Microscope
Source of illumination for Image Formation	Visible light	Visible light	Visible light	Electrons	Electrons
Types of cells visualized	Individual cells can be visualised, even living ones.	Individual cells can be visualised, even living ones.	Individual cells can be visualised, even living ones.	Thin sections of the specimen are obtained. The electron beam pass through the sections and form an image with high magnification and high resolution.	The specimen is coated with gold and the electrons are reflected back and give the details of surface topography of the specimen.
Image	2-D	2-D	2-D	2-D	3-D
Nature of Lenses	Glass lenses	Glass lenses	Glass lenses	One electrostatic lens with few electromagnetic lenses	One electrostatic lens with few electromagnetic lenses
Medium	Air/oil	Air/oil	Air/oil	Vacuum	Vacuum
Specimen mounting	Glass slides	Glass slides	Glass slides	Mounted on coated or uncoated copper grids	Mounted on aluminium stubs and are coated in gold
Focusing and Magnification Adjustments	Changing objectives	Changing objectives	Changing objectives	Electrical, using deflection coil	Electrical, using deflection coil
Means for obtaining specimen Contrast	Light diffraction	Through patch stop	Through phase plate	Electron scattering	Electron scattering
Microscope picture					

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 6.5 a and b).

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.

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 Cell Doctrine (Cell Principle)

The features of cell doctrine are as follows:

- All organisms are made up of cells.
- New cells are produced from the pre-existing cells.
- Cell is a structural and functional unit of all living organisms.
- A cell contains hereditary information which is passed on from cell to cell during cell division.
- All the cells are basically the same in chemical composition and metabolic activities.
- The structure and function of cell is controlled by DNA.
- Sometimes the dead cells may remain functional as tracheids and vessels in plants and horny cells in animals.

6.3.3 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 contents 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 exist 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 on coming 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 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 cell protoplasm.

6.3.4 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

1 cm = 1/100 meter

1 mm = 1/1000 meter =1/10 cm

1 μm = 1/1000,000 meter = 1/10,000 cm

1 nm = 1/1,000,000,000 meter = 1/10,000,000 cm

1 Å = 1/10,000,000,000 meter =1/100,000,000 cm

or

$1\ m = 10^2 cm = 10^3 mm = 10^6 \mu m = 10^9 nm = 10^{10}$Å

m = meter   cm = centimetre   mm = millimeter   μm = micrometer

nm = nanometer   Å=Angstrom

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 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).

Size:

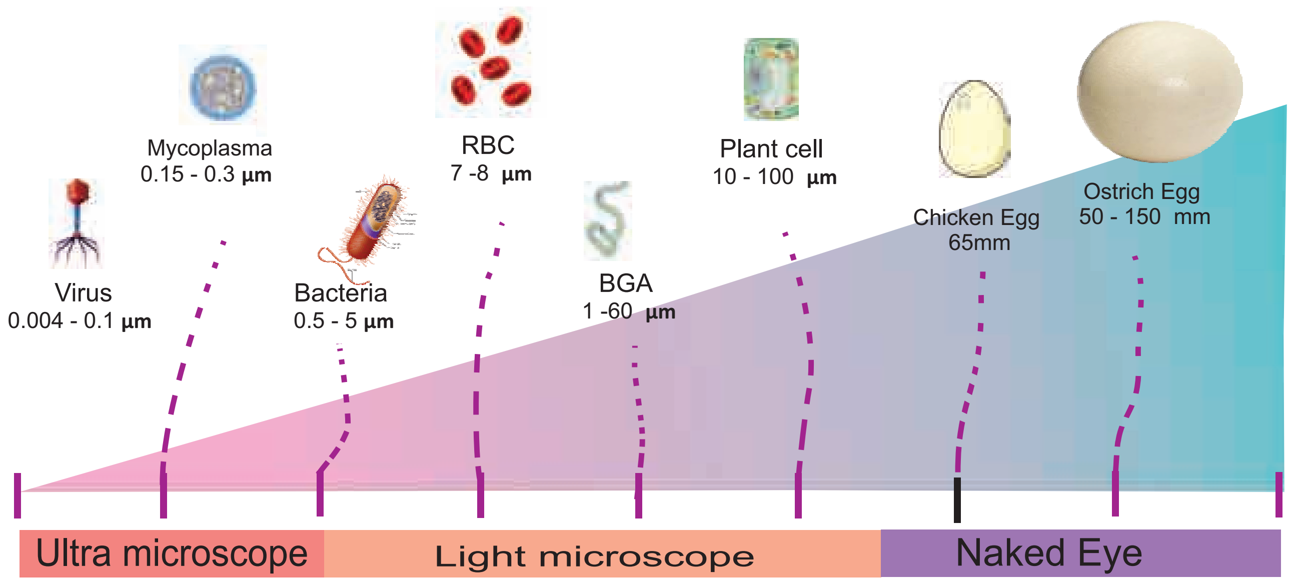


Figure 6.6: Cell size variation of few organisms

6.4. Types of cells

On the basis of the cellular organization and the nuclear characteristics, the cell can be divided 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 coworkersproposedanotherkindoforganisms 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 protein bound histones forming the chromosomes. Membrane bound organelles are present. Few organelles may be arisen by **endosymbiosis** which is a cell living inside another cell. The organelles like mitochondria and chloroplast well support this theory.

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

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.

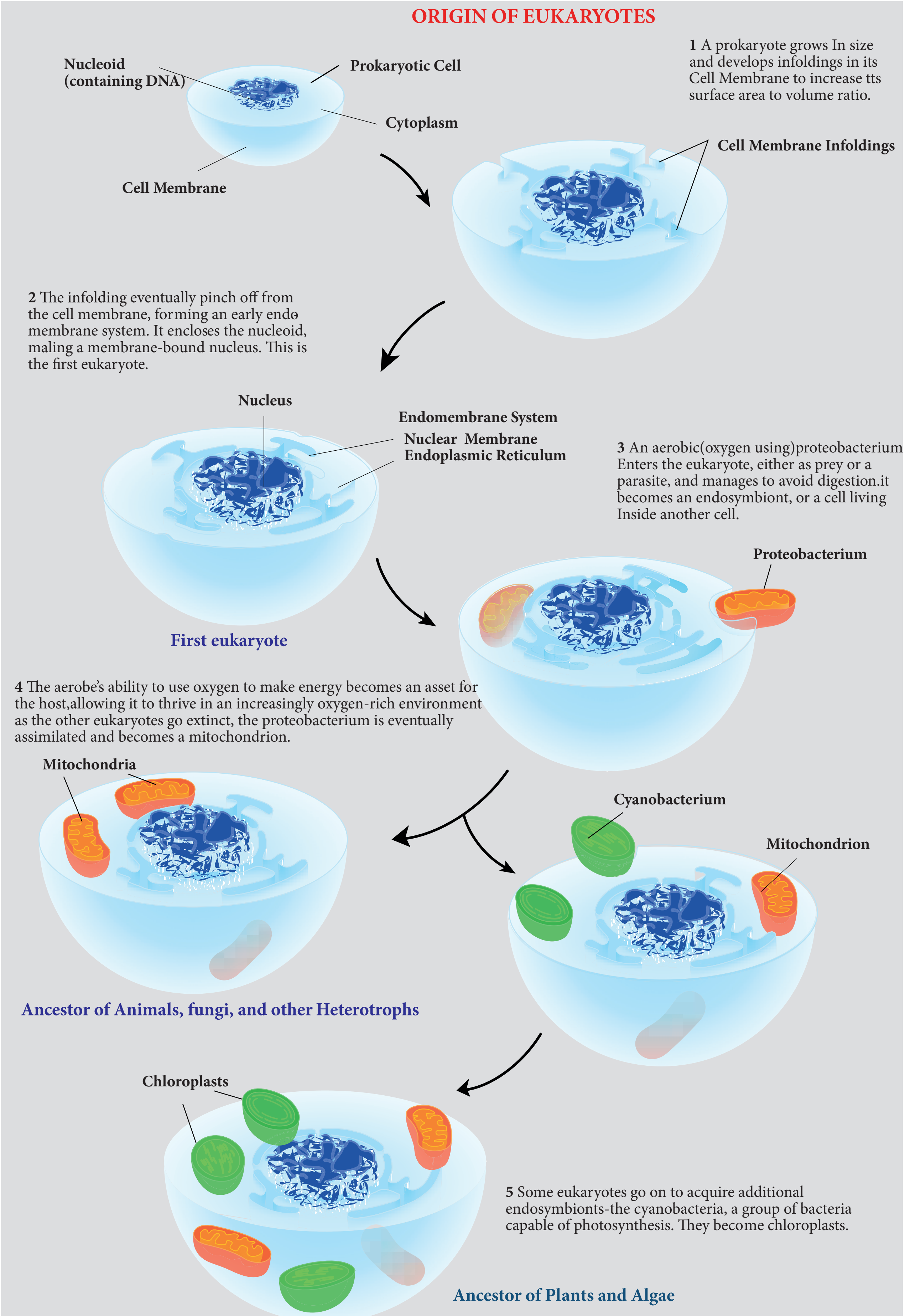


Figure 6.7: A model of endosymbiotic theory

The first cell might have evolved approximately 3.8 billion years ago. The primitive cell would have been similar to present day protists (Figure 6.7).

6.5. Plant and Animal cell

6.5.1 Ultra Structure of Eukaryotic Cell

The eukaryotic cell is highly distinct in its organisation. It shows several variations in different organisms. For instance, the eukaryotic cells in plants and animals vary greatly (Figure 6.8).

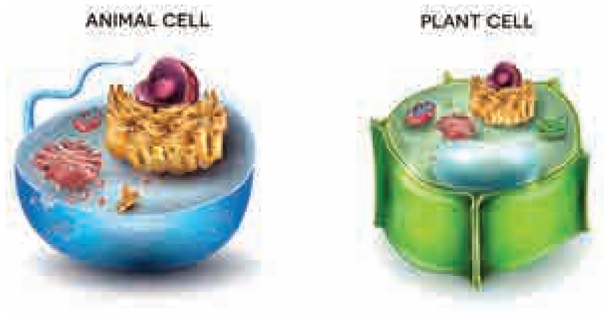


Figure 6.8: Animal and Plant cell

Animal Cell

Animal cells are surrounded by cell membrane or plasma membrane. Inside this membrane the 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 6.9 and 6.10).

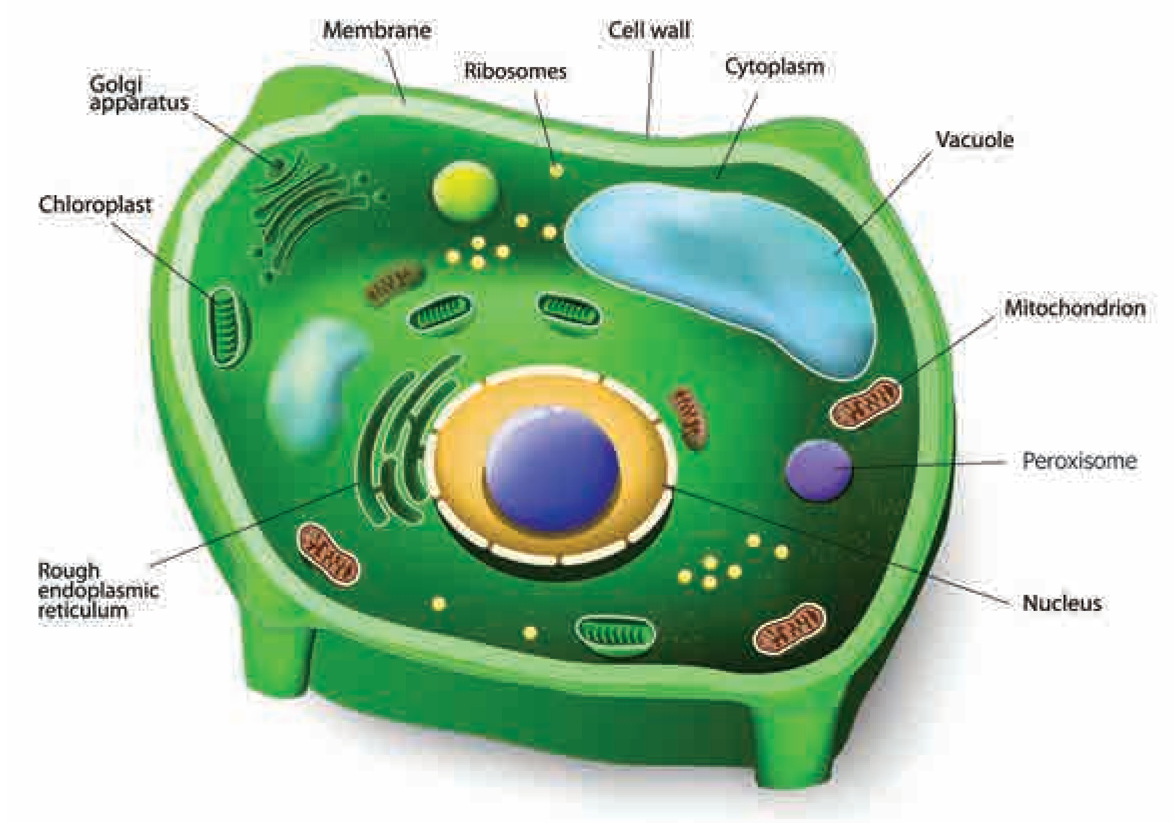


Figure 6.9: Ultra Structure of Plant Cell

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

6.5.2 Protoplasm

Protoplasm is the living content of the cell that is surrounded by plasma membrane. It is a colourless material that exists throughout the cell together with the cytoplasm, nucleus and other organelles. Protoplasm is composed of a mixture of small particles, such as 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.

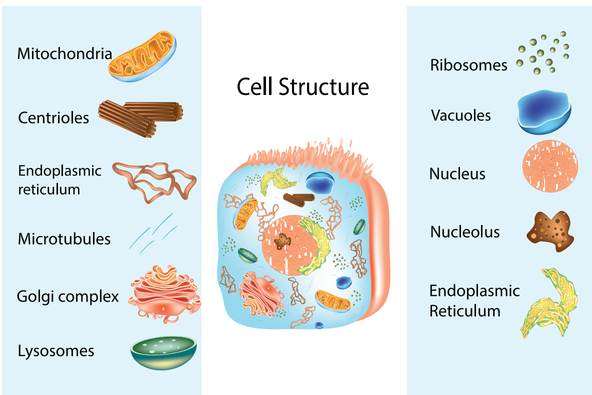


Figure 6.10: Cell structure and components

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 6.11).

a. Primary wall

It is the first layer inner to middle lamellae, 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.

b. Secondary wall

Secondary wall is laid during maturation. 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.

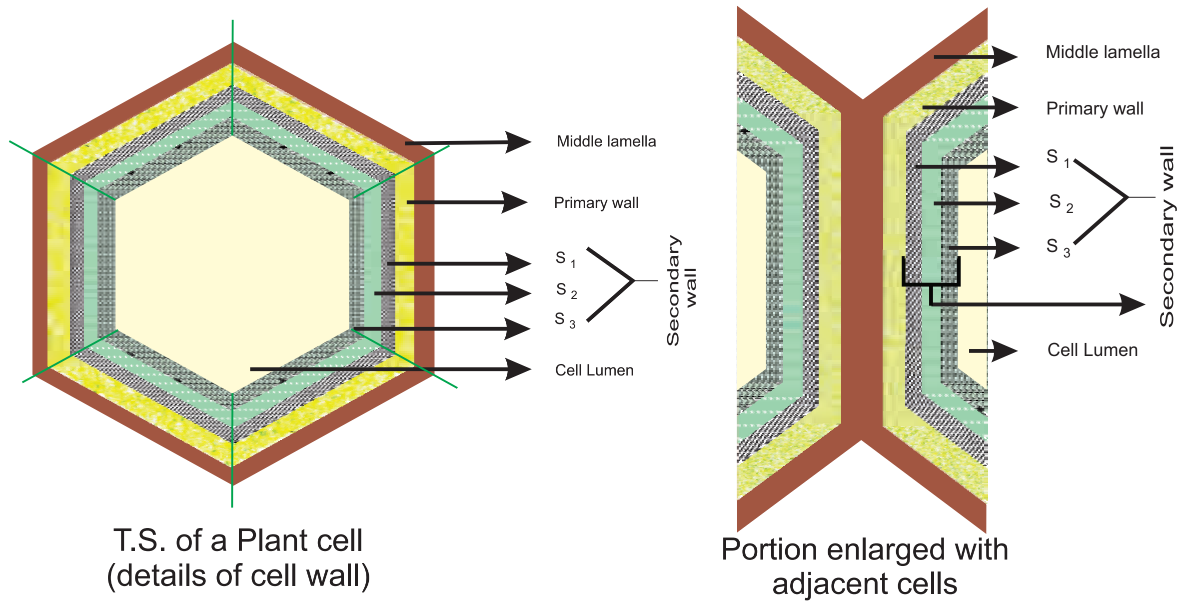


Figure 6.11: Plant cell wall

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).

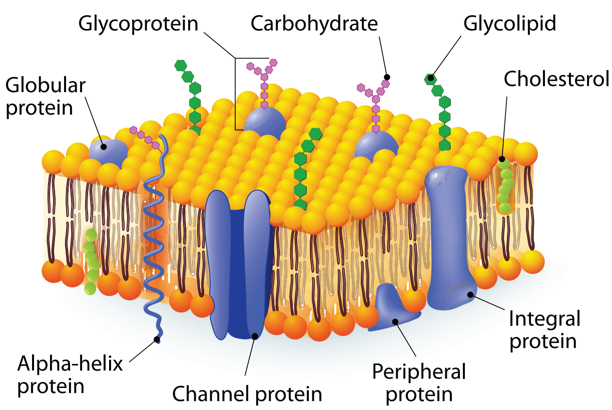


Figure 6.12: Model of Cell membrane

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.

The Carbohydrate molecules of cell membrane are short chain polysaccharides. These are either bound with '**glycoproteins**' or '**glycolipids**' and form a '**glyocalyx'** (Figure 6.12).

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 the phospholipids have smaller polar regions, whereas the proteins cannot flip flop because the polar region is extensive.

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

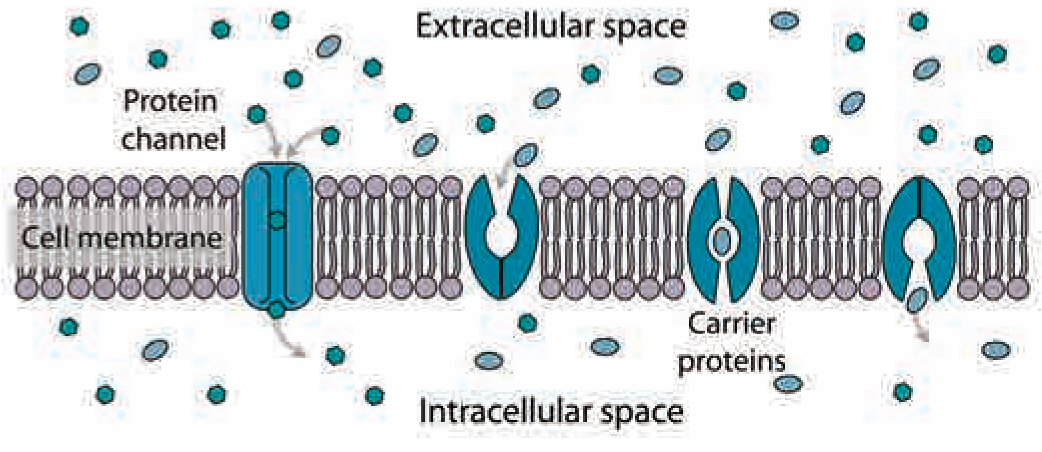


Figure 6.13: Transport of molecules through cell membrane

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.

Cell Transport

Cell membrane act as a channel of transport for molecules. The membrane is selectively permeable to molecules. It transports molecules through energy dependant process and energy independent process. The membrane proteins (channel and carrier) are involved in movement of ions and molecules across the membrane (Figure 6.13).

Endocytosis and Exocytosis

Cell surface membrane are able to transport individual molecules and ions. There are processes in which a cell can transport a large quantity of solids and liquids into cell (**endocytosis**) or out of cell (**exocytosis**) (Figure 6.14).

Endocytosis: During endocytosis the cell wraps the cell surface membrane around the material and brings it into

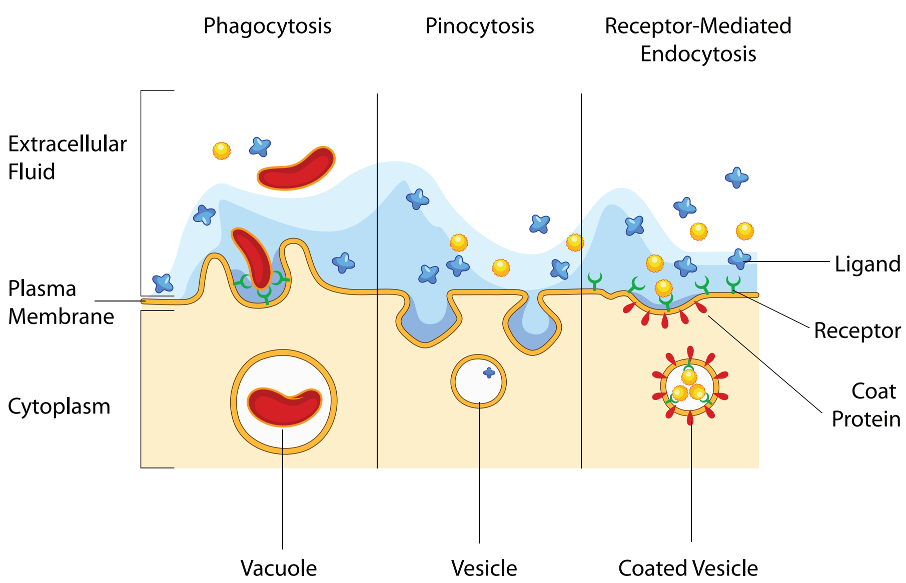


Figure 6.14: Endocytosis and exocytosis

cytoplasm inside a vesicle. There are two types of endocytosis:

1. **Phagocytosis** – Particle is engulfed by membrane, which folds around it and forms a vesicle. The enzymes digest the material and products are absorbed by cytoplasm.
2. **Pinocytosis** – Fluid droplets are engulfed by membrane, which forms vesicles around them.

Exocytosis: Vesicles fuse with plasma membrane and eject contents. This passage of material out of the cell is known as **exocytosis**. This material may be a secretion in the case of digestive enzymes, hormones or mucus.

Signal Transduction

The process by which the cell receive information from outside and respond is called **signal transduction**. Plants, fungi and animal cell use nitric oxide as one of the many signalling molecules. The cell membrane is the site of chemical interactions of signal transduction. Receptors receives the information from first messenger and transmit the message through series of membrane proteins. It activates second messenger which stimulates the cell to carry out specific function.

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

The system of membranes in a eukaryotic cell, comprising 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 6.15).

6.6.2 Endoplasmic Reticulum

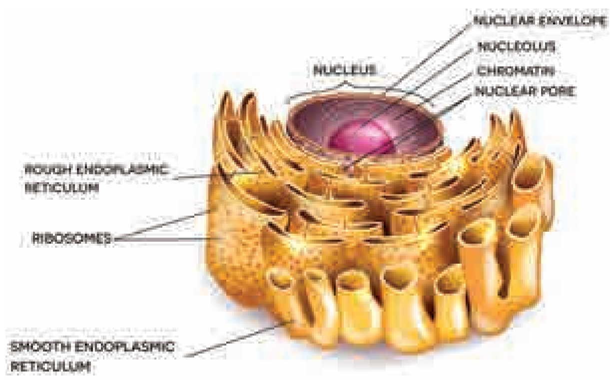


Figure 6.15: Structure of Endoplasmic reticulum

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:

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 shape, branched, smooth walled, enclosing a space

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 filled with granular or amorphous substance, some function like lysosomes. The Golgi apparatus compartmentalises a series of steps leading to the production of functional protein.

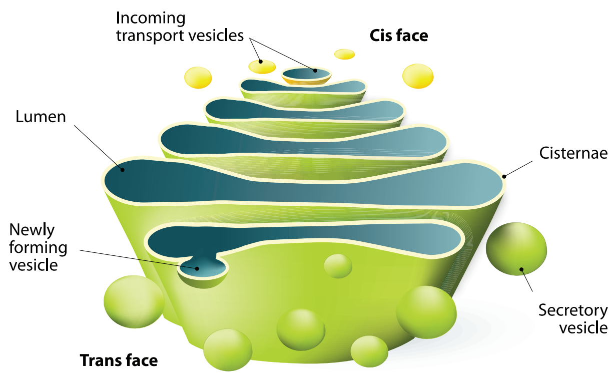


Figure 6.16: Structure of Golgi apparatus

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 glycosidation of lipids (Figure 6.16 and 6.17).

Functions:

- Glycoproteins and glycolipids are produced
- Transporting and storing lipids.

- Formation of lysosomes.
- Production of digestive enzymes.
- Cell plate and cell wall formation
- Secretion of Carbohydrates for the formation of plant cell walls and insect cuticles.
- **Zymogen granules** (proenzyme/pre-cursor of all enzyme) are synthesised.

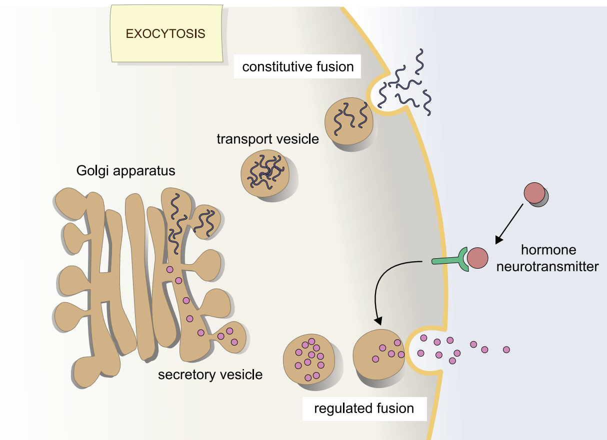


Figure 6.17: Exocytosis

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 the mitochondrion into two compartments, outer chamber between two membranes and the inner chamber 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 6.18).

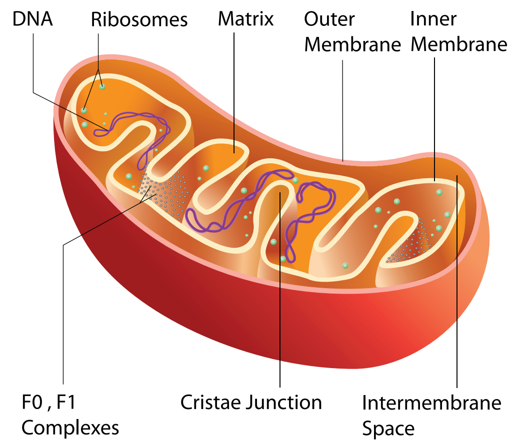


Figure 6.18: Structure of Mitochondria

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.

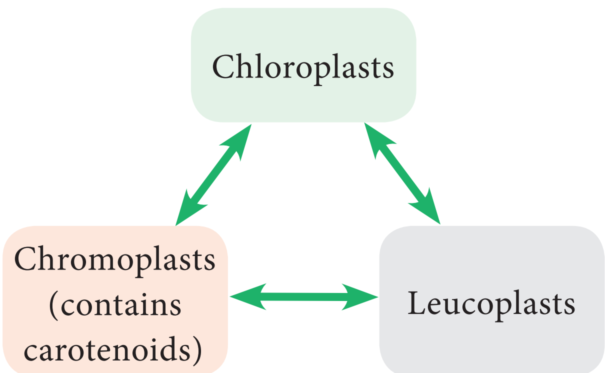
All the enzymes of Kreb's cycle are found in the matrix except succinate dehydrogenase. Mitochondria consist of circular DNA and 70S ribosome. They multiply by fission and replicates by strand displacement model. Because of the presence of DNA it is semi-autonomous organelle. Unique characteristic of mitochondria is that they are inherited from female parent only. Mitochondrial DNA comparisons are used to trace human origins. Mitochondrial DNA is 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** store – 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 is 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**. It is a semi-autonomous organelle and divides by fission (Figure 6.19).

Functions:

- Photosynthesis
- Light reactions takes place in granum,
- Dark reactions take place in stroma,
- Chloroplast is involved in photo-respiration.

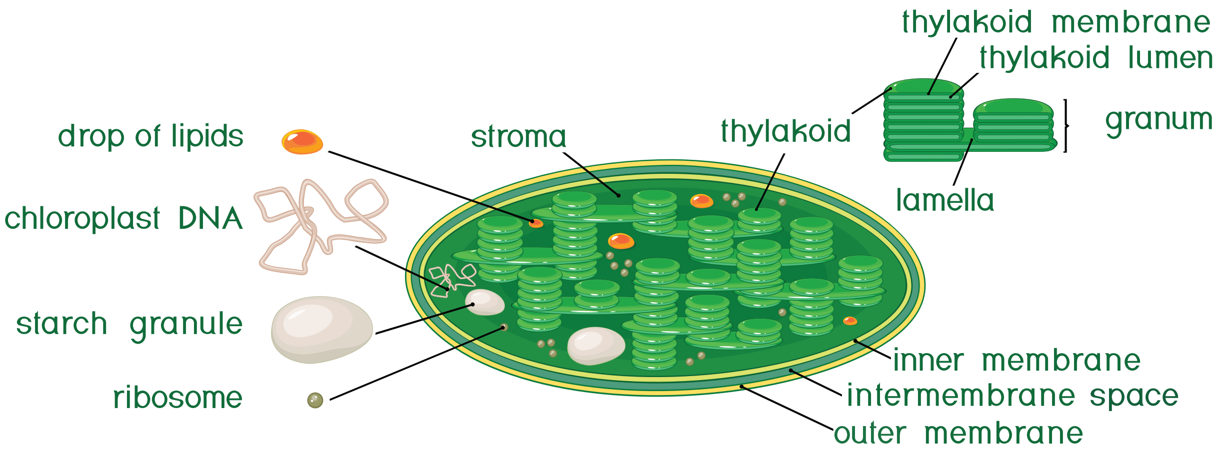


Figure 6.19: Structure of Chloroplast

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 are *denova* 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 6.20).

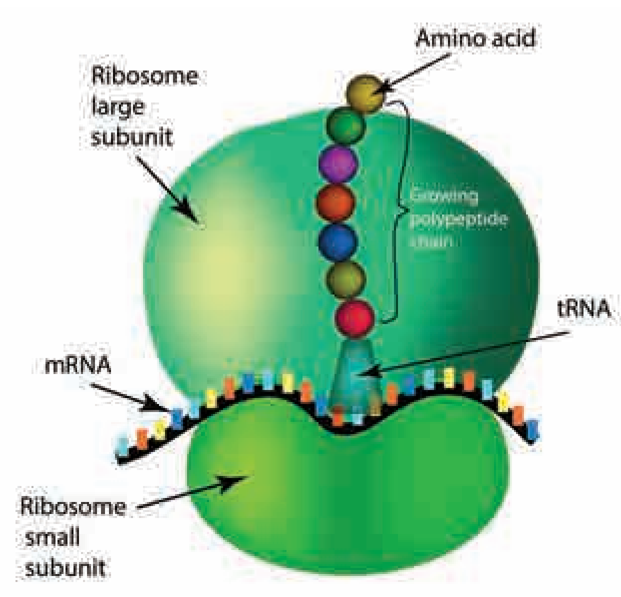


Figure 6.20: Structure of Ribosomes

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)**

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 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.

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 6.21).

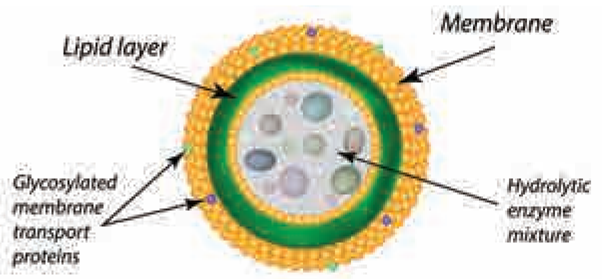


Figure 6.21: Structure of Lysosome

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 on insight of disease they destroy the cells.
- **Ageing:** Lysosomes have autolytic enzymes that disrupts intracellular molecules.
- **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 6.22).

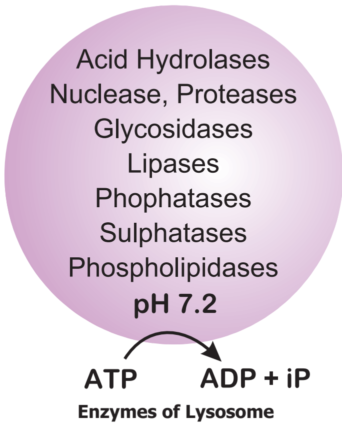


Figure 6.22: Enzymes of Lysosome

6.6.9 Peroxisomes

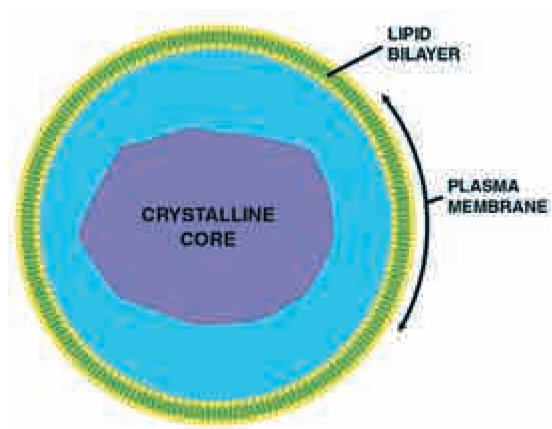


Figure 6.23: Structure of Peroxisome

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 6.23).

6.6.10 Glyoxysomes

Glyoxysome was discovered by **Harry Beevers** (1961). Glyoxysome 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.

6.6.11 Microbodies

Eukaryotic cells contain many enzyme bearing membrane enclosed vesicles called **microbodies**. They are single unit membrane bound cell organelles: Example: peroxisomes and glyoxysomes.

6.6.12 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

Centriole consist 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 6.24).

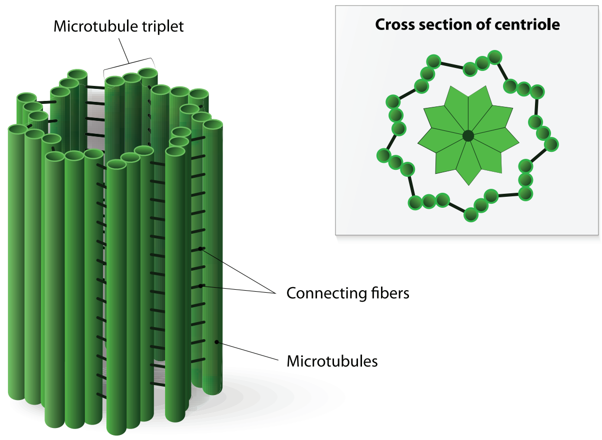


Figure 6.24: Structure of Centriole

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 contains 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 vacuoles 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*.

v. Tannins in *Mimosa pudica*.

vi. Raphide crystals in *Dieffenbachia*.

vii. Heavy metals in Mustard (*Brassica*).

viii. Latex in Rubber tree and *Dandelion stem*.

Cell Inclusions

The cell inclusions are the non-living materials present in the cytoplasm. They are organic and inorganic compounds.

Inclusions in prokaryotes

In prokaryotes, reserve materials such as phosphate granules, cyanophycean granules, glycogen granules, poly β-hydroxy butyrate granules, sulphur granules, carboxysomes and gas vacuoles are present. Inorganic inclusions in bacteria are polyphosphate granules (volutin granules) and sulphur granules. These granules are also known as **metachromatic granules.**

Inclusions in Eukaryotes

- Reserve food materials: Starch grains, glycogen granules, aleurone grains, fat droplets
- Secretions in plant cells are essential oil, resins, gums, latex and tannins
- **Inorganic crystals** – plant cell have calcium carbonate, calcium oxalate and silica
- **Cystolith** – hypodermal leaf cells of *Ficus bengalensis*, calcium carbonate
- **Sphaeraphides** – star shaped calcium oxalate, *Colocasia*
- **Raphides** – calcium oxalate, *Eichhornia*
- **Prismatic crystals** – calcium oxalate, dry scales of *Allium cepa*

6.7. Nucleus

Nucleus is an important unit of cell which control 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 is 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 forms the **pore complex**. The space between two membranes is called **perinuclear space**.

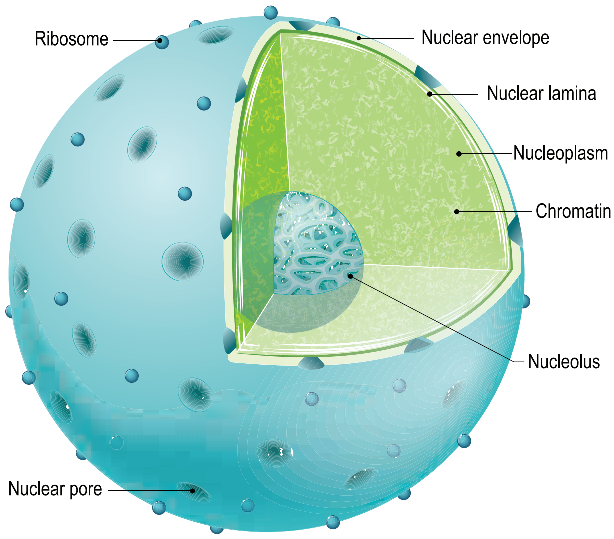


Figure 6.25: Structure of a Nucleus

Nuclear space is filled with **nucleoplasm**, a gelatinous matrix has uncondensed

chromatin network and a conspicuous **nucleoli**. The chromatin network is the 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 6.25).

> 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.

During cell division chromatin is condensed into an organized form called **chromosome**. The portion of Eukaryotic chromosome which is transcribed into mRNA contains active genes that are not tightly condensed during interphase is called **Euchromatin**. The portion of a Eukaryotic chromosome that is not transcribed into mRNA which remains condensed during interphase and stains intensely is called **Heterochromatin.** I **Nucleolus** is a small, dense, spherical structure either present singly or in multiples inside nucleus and it's not membrane bound. Nucleoli possesses genes for rRNA and tRNA.

Functions of the nucleus

- Controlling all the cellular activities
- Storing the genetic or hereditary information.
- Coding the information in the 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 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. The 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 **secondary constrictions,** represented with few occurrence. Nucleoli develop from these secondary constrictions are called **nucleolar organizers**. Secondary constrictions contains the genes for ribosomal RNA which induce the formation of nucleoli and are called **nucleolar organizer regions** (Figure 6.26).

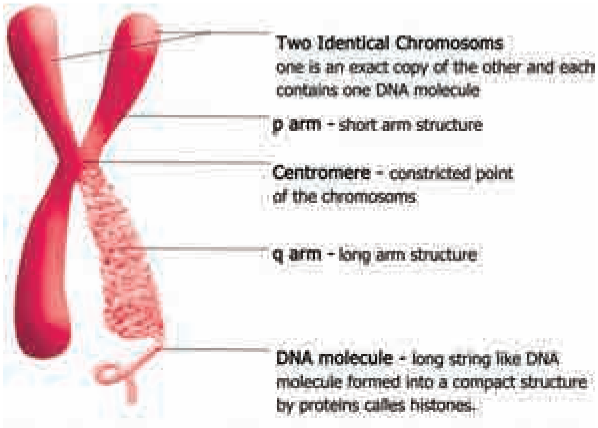


Figure 6.26: Structure of a Chromosome

A **satellite** or SAT Chromosome are short chromosomal segment or rounded body separated from main chromosome by a relatively elongated secondary constriction. It is a morphological entity in certain chromosomes.

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 chromosomes may be rod

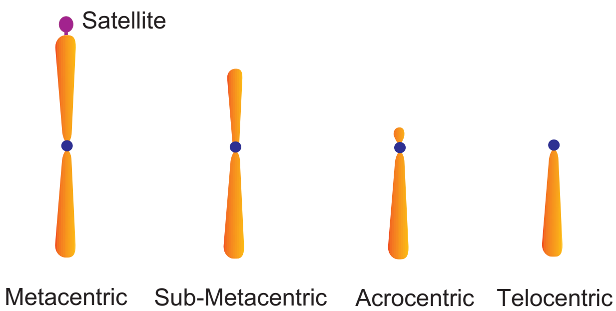


Figure 6.27: Types of chromosomes based on centromere

DO YOU KNOW?

Chromonema fiber: It is a chromatin fibre, 100 – 130 nm in diameter thought to be an element of higher order packing of chromatin within chromosome. During prophase the chromosomal material becomes visible as very thin filaments 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.

shaped (telocentric and acrocentric), L-shaped (sub-metacentric) and V-shaped (metacentric) (Figure 6.27).

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 prevents the fusion of chromosomal ends with one another.

Holocentric chromosomes have centromere activity distributed along the whole surface of the chromosome during mitosis. Holocentric condition can be seen in *Caenorhabditis elegans* (nematode) and many insects. There are three types of centromere in eukaryotes. They are as follows:

Point centromere: the type of centromere in which the kinetochore is assembled as a result of protein recognition of specific DNA sequences. Kinetochores assembled on point centromere bind a single microtubule. It is also called as **localized centromere**. It occurs in budding yeasts

Regional centromere: In regional centromere where the kinetochore is assembled on a variable array of repeated DNA sequences. Kinetochore assembled on regional centromeres bind multiple microtubules. It occurs in fission yeast cell, humans and so on.

Holocentromere- The microtubules bind all along the mitotic chromosome. Example: *Caenorhabditis elegans* (nematode) and many insects.

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 are found only in certain special tissues. 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 **C.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**. Polyteny is achieved by repeated replication of chromosomal DNA several times without nuclear division and the daughter chromatids aligned side by side and do not separate (called **endomitosis**). Gene expression, transcription of genes and RNA synthesis occurs in the bands along the polytene chromosomes. Maternal and paternal homologues remain associated side by side is called somatic pairing.

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.

6.8. Flagella

6.8.1 Prokaryotic 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

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.

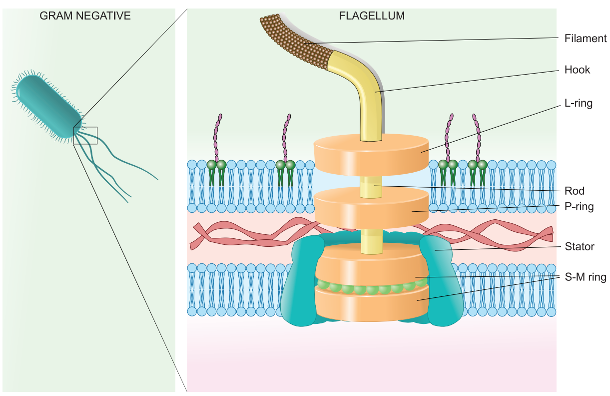


Figure 6.28: Structure of Bacterial Flagellum

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 6.28).

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 6.29).

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.

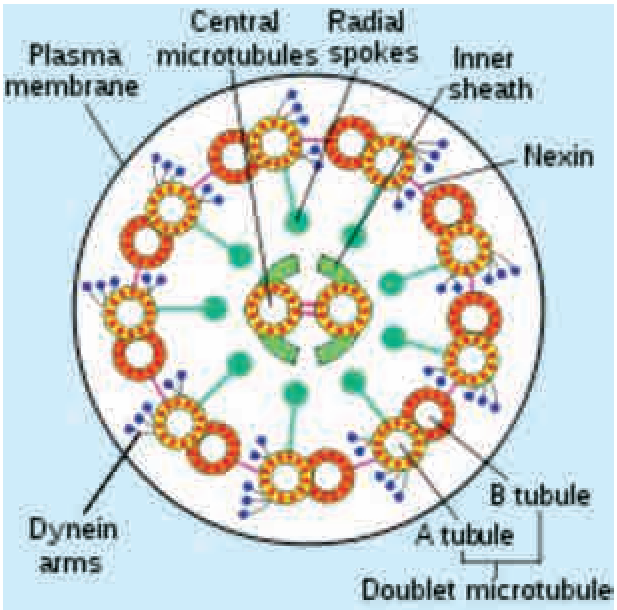


Figure 6.29: Structure of Eukaryotic flagellum

6.8.3 Cilia

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 6.30).

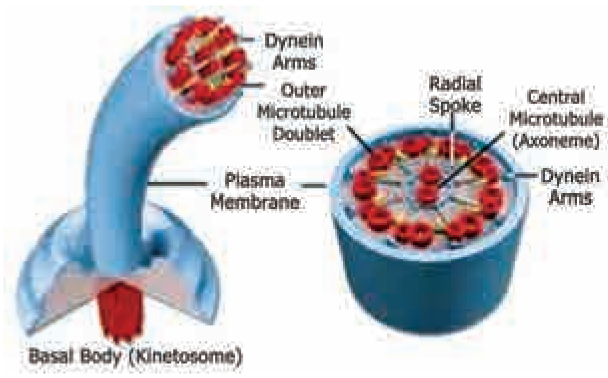


Figure 6.30: Structure of Cilia & flagella

6.9. Cytological Techniques

6.9.1 Preparation of Slides

5RBIAH

There are different types of mounting based on the portion of a specimen to be observed

a. **Whole mount:** The whole organism or smaller structure is mounted over a slide and observed.

b. **Squash**: Is a preparation where the material to be observed is crushed/ squashed on to a slide so as to reveal their contents. Example: Pollen grains, mitosis and meiosis in root tips and flower buds to observe chromosomes.

c. **Smears:** Here the specimen is in the fluid (blood, microbial cultures etc.,) are scraped, brushed or aspirated from surface of organ. Example: Epithelial cells.

d. **Sections:** Free hand sections from a specimen and thin sections are selected, stained and mounted on a slide. Example: Leaf and stem of plants.

6.9.2 Recording the Observations

The observations made through a microscope can be recorded by hand diagrams or through microphotographs.

Hand diagrams: Hand diagrams are drawn using ordinary pencil by observing the slide and drawing manually.

Microphotograph: Images of structures observed through microscopes can be further magnified, projected and saved by attaching a camera to the microscope by a microscope coupler or eyepiece adaptor. Picture taken using a inbuilt camera in a microscope is called **microphotography** or **microphotograph**.

6.9.3 Staining Techniques

Staining is very important to observe different components of the cell. Each component of the cell has different affinity towards different stains. The technique of staining the cells and tissue is called '**histochemical staining**' or '**histochemistry**'.

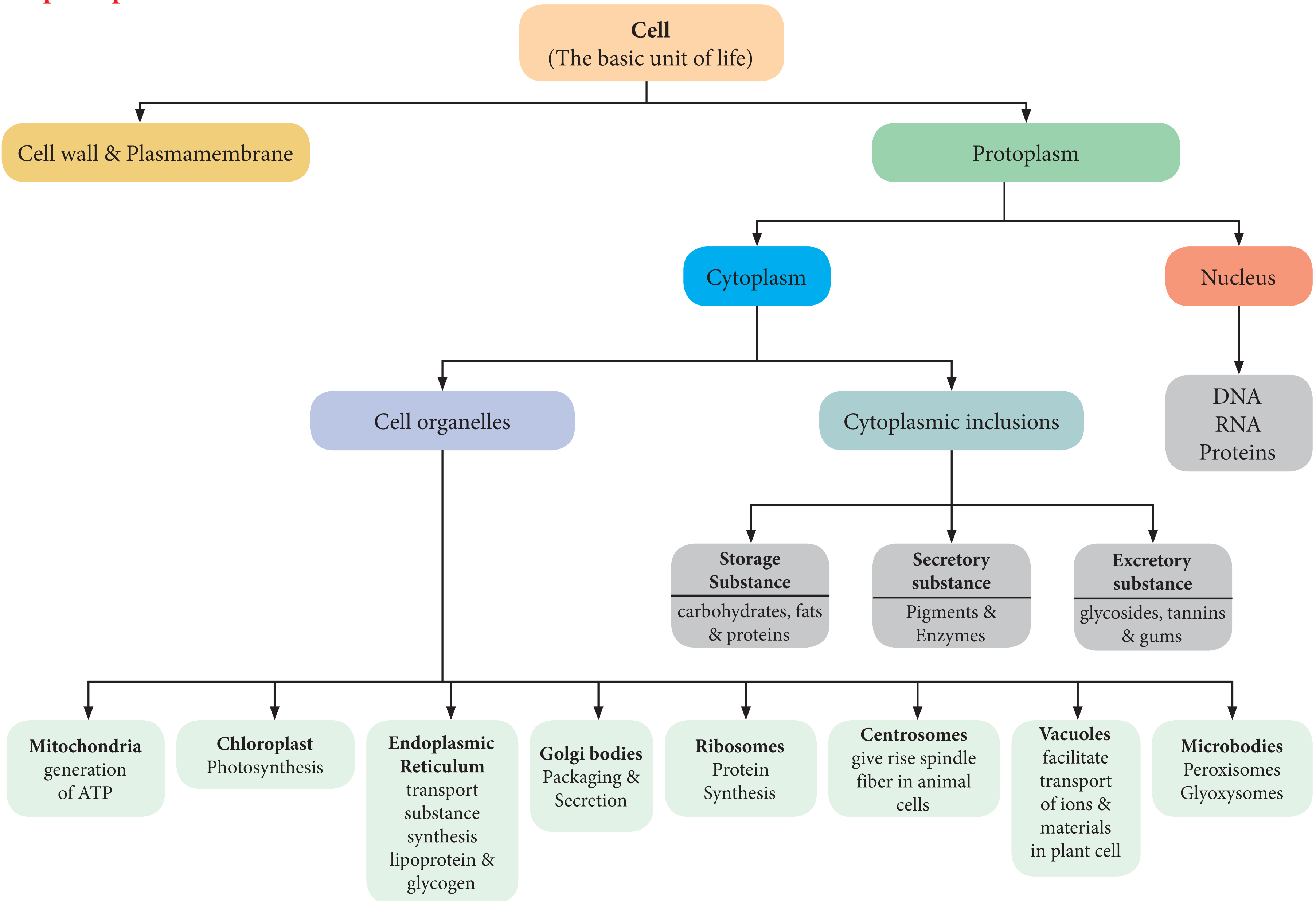
Common stains used in Histochemistry

S. No.	Stain	Colour of staining	Affinity
1.	Eosin	Pink, Red	Cytoplasm, cellulose
2.	Acetocarmine/ Haematoxylin	Pink/ Red	Nucleus, Chromosomes
3.	Methylene Blue	Blue	Nucleus
4.	Saffranine	Red	Cell wall (Lignin)
5.	Cotton blue	Blue	Fungal Hyphae
6.	Sudan IV, Sudan Black	Scarlet Red/Black	Lipids
7.	Coomasie brilliant Blue	Blue	Protein
8.	Janus Green	Greenish Blue	Mitochondria
9.	I_2KI	Bluish black to brown	Starch
10.	Toluidine blue	Blue, greenish blue	Xylem, Parenchyma & Epidermis

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

Concept Map



Cell
(The basic unit of life)
Cell wall & Plasmamembrane
Protoplasm
Cytoplasm
Nucleus
DNA
RNA
Proteins
Cell organelles
Cytoplasmic inclusions
Storage Substance
carbohydrates, fats & proteins
Secretory substance
Pigments & Enzymes
Excretory substance
glycosides, tannins & gums
Mitochondria
generation of ATP
Chloroplast
Photosynthesis
Endoplasmic Reticulum
transport substance synthesis lipoprotein & glycogen
Golgi bodies
Packaging & Secretion
Ribosomes
Protein Synthesis
Centrosomes
give rise spindle fiber in animal cells
Vacuoles
facilitate transport of ions & materials in plant cell
Microbodies
Peroxisomes
Glyoxysomes

organisms are classified into prokaryote, eukaryote and mesokaryote.

The eukaryotic cells originated by endosymbiosis of prokaryotic organism. 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. Cytological techniques include preparation of slides, staining and recording the observation.

5RKECJ

Evaluation

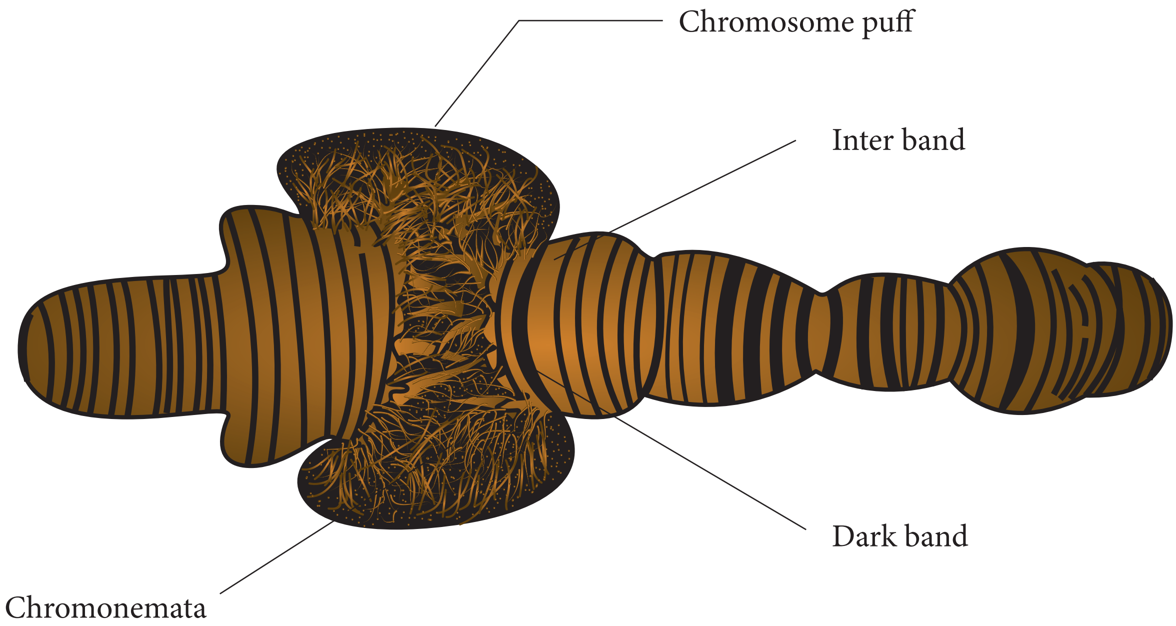
1. The two subunits of ribosomes remain united at critical ion level of
   a. Magnesium b. Calcium
   c. Sodium d. Ferrous
2. Sequences of which of the following is used to know the phylogeny
   a. mRNA b. rRNA
   c. tRNA d. Hn RNA
3. Many cells function properly and divide mitotically even though they 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

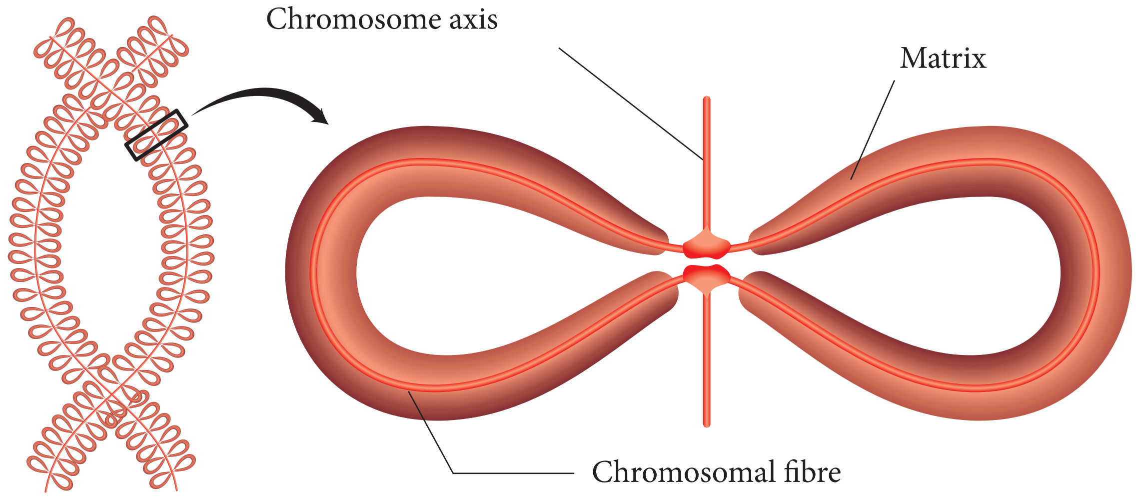
	(a)	(b)	(c)	(d)
(1)	(iii)	(iv)	(ii)	(i)
(2)	(iv)	(iii)	(i)	(ii)
(3)	(iii)	(iv)	(i)	(ii)
(4)	(iii)	(i)	(iv)	(ii)

6. Bring out the significance of phase contrast microscopy
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

Giant Chromosomes



Polytene chromosomes



Lampbrush chromosomes

ICT Corner

Cell structure

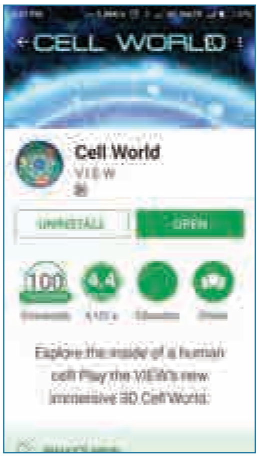
Cell-The unit of Life →

Steps

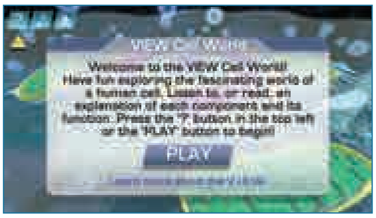
- Scan the QR code & install the app from Android app store
- Open the app & move the cell organelles by moving left bottom button
- Select the cell organelles by pointer
- Play the audio notes of cell organelles by click the right center button
- Use pointer & observe the structure of cell organelles

Activity

- Observe the structures of cell organelles and record it.

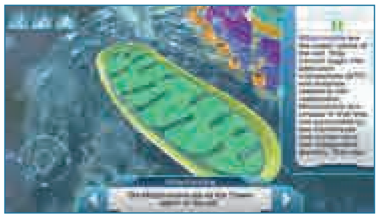


Step 1



Step 2

Step 3



Step 4

Step 5

URL:

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

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* Pictures are indicative only

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.*
- *Understand how a single cell divides to a whole organism.*
- *Familiarize the behaviour of chromosomes in plants and animal cells during meiosis.*
- *Know about crossing over and random assortment of homologous chromosomes and its importance.*

Chapter Outline

5RUAE7

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.

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).

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

7.1 History of a Cell

Table 7.1: History of Cell

Year	Scientist	Events
1665	Robert Hooke	Coined word "Cell"
1670–74	Antonie 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

7.1.1 The Role of the Nucleus

As studied earlier, the nucleus is the organising centre of the cell. The information in the nucleus is contained within structures called **chromosomes**. These uniquely:

- Control activities of the cell.
- Genetic information copied from cell to cell while the cell divides.
- Hereditary characters are passed on to new individuals when gametic cells fuse together in sexual reproduction.

7.1.2 Chromosomes

At the time when a nucleus divides, the chromosomes become compact and multicoiled structure. Only in this condensed state do the chromosomes become clearly visible in cells. All other times, the chromosomes are very long, thin, uncoiled threads. In this condition they give the stained nucleus the granular appearance. The granules are called **chromatin**.

The four important features of the chromosome are:

- **The shape of the chromosome is specific:** The long, thin, lengthy structured chromosome contains a short, constricted region called **centromere**. A centromere may occur anywhere along the chromosome, but it is always in the same position on any given chromosome.
- **The number of chromosomes per species is fixed:** for example the mouse has 40 chromosomes, the onion has 16 and humans have 46.

- **Chromosomes occur in pairs:** The chromosomes of a cell occur in pairs, called **homologous pairs**. One of each pair come originally from each parent. Example, human has 46 chromosomes, 23 coming originally from each parent in the process of sexual reproduction.
- **Chromosomes are copied:** Between nuclear divisions, whilst the chromosomes are uncoiled and cannot be seen, each chromosome is copied. The two identical structures formed are called **chromatids**.

7.1.3 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**.

7.2 Cell Cycle

Definition: A series of events leading to the formation of new cell is known as **cell cycle**. The phenomenonal changes leading to formation of new population take place in the cell cycle. It was discovered by **Prevost** and **Dumans** (1824). The series of events include several phases.

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 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.

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. The cells become metabolically active and grows by producing proteins, lipids, carbohydrates and cell organelles including mitochondria and endoplasmic reticulum. Many checkpoints control

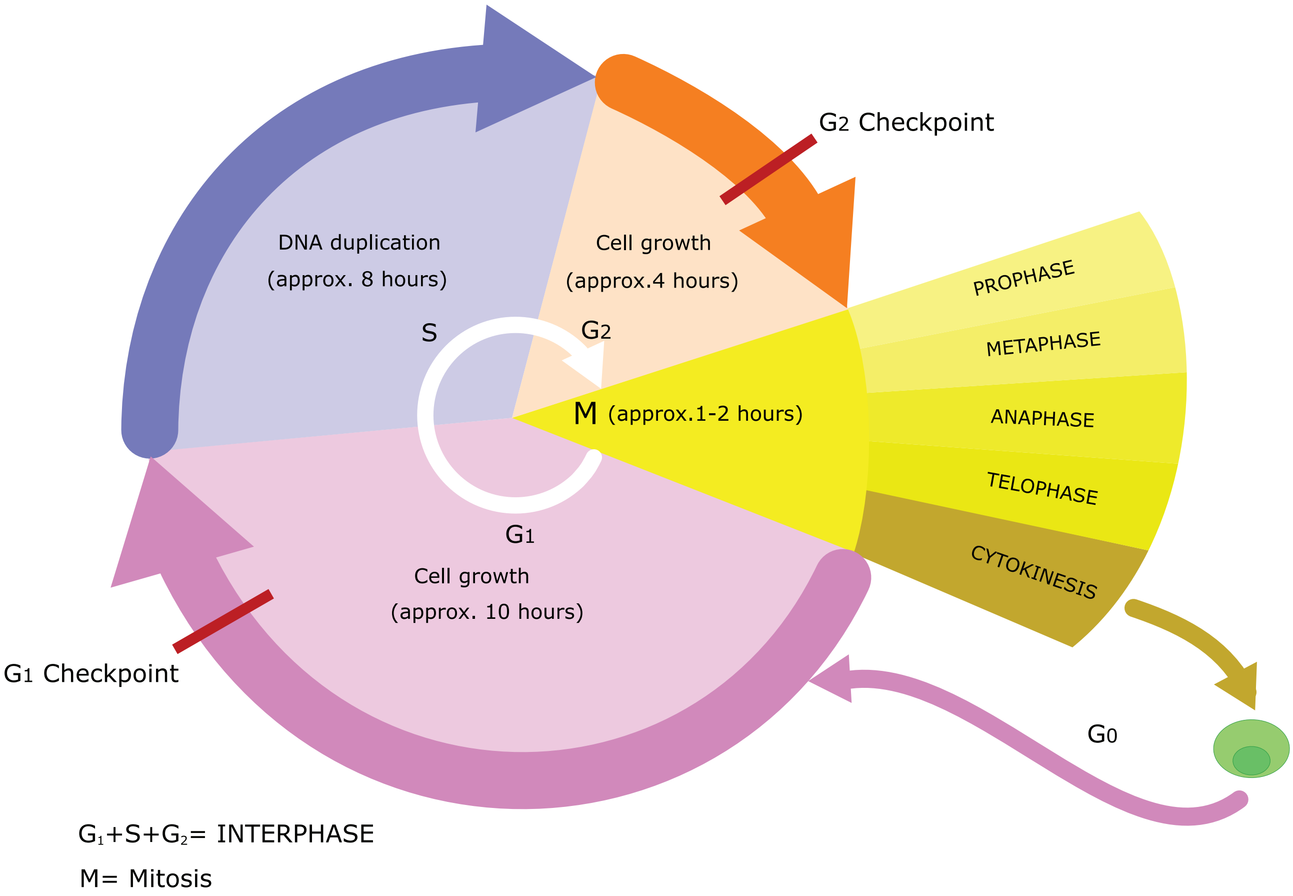


Figure 7.1: Cell cycle

the cell cycle. The checkpoint called the **restriction 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 $\mathbf{G_0}$ as a quiescent stage and 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 cells 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. The researcher 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 cells remain 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).

❖ **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.

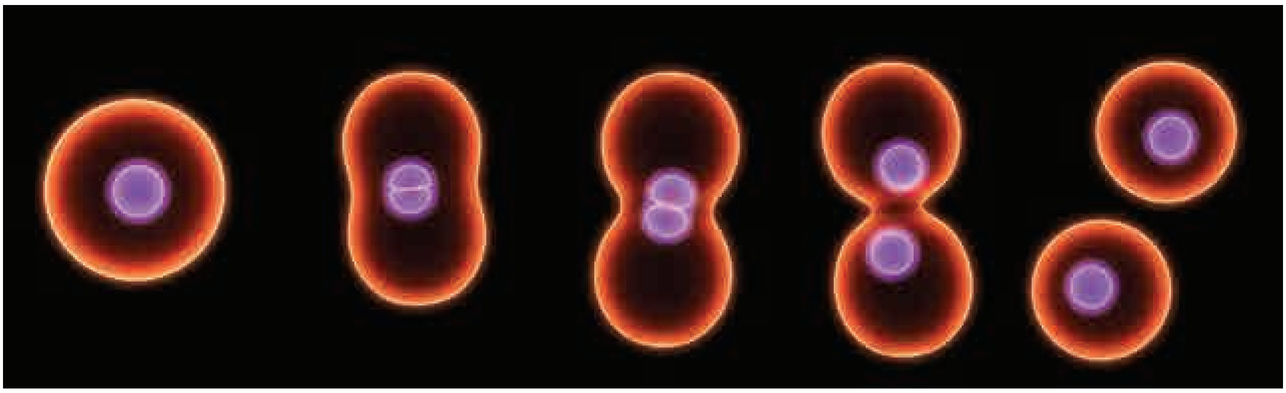


Figure 7.2: Amitosis

Drawbacks of Amitosis

- Causes unequal distribution of chromosomes.
- Can lead to abnormalities in metabolism and reproduction.

7.3.2 Mitosis

The most important part of cell division concerns events inside the nucleus. 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 the whole parts of the body.

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 are not seen.

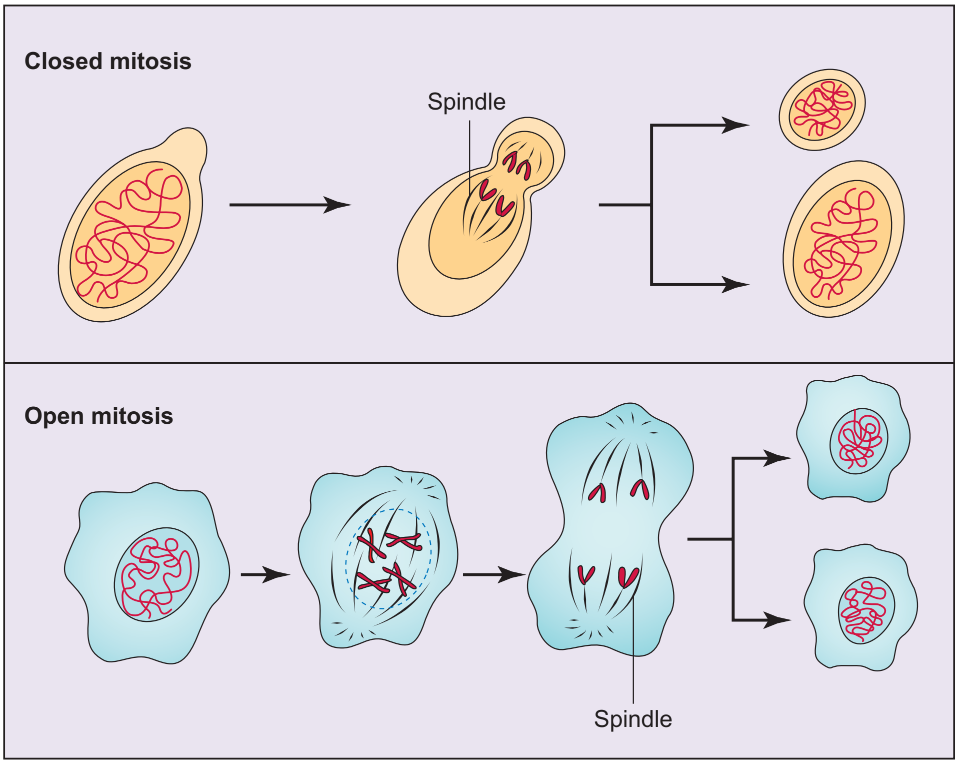


Figure 7.3: Closed and Open mitosis

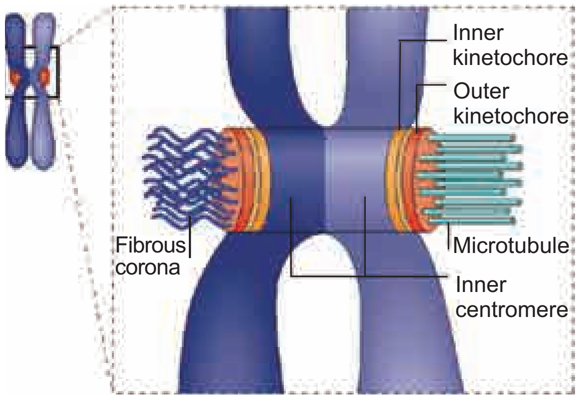


Figure 7.4: Centromere

In animal cell the centrioles extend a radial array of microtubules (Figure 7.4) towards the plasma membrane when they 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 is 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 chromosome morphology can be easily studied.

Kinetochore is a DNA–Protein complex present in the centromere DNA where the microtubules are attached. It is a trilaminar disc like plate.

The spindle assembly checkpoint which decides the cell to enter anaphase.

Anaphase

Each chromosome split simultaneously and two daughter chromatids begins to migrate towards two opposite poles of a cell. Each centromere splits longitudinally into two, freeing the two sister chromatids from each other. Shortening of spindle fibre and longitudinal splitting of centromere creates a pull which divides chromosome into two halves. Each half receive two chromatids (that is sister chromatids are separated). When the sister chromatids separate the actual partitioning of the replicated genome is complete.

A ubiquitine ligase is activated called as the **anaphase-promoting complex cyclosome (APC/C)** leads to degradation of

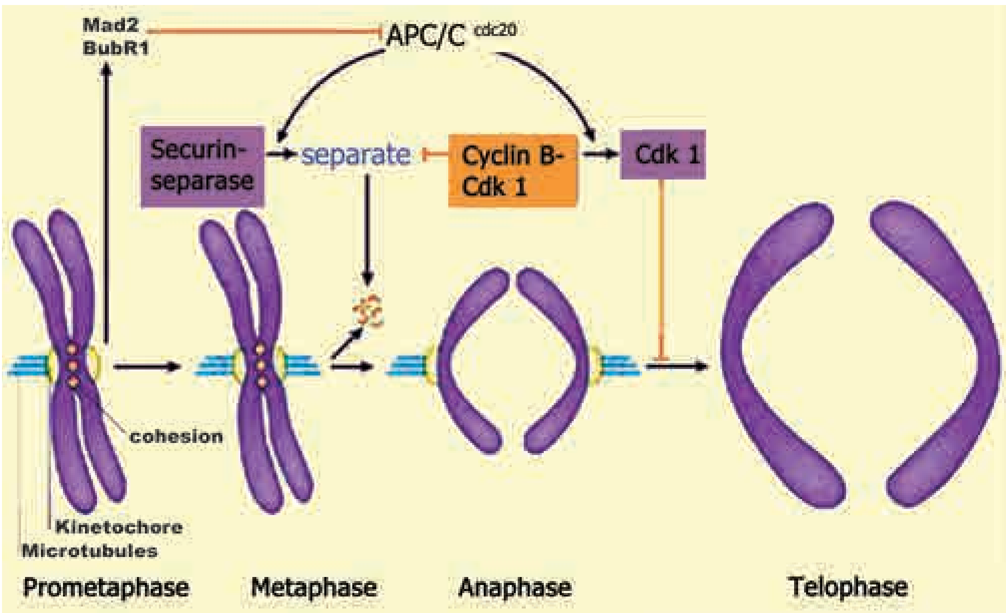


Figure 7.5: Anaphase promoting complex cyclosome

the key regulatory proteins at the transition of metaphase to anaphase. APC 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).

Telophase

Two sets of daughter chromosomes reach opposite poles of the cell, mitotic spindle disappears. Division of genetic material is completed after this karyokinesis, cytokinesis (division of cytoplasm) is completed, nucleolus and nuclear membranes reforms. Nuclear membranes form around each set of sister chromatids now called **chromosomes**, each has its own centromere. 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 the cells are separated by the distribution of organelles, macromolecules into two newly formed daughter cells.

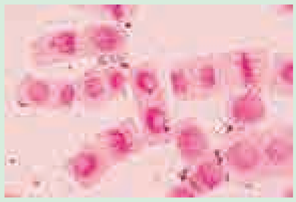
A Culture of animal cells in which the cell cycles were asynchronous was incubated with 3H-Thymidine for 10 minutes. Autoradiography showed that 50% of the cells were labelled. If the cell cycle time (generation time) was 16 hrs how long was the S period?

Length of the S period = Fraction of cells in DNA replication × generation time

Length of the S period = 0.5 × 16 hours = 8 hours

Activity

Squash preparation of onion root tip to visualize and study various stages of mitosis.



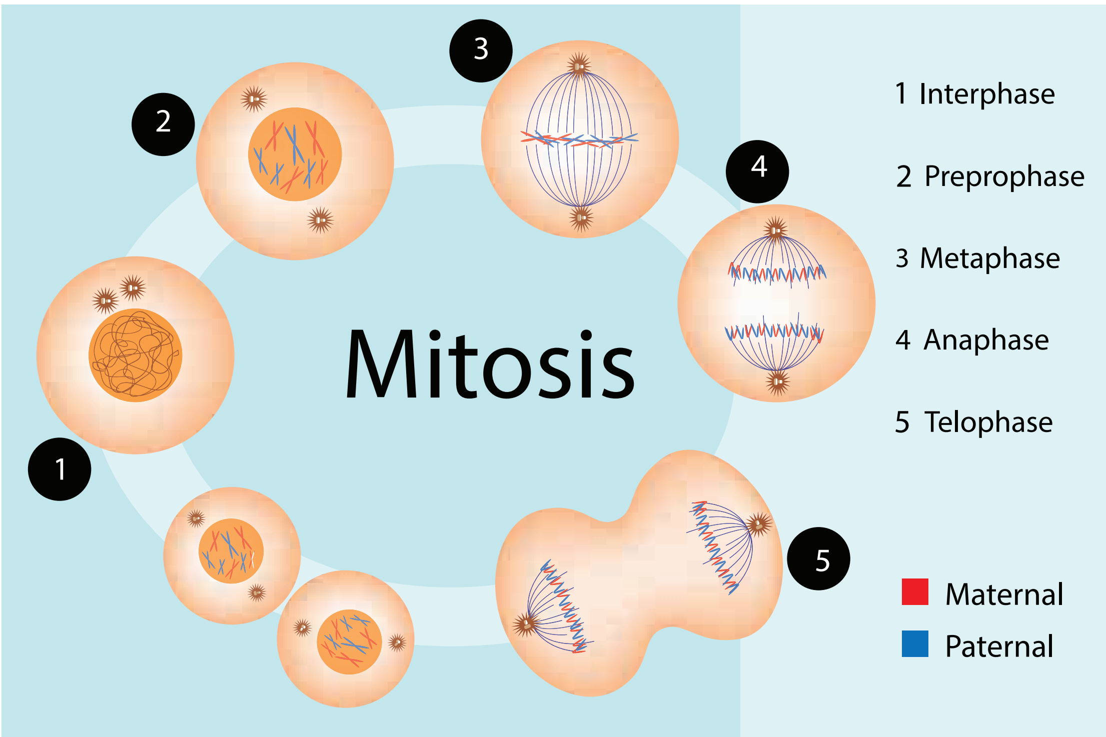


Figure 7.6: Mitosis

7.3.4 Cytokinesis

Cytokinesis in Animal Cells

It is a contractile process. The contractile mechanism contained in contractile ring located inside the plasma membrane. The ring consists of a bundle of microfilaments assembled from **actin** and **myosin**. This fibril helps for the generation of a contractile force. This force draws the contractile ring inward forming a cleavage furrow in the cell surface dividing 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, cytokinesis cell plate grows from centre towards lateral walls - centrifugal manner of cell plate formation.

Phragmoplast contains microtubules, actin filaments and vesicles from golgi apparatus and ER. The golgi vesicles contains carbohydrates such as pectin, hemicellulose which move along the microtubule of the pharagmoplast to the equator fuse, forming a new plasma membrane and the materials which are placed their 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.

DO YOU KNOW?

Skin cells and the cells lining your 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).*

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).

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. The chromosomes are very actively transcribed in females as the egg stores up materials for use during embryonic development. In animals, the chromosomes have prominent loops called **lampbrush chromosome**.

Diakinesis – Terminalisation of chiasmata. Spindle fibres assemble. Nuclear envelope breaks down. Homologous chromosomes become short and condensed. Nucleolus disappears.

Metaphase I

Spindle fibres are attached to the centromeres of the two homologous chromosomes. Bivalent (pairs of homologous chromosomes) aligned at the

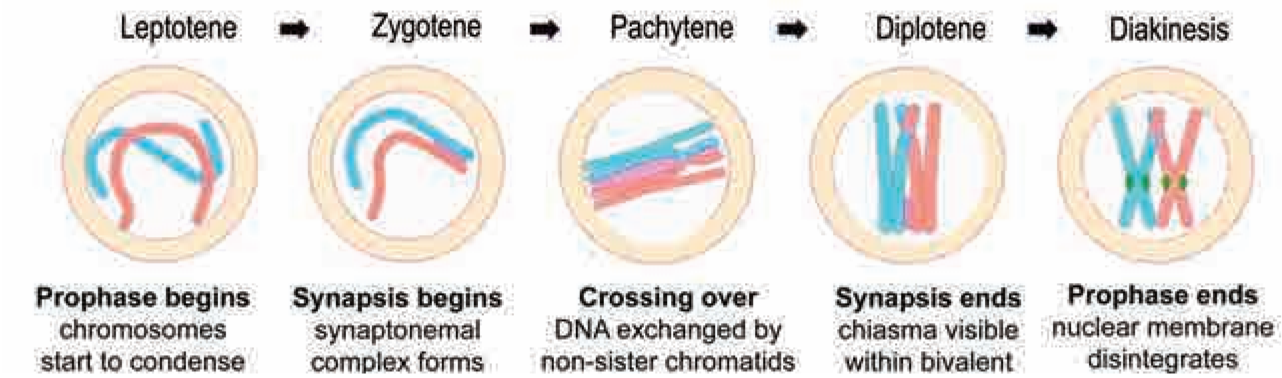


Figure 7.7: Prophase I

equator of the cell known as **metaphase plate**. Each bivalent consists of two centromeres and four chromatids.

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. Shortening of spindle fibers takes place. 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. Nuclei are 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**. 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 microtubules. Centromere of each chromosome split, allowing to move towards opposite poles of the cells holding the sister chromatids.

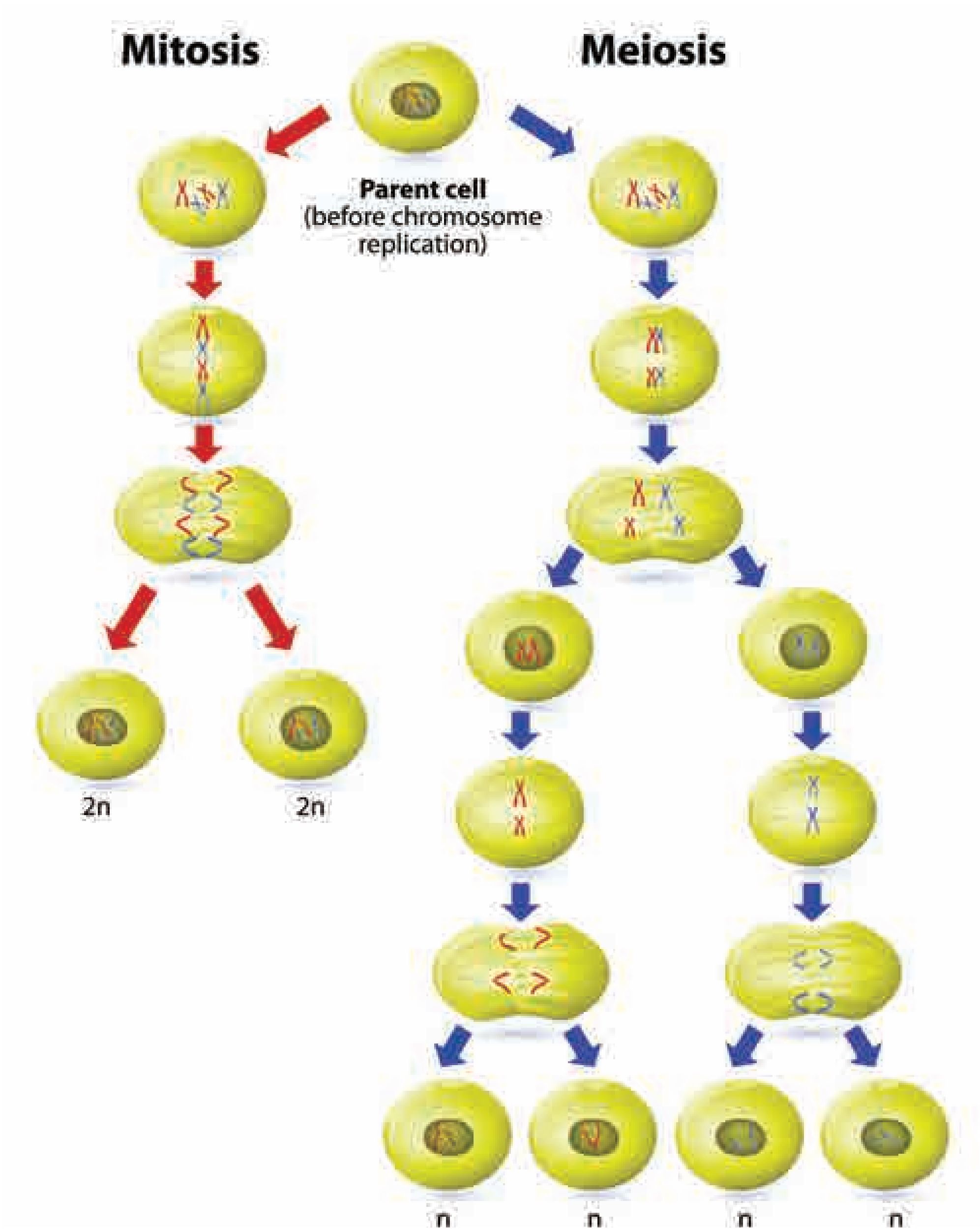


Figure 7.8: Meiosis

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.

7.4 Difference Between Mitosis and Meiosis

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 formation of a cell plate	Cell division involves furrowing and cleavage of cytoplasm
Occurs mainly at meristem	Occurs in tissues throughout the body

Table 7.4: Difference Between Mitosis and Meiosis (Figure 7.8)

Mitosis	Meiosis
One division	Two divisions
Number of chromosomes remains 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 the parent cells
Two daughter cells are formed	Four daughter cells are formed

7.5 Mitogens

The factors which promote cell cycle proliferation is called **mitogens**. Plant mitogens include gibberellin, ethylene, Indole acetic acid, kinetin. These increase mitotic rate.

Mitotic Poisons (Mitotic Inhibitors)

Certain chemical components act as inhibitors of the mitotic cell division and they are called **mitotic poisons**.

Endomitosis

The replication of chromosomes in the absence of nuclear division and cytoplasmic division resulting in numerous copies within each cell is called **endomitosis**. Chromonema do not separate to form chromosomes, but remain closely associated with each other. Nuclear membrane does not rupture. So no spindle formation. It occurs notably in the salivary glands of *Drosophila* and other flies. Cells in these tissues contain giant chromosomes (polyteny), each consisting of over thousands of intimately associated, or synapsed, chromatids. Example: Polytene chromosome.

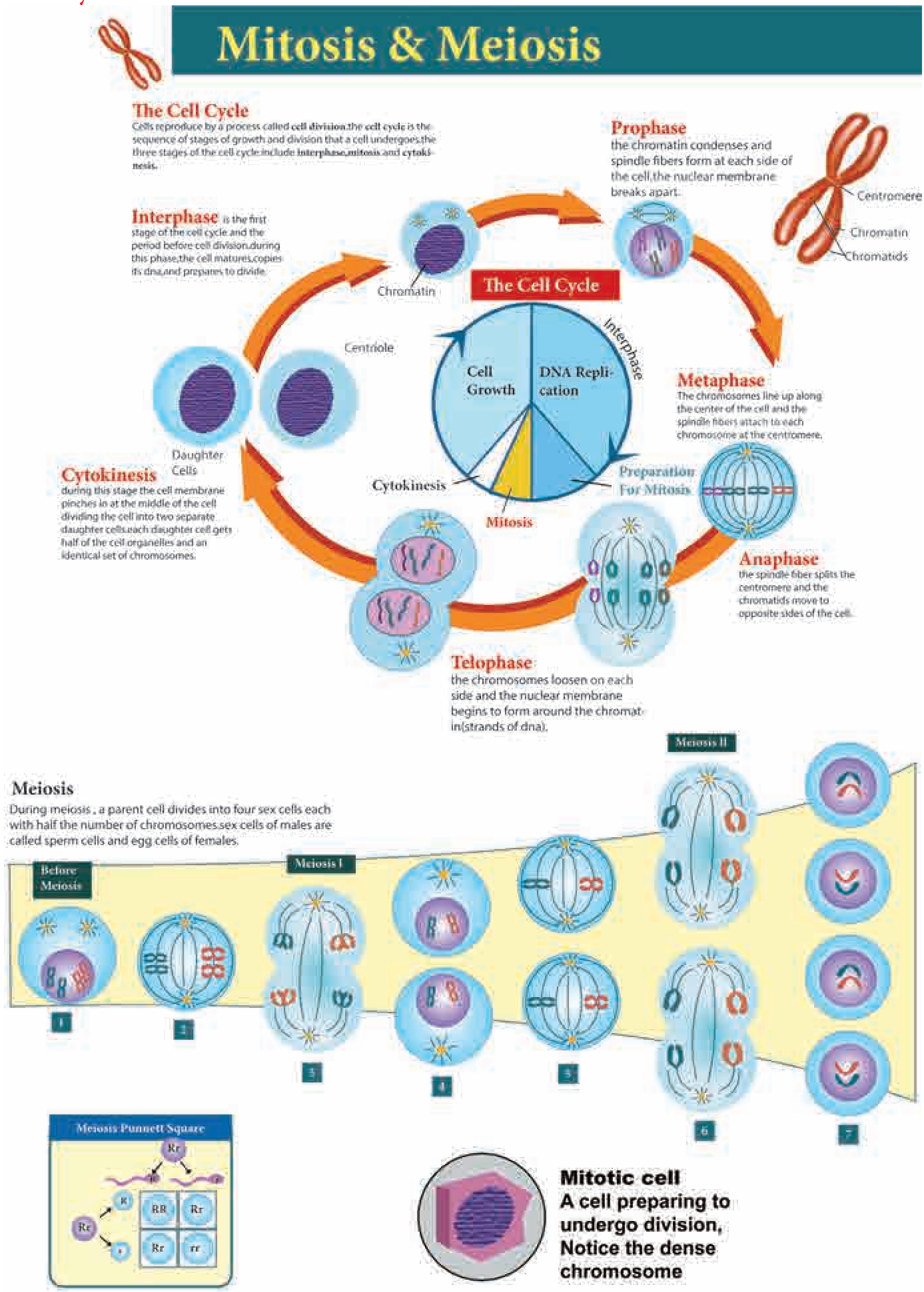
Anastral

This is present only in plant cells. No asters or centrioles are formed only spindle fibres are formed during cell division.

Amphiastral

Aster and centrioles are formed at each pole of the spindle during cell division. This is found in animal cells.

Summary


Mitosis & Meiosis
The Cell Cycle
Cells reproduce by a process called cell division.the cell cycle is the sequence of stages of growth and division that a cell undergoes.the three stages of the cell cycle include interphase,mitosis and cytokinesis.
Interphase is the first stage of the cell cycle and the period before cell division.during this phase,the cell matures,copies its dna,and prepares to divide.
Chromatin
Centriole
Daughter Cells
Cytokinesis
during this stage the cell membrane pinches in at the middle of the cell dividing the cell into two separate daughter cells.each daughter cell gets half of the cell organelles and an identical set of chromosomes.
Prophase
the chromatin condenses and spindle fibers form at each side of the cell,the nuclear membrane breaks apart.
Centromere
Chromatin
Chromatids
The Cell Cycle
Interphase
Cell Growth
DNA Replication
Cytokinesis
Mitosis
Preparation For Mitosis
Metaphase
The chromosomes line up along the center of the cell and the spindle fibers attach to each chromosome at the centromere.
Anaphase
the spindle fiber splits the centromere and the chromatids move to opposite sides of the cell.
Telophase
the chromosomes loosen on each side and the nuclear membrane begins to form around the chromatin(strands of dna).
Meiosis
During meiosis , a parent cell divides into four sex cells each with half the number of chromosomes.sex cells of males are called sperm cells and egg cells of females.
Before Meiosis
Meiosis I
Meiosis II
1
2
3
4
5
6
7
Meiosis Punnett Square
Rr
RR
Rr
Rr
rr
Mitotic cell
A cell preparing to undergo division, Notice the dense chromosome

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

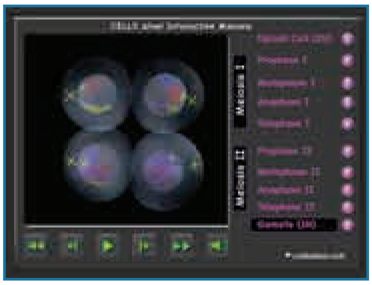
5SD2HH

2. If cell 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
   b. Pachytene
   c. Leptotene
   d. Zygotene
8. Colchicine prevents the mitosis of the cells at which of the following stage
   a. Anaphase
   b. Metaphase
   c. Prophase
   d. interphase
9. The paring of homologous chromosomes on meiosis is known as
   a. Bivalent
   b. Synapsis
   c. Disjunction
   d. Synergids
10. Anastral mitosis is the characteristic feature of
    a. Lower animals
    b. Higher animals
    c. Higher plants
    d. All living organisms
11. Write any three significance of mitosis
12. Differentiate between mitosis and meiosis
13. Given an account of G_0 phase
14. Differentiate cytokinesis in plant cells and animal cells
15. Write about Pachytene and Diplotene of Prophase I

ICT Corner

Cell division

How cells are multiply? →

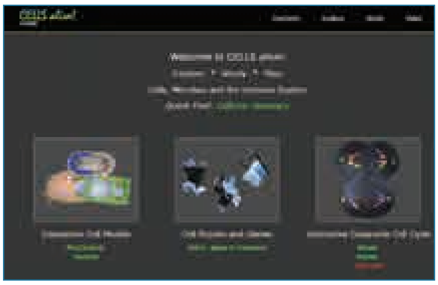


Steps

- 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

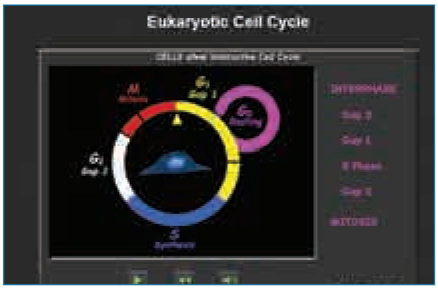
Activity

- Select meiosis and cell cycle.
- Record your observations.



Step 1

Step 3



Step 2

Step 4

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https://www.cellsalive.com/

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* Pictures are indicative only

Chapter 8

Biomolecules

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Learning Objectives

The learner will be able to,

- *List out the inorganic and organic components of a cell.*
- *Understand about bonding pattern of water and properties of water.*
- *Familiarise with the classification of carbohydrates and its functions.*
- *Recognise the basic structure of carbohydrates, proteins, lipids and nucleic acids and differentiate the various pattern of classification with respect to structure.*
- *Identify the structure and functions of carbohydrates.*
- *Familiarise with the general structure of amino acids and its classification based on the functional group.*
- *Comparative study of the primary, secondary, tertiary and quaternary structure of proteins.*
- *Know the structure and classification of enzymes.*
- *Know about the factors affecting the mode of action of enzymes with relevant examples.*
- *Understand lipids as a biomolecule and discuss the properties of lipids.*
- *Have a deeper knowledge about structure of nucleic acids.*
- *Recognize nucleic acids as a polymer which plays a vital role in carrying the genetic information.*
- *Learn about the different forms of DNA and types of RNA.*

Chapter Outline

Biomolecules

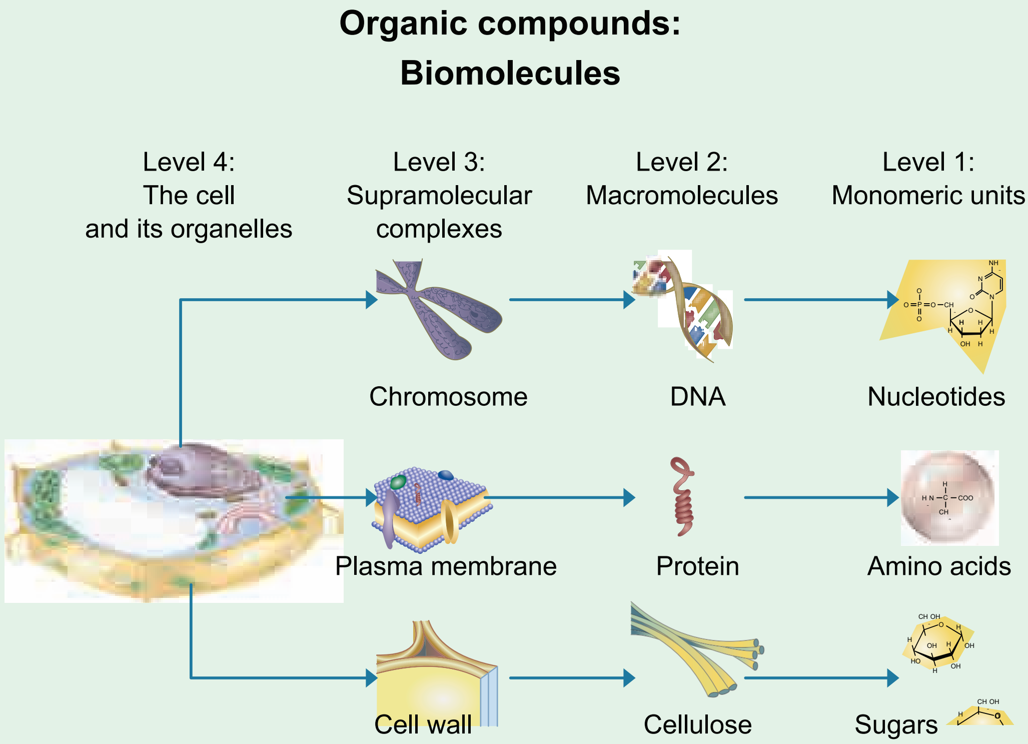


Figure 8.1: Components of cell

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 are 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).

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) and 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

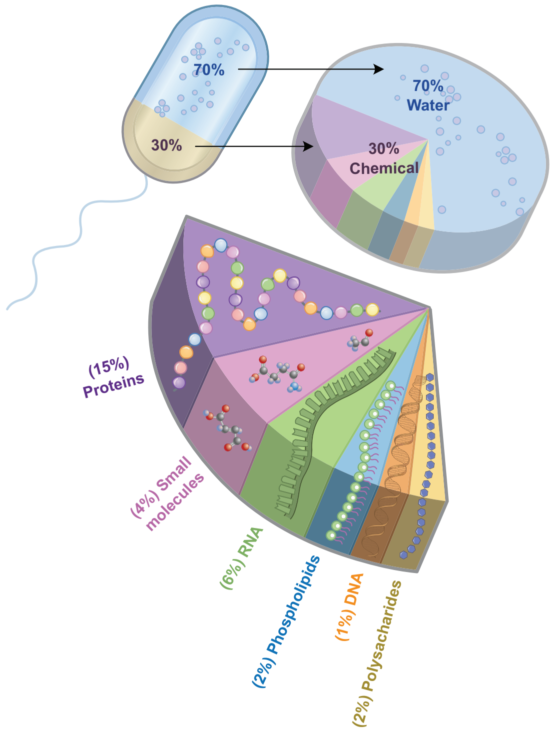


Figure 8.2: Percentage of biomolecules in cell

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).

DO YOU KNOW?

Masaru Emoto discovered that crystals formed in frozen water reveal changes when specific, concentrated thoughts are directed toward them. This crystal structure shows joy mood

Figure 8.3

8.1.1 Chemistry of Water

Water is a tiny polar molecule and 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 8.4).

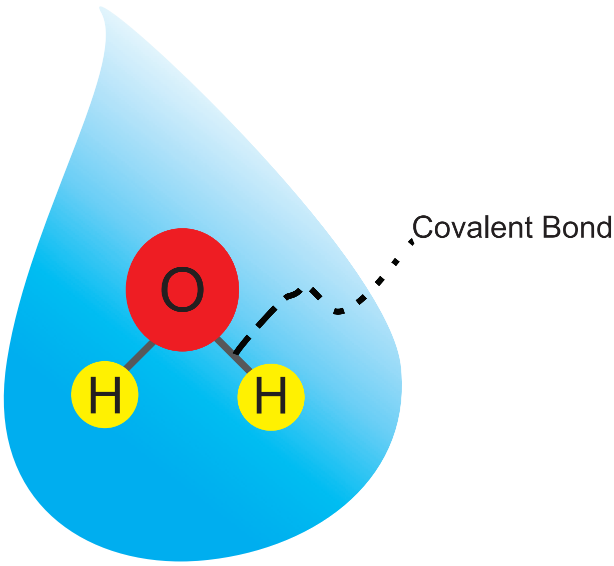


Figure 8.4: Water molecule

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

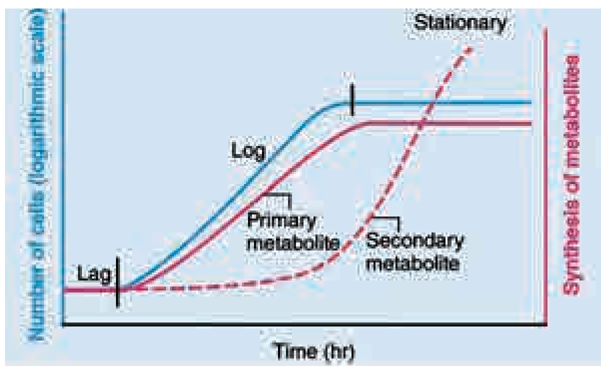


Figure 8.5: Synthesis of metabolites during growth

8.2 Primary and Secondary Metabolites

Most plants, fungi and other microbes synthesizes a number of organic compounds. These components are 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 8.5).

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.

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

DO YOU KNOW?

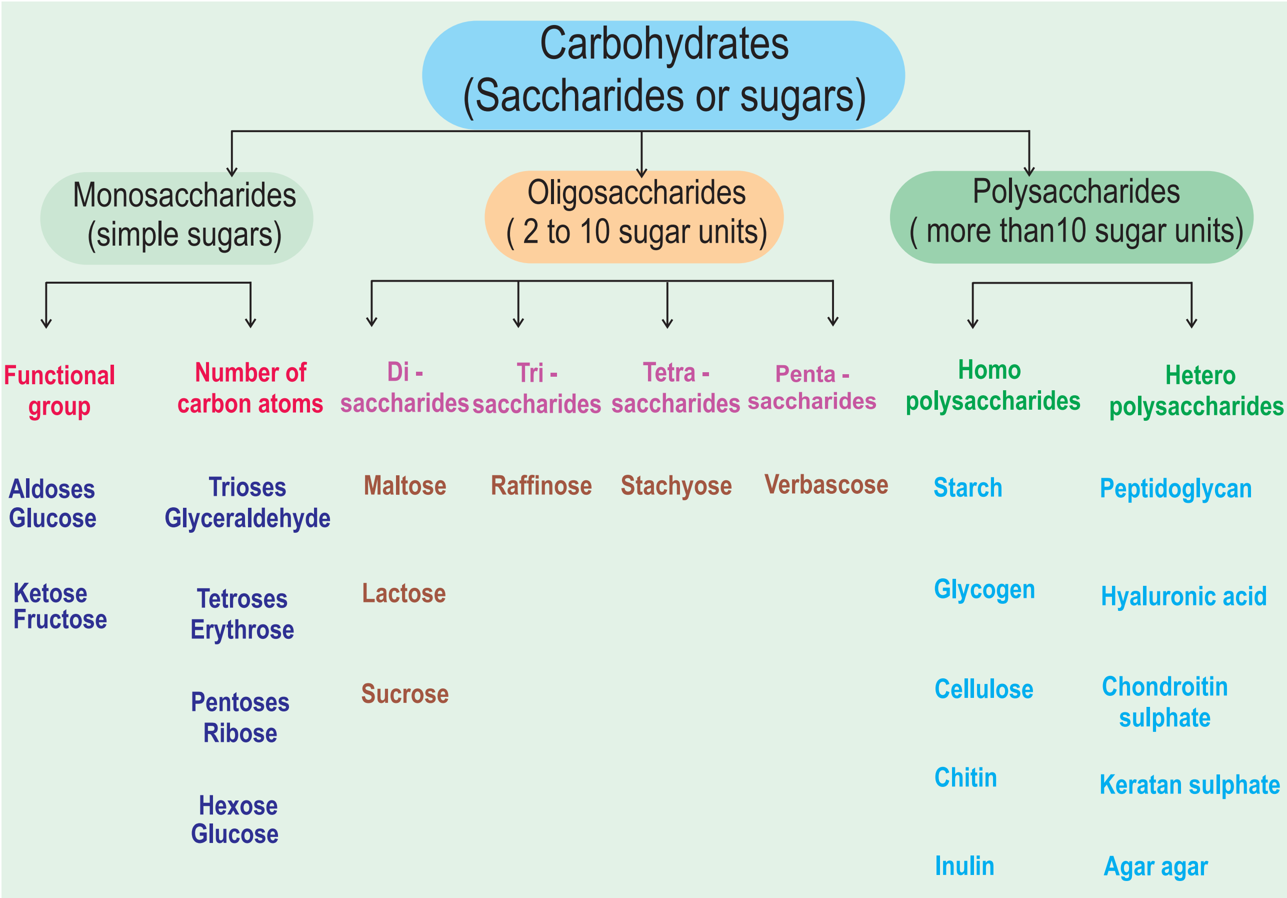
Morphine is the first alkaloid to be found. It comes from the plant Opium poppy (*Papaver somniferum*). It is used as a pain reliever in patients with severe pain levels and cough suppressant.

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 $\mathbf{(CH_2O)_n}$ 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. Glucose has a chemical formula of $C_6H_{12}O_6$. It is a six carbon molecule and hence is called as **hexose** (Figure 8.6).

All monosaccharides contain one of two functional groups. Some are aldehydes, like glucose and are referred as **aldoses**; other are ketones, like 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.

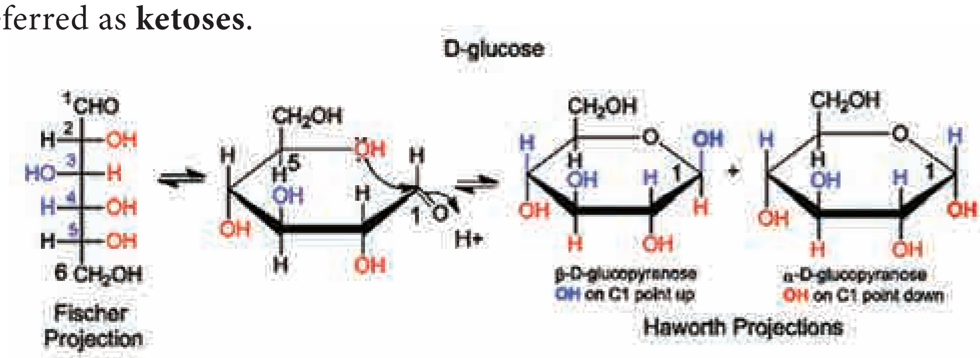


Figure 8.6: Structure of Glucose

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.

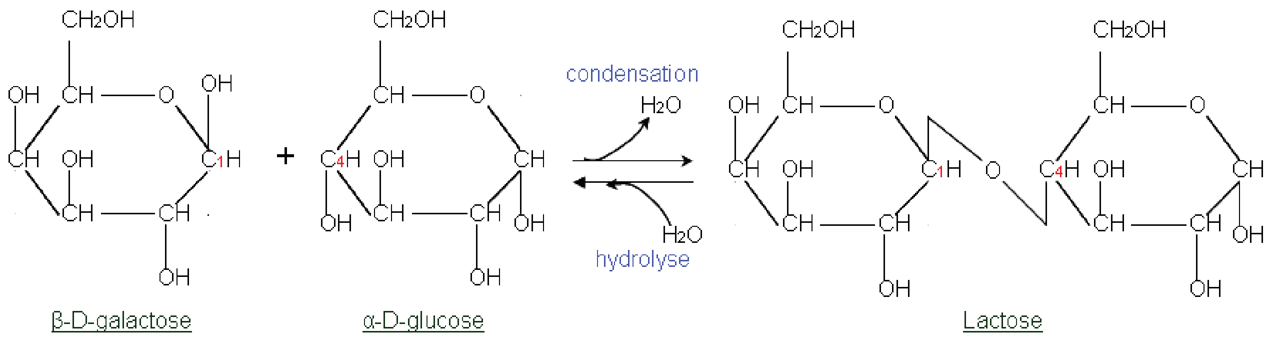


Figure 8.7: structure of carbohydrates

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.

Depending on the function, polysaccharides are of two types - **storage polysaccharide and structural polysaccharide** (Figure 8.8).

8.3.4 Starch

Starch is a storage polysaccharides 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.

Figure 8.8: Branched and linear polysaccharides

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, creating a **blue-black colour** (Figure 8.9).

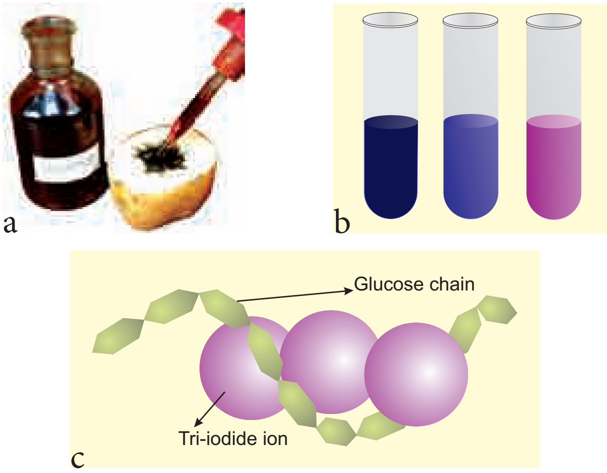


Figure 8.9: Test for starch

a. Test on potato; b. test on starch at varied concentrations; c. starch – iodine reaction

8.3.6 Glycogen

Glycogen is also a storage polysaccharide otherwise called as **animal starch**. It is the only carbohydrate stored in animals and fungi. Like amylopectin glycogen is a polymer of glucose with (α1-6) linked branches. Glycogen is seen in liver cells, skeletal muscle fibre and throughout the human body except brain (Figure 8.10).

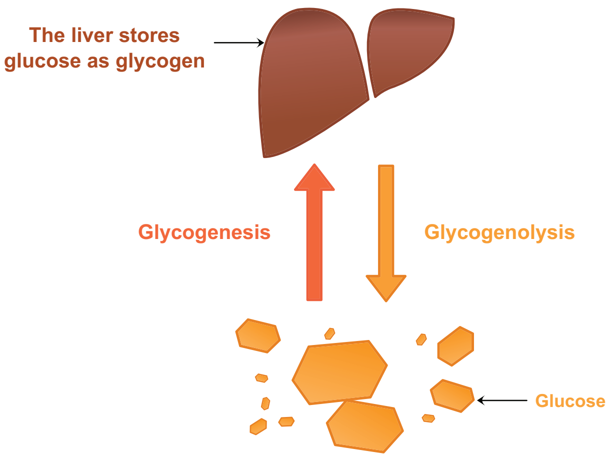


Figure 8.10: Glycogen: Glycogen in liver

8.3.7 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 8.11).

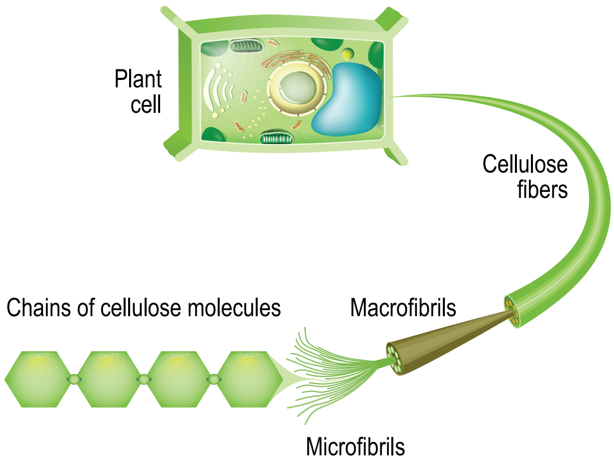


Figure 8.11: Cellulose molecule

Most herbivores have a problem:

- Cellulose is one of the most abundant organic compound in the biosphere.
- eat grass: principle component is cellulose
- cannot produce cellulase

Solution: Mutualistic bacteria in digestive system produce cellulases.

8.3.8 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 8.12).

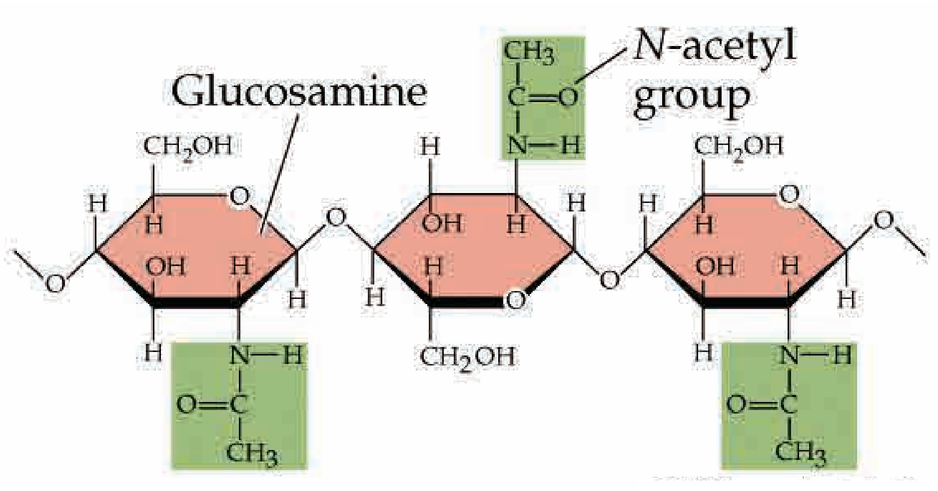


Figure 8.12: Structure of Chitin molecule

DO YOU KNOW?

Does mushroom cells have cell wall?

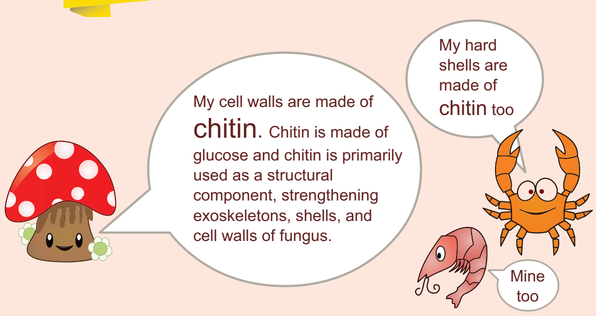


Figure 8.13

8.3.9 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 (Figure 8.14).

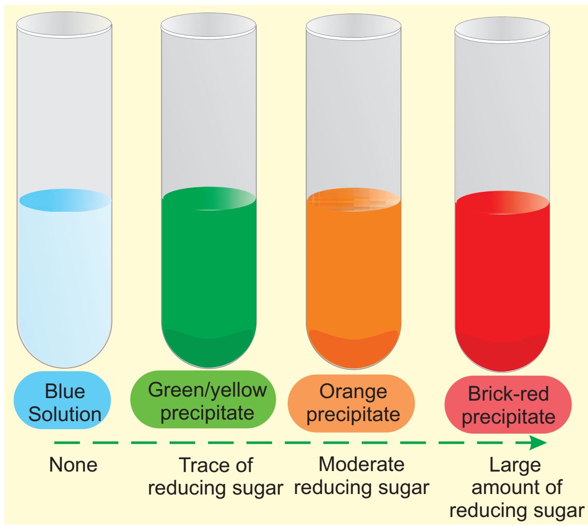


Figure 8.14: Test for sugar

- 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

DO YOU KNOW?

Human can't digest cellulose but herbivores can digest them with the help of bacteria present in the gut which produces enzyme **cellulase.** This is an example of **mutualism.**

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 dissolve in non-polar solvents such as benzene, ether, chloroform. This is because they contain long hydrocarbon chains that are non-polar and thus 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.

8.4.2 Membrane Lipids

A class of lipids that serves as major structural component of cell membrane is **phospholipids**. These contain only 2 fatty acids attached to the glycerol, while the third glycerol binding site holds a phosphate group. This phosphate group is in turn bonded to an alcohol. These lipids have both hydrophobic and hydrophilic regions. The structure of lipid bilayer helps the membrane in function such as selective permeability and fluid nature (Figure 8.15).

8.4.3 Steroids

These are complex compounds commonly found in cell membrane and animal hormones. Eg. Cholesterol which reinforces the structure of the cell membrane in animal cells and in an unusual group of cell wall deficient bacteria – Mycoplasma.

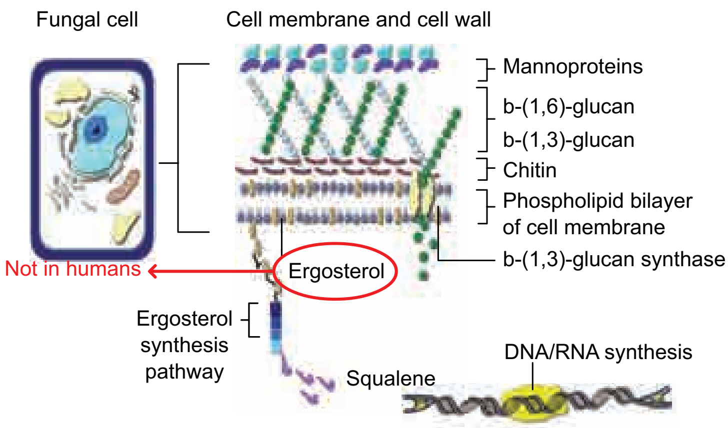


Figure 8.15: Complex molecules in cell wall

8.4.4 Waxes

These are esters formed between a long chain alcohol and saturated fatty acids. Fur, feathers, fruits, leaves, skin and insect exoskeleton are naturally waterproofed with a coating of wax (Figure 8.16 and 8.17).

Figure 8.16: Lecithin

Lecithin is a food additive and dietery supplement

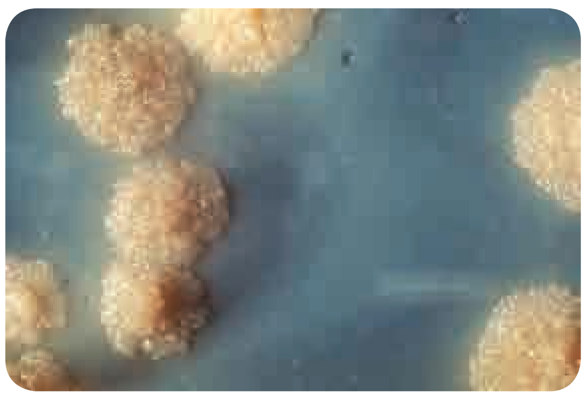
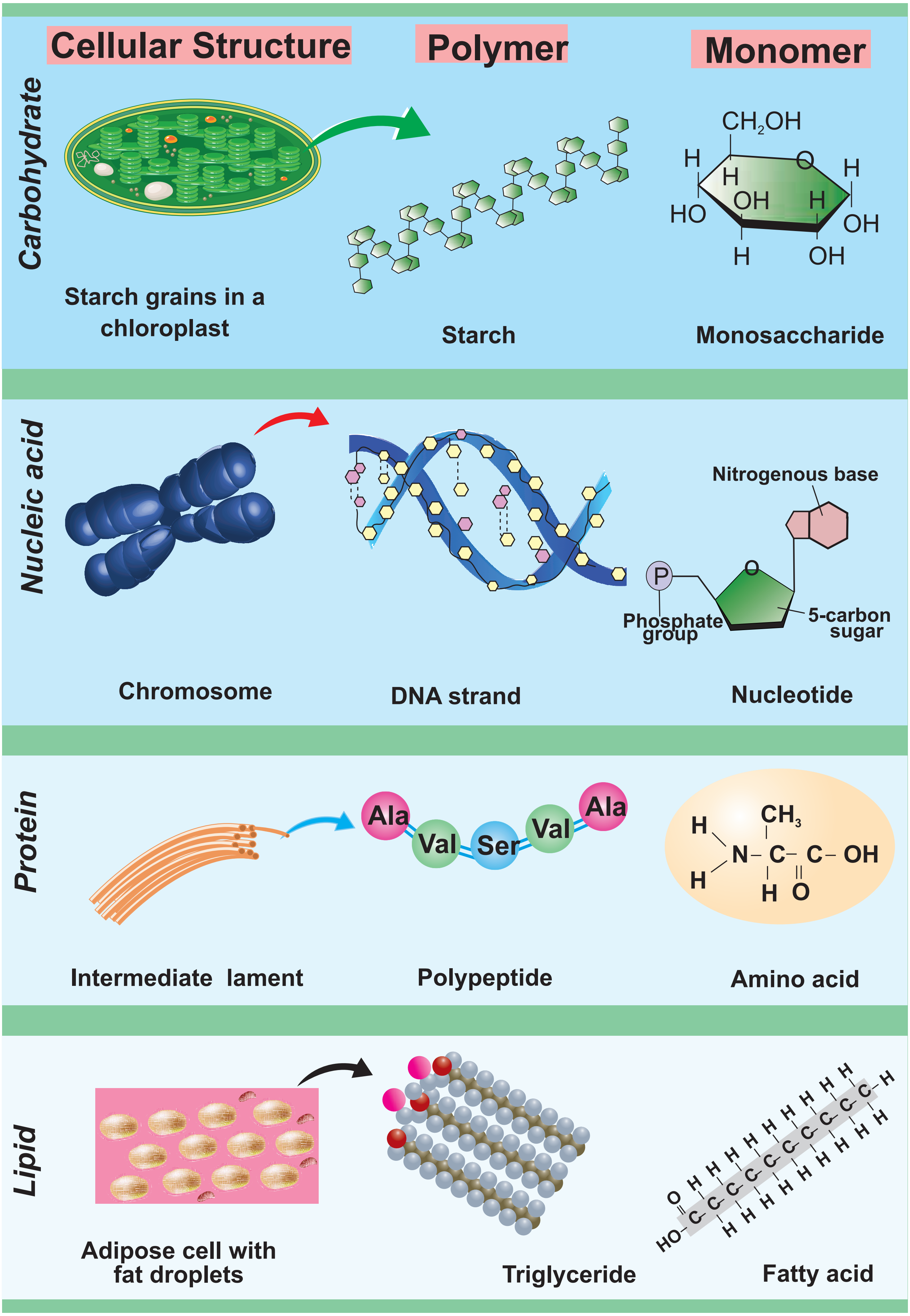


Figure 8.17: Wax D present in cell wall of TB and Leprosy causing bacteria is infectious



Cellular Structure
Polymer
Monomer
Carbohydrate
Starch grains in a chloroplast
Starch
CH2OH
H
O
H
H
OH
H
HO
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
H
CH3
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.

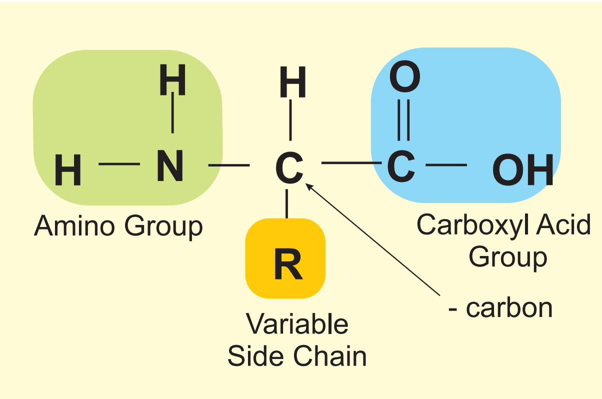


Figure 8.18: Structure of basic amino acid

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.

(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 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 8.19).

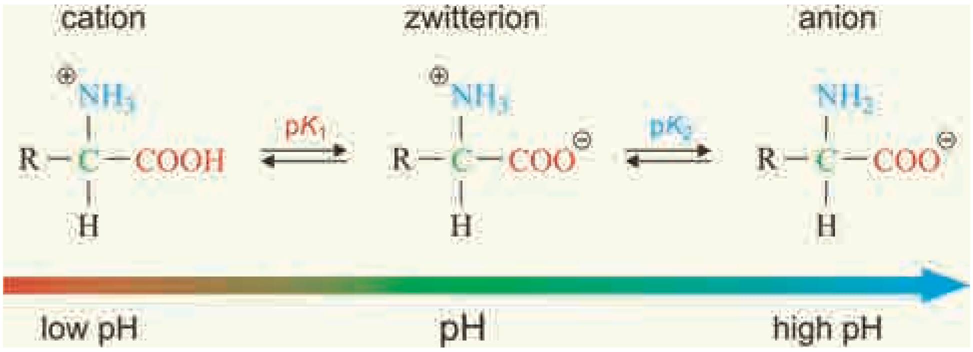


Figure 8.19: Structure of amino acid

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 8.18 and 8.20 a and b).

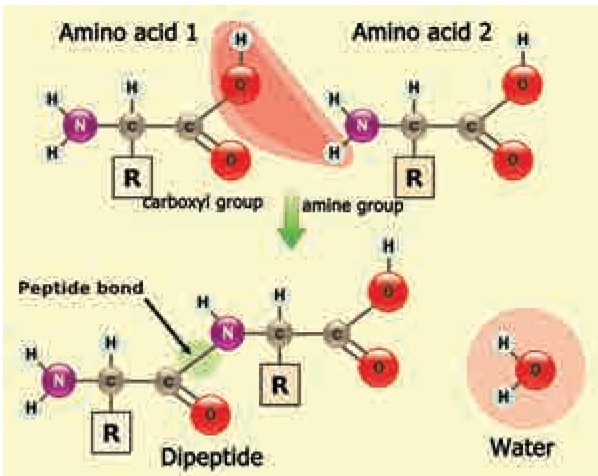


Figure 8.20(a): Amino acid reaction

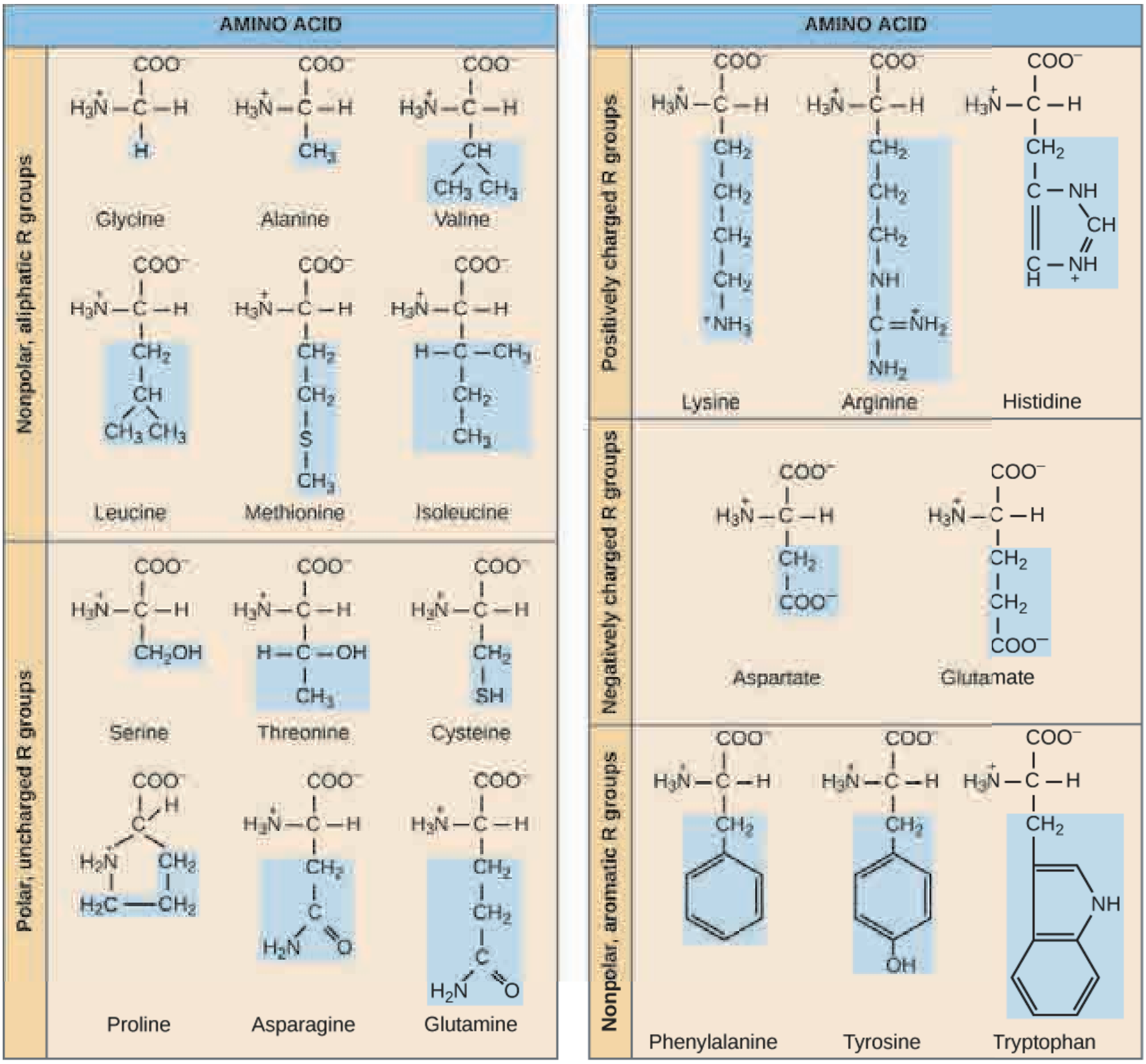


Figure 8.20(b): Classification of Amino Acids

First protein Insulin was sequenced by Fred Sanger

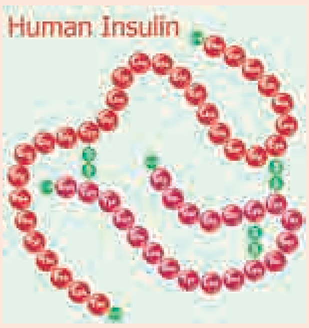


Figure 8.21

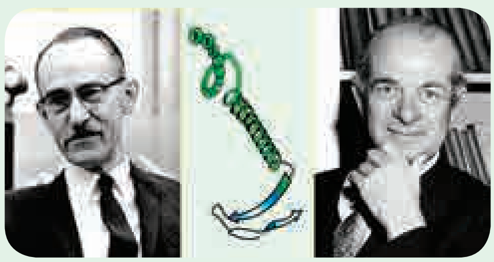


Figure 8.22

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

8.5.2 Structure of Protein

Protein is 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 8.23).

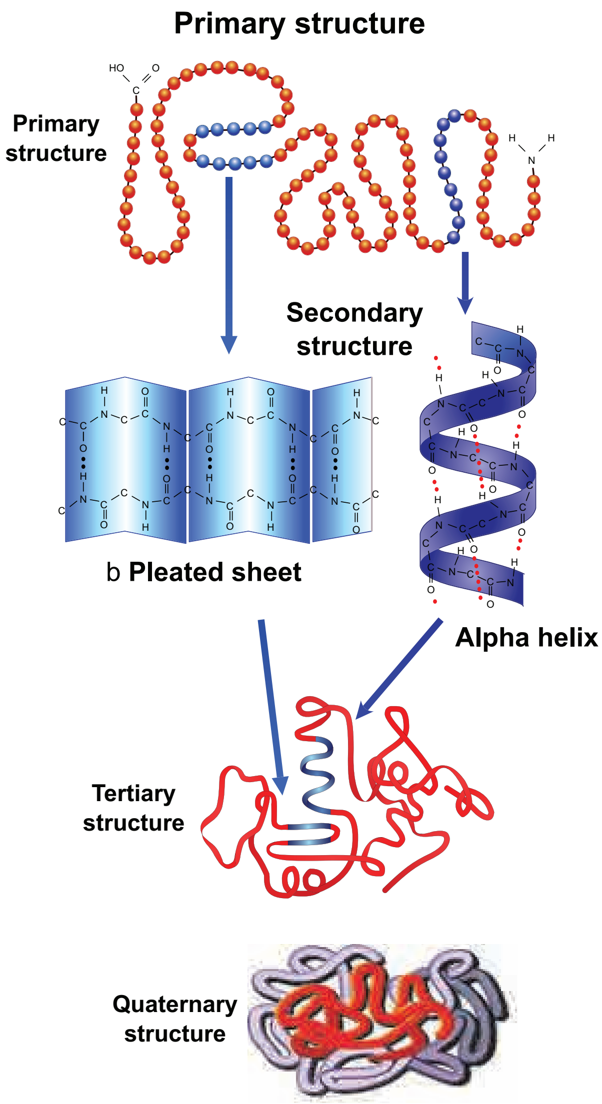


Figure 8.23: Structure of Protein

- 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.

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 8.25).

Christian Anfinsen explained denaturation of proteins by heat treatment leading to breakage of non-covalent bond.

Figure 8.24

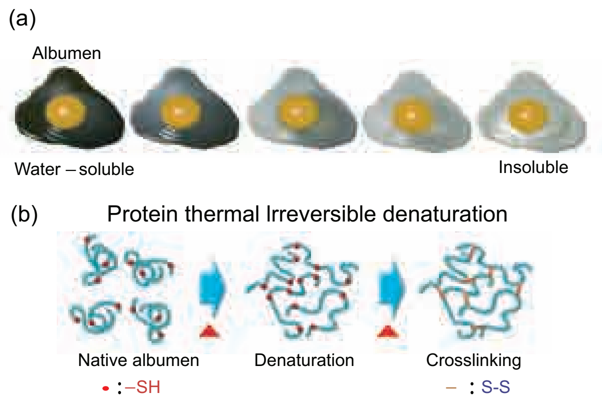


Figure 8.25: Protein denaturation

8.5.4 Protein Bonding

There are three types of chemical bonding

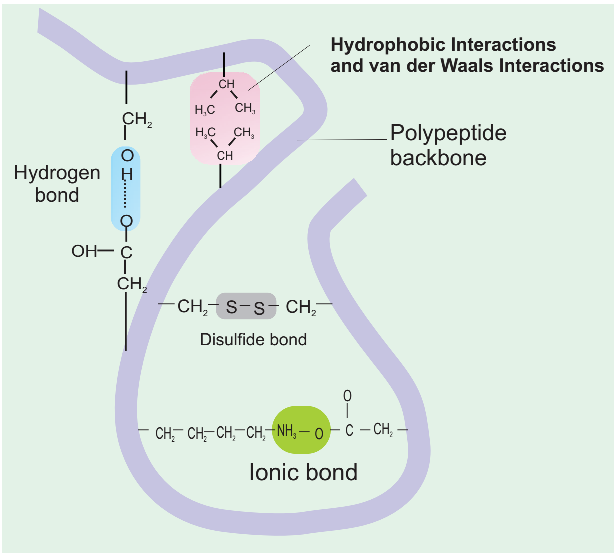


Figure 8.26: Protein bonding

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 8.26).

Ionic Bond

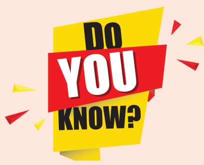
It is formed between any charged groups that are not joined together by peptide bond. It is stronger than hydrogen bond and can be broken by changes in pH and temperature.

Disulfide Bond

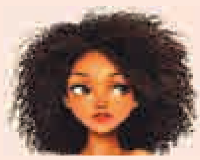
Some amino acids like cysteine and methionine have sulphur. These form disulphide bridge between sulphur atoms and amino acids.

Hydrophobic Bond

This bond helps some protein to maintain structure. When globular proteins are in solution, their hydrophobic groups point inwards away from water.



The more the distance between the sulphur atoms, the more the proteins bend; the more the hair curls.



8.5.5 Test for Proteins

The biuret test is used as an indicator of the presence of protein because it gives a purple colour in the presence of peptide bonds (–C–N–). To a 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 8.27 a and b).

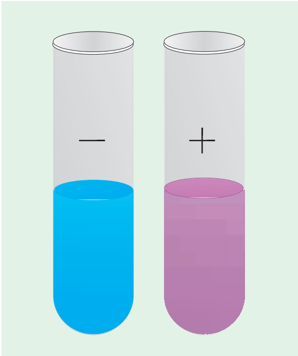


Figure 8.27(a): Biuret test

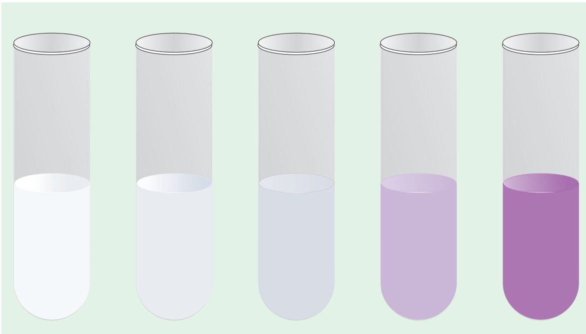


Figure 8.27(b): Colour intensity increases with increase in concentration

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 8.28).

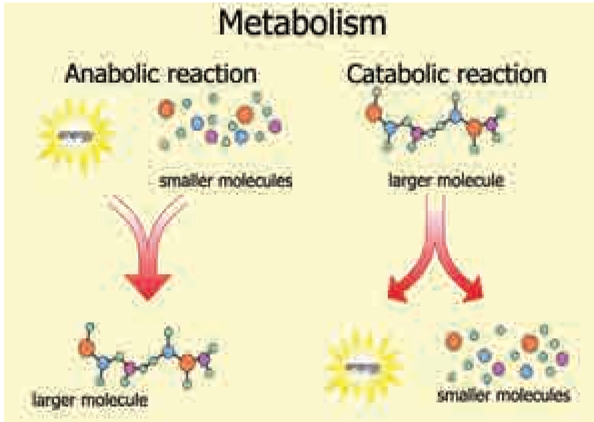
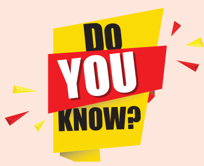


Figure 8.28: Enzyme reaction

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

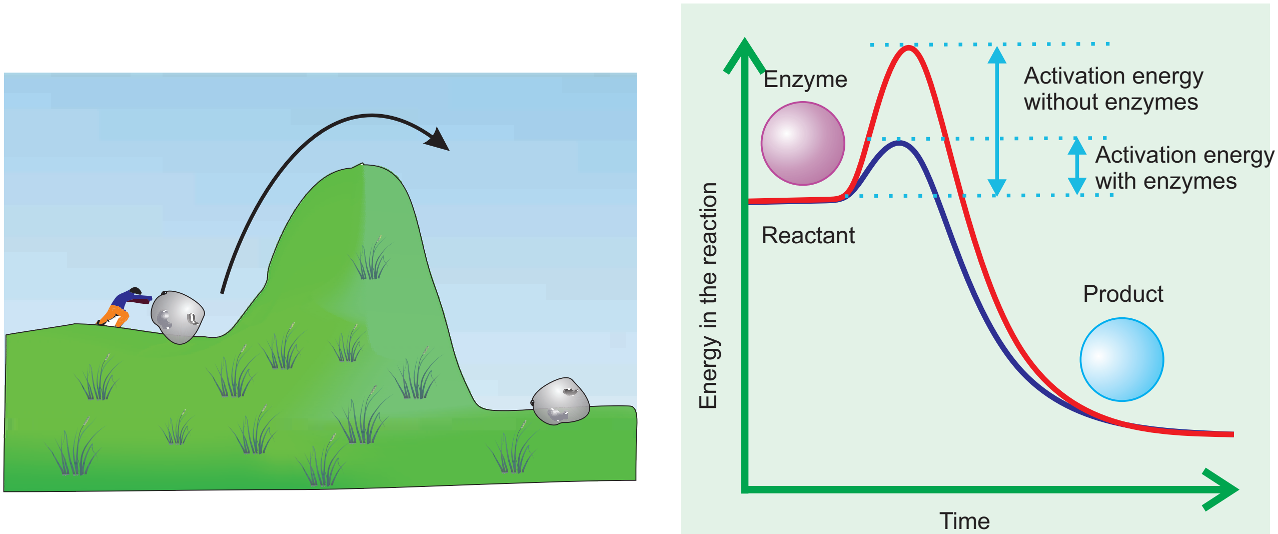
8.6.1 Properties of Enzyme

- 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.



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 8.29).



This graph shows the activation energies of a reaction with and without enzymes

Figure 8.29: Activation energy

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 8.30).

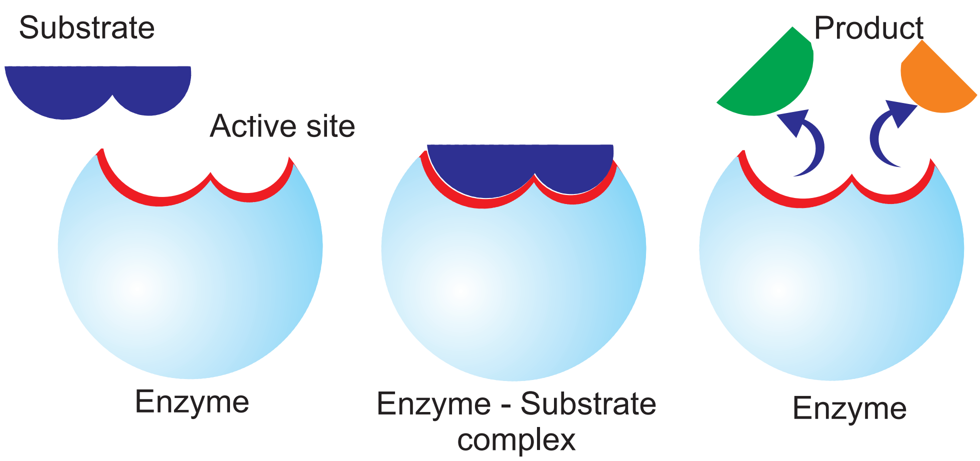


Figure 8.30: Enzyme mechanism

8.6.3 Factors Affecting the Rate of Enzyme Reactions

Enzymes are sensitive to environmental condition. It could be affected by temperature, pH, substrate concentration and enzyme concentration.

The rate of enzyme reaction is measured by the amount of substrate changed or amount of product formed, during a period of time.

8.6.4 Temperature

Heating increases molecular motion. Thus the molecules of the substrate and enzyme move more quickly resulting in a greater probability of occurence of the reaction. The temperature that promotes maximum activity is referred to as optimum temperature (Figure 8.31a).

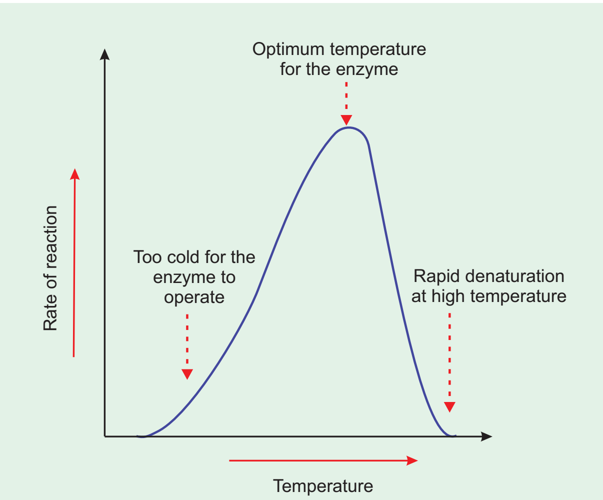


Figure 8.31(a): Temperature

8.6.5 pH

The optimum pH is that at which the maximum rate of reaction occurs. Thus the pH change leads to an alteration of enzyme shape, including the active site. If extremes of pH are encountered by an enzyme, then it will be denatured (Figure 8.31b).

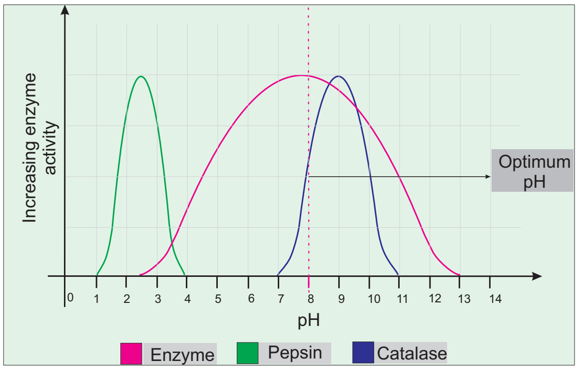


Figure 8.31(b): pH

8.6.6 Substrate Concentration

For a given enzyme concentration, the rate of an enzyme reaction increases with increasing substrate concentration (Figure 8.32).

8.6.7 Enzyme Concentration

The rate of reaction is directly proportional to the enzyme concentration.

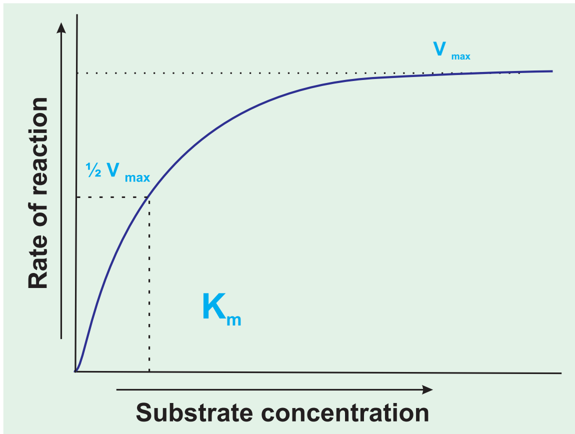


Figure 8.32: Rate of enzyme reaction

8.6.8 Introducing the Michaelis-Menton Constant (Km) and Its Significance

When the initial rate of reaction of an enzyme is measured over a range of substrate concentrations (with a fixed amount of enzyme) and the results plotted on a graph. With increasing substrate concentration, the velocity increases – rapidly at lower substrate concentration.

However the rate increases progressively, above a certain concentration of the substrate the curve flattened out. No further increase in rate occurs.

This shows that the enzyme is working at maximum velocity at this point. On the graph, this point of maximum velocity is shown as V_{max}.

8.6.9 Inhibitors of Enzyme

Certain substances present in the cells may react with the enzyme and lower the rate of reaction. These substances are called **inhibitors**. It is of two types **competitive and non-competitive** (Figure 8.33).

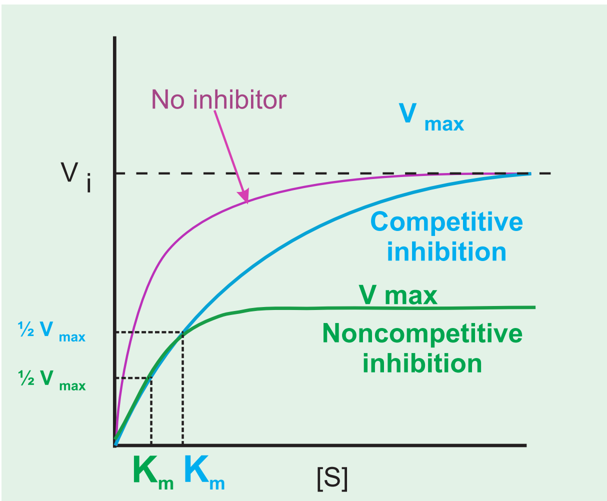


Figure 8.33: Enzyme inhibitors

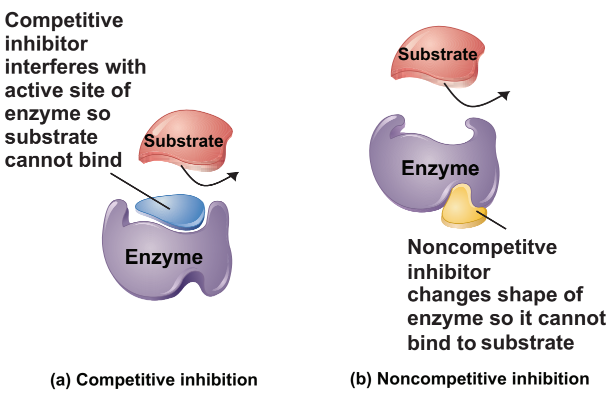


Figure 8.34: Action of Enzyme inhibitors

8.6.10 Competitive Inhibitor

Molecules that resemble the shape of the substrate and may compete to occupy the active site of enzyme are known as **competitive inhibitors**. For Example: the enzyme that catalyses the reaction between carbon di oxide and the CO_2 acceptor molecule in photosynthesis, known as **ribulose biphosphate carboxylase oxygenase (RUBISCO)** is competitively inhibited by **oxygen/carbon-di-oxide** in the chloroplast. The competitive inhibitor is **malonate** for **succinic dehydrogenase** (Figure 8.34).

8.6.11 Non-competitive Inhibitors

There are certain inhibitors which may be unlike the substrate molecule but still combines with the enzyme. This either blocks the attachment of the substrate to active site or change the shape so that it is unable to accept the substrate. For example the effect of the amino acids alanine on the enzyme pyruvate kinase in the final step of glycolysis.

Certain **non-reversible/irreversible inhibitors** bind tightly and permanently to an enzyme and destroy its catalytic properties entirely. These could also be termed as **poisons**. Example – **cyanide ions** which blocks **cytochrome oxidase** in terminal oxidation in cell aerobic respiration, the **nerve gas sarin** blocks a neurotransmitter in synapse transmission.

8.6.12 Allosteric Enzymes

They modify enzyme activity by causing a reversible change in the structure of the enzyme active site. This in turn affects the ability of the substrate to bind to the enzyme. Such compounds are called

allosteric inhibitors. Eg. The enzyme hexokinase which catalysis glucose to glucose-6 phosphate in glycolysis is inhibited by glucose 6 phosphate. This is an example for **feedback allosteric inhibitor**.

8.6.13 End Product Inhibition (Negative Feedback Inhibition)

When the end product of a metabolic pathway begins to accumulate, it may act as an allosteric inhibitor of the enzyme controlling the first step of the pathway. Thus the product starts to switch off its own production as it builds up. The process is self – regulatory. As the product is used up, its production is switched on once again. This is called **end-product inhibition** (Figure 8.35).

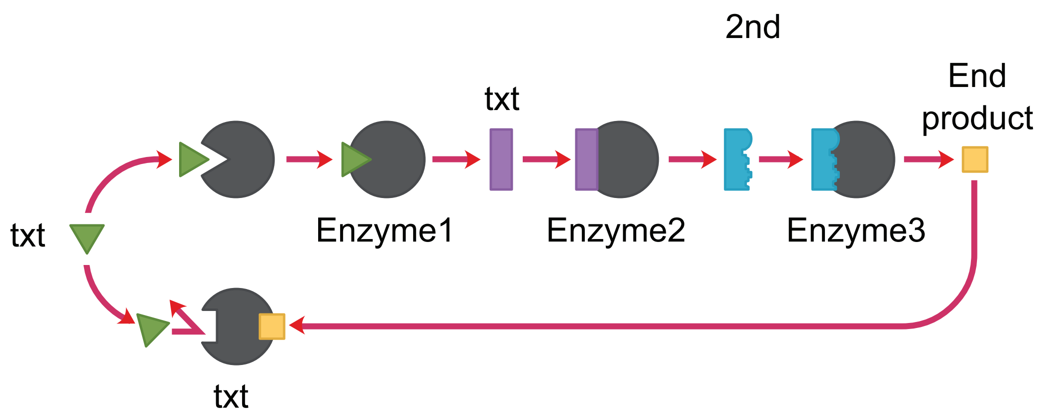


Figure 8.35: Negative feedback inhibition of enzyme

8.6.14 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 8.36).

- **Holoenzyme** – active enzyme with its non protein component.

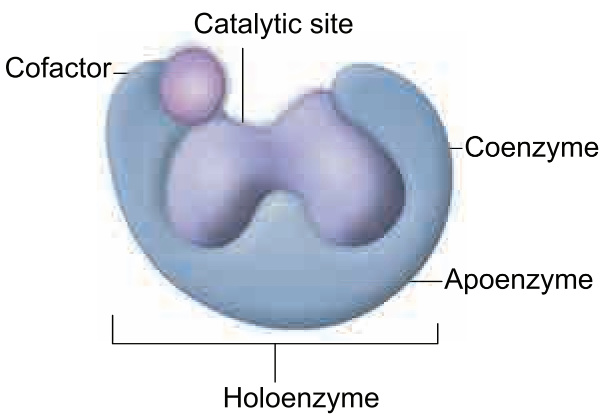


Figure 8.36: Enzyme components

- **Apoenzyme** – the inactive enzyme without its non protein component.
- **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

Ribozyme – Non Protein Enzyme

A Ribozyme, also called as **catalytic RNA**; is a ribonucleic acid that acts as enzyme. It is found in ribosomes.

8.6.15 Nomenclature of Enzymes

Most of the enzymes have a name based on their substrate with the ending **–ase**. For example lactase hydrolyses lactose and amylase hydrolyses amylose. Other enzymes like renin, trypsin do not depict any relation with their function.

8.6.16 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, phosphotransferase
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

(Continued)

Enzymes	Mode of action	General scheme of reaction	Example
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

DO YOU KNOW?

Telomerase – A Ribonucleo Protein

Telomere protects the end of the chromosome from damage. Telomerase is a ribonucleo protein also called as *terminal transferase.*

8.6.17 Uses of Enzymes

Enzyme	Source	Application
Bacterial protease	Bacillus	Biological detergents
Bacterial glucose isomerase	Bacillus	Fructose syrup manufacture
Fungal lactase	Kluyveromyces	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.

DO YOU KNOW?

Friedrich Miescher *was the first to isolate a non-protein substance in nuclei of pus cells and named it as* '**Nuclein**'.

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 8.38)**.**

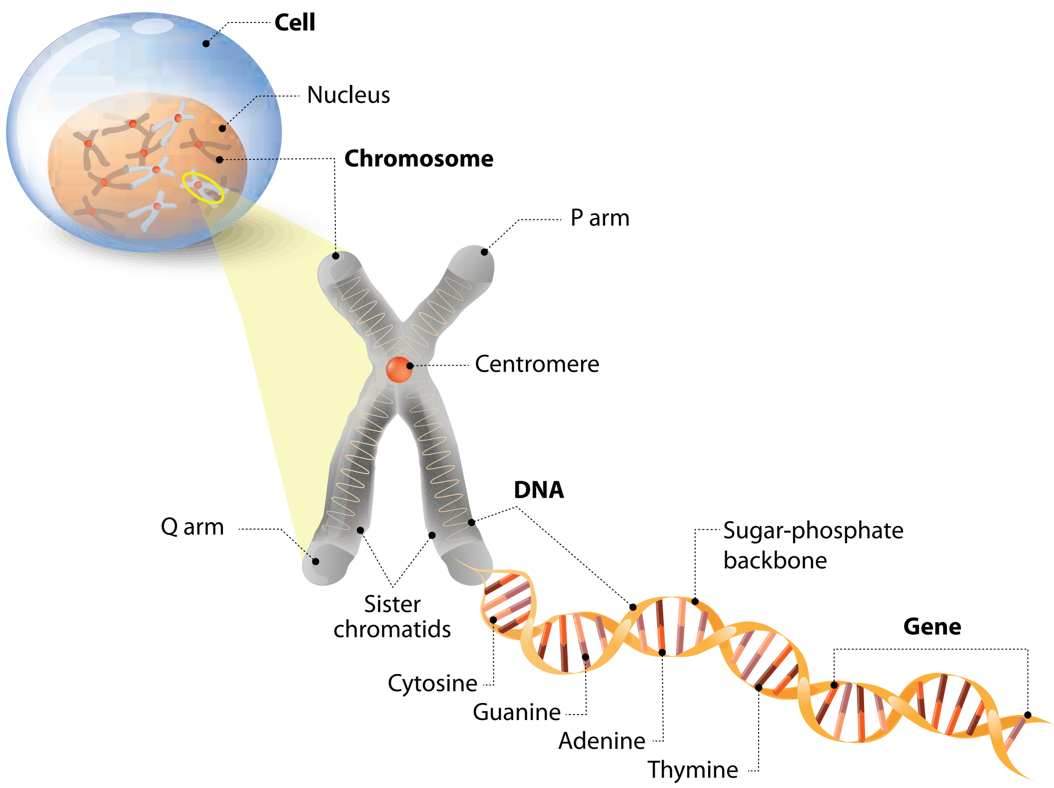


Figure 8.37: Position of DNA in the cell

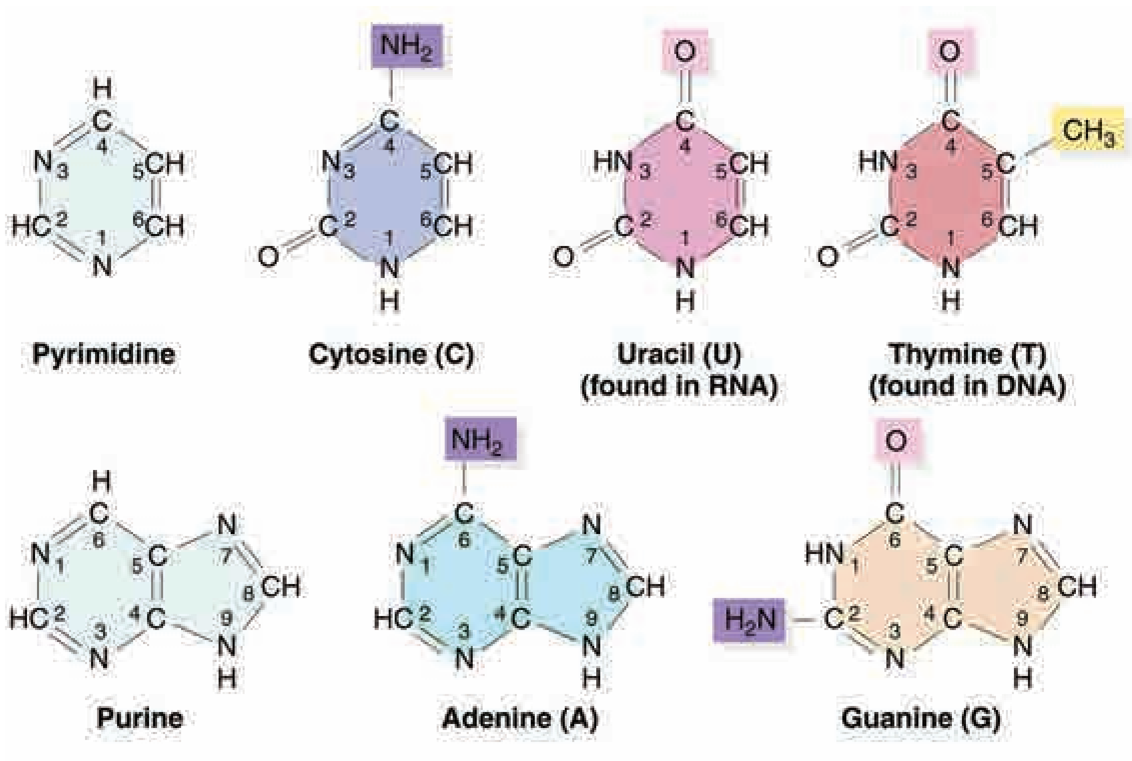


Figure 8.38: Structure of nucleic acid component

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 8.39).

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

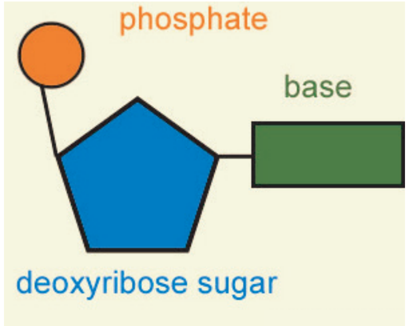


Figure 8.39: Basic component of DNA and RNA

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** (Figure 8.40) 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.

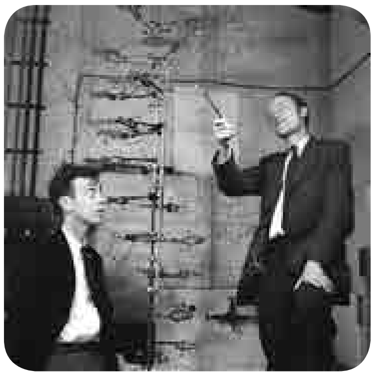


Figure 8.40: Watson and Crick

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.

Chargaff's Rule:

- **A = T; G ≡ C**
- **A + G = T + C**
- **A : T = G : C = 1**

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.

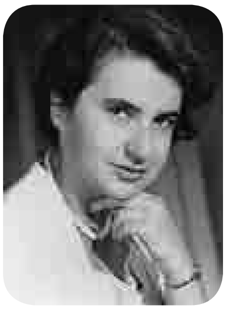


Figure 8.41: Rosalind franklin

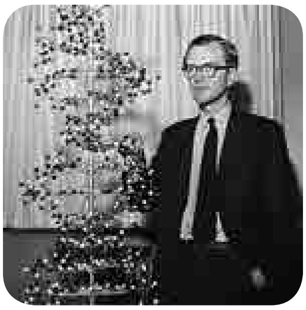
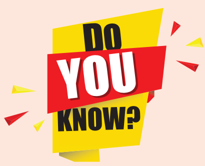


Figure 8.42: Erwin Chargaff



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 (Π – Π) 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 8.43).

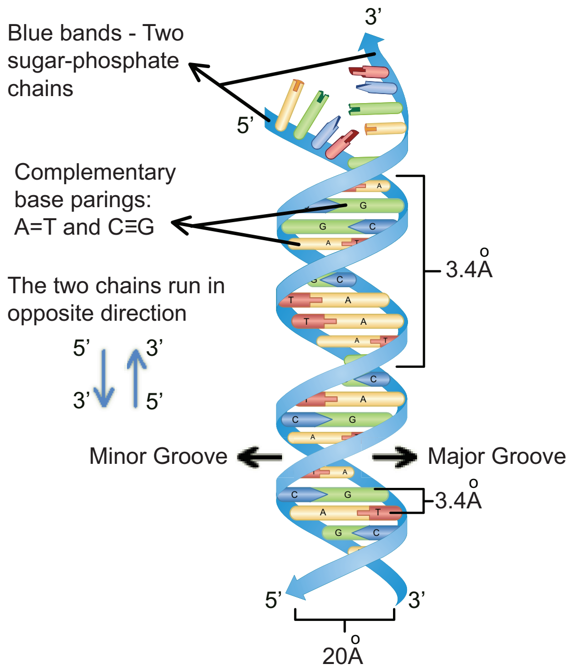


Figure 8.43: Structure of DNA

- 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 8.43) .

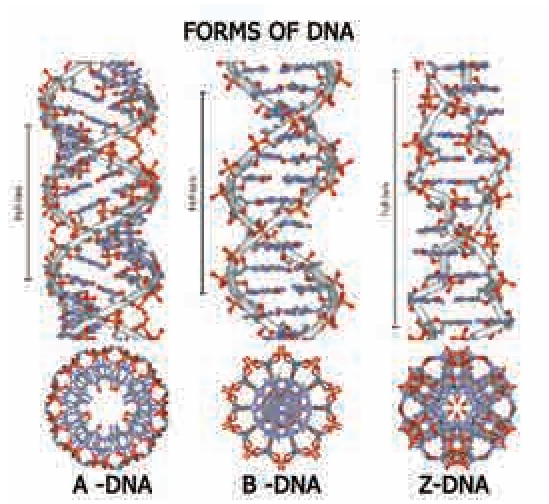


Figure 8.44: Forms of DNA

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

8.7.4 Ribonucleic Acid (RNA)

Ribonucleic acid (**RNA**) is a polymeric molecule essential in various biological roles in coding, decoding, regulation and expression of genes. RNA is single stranded and is unstable when compared to DNA (Figure 8.45).

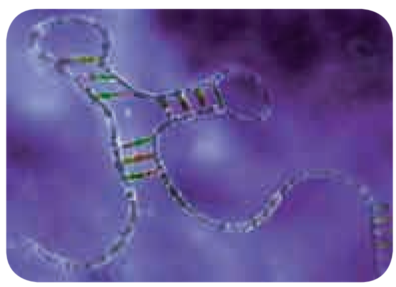


Figure 8.45: Structure of RNA

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 8.46).

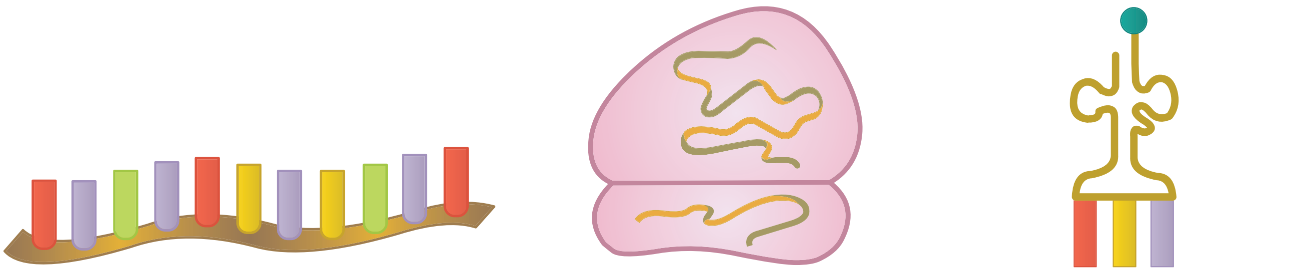


Figure 8.46: Types of RNA

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. Hydrogen bonding between complementary base pairs allows nucleic acids to direct their self replication.

Evaluation

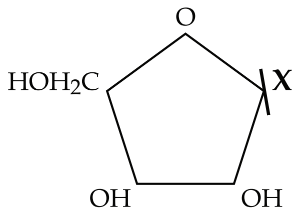
1. The most basic amino acid is
   a. Arginine
   b. Histidine
   c. Glycine
   d. Glutamine

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. Enzymes that catalyse interconversion of optical, geometrical or positional isomers are
   a. Ligases
   b. Lyases
   c. Hydrolases
   d. Isomerases

4. 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

5. 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



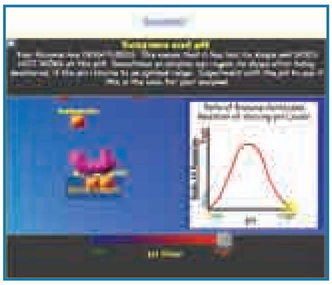
Category	Compound
Cholesterol	Guanine
Amino acid	NH_2
Nucleotide	Adenine
Nucleoside	Uracil

6. Distinguish between nitrogenous base and a base found in inorganic chemistry.
7. What are the factors affecting the rate of enzyme reaction?
8. Briefly outline the classification of enzymes
9. Write the characteristic feature of DNA
10. Explain the structure and function of different types of RNA

ICT Corner

ENZYMES

Bio Catalyst →



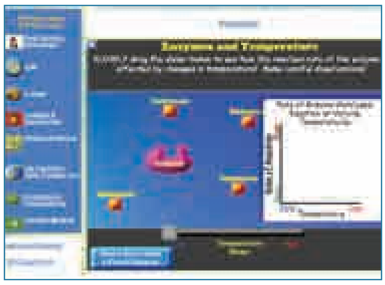
Steps

- 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

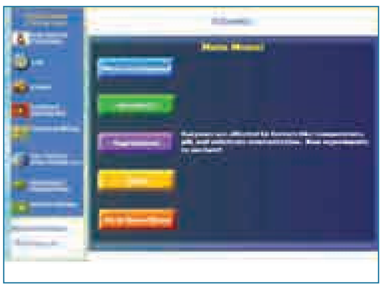
Activity

- Move the slide to change temperature
- Go to next concept
- Try Quiz after experiments

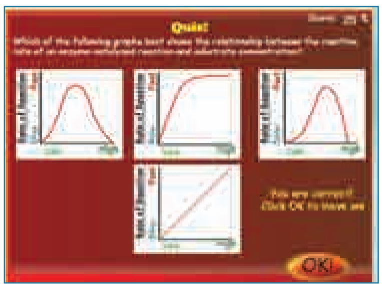
Step 1



Step 3



Step 2



Step 4

URL:

https://www.biomanbio.com/HTML5GamesandLabs/LifeChemgames/lifechem.html

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* Pictures are indicative only

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Glossary

Acetyl CoA	Small, water-soluble metabolite comprising an acetyl group linked to coenzyme A (CoA).
Active site	Region of an enzyme molecule where the substrate binds and undergoes a catalyzed reaction.
Akinetes	Thick walled, dormant, non motile asexual spores.
Aleurone	Outer layer of the endosperm
Anamorph	Asexual or imperfect state of fungi
Anisogamy	Fusion of morphologically and physiologically dissimilar gametes
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
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.
Carcinogen	Any chemical or physical agent that can cause cancer when cells or organism s are exposed to it.
Chemotaxonomy	Classification based on the biochemical constituents of plants
Clades	Group of species comprising common ancestor and its descendants
Cladistics	Methodology used to classify organisms into monophyletic group
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
Dalton	Unit of molecular mass approximately equal to the mass of a hydrogen atom ($1.66 \times 10–24$ g)
Endosperm	Nutritive tissue for the embryo
Endospore	Thick walled, resting spores
Eusporangiate	Sporangium formed from a group of initials
Fossil	The remains or impression of plant or animal of the past geological age
Gametophyte	The haploid plant body
Genome	Complete set of genes in an organism
Germ	Protein rich embryo

Heterospory	Production of spores of different sizes: megaspores and microspores
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;
Leptosporangiate	Sporangium formed from a single initial
Merosity	Number of parts per whorls
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
Nucleoid	Genetic material of bacterium
Oogamy	Fusion of morphologically and physiologically dissimilar gametes
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
Phylogeny	Evolution of group of organisms
Pistillode	Sterile pistil
Plasmogamy	Fusion of cytoplasm
Pluriocular	An ovary with two or more locus
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
Rachilla	Central axis of a spikelet
Sporophyte	Diploid plant body
Teloemorph	Sexual or perfect state of the fungi
Thallospores	Asedual spores formed due to the fragmentation of hyphae
Triplicate	Pollen grain with three furrows or pores
X-Ray crystallography	Most commonly used technique for determining the three-dimensional structure of macromolecules (particularly proteins and nucleic acids) by passing x-rays
Zoospore	Motile, asexual spores
Zygospore	Thick walled diploid resting spores

English – Tamil Terminology

Acropetal succession (arrangement)	நுனி நோக்கிய வரிசை
Aggregatte fruit	திரள்கனி
Akinetes	உறக்க நகராவித்து
Anamorph	பாலிலாநிலை
Anisogamy	சமமற்ற கேமீட்களின் இணைவு
Anthrophytes	பூக்கும் தாவரங்களின் முன்னோடிகள்
Apogamy	பாலிணைவின்மை
Apospory	குன்றலில்லா வித்துத்தன்மை
Arbitary marker	தன்னிச்சையான குறிப்பான்
Basipetal succession	அடி நோக்கிய வரிசை
Biosphere	உயிர்க்கோளம்
Buttress root	பலகை வேர்
Centrifugal	மையம் விலகியது
Centripetal	மையம் நோக்கியது
Cladogram	கிளை வரைபடம்
Coenocytic	பல்உட்கரு நிலை
Conjugation	இணைவு
Cotyledons	விதையிலைகள்
Dry dehiscent fruit	உலர் வெடிகனி
Dry indehiscent fruit	உலர் வெடியாக்கனி
Embryo	கரு
Endosperm	கருவூண்திசு
Endospores	அகவித்துகள்
Eukaryote	உண்மை உட்கரு உயிரி
Eusporangiate	உண்மை வித்தகத்தன்மை
Fossil	தொல்லுயிரெச்சம்
Funicle	சூல்காம்பு
Gametophyte	கேமீட்டக தாவரம்
Gene marker	மரபணு குறிப்பான்
Genome	மரபணுத் தொகுப்பு
Geocarpic fruit	புவிபுதை கனி/நிலத்தகத்துக் கனி
Geophytes	நிலத்தகத்துத் தூண்சேர் தாவரம்
Gynobasic	சூற்பை அடி சூலகத்தண்டு
Heterospory	மாற்று வித்தகத்தன்மை
Homeostasis	சமச்சீர் நிலை
Hydrochory	நீர்மூலம் பரவுதல்
Indeterminate	வரம்பற்ற வளர்ச்சி
Irritability	உறுத்துணர்ச்சி
Isogamy	ஒத்த கேமீட்களின் இணைவு
Karyogamy	உட்கரு இணைவு
Karyokinesis	காரியோகைனசிஸ்
Leaf primodium	இலைத்தோற்றுவி
Legume / Pod	விதைப்பை

Leptosporangiate	மெலி வித்தகத்தன்மை
Maturation promoting factor (MPF)	முதிர்ச்சியை ஊக்கப்படுத்தும் காரணி
Merosity	எண்ணிக்கை அமைவு
Metabolism	வளர்சிதைமாற்றம்
Middle Lamella	இடைமென் அடுக்கு
Monograph	தனிக்கட்டுரை
Multiple fruit	கூட்டுக்கனி
Mycobank	பூஞ்சை வங்கி
Nuclear envelope	நியூக்ளியர் உறை
Nuclear organizer	நியுக்ளியோலார் அமைப்பான்கள்
Nucleoid	உட்கரு ஒத்த அமைப்பு
Oogamy	முட்டை கருவுறுதல்
Pendulous	தொங்குகின்ற
Pericarp	கனி உறை
Petrification	கல்லாதல்
Pili or Fimbriae	நுண் சிலும்புகள்
Pistillode	மலட்டு சூலகம்
Plasmogamy	சைட்டோபிளாச இணைவு
Plumule	முளைக்குருத்து
Plurilocular	பல்லறை சூற்பை
Polymorphism	பலபடிவுடமை
Primary adapter	முதன்மை மாற்றி
Probe	ஆய்வி
Prokaryote	தொல்லுட்கரு உயிரி
Prophage	ஃபாஜ் முன்னோடி
Rachilla	சிறுகதிரின் மையஅச்சு
Radicle	முளை வேர்
Restriction site	வரையறு தளம்
Seed	விதை
Seed coat	விதை உறை
Serotaxonomy	ஊநீர் வகைப்பாட்டியல்
Sporophyte	வித்தகத்தாவரம்
Synaptonemal complex	சைனாப்டினிமல் தொகுதி
Systematics	முறைப்பாட்டு தாவரவியல்
Tandem repeat	ஒருசெயல நிகழும் மாறிகள்
Taxon	வகைப்பாட்டுத் தொகுதி
Telomorph	பால்நிலை
Thallospores	உடல வித்துகள்
Transduction	மரபணு ஊடுகடத்தல்
Transformation	மரபணு மாற்றம்
True fruit	மெய்க்கனி
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 archegonio-phore 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. Gymnospermsareboth 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

BOTANICAL NAMES AND COMMON NAMES

S.No	Botanical name	Common name	Tamil name
1	*Abrus precatorius*	Crab's eye	குன்றிமணி
2	*Acacia nilotica*	Babul tree	கருவேலம்
3	*Acalypha indica*	Indian Acalypha	குப்பைமேனி
4	*Achyranthes aspera*	Chaff flower	நாயுருவி
5	*Albizia lebbeck*	Indian siris	வாகை
6	*Allium cepa*	Onion	வெங்காயம்
7	*Allium sativum*	Garlic	வெள்ளைப்பூண்டு
8	*Aloe vera*	Indian aloe	சோற்றுக்கற்றாழை
9	*Alstonia scholaris*	Devilwood	ஏழிலைப்பாலை
10	*Amorphophallus paeoniifolius*	Elephant foot yam	கருணைக் கிழங்கு
11	*Argemone mexicana*	Mexican poppy	குடியோட்டிப் பூண்டு
12	*Areca catechu*	Betel nut	பாக்கு / கமுகு
13	*Avicennia marina*	White mangrove	வெள்ளை அலையாற்றி
14	*Azadirachta indica*	Neem	வேம்பு
15	*Beta vulgaris*	Beetroot	பீட்ருட்
16	*Bombax ceiba*	White Silk cotton	இலவம் பஞ்சு
17	*Bambosa bambos*	Bamboo	மூங்கில்
18	*Borassus flabellifer*	Palmyra palm	பனை
19	*Bougainvillea*	Paper flower	காகிதப்பூ
20	*Brassica juncea*	Mustard	கடுகு
21	*Brassica oleracea var. botrytis*	Cauliflower	காலிஃபிளவர்
22	*Brassica oleracea var. capitata*	Cabbage	முட்டைக்கோசு
23	*Caesalpinia pulcherrima*	Peacock flower	மயிற்கொன்றை
24	*Calotropis gigantea*	Giant milkweed	எருக்கு
25	*Canna indica*	Canna	கல்வாழை
26	*Carica papaya*	Papaya	பப்பாளி
27	*Cassia auriculata*	Avaram	ஆவாரை
28	*Cassia fistula*	Indian laburnum	கொன்றை
29	*Casuarina equisetifolia*	Whistling pine	சவுக்கு

30	*Ceiba pentandra*	Red silk cotton	செவ்விலவ மரம்
31	*Centella asiatica*	Indian penny wort	வல்லாரை
32	*Chrysanthemum indicum*	Chrysanthemum	சாமந்தி
33	*Cinnamomum zeylanicum*	Cinnamon	பட்டை
34	*Cocos nucifera*	Coconut	தென்னை
35	*Coffea arabica*	Coffee plant	காஃபி தாவரம்
36	*Colocasia esculenta*	Cocoyam	சேனைக் கிழங்கு
37	*Coriandrum sativum.*	Coriander	கொத்துமல்லி
38	*Corypha umbraculifera*	Talipot palm	தாழிப்பனை
39	*Couroupita guianensis*	Cannonball tree	நாகலிங்கமரம்
40	*Crotalaria retusa*	Rattle weed	கிலுகிலுப்பை
41	*Cucumis sativus*	Cucumber	வெள்ளரி
42	*Curcuma amada*	Mango ginger	மா இஞ்சி
43	*Cuscuta reflexa*	Dodder plant	அம்மையார் கூந்தல்
44	*Daucus carota*	Carrot	காரட்
45	*Delonix regia*	Gulmohar,flame tree.	செம்மயிற்கொன்றை.
46	*Dioscorea bulbifera*	Potato yam	கொடிக்கிழங்கு
47	*Dolichos biflorus*	Horsegram	கொள்ளு
48	*Eugenia jambolana*	Jamun	நாவல்
49	*Ficus benghalensis*	Banyan.	ஆலமரம்
50	*Ficus carica*	Common fig	சீமை அத்தி
51	*Ficus racemosa*	Indian fig	அத்தி
52	*Ficus religiosa*	Peepal.	அரச மரம்
53	*Gloriosa superba*	Malabar glory lilly	செங்காந்தள்
54	*Gossypium herbaceum*	Cotton	பருத்தி
55	*Hibiscus rosa-sinensis*	Shoe flower, China rose.	செம்பருத்தி
56	*Hiptage benghalensis*	Clustered hiptage	மாதவிக்கொடி
57	*Hordeum vulgare.*	Barley	பார்லி
58	*Jasminum officinale*	Jasmine	மல்லிகை
59	*Mangifera indica*	Mango	மா
60	*Mimosa pudica*	Touch me not plant	தொட்டாற்சுருங்கி
61	*Mitrogyna parvifolia*	Kadamb	கடம்பு
62	*Moringa oleifera*	Drumstick	முருங்கை
63	*Murraya koenigii*	Curry leaf	கறிவேப்பிலை

64	*Musa paradisiaca*	Banana	வாழை
65	*Nelumbo nucifera*	Indian lotus	தாமரை
66	*Neolamarckia cadamba*	Ven Kadambu	வெண்கடம்ப மரம்
67	*Nerium oleander*	Oleander	அரளி
68	*Numphaea rubra*	Red Water lilly	செவ்வல்லி
69	*Nymphaea nouchali*	Blue water lilly	நீல ஆம்பல்
70	*Nymphaea pubescens*	White water lilly	வெள்ளை அல்லி, நெய்தல்
71	*Ocimum sanctum*	Tulsi	துளசி
72	*Ocimum tenuiflorum*	Tulsi	கருந்துளசி
73	*Oryza sativa*	Paddy, Rice	நெல்
74	*Phaseolus vulgaris.*	Beans	பீன்ஸ்
75	*Physalis angulata*	Balloon cherry	சொடக்குத்தக்காளி
76	*Piper nigrum*	Pepper	மிளகு
77	*Prosopis juliflora*	Honey mesquite	சீமைக்கருவேலம்
78	*Raphanus sativus*	Radish	முள்ளங்கி
79	*Saraca indica*	Ashoka	அசோக மரம்
80	*Solanum nigrum*	Black night shade	மணித்தக்காளி
81	*Solanum lycopersicum*	Tomato	தக்காளி
82	*Solanum melongena*	Brinjal	கத்திரி
83	*Solanum tuberosum*	Potato	உருளை
84	*Sorghum bicolor*	Sorghum	சோளம்
85	*Theobroma cacao*	Cocoa tree	கொக்கோ மரம்
86	*Triticum aestivum*	Wheat	கோதுமை
87	*Vitis vinifera*	Grapes	திராட்சை
88	*Zea mays*	Maize, corn	மக்காச்சோளம்
89	*Zingiber officinale*	Ginger	இஞ்சி
90	*Zizyphus jujuba*	Jujube	இலந்தை

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