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STUDY MATERIAL FOR HSE-I (BOTANY) BASED ON JKBOSE SYLLABUS

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PREFACE

Scientific literacy transcends a basic understanding of scientific principles and processes to include the ability to make sense of the myriad instances where people encounter science in day-to-day life. This content for class HSE-I (Botany) has been created in accordance with the syllabus prescribed by JKBOSE, with several goals in mind: accessibility, customization, and student engagement: all while encouraging students towards high levels of academic scholarship. Instructors and students alike are expected to find that this content offers a strong and comprehensive introduction to botany in an accessible format. The material for the content has been prepared by:

I. Dr. Pervez Maqbool Lone:

Unit-I Diversity of Life, Unit-II Kingdom Plantae, Unit-III-(A) Anatomy of Flowering Plants

II. Dr. Syed Sabhi Ahmad Indrabi:

Unit-III-(B) Plant Physiology, Unit-IV Mineral Nutrition.

Students do much better when they understand why botany is relevant to their everyday lives; we strive to offer the interconnectedness of topics within this extremely broad discipline. As such, this course represents an important opportunity for students to develop the necessary knowledge, tools, and skills to make informed decisions. In order to meet the needs of teachers as well as students, we maintain the overall organization and coverage found in most syllabi for this course. Strength of this content is that instructors can customize adapting it to the approach that works best in their classroom. Moreover, it incorporates critical thinking to help students understand and apply key concepts.

Efforts have been made to create this content not only to fulfil the basic needs of the students but also develop a comprehensive understanding of the concepts and facts. To broaden access and encourage community curation, this content is an "open source". The scientific community is invited to submit examples, emerging research, and other feedback to enhance and strengthen the material and keep it current and relevant for students. Other features of this content include looking closer, a chance to expand a topic more than a typical textbook would. We have tried to make the topics more relevant and appealing to the students at this level.

Any attempt at any level can't be satisfactorily completed without guidance, support and patronage. We would like to express our special thanks of gratitude to **Mr Mohammad Younis Malik**, Director School Education Kashmir, as well as **Ms Suriya Jabeen**, Joint Director Trainings/Principal, State institute of Education, Kashmir who made us able to avail the golden opportunity to contribute for this sacred project that helped us in doing a lot of Research through which we came to learn so many new things. We are really indebted and thankful to them.

The authors are overwhelmed in all humbleness and gratefulness to acknowledge our depth to all those whose resource (online & offline) helped us in gathering information, and collecting data for making this manuscript a success, well above the level of simplicity and into something concrete.

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UNIT-I: DIVERSITY OF LIFE

Syllabus

Variety of Living organisms:

Systematics, need, history and Classification (Artificial, Natural and Phylogenetic).

Biosystematics: Binomial Nomenclature, Two Kingdom System, Five kingdom System- Their Merits and Demerits.

Detailed Study of Kingdom; Monera, Protista and Fungi.

Status of Some Acellular Organisms: (Slime Moulds Like: Viruses and Viroids), Lichens.

Taxonomic Aids: Botanical Garden, Herbaria, Museum & Keys.

Introduction

Biology refers to the study of living organisms, their origins, anatomy, morphology, physiology, behaviour, and distribution.

The term "Biology", in the modern sense, was introduced through the works of Michael Christoph Hanow in 1766. However, it was introduced independently four more times through the works of Thomas Beddoes (1799), Karl Friedrich Burdach (1800), Gottfried Reinhold Treviranus (1802) and Jean-Baptiste Lamarck (1802).

Life

According to scientists life is a unique, complex organisation of ions and molecules which perform certain chemical reactions in order to bring about life activities.

Life is teeming in every corner of the globe – from the frozen Arctics to the searing Sahara. And with over 1.7 million species documented till date, the earth is the only planet in the universe where life is known to exist.

Characteristics of Living Organisms:

All living organisms have some important characteristics which differentiate them from non-living ones. The important one are as under

1. **Individuality:** Each individual has distinct individuality. It cannot be broken into parts.
2. **Protoplasm:** It is most significant part of all living organisms. It is a viscous fluid that fills the cells and is complex of numerous chemical components. Huxley called it 'physical basis of life'.
3. **Cellular Structure:** The bodies of all living organisms are composed of cells. Numerous organelles of the cell carry out variety of co-ordinated functions.



4. **Nutrition:** It is the process of obtaining food. The energy stored within the food material is necessary to maintain all vital activities. Living organisms have are classified into two types autotrophs and heterotrophs.
5. **Metabolism:** The various chemical reactions that take place within living cells and make life possible are together known as metabolism or biochemical reactions. They may be anabolic or catabolic.
6. **Respiration:** Respiration is a catabolic process which involves oxidation of complex food into simpler ones with the release of energy. The released energy is used in various cellular processes.
7. **Movements:** It is one of the important characteristics of life. Animals can move freely, from one place to another while plants being encroached to the soil, they show movements of curvature or variation.
8. **Growth:** The growth of a living organism is an internal and biological process controlled by protoplasm while non- living things grow mostly due to external factors.
9. **Reproduction:** All living organism have the power of reproduction. It is the capacity to produce young ones of the similar kind. The process is essential to maintain the continuity of species.
10. **Life-cycle:** Each living organism completes a life cycle that involves the growth, reproduction and death.
11. **Homeostasis:** It is the ability of living organisms to maintain a favourable internal environment despite changes in the external environment.
12. **Genetic Material:** All living organisms possess genetic or hereditary material in the form of DNA.
13. **Definite shape and size:** All living organisms have a definite shape and size. Due to this property living organisms are called morphous while as non-living matter is called amorphous.

Diversity of Living Organisms or (Biodiversity):

The Greek scholar **Theophrastus** was one of the early Botanists of the world. He is also known as the "**Father of Botany**" due to his major writings on plants. One of his books called "Enquiry into Plants" classified the plants based on the geographical ranges, sizes, uses and growth patterns. The other work called "On the Causes of Plants" explained the economics of growing plants.

Pedanius Dioscorides was another Greek physician from 90-40 A.D. who wrote an encyclopaedia about herbal medicines known as "*De Materia Medica*". This book was used as an important medicinal guidebook for over 1500 years until the invention of compound microscope.

Biodiversity or (biological diversity) is a collective term meaning the totality and variety of life on earth. Biodiversity includes genetic diversity within species, the



variety among species, and range of ecosystem within which life exists and interacts.

The UN convention on biodiversity says there are some 13 million species of organisms, of which 1.75 million have been described. According to International Union for Conservation of Nature (IUCN) estimates above 1.8 million species have been described out of an estimated 5 million to 30 million in existence.

Out of 1.7 to 1.8 million species 1.2 million are animals and 0.5 million are plants and remaining are microorganisms. Every year about 15,000 new species are discovered from tropical rain forests and coral ecosystems.

Number of described species on earth.

1. Bacteria -----	4,000
2. Protista (Algae, Protozoa)-----	80,000
3. Animal (vertebrates) -----	52,000
4. Animal (invertebrates) -----	1,272,000
5. Fungi-----	72,000
6. Plants -----	270,000
Total-----	=1,750,000

Biodiversity Definition:

"Biodiversity is the variation among living organisms from different sources including terrestrial, marine and desert ecosystems, and the ecological complexes of which they are a part".

Biodiversity describes the richness and variety of life on earth. It is the most complex and important feature of our planet. Without biodiversity, life would not sustain.

The term biodiversity was coined by Walter G. Rosen in 1985. It is important in natural as well as artificial ecosystems. It deals with nature's variety in biosphere. It refers to variabilities among plants, animals and microorganism species.

Biodiversity includes the number of different organisms and their relative frequencies in an ecosystem. It also reflects the organisation of organisms at different levels.

Biodiversity holds ecological and economic significance. It provides us with nourishment, housing, fuel, clothing and several other resources. It also extracts monetary benefits through tourism. Therefore, it is very important to have a good knowledge of biodiversity for a sustainable livelihood.



Types of Biodiversity

There are the following three different types of biodiversity:

- I. Species Biodiversity
- II. Genetic Biodiversity
- III. Ecological Biodiversity

I. Species diversity

Species diversity refers to the variety of different types of species found in a particular area. It is the biodiversity at the most basic level. It includes all the species ranging from plants to different microorganism.

No two individuals of the same species are exactly similar. For example, humans show a lot of diversity among themselves.

II. Genetic diversity

It refers to the variations among the genetic resources of the organisms. Every individual of a particular species differs from each other in their genetic constitution. That is why every human looks different from each other. Similarly, there are different varieties in the same species of rice, wheat, maize, barley, etc.

III. Ecological diversity

An ecosystem is a collection of living and non-living organisms and their interaction with each other. Ecological biodiversity refers to the variations in the plant and animal species living together and connected by food chains and food webs. It is the diversity observed among the different ecosystems in a region. Diversity in different ecosystems like deserts, rainforests, mangroves, etc., includes ecological diversity.

Importance of Biodiversity

Biodiversity and its maintenance are very important for sustaining life on earth. Few of the reasons explaining the importance of biodiversity are:

1. Ecological Stability

Every species has a specific role in an ecosystem. They capture and store energy and also produce and decompose organic matter. The ecosystem supports the services without which humans cannot survive. A diverse ecosystem is more productive and can withstand environmental stress.

2. Economic Importance

- i. Biodiversity is a reservoir of resources for the manufacture of food, cosmetic products and pharmaceuticals.
- ii. Crops livestock, fishery, and forests are a rich source of food.
- iii. Wild plants such as Cinchona and Foxglove plant are used for medicinal purposes.



- iv. Wood, fibres, perfumes, lubricants, rubber, resins, poison and cork are all derived from different plant species.
- v. The national parks and sanctuaries are a source of tourism. They are a source of beauty and joy for many people.

3. Ethical Importance

All the species have a right to exist. Humans should not cause their voluntary extinction. Biodiversity preserves different cultures and spiritual heritage. Therefore, it is very important to conserve biodiversity.

Biodiversity in India

India is one of the most diverse nations in the world. It ranks ninth in terms of plant species richness. Two of the world's 25 biodiversity hotspots are found in India. It is the native to important crop species such as pigeon pea, eggplant, cucumber, cotton and sesame. India is also a centre of various domesticated species such as millets, cereals, legumes, vegetables, medicinal and aromatic crops, etc.

There are about 91000 animal species found here. However, diversity is depleting at a drastic rate and various programmes on biodiversity conservation are being launched to conserve nature.

Systematics:

The term "systematics" has been derived from a Greek word, "Systema" meaning "Order" or "sequence". It was coined by Carolus Linnaeus (1707-1778).

Systematics is the study of identification, classification and inter-relationships amongst living organisms. Thus systematics is the science of diversity of organisms. Scientists dealing with systematics are called systematists.

G. G. Simpson (1961) considers systematics as the study of diversity of organisms and all their comparative and evolutionary relationships based on comparative studies of anatomy, ecology, physiology and biochemistry. According to him classification is sub topic of systematic.

Biosystematics or New systematics or Neo systematics:

Biosystematics deals with the variation within a species and its general evolution. It incorporates evidences from genetics, cytology, anatomy and physiology of an organism. It was coined by Camp and Gily in the year 1943.

Uses of Systematics:

1. Systematics gives information about the various kinds of organisms found with their specific habits, habitats, characteristics, affinities etc.
2. Systematics is essential for knowing organisms being used in study of genetics, cytology, physiology, pathology and other branches.
3. Systematics is helpful in recognising weeds, pests and pathogens.



4. Systematics helps to know about food chains, food webs and biological control.
5. Systematics is helpful in knowing different traits present in various varieties, species and sub-species for breeding programmes.

Systematics includes following four fields.

- I. Identification.
- II. Classification.
- III. Nomenclature.
- IV. Taxonomy.

I. Identification:

Finding of correct name and place of an organism in a system of classification is called *identification*. Identification for taxonomic classification is carried out for an organism to determine its similarities with an already known organism.

Identification is aimed at finding the correct name and the proper position of an organism in the already established plan of classification. This is done by examining its morphological and anatomical characters. Identification is done with the help of keys.

II. Classification:

Classification may be defined as the scientific ordering of organisms (Bacteria, Protista, Fungi, Plants and Animals) in a hierarchical series of groups on the basis of their relationships - morphological, evolutionary and others.

Biological Classification:

It is a system of arrangement of organisms into groups on the basis of their similarities, differences and relationships.

The purpose of biological classification is to organise the vast number of known plants and animals into categories that could be named, remembered and studied. It includes collection, preservation and study of specimens and also the analysis of data observed.

The categories used in classification of animals and plants are Kingdom, Phylum (Division in plants), class, Order, family, Genus and Species. Each category is a unit and is also called taxon (Pl. taxa).



Need for biological classification:

A good system of classification is a must for the identification, study and bringing out relationships amongst the organisms. Under water reefs and tropical rain forests seem to possess innumerable undiscovered species. In order to understand living world, it is essential to make inventory of organisms based on their similarities or evolutionary relationships (phylogeny).

History of Biological Classification:

Classification of organisms is almost as old as man himself. Organisms have been classified from different points of view at different times.

Aristotle (384-322 BC), known as "Father of Zoology" studied and described a number of animals in his book "Historia Animalium". Theophrastus (370-284), "father of Botany" described a number of plants in his book "Historia Plantarum". Pliny and Elder (23-79 AD) described 2000 plants and animals. Gaspard Bauhin (Casper Bauhin, 1560-1624) was the first to give two-word names to organisms. John Ray (1627-1705) introduced the word "species".

Carolus Linnaeus (1707-1778), known as "Father of Taxonomy" introduced "binomial nomenclature" in his book "Philosophia Botanica" and described 5900 species of plants in "Species Planetarium" and 4326 species of animals in "Systema Naturae". Lamarck introduced the term 'phylogeny' or developmental history of a race.

First natural system of plant classification was given by Bentham and Hooker (Genera Plantarum 1862-1883) and first phylogenetic system of classification was given by Adolf Engler and Karl Anton Prantl (1887-1915) in their work "Die Natürlichen Pflanzenfamilien; though its outline was proposed by Eichler (1883).

Modern classification is an expanded form of Linnaeus classification. Linnaeus proposed only four units or categories in classification: Class, Order, Genus and Species. However, in modern classification two more categories have been added to these. They are phyla between the kingdom and the class, and family between the order and genus. The main units in the modern classification are phyla, classes, orders, families, genera and species.

Basis of Classification:

The history of biological classification began with Aristotle, the Greek philosopher, who is often called the father of biological classification. He described animal classification based on their habitat i.e., air, water and land. He was the first person to recognize the need for groups and group names in the study of the animal kingdom.

Later, biologists started to work on the classification of living organisms based on their characteristics. Characteristics can be explained in many ways. A group of organisms are similar enough to be classified together by certain



characteristics. Characteristics are the appearance/form and behaviour/function of something. These characteristics decide which organism will be in which group.

Some of the characteristics which are used today to classify organisms are as follows:

- i. Prokaryotic or Eukaryotic cell.
- ii. Unicellular or Multicellular.
- iii. Autotrophs (Photosynthetic) or Heterotrophs (Non-photosynthetic).
- iv. The level of organization and development of organs.

The fundamental characteristic to classify a plant and an animal is their body design. The next level of the hierarchy is, whether the plant is a tree or a shrub. Based on different characteristics, more subgroups will be formed.

Advantages of Biological classification:

Classifying organisms in a systematic way or according to a definite plan is very useful because:

1. It makes their study convenient.
2. It facilitates identification of organisms.
3. It reveals relationships among the various groups of organisms.
4. It reveals evolutionary trends by showing gradually increasing complexity of structure in the various groups of organisms.
5. It helps biologists interpret the poorly visible structures of fossil organisms.

Types of classification:

The different types of classification proposed by botanists have been grouped under three types:

1. Artificial Systems of Classification,
2. Natural Systems of Classification,
3. Phylogenetic Systems of Classification,
4. Phenetic Systems of Classification

1. Artificial Systems:

These systems were used between 300 B.C and 1830. In an artificial system plants are classified into different groups on the basis of only one or more superficial characters mostly for convenience without considering phylogenetic relationships of individuals of a group. In artificial system of classification morphological features, habit and habitats are used for grouping organisms.

All early systems of classification given by Aristotle, Theophrastus, Pliny, Bauhin, John Ray, Linnaeus etc. are artificial systems of classification.



Theophrastus System:

Theophrastus (370 -283 B.C), a Greek naturalist considered as the Father of Botany, classified plants into following four groups on the basis of their habit:

- i. Herbs.
- ii. Under shrubs.
- iii. Shrubs and
- iv. Trees.

This system was described in his book *Historia Plantarum*.

Linnaeus System:

Carolus Linnaeus, the *Father of Taxonomy*, classified plants into 24 groups on the basis of sexual characters. He took only the number, length and union of stamens and carpels into consideration. Hence Linnaeus system is also known as "Sexual System of Classification". His work was published in his book "*Species Plantarum*" published in 1753, in which he described some 7300 plant species.

Disadvantage of artificial system of classification:

The drawback of this system is that plants closely resembling one another become widely separated instead of being grouped together.

1. The criteria used for classification are arbitrary and don't reflect natural relationships.
2. The grouping is based on external features which may appear due to parallel evolution, retrogressive evolution or progressive evolution.
3. Organisms of different affinities may come in the same group.
4. Related organisms are placed in different groups.
5. Artificial classification does not reflect this evolution of organisms.

2. Natural Systems of Classification:

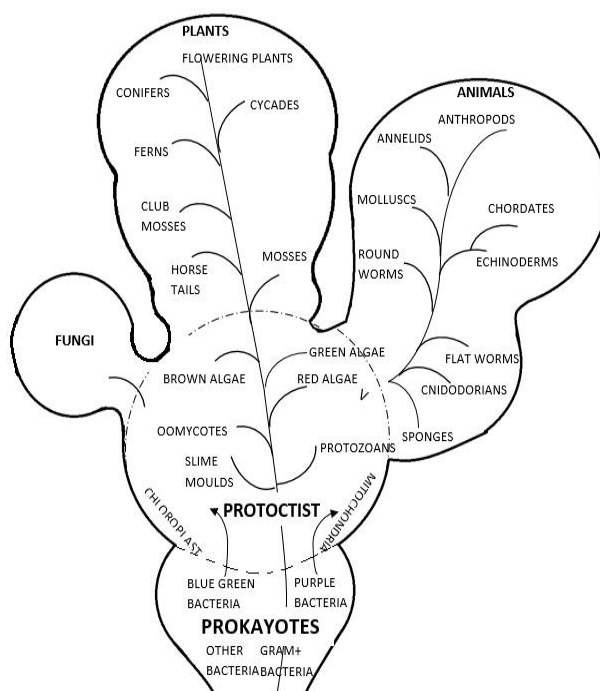
In these systems of classification organisms are classified according to their natural affinities. They include internal as well as external features like embryology, morphology anatomy, physiology, biochemistry, cell- structures and behaviour of organisms. However, evolutionary characters are not considered. As a result some unrelated plants have been grouped together. Despite this drawback, natural system still provides an easy means of the identification of plants and most of the world flora is based on this system.

Systems of classification proposed Schimper (1879), Eichler (1883), Bentham and Hooker (1862-1883), Hutchinson (1962, 1934, 1948, and 1973), Takhtajan, Cronquist etc. are all natural systems of classification.

G. Bentham and J. D Hooker worked together at Royal Botanical Garden Kew, England. Their system of classification was published in their book "Genera Plantarum" written in Latin language.

3. Phylogenetic System of Classification:

The classification of organisms based on the evolutionary relationships is called phylogenetic classification. In this classification organisms believed to be originated from same ancestors are placed in the same group. Phylogenetic classification was introduced by Engler and Prantl. It attempts to draw an evolutionary heritage in the shape of a family tree called Cladogram.



Figure; Family tree Cladogram

Examples are: 1. Engler and Prantl system of classification (1887 – 1899)
2. Hutchinson (1926 – 73)
3. Takhtajan etc.

4. Phenetic System of Classification:

Phenetic (Greek: phainein, to appear)

This type of classification is based on observable characters and all characters are of equal importance. This involves the collection of data and degrees of similarities between different organisms. Phenetic classification resembles phylogenetic classification. In this type of classification complex data are calculated by component's and thus involves numerical taxonomy.



III. Nomenclature:

Nomenclature is defined as assigning proper, specific and distinguishing name to each and every organism as per the universal rules and practices. 12th International Congress at Leningrad in 1975, laid down certain general principles of nomenclature, which were published in 1978 in the form of International Code of Botanical Nomenclature (ICBN).

IV. Taxonomy:

Taxonomy is the branch of biology that deals with the systematic grouping of living organisms. It deals with identification, nomenclature and classification of organisms.

The word "Taxonomy" has been derived from Greek words, "Taxis", meaning 'arrangement or division', and "nomos" meaning 'law or method'. The term taxonomy was coined by *de Candolle* (1813) in his book, "*Theorie Elementaire de la Botanique* (Theory of Elementary Botany)".

A taxon is referred to as a group of organisms classified as a unit. Taxonomy and systematics are complimentary to one another.

Forms or types of Taxonomy:

There are many types of taxonomy depending upon its utility.

1. **Classical Taxonomy:**

Taxonomy based on all available information and attempting to classify living organisms according to their origin, evolution and variations is called classical taxonomy.

2. **Morpho Taxonomy:**

Taxonomy based on the structural features of living organisms is called morphotaxonomy.

3. **Cytotaxonomy:**

Classification of organisms based on cell, chromosome number, structure and behaviour of chromosomes during meiosis is called cytotaxonomy.

4. **Biochemical or Chemotaxonomy:**

Classification of organisms based on the chemical composition like protein and serum etc. is called biochemical or chemotaxonomy.

5. **Numerical Taxonomy:**

Classification of organisms base on the quantitative assessment of similarities and differences in order to make objective assessment is referred to as numerical taxonomy. In this type of taxonomy, relationships of the organisms are determined numerically with the aid of computers.

6. **Experimental Taxonomy:**

It is based on the genetic relationships determined with the help of experiments.



Taxonomic Categories:

In classification, the organisms that closely resemble one another are placed in a group, the groups which have similarities are combined together into larger groups, and these still into larger ones. The various grouping levels or ranks in classification are known as taxonomic categories. Each category has a name allotted to it.

- i. **Taxon:** The term taxon is used to represent any unit of classification. The unit (i.e, taxon) may be large (e.g, Plant kingdom) or small (e.g, Algae, fungi or a single species).
- ii. **Category:** Various sub – divisions of plant kingdom such as division, class, order, family etc are referred to as categories. Kingdom is the highest and species is the lowest category.

Difference between Taxon and Category:

Taxon	Category
A taxon represents real biological objects and is assigned to a category.	A category is an abstract term that simply represents a rank or level of classification.
A taxon can be monotypic or polytypic.	A category may belong to minor or major rank.
The taxon of bacteria is Monera and category is kingdom.	The taxon of birds is Aves and their category is class.

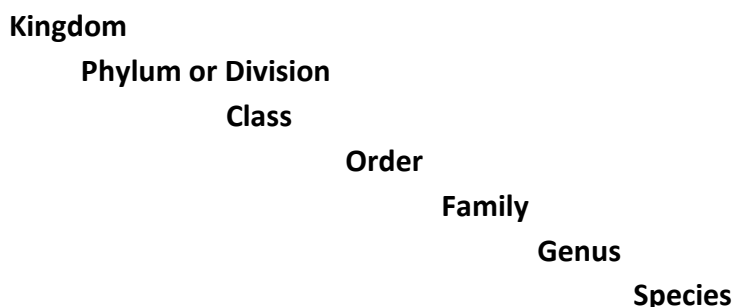


Taxonomic Hierarchy:

"Taxonomic hierarchy is the process of arranging various organisms into successive levels of the biological classification either in a decreasing or an increasing order from kingdom to species and vice versa." Each of this level of the hierarchy is called the taxonomic category or rank.

The various categories used in classification of organisms can be arranged in a hierarchy that indicates levels of kinship. Nearer the categories in hierarchy the greater is the similarity between the organisms.

The hierarchical system was introduced by Linnaeus in the year 1735; however his classification lacked two categories; phyla and families. These were added later. Hierarchy of major categories is given as under:



Taxonomic Hierarchy Categories:

The International Botanical Congress has established seven taxonomic categories in which different organisms are classified. They are also called as Obligate Categories.

1. Kingdom
2. Division
3. Class
4. Order
5. Family
6. Genus
7. Species

1. Species (John Ray 1693):

It is the basic or lowest taxonomic category, which consists of one or more natural populations of individuals that resemble one another more closely than individuals of other species, interbreed freely, having distinct genetic set up and are reproductively isolated from others. e.g., *Panthera Leo* (Lion), *Mangifera indica* (Mango), *Solanum tuberosom* (Potato), *Juglans regia* (walnut).



2. Genus (John Ray 1693):

It is the first higher category above the level of species. A genus may have one or several species. A genus having single species is called monotypic. e.g. genus. *Homo* is monotypic having single species, *Homo sapiens*. The genus, *Solanum* is polytypic have three species, like, *S.tuberosum* (potato), *S. melongena* (Brinjal) and *S. lycopersicum*. All the species of a genus have a number of common features called correlated characters.

3. Family: (John Ray 1693):

It is a taxonomic category which includes one or more related genera. All the genera of a family have some common or correlated features. In plants the family ends in the suffix- *aceae*, and sub-family in *-oideae*.

Examples: The plant family ends with suffix '*aceae*'. Family *Solanaceae* of dicots has genera like *Solanum*, *Datura*, *Petunia* and *Atropa*.

Animal family ends with suffix '*idea*'. eg., the families in the order *Carnivora* include *Canidae*, *Felidae*, *Ursidae*, etc.

4. Order: (Linnaeus 1735):

It is a taxonomic category having one or more related families that possess some similar correlated characters which are lesser in number as compared to correlated characters of genera of a family. e.g., Order *Malwales* consists two families, viz, *Malwaceae*, *Calyciflorae*. The name of order ends with suffix – *ales*.

5. Class: (Linnaeus 1735):

Class was the most general rank in the taxonomic hierarchy until phyla were not introduced. It is the next category above the order. It is made up of one or more orders.

Kingdom *Animalia* includes 108 classes including class *mammalia*, *reptilia*, *aves*, etc. However, the classes used today are different from those proposed by Linnaeus and are not used frequently.

In plants suffix used for class is; *nae*, *-phyceae*, *-opsida*. e.g., *Dicotyledonae*.

6. Phylum (Ernst Haeckel 1866)/Division (Eichler 1883):

It is a taxonomic category higher than class and lower in rank to kingdom. The term *Phylum* is used for animals while the term *division* is employed for plants. *Division/Phylum* consists of one to several related classes having similar characters. There is no fixed suffix for animals, however The *division* is given the



suffixes –phyta and the sub-division –phytina.. There are 35 phyla in kingdom Animalia. For Example – Porifera, Chordata, Arthropoda, etc.

7. Kingdom (Linnaeus 1735):

It is the highest taxonomic category or level of classification. It includes all organisms that share a set of distinguishing common characters. There are 5 kingdoms in which the living organisms are classified, namely, Animalia, Plantae, Fungi, Protista, and Monera.

It is observed that the number of common or correlated characters is maximum in lower rank categories. The number progressively decreases with the rise in rank of category.

Example of Taxonomic Hierarchy:

Following is the example of taxonomic hierarchy:

Taxonomic Hierarchy	Examples	Characteristics
Kingdom	Animalia	Organisms able to move on their own.
Phylum	Chordata	Animals with a backbone.
Class	Mammalia	Chordates with fur or hair and milk glands.
Order	Primates	Mammals with collar bones and grasping fingers.
Family	Hominidae	Primates with relatively flat faces and three dimensional vision.
Genus	<i>Homo</i>	Hominides with upright posture and large brains.
Species	<i>sapiens</i>	Members of the genus <i>homo</i> a high forehead and thin skull.

Biosystematics

Biosystematics (Camp and Gilly 1951) is the science through which life forms are discovered, identified, described, named, classified and catalogued with their diversity, life histories, living habits, role in an ecosystem, and spatial and geographical distribution recorded.

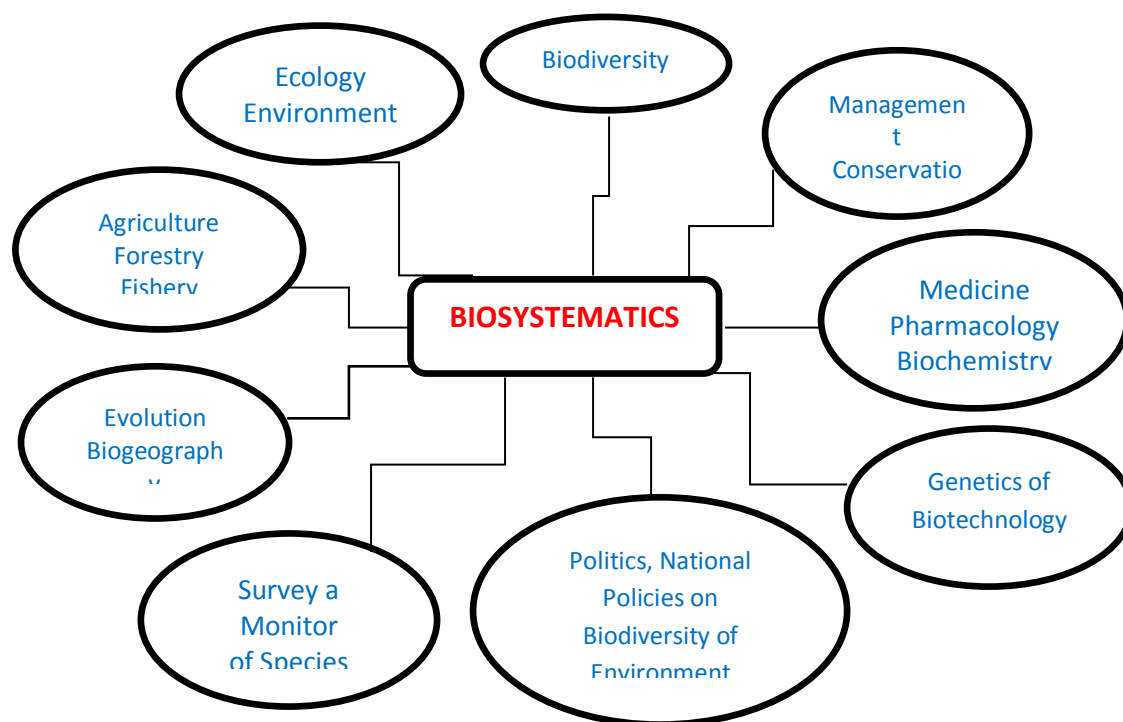


Figure: Flow chart Biosystematics

The centre of this chart depicts biosystematics whose function is to generate fundamental knowledge of living things on which other fields of biological research and applied programs (surrounding circles) depend.

Biosystematics is a sub-division of biological and zoological objectives that focuses upon origin evolutions and diversification of life from the beginnings of the most primitive micro-organisms through to the present day species. It looks closely at how the animal kingdoms and subsequent sub divisional ranks came into being and studies and explains the relationship between them. The subject itself is broken down into more specific areas of study such as cladistics, phylogenetics and morphology.

Systems of Scientific names:

- I. Binomial Nomenclature
- II. Trinomial Nomenclature
- III. Polynomial Nomenclature



I. Binomial Nomenclature:

Binomial Nomenclature ("two-term naming system"), also called binominal nomenclature ("two-name naming system") or binary nomenclature, is a scientific system of naming an organism.

A scientific name according to binomial system of nomenclature is composed of two parts, both of which use Latin grammatical forms, although they can be based on words from other languages. Such a name is called a binomial name (which may be shortened to just "binomial"), a binomen, binominal name or a scientific name; more informally it is also called a Latin name.

The credit of giving binomial system of nomenclature goes to Swedish naturalist Carolus Linnaeus. He explained this system in the 10th Edition of his famous book, *Systema Naturae* published in 1758.

According to this system the name of a plant or animal is composed of two Latin words, e.g., *Solanum tuberosum*. The first word indicates the name of the genus, called generic name, and the second word denotes the name of the species called specific name.

The generic and specific names always have some meaning. They are based on some special characters of the plant, on the name of any scientist or on some legend.

II. Trinomial Nomenclature:

Naming of organisms with subspecies or varieties is called trinomial nomenclature. It includes three words such as genus, species and sub-species or variety. E.g. *Brassica campestris botrytis*; *Homo sapiens europaeus* (Man of European race).

III. Polynomial Nomenclature:

Naming of organisms based on different characteristics such as habit and habitat, that consist of many words is called Polynomial nomenclature. However this was practiced before 1750.

E.g. *Caryophyllum saxatile folis gramineis umbellatis corymbis*. Meaning, *Caryophyllum* growing on rocks, having grass like leaves with umbellate corymbose inflorescence.

Catnip (a perennial herb from the mint family Labiatae) was named, *Nepta floribus interrupte spicatus pendunculatis*, meaning *Nepta* with flowers in an interrupted pedunculated spike.



Rules for Scientific Names:

The International Code of Botanical Nomenclature (ICBN, 1961) has formulated following principles or guidelines for naming of plants.

1. Each organism has a distinct scientific name having two words, generic and specific.
2. The generic and specific words should not have less than three letters or more than twelve letters.
3. The generic name is written first. It is like a noun. Its first letter is always capital.
4. The same generic name cannot be given twice in the same kingdom. Rather, its repetition in the other kingdoms should also be avoided. The same specific word can be used several times but with different genera. e.g. *Magnifera indica*, *Spirogyra indica*.
5. The specific word or epithet is written after the generic name. It should be short, simple but can be compound. e.g. *Hibiscus rosa-sinensis*.
6. The names are derived from Latin language (Latin Homo – man). When words are used from other languages, they are Latinised with suitable ending. E.g. *Magnifera indica*.
7. Very rarely generic and specific names are the same. E.g., *Gorilla gorilla*
8. The name of the discoverer is appended to the two-word scientific name either in full or abbreviated form.
9. Scientific name is printed in italics and when hand written they are underlined separately. Exceptions are made when the name is used as a title of a book, chapter or Para. The name of the discoverer is appended on roman script without any break or comma, e.g., *Homo sapiens*-L.
10. Scientific names given prior to 01/05/1753 for plants (Species Plantarum) and 01/08/1758 for animals (Systema Naturae) are not recognised.
11. When an organism has been given different names by different workers; the earlier one is given validity. This is called law of priority.
12. Families or sub-families should be named after some prominent genus e.g., Asteraceae after *Aster*, Rosaceae after *Rosa*.

Advantages of Scientific Names:

The scientific names have following advantages.

1. Scientific names help in the classification of organisms.
2. A newly organism can be easily described and named.
3. Scientific names minimize the number of names one is required to learn. It also eliminates the likely confusion of multiple naming.
4. An incorrect or inappropriate name can be easily set right.



5. The scientific names are universal and are used all over the world irrespective of the language of particular region or country.
6. The scientific names indicate relationship of the species with others placed in the same genus.
7. The scientific names are often descriptive, indicating some important characteristics of organisms.

Disadvantages of Binomial Nomenclature:

Some of the basic drawbacks of binomial nomenclature are:

1. If two or more names are currently in use, according to the Law of Priority, the correct name will be the one used first and the others end up being synonyms as validity is the senior synonym. Providing stability in the naming and classification of organisms must be emphasized.
2. The names used prior to those included in the "Systema Naturae", by Linnaeus are not recognized.
3. The usefulness of scientific names is limited by the fact that the taxonomic groups are not fixed in size; a taxon may have a varying circumscription.
4. The group of a particular scientific name refers to, can be quite small according to some people and quite big according to others. This will depend on taxonomic system. E.g. the traditional view of the family Malvaceae includes over a thousand species, but in some modern approaches it contains over four thousand species.
5. Some scientific names refer to groups that are very stable e.g. Equisetaceae, Magnoliaceae, while for other names a careful check is needed to see which circumscription is being used e.g. Fabaceae, Scrophulariaceae, Urticaceae, etc.
6. Latin names are mostly difficult to memorise. For these reasons, some organizations and governments agencies should attempt to create a list of official names based on the country's native or official language.
7. Scientific names are difficult to learn. To ordinary people they are, being in Latin or in Latinised Greek meaningless.

Codes of Biological Nomenclature:

Five codes of biological nomenclature have been drawn up.

1. International Code for Botanical Nomenclature (ICBN)
2. International Code for Zoological Nomenclature (ICZN)
3. International Code of Nomenclature for Bacteria (ICNB)
4. International Code of Viral Nomenclature (ICVN)
5. International Code for Nomenclature of Cultivated Plants (ICNCP)

Kingdom systems of classification:

1. Two Kingdom System of Classification:

The two kingdom system of classification was proposed by Carolus Linnaeus in 1758. He divided the living organisms into two groups on the basis of certain characters that differentiated the two from one another. The two Kingdoms were 'Plantae' for plants and 'Animalia' for animals. The Kingdom 'Plantae' included bacteria, fungi, algae, liverworts, mosses, ferns, conifers and flowering plants, whereas the kingdom Animalia included Protozoans, sponges, fishes, worms, insects, crabs, centipedes, millipedes, spiders, snails, reptiles, birds and Mammals.

Each Kingdom was then divided into smaller taxa I.e., phyla, classes, orders, Families, Genera and species.

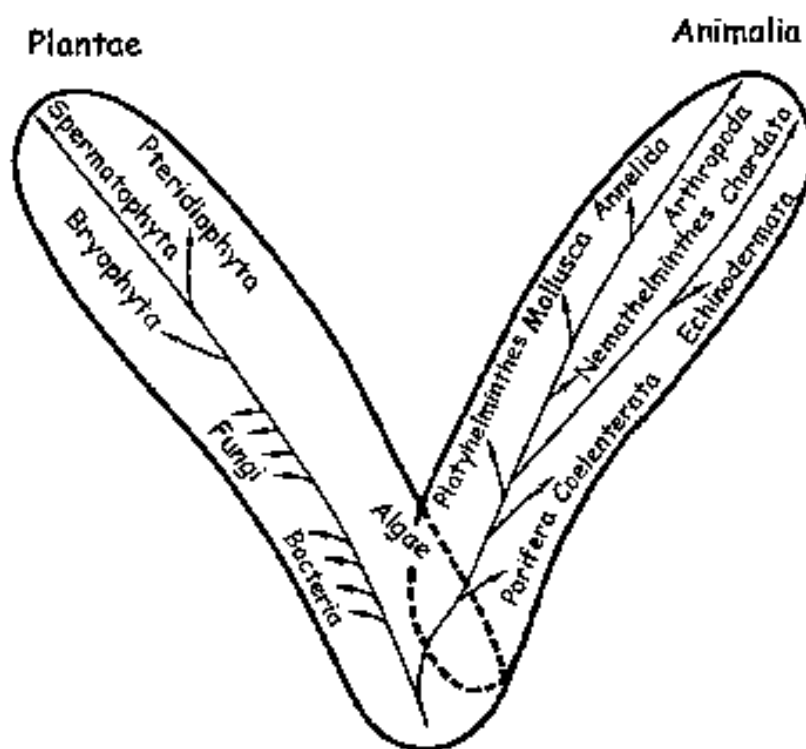


Figure: Evolutionary Scheme of Two Kingdom System



Characteristic features of Two-Kingdoms:

I. Kingdom Plantae:

The original plant kingdom included bacteria, fungi, algae, liverworts, mosses, ferns, conifers and flowering plants. The plants have the following distinguishing features:

1. Form, size and symmetry:

The form and size in plants is generally variable. Plant body is usually asymmetrical due to irregular form. However, in higher plants structures like leaves and flowers have a definite form and shape.

2. Movement and Locomotion:

Plants move their parts slowly towards stimuli. They lack locomotion as they are rooted.

3. Growth:

In plants growth occurs at growing points only. It is unlimited and continues as the plant live.

4. Metabolism:

- i. **Nutrition:** Plants are generally autotrophs. Some are saprotrophs. Only materials in solution are absorbed.
- ii. **Respiration:** Plants take up CO_2 and release O_2 during the day time to carry on photosynthesis.
- iii. **Excretion:** Plants being passive organisms, form little nitrogenous wastes. Hence they lack excretory organs.

5. Irritability:

Plants respond external stimuli very slowly because they lack sense organs, nervous system and muscles.

6. Reproduction and regeneration:

Plants reproduce both sexually as well as asexually. They take services of biotic and abiotic agencies in sexual reproduction.

7. Reserve Food:

Plants store food in the form of starch.

8. Cell Structure:

Plant cell:

- i. Is bound by a thick rigid cell wall.
- ii. Contains a large central vacuole.
- iii. Usually lack centrosomes.
- iv. Generally have plastids.
- v. Lack contractile vacuole.



9. Cell Function:

Cell can synthesis all the needed amino acids, coenzymes and vitamins.

II. Kingdom Animalia:

The kingdom Animalia included Protozoans, sponges, jelly fishes, worms, insects, crabs, centipedes, spiders, snails, starfishes, sharks, bony fishes, birds and mammals etc. They have the following general characters.

1. Form size and symmetry:

Forms and size are almost constant in animals. Animal body is usually symmetrical because of its regular form.

2. Movement and locomotion:

Animals move their parts rapidly due to the presence of muscles. They also show locomotion.

3. Growth:

In animals growth is uniform. It is limited. Animal growth involves enlargement of organs already present in the young. New organs are not formed during growth.

4. Metabolism:

- i. **Nutrition:** Nutrition in animals is heterotrophic or holozoic. Some are saprotrophs or even autotrophs (Euglena).
- ii. **Respiration:** Animals take up oxygen and release CO₂.
- iii. **Excretion:**
Animals being active organisms form nitrogenous waste matter, which is eliminated by excretory organs.

5. Irritability:

Animals respond to external stimuli quickly because they mostly have sense organs, nervous system and muscles.

6. Reproduction and regeneration:

Most of the animals reproduce sexually and do not depend on external agencies. Asexual reproduction and regeneration is confined to lower organisms.

7. Reserve food:

Animals store food in the form of glycogen.

8. Cell structure:

Animal cell:

- i. Lack rigid cell wall.
- ii. Have only small vacuoles instead of large central one.
- iii. Usually contains a centrosome.
- iv. Plastids are absent.
- v. May have contractile vacuole.
- vi. Does not contain inorganic crystals.

9. Cell functions:

Animal cells:



- i. Cannot synthesize all the needed amino acids, coenzymes and vitamins.
- ii. Divide by cell furrowing.

Merits of Two Kingdom System of Classification:

1. Plants and animals were derived into two kingdoms not abruptly but based upon specific characters.
2. It initiated systematic methods to classify the organisms. More and more characters were later into consideration for development of better methods.

Demerits of Two Kingdom System of Classification:

1. Distinction between higher and more familiar plants and animals is quite clear. There is no difficulty in considering a tree or a moss a plant and a cow or grasshopper an animal. However, lower organisms cannot be recognised easily as plants or animals. Some of them have characters of both the kingdoms, and may be placed in any. A few examples are as under:

- i. **Euglena**: It is a unicellular organism which has both animal and plant features. It possesses a whip like flagellum for locomotion, a mouth, a contractile vacuole, power of contracting body, reproduction by binary fission, and lack a cell wall. On the basis of these features it can be considered as animal. But many species of Euglena have chlorophyll and Pyrenoids, and carry on photosynthesis. The dual mode of nutrition is called mixotrophic. The chlorophyll bearing species if kept in dark, they lose chlorophyll and start heterotrophic nutrition.
- ii. **Chlamydomonas**: It is a unicellular algae. It is motile, has a fixed shape and possesses a photosensitive organelle like the animals and is autotrophic like the plants.
- iii. **Slime Moulds**: Slime moulds, a group of fungi, lack cell wall, can creep, and ingest particulate matter in the vegetative phase, but develop a cell wall in the reproductive phase. Thus they resemble animals at one stage and plants at another.
- iv. **Sponges**: These are fixed, branched and irregular creatures like the plants. They lack sense organs and nervous system. They have holozoic nutrition and excrete nitrogenous waste material like the animals.

2. **Lichens** are peculiar organisms which take plant as well as animal characters. They are composed of algae and fungi living in association.

3. Unicellular plants (diatoms) and animals (protozoans) are clearly related. They have the same level of organisation and reproduce by fission. But they are placed in different kingdoms.



4. There was no distinction between eukaryotes and prokaryotes. e.g., bacteria which lack nuclear envelope and cytoplasmic organelles but still they are placed in kingdom Plantae.

5. It kept photosynthetic and non- photosynthetic organisms together in plant kingdom. e.g., Fungi which lack chlorophyll and are saprotrophic still placed in Kingdom Plantae.



2. Five Kingdom system of classification:

The system of assembling organisms into groups or sets on the basis of likenesses and variances is called classification. It simplifies the study of a wide variety of organisms in a very systematic manner.

The five kingdom classification was proposed by Robert. H. Whittaker, an English ecologist in 1969 to show the phylogenetic relationships of organisms. In this system organisms have been placed according to their structure and evolution. Whittaker divided the living world into five kingdoms: Monera, Protista, Fungi, Animalia and Plantae.

Origin of five Kingdoms:

In the five kingdom system of classification, the Monera are thought to have given rise to the Protista, from which the remaining three kingdom of multicellular organisms. Fungi, Plantae and Animalia, evolved along separate lines. Fungi were the first to arise from the Protista. Later about a billion years ago, certain Protists evolved into Animalia. Later some years ago some Protists evolved into Plantae.

The five kingdoms are proposed by Whittaker are:

- i. Kingdom Monera (The kingdom of Prokaryotes).
- ii. Kingdom Protista (The kingdom of unicellular eukaryotes).
- iii. Kingdom Fungi (The kingdom of multi cellular Decomposers).
- iv. Kingdom Plantae (The kingdom of multi cellular Producers).
- v. Kingdom Animalia (The kingdom of multi cellular Consumers).

Basis of Five Kingdom System of Classification:

1. Complexity of cell structure:

Two types of cell structures are recognised:

- i. **Prokaryotic Cells:** The prokaryotic cells are single membrane systems, carry respiratory enzymes in the plasmalemma, lack streaming movements in the cytoplasm, lack sub cellular organelles except 70S ribosomes and thylakoids, lack membrane around the genetic material, have circular DNA, are haploid, do not form mitotic apparatus and lack meiosis, gametogenesis and fertilization,
- ii. **Eukaryotic cells:** They are double membrane systems carry respiratory enzymes in mitochondria, contain sub cellular organs like mitochondria, Golgi apparatus, plastids and have nuclear envelope round the genetic material forming a distinct nucleus, have linear DNA associated with proteins, may be haploid or diploid, have mitotic apparatus during cell divisions and undergo meiosis, gametogenesis and fertilization.



Difference between Prokaryotic and Eukaryotic Cells:

Though these two classes of cells are quite different, they do possess some common characteristics. For instance, both possess cell membrane and ribosomes, but the similarities end there. The complete list of differences between prokaryotic and eukaryotic cells is summarized as follows:

Characteristic feature	Prokaryotes	Eukaryotes
Type of Cell	Always unicellular	Unicellular and multi-cellular
Cell size	Ranges in size from 0.2 μm – 2.0 μm in diameter	Size ranges from 10 μm – 100 μm in diameter
Cell wall	Usually present; chemically complex in nature	When present, chemically simple in nature
Nucleus	Absent	Present
Ribosomes	Present. Smaller in size and spherical in shape	Present. Comparatively larger in size and linear in shape
DNA arrangement	Circular	Linear
Mitochondria	Absent	Present
Cytoplasm	Present, but cell organelles absent	Present, cell organelles present
Endoplasmic reticulum	Absent	Present
Plasmids	Present	Very rarely found in eukaryotes
Ribosome	Small ribosomes	Large ribosomes
Lysosome	Lysosomes and centrosomes are absent	Lysosomes and centrosomes are present
Cell division	Through binary fission	Through mitosis
Flagella	The flagella are smaller in size	The flagella are larger in size
Reproduction	Asexual	Both asexual and sexual
Example	Bacteria and Archaea	Plant and Animal cell

2. Mode of nutrition:

Two types of nutrition are recognized:

- i. **Autotrophic Nutrition**
- ii. **Heterotrophic Nutrition**

Autotrophic nutrition is of two types: Chemosynthesis and Photosynthesis. Likewise heterotrophic nutrition is also of two types i.e., ingestive or holozoic and absorptive or saprophytic. They correspond to three life styles of organisms: Producers, Consumers and Decomposers.



3. Phylogenetic Relationships:

Phylogenetic Relationships of organisms are index of their true Kinship. Fossil records provide information about the evolutionary relationships of organisms. These relationships are ascertained from morphology, cytology, genetic, biochemistry and physiology of organisms for correct classification of organisms.

Merits of Five Kingdom System of Classification:

1. Separation of the Prokaryotes from the plants into an independent kingdom Monera was of much importance as they differ from all other organisms in their morphological and physiological organisations.
2. Eukaryotes like Euglena had earlier been included both in plants as well as animals. Grouping of unicellular eukaryotes into separate Kingdom, Protista eliminated this anomaly.
3. Elevation of Fungi to the rank of a Kingdom is fully correct because they differ in morphology as well as physiology from the plants with which they were grouped earlier.
4. The Plant and Animal Kingdoms are now more homogenous groups than they were in the earlier Two-Kingdom System of Classification.
5. Five Kingdom system of Classification is based on cellular organization and modes of nutrition, the characters which evolved very early in the organic world.
6. Five Kingdom system of Classification seems more phylogenitically reasonable because it indicates the gradual evolution of early organisms into plants and animals to a larger extent.

Demerits of Five Kingdom System of Classification:

1. The position of viruses is not clear.
2. Kingdom Protista includes organisms, having diverse form, structure and life cycle, hence does not seem to be proper grouping.
3. Some organisms included under Protista (e.g., Dinoflagellates) are not eukaryotic rather mesokaryotic.
4. Slime moulds placed under Protista differ considerably from the rest Protists.
5. Both the kingdom Monera & Protista includes organisms which have cells with cell wall as well as without cell wall.
6. The kingdom Protista and Monera include diverse, heterogeneous forms of life, as both the kingdoms, there are both autotrophic as well as heterotrophic organisms.



Detailed study of various Kingdoms

I. Kingdom Monera:

The kingdom Monera includes bacteria, cyanobacteria (Blue-green-algae), Archaeobacteria and some smaller groups like Mycoplasmas, Rickettsias, Actinomycetes etc.

Bacteria

Bacteria were first discovered by a Dutch (Holland), Antony Von Leeuwenhoek in 1676. He observed them in a rain drop with the help of simple microscope designed by him. The name bacteria (Greek= small stick) was given to these organisms by a German Biologist Christian G. Ehrenberg (1828). Louis Pasteur laid the scientific foundation of Bacteriology.

General Characters:

The following are some of the major characters of bacteria.

1. Bacteria are the simplest and the most primitive organisms. They are cosmopolitan and found in all places where life is possible.
2. Bacteria are considered to be plants because they have a rigid cell wall.
3. Bacteria are Prokaryotes.
4. Bacteria are unicellular and generally occur singly. Some of them are found in groups.
5. Bacteria lack nuclear membrane and therefore, distinct nucleus and nucleoli are absent.
6. Bacteria also lack membrane bound organelles, like Endoplasmic reticulum, Golgi bodies, Mitochondria, Plastids etc.
7. Most of the bacteria lack chlorophyll, hence, they are heterotrophic. However, few bacteria possess chlorophyll and are autotrophic. The chlorophyll remains scattered in the cytoplasm.
8. Genetic material is represented by histone free DNA.
9. The commonly reproduce vegetatively by fission.
10. Variation in the genetic characters is due to genetic recombination brought about by conjugation, transformation and transduction. Flagellated gametes are however, not produced.

Distribution:

Bacteria are found in all the habitable places. They are widely distributed in air, water and land. Large number of bacteria also occurs in animal and human bodies. Bacteria can live both aerobically as well as anaerobically. They can survive in extreme cold (-190°C) and can also tolerate very high temperature (80°C) and drought. The presence of bacteria in variety of habitats is due to



- i. Their resistant nature.
- ii. Characteristic mode of nutrition.
- iii. Formation of resistant endospores.

Shapes of Bacteria:

Following four fundamental shapes of bacteria are recognised.

1. **Bacillus or rod – shaped:** These are small stick – shaped or rod- shaped bacteria. This is the commonest shape found in bacteria. Bacilli may occur in following two forms.

- i. **Diplobacillus:** In this form two or more bacilli occur in pair e.g., *Corynebacterium diphtheriae*.
- ii. **Streptobacillus:** In this type many bacilli occur in a chain e.g., *Bacillus tuberculosis*
- iii. Palisade. Occur in stacks.

2. **Coccus or Spherical:** These bacteria are oval or spherical in shape. Cocci are generally non- mobile and are smallest amongst all known bacteria. Cocci occur in the following forms:

- i. Micrococcus – occur singly, e.g., *Micrococcus luteus* etc.
- ii. Diplococcus – cocci remain attached in pairs e.g., *Diplococcus pneumoniae*.
- iii. Streptococcus – occurs in chains e.g., *Streptococcus lactis*.
- iv. Tetra coccus or tetrad – Here four cocci form a characteristic group e.g., *Neisseria*.
- v. Staphylococcus – Here cells form irregular groups or bunches e.g., *Staphylococcus aureus* etc.
- vi. Sarcinae – Here 8 – 64 cocci are arranged in cubes e.g., *Sarcina lutea* etc.

3. **Spiral or helical:** These bacteria are helical or cork screw shaped or coiled e.g., *Spirillum volutans*.

- i. **Vibrio:** These bacteria are rod – shaped with single curve C-shaped or comma - shaped. They have one or more flagella at one pole e.g., *Vibrio*.
- ii. **Filament:** The body of the bacterium is filamentous like a fungi mycelia. The filamentous are very small e.g., *Beggiatira*, *Thiothrix* etc.
- iii. **Stalked:** The body of a bacterium possess a stalk e.g., *Caulobacter*.
- iv. **Budded:** The body of bacterium is swollen at places e.g., *Rhodomicrobium*.

Size of Bacteria:

Bacteria vary considerably in size. The average size of bacterial cell ranges from 1µm to 10µm in length and from 0.7 µm to 1.5 µm in width. The size of smallest bacterium (e.g. cocci) is not more than 0.1 µm while the largest reaches up to 500µm.



Staining of Bacteria:

Hans Gram (1884) introduced a specific stain for bacteria, now known as Gram stain. This widely used stain differentiates two types of bacteria, called Gram positive (Gram⁺) and Gram negative (Gram⁻).

Cell Structure of Bacteria:

1. Cell wall:

Bacteria are considered plants due to the presence of cell wall. It is about 100 – 250 Å⁰ thick. It is made up of Peptidoglycan also known as murein or mucopeptide. Chemically it is composed of Acetylglucosamine (AGA), Acetyl muramic acid and four or five amino acids viz, L – alanine, D – glutamic acid, diaminopimelic acid and D – alanine. Besides cell wall also have small quantities of carbohydrates and lipids. Cell wall of Gram⁺ bacteria is characterised by the presence of teichoic acid.

In *Acetobacter xylinum*, *A. Acetigenum* and *Zymosarcinaventriculi*, the cell wall is made up of cellulose only.

The cell wall is permeable to water and ions of small molecules. But large molecules of proteins and nucleic acids cannot pass through the cell wall.

2. Flagella:

Flagellum helps in locomotion of bacteria. Mobile bacteria have one or more flagella. Bacterial flagellum is much simpler than eukaryotic flagellum. It is not surrounded by any membrane. It consists of single thread. On the basis of number of flagella and their arrangement following types of bacteria are recognised.

- i. **Atrichous:** Bacteria without flagella e.g., *Pasteurella*.
- ii. **Monotrichous:** Bacteria with single flagellum situated at one end of the cell only e.g., *Pseudomonas*.
- iii. **Cephalotrichous** or **Lophotrichous:** Bacteria with a group of flagella at one end of the cell only. E.g., *Spirillum volutans*.
- iv. **Amphitrichous:** Bacteria with more than two flagella or a group of flagella at both the ends of a cell e.g., *Nitrosomonas*.
- v. **Peritrichous:** Bacteria with flagella all over the cell e.g., *Escherichia*.

3. Pilli or Fimbriae:

These are minute non-flagellar hair-like structures projecting from the wall of many Gram negative bacteria. Pilli or fimbriae are rigid and are entirely composed of a protein, called Pillin. Pilli are much shorter and thinner than flagella. They occur all over the body and are concerned with cell to cell or cell to surface attachment during conjugation. Hence, they are also known as sex-pilli.



4. **Slime Layer or Capsule (Glycocalyx):**

Some bacterial cells are completely enveloped by a viscous or gelatinous substance secreted by the protoplast. This envelope is known as slime layer. This slime sometimes becomes relatively thick and forms a capsule around the cell wall. Chemically, capsule is made of many types of polysaccharides such as dextrin, levan, cellulose etc. Besides this, in *Bacillus anthracis*, polypeptides are also found in the capsule which is polymers of D – glutamic acid.

The capsule protects the cell from antibodies and desiccation. It also increases the infectivity of the bacterium. Non-capsulated bacteria are less harmful and can be easily destroyed.

5. **Plasma Membrane or Cytoplasmic Membrane:**

The bacterial cell membrane is made up of lipo-protein as in all living organisms. It is a tri-lamellar structure representing unit membrane. This differentially permeable membrane controls the passage of many solutes and solvents. Besides this, cytochromes, enzymes associated with lipid metabolism, those essential for synthesis of cell wall components, enzymes of electron transport and oxidative phosphorylation etc are also present in the cell membrane.

6. **Mesosomes:**

In many bacteria (specially Gram positive), the plasma membrane gives rise to infoldings called mesosomes. These are finger-like spherical or villi form structures which may help in compartmentalize the cell. Mesosomes participate in the formation Septa during cell division and secretion of intracellular substances from inside to outside. They also take part in the separation of nucleoid.

7. **Cytoplasm:**

It is a complex of proteins, lipids, minerals, nucleic acids and water. Glycogen is the may reserve food material present in the cytoplasm. Cytoplasm does not show streaming movement. Cytoplasm contains 70S type ribosomes. They occur either scattered or may form a chain called Polysome. Ribosomes are the site of protein synthesis.

Also scattered in the cytoplasm are photosynthetic lamellae. Since bacteria lack organised plastids, Pigments occur in these lamellae. These Pigments are bacteriochlorophyll and bacterioviridin. Such bacteria are able to photosynthesize and are thus autotrophic. e.g., *Rhodospirillum*, *Chlorobium*, *Chromatium*.

8. **Nucleoid or Genephore:**

Bacteria lack nuclear membrane, nucleolus and nucleoplasm. Chromosomes in real sense of word are absent. Genetic material, however, occurs in the form of histone free DNA.

It is generally located in the centre of the cell. Such a structure is variously called genome, genepore or nucleoid.

9. Plasmids:

In addition to bacterial chromosomes, many bacteria (e.g., *E. coli*) have accessory rings of DNA, called Plasmids. The Plasmids DNA replicates independently, maintains independent identity and may carry some important genes like-Fertility factor (F-factor) nitrogen fixing genes (Nif genes) etc. The plasmids which temporarily get associated with nucleoid DNA are known as episomes. Plasmids are useful in genetic engineering while episomes are of great importance in genetic recombination in bacteria.

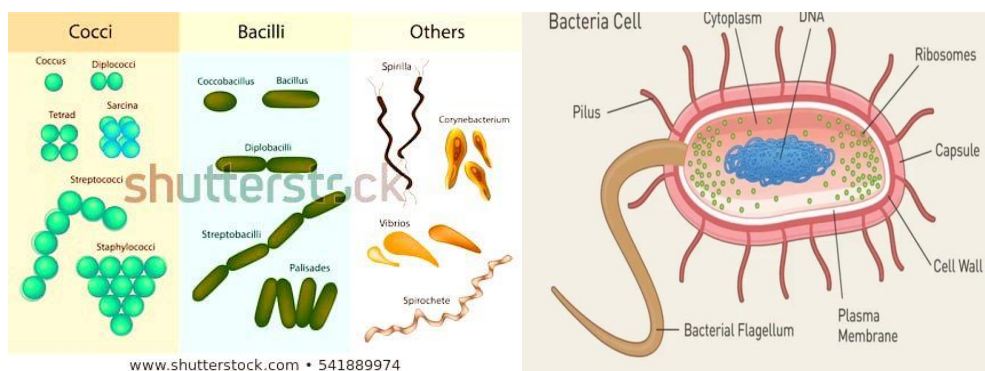


Figure: Shapes of Bacteria, Structure of a bacterial cell (Source: shutterstock.com)

Reproduction in Bacteria:

Bacteria reproduce by

1. Vegetative Reproduction.
2. Asexual reproduction and
3. Genetic recombination or sexual methods.

1. Vegetative Reproduction: Fission and budding are two methods of vegetative reproduction.

- i. **Binary Fission:** This is the commonest and the most important method. In this method, the cell elongates followed by formation of transverse wall. This results in the production of two daughter cells. Each daughter cell grows into a new bacterium. Thus with every division the number of bacterial cells becomes double. *E.coli* divides every 15 – 20 minutes. This is called generation time.
- ii. **Budding:** In this process, the cell produces outgrowths called buds. Cytoplasm and Chromatin material also enter the bud which later separates from the parent cell by constriction. The separated bud takes the form of a new bacterial cell. Budding is commonly observed in the genus *Hyphomicrobium*.



2. Asexual Reproduction:

The most common method of asexual reproduction is the formation of endospores. However, Conidia, Zoospores and cysts are also formed in a few species.

i. Endospore:

In bacteria like *Clostridium*, *Bacillus* etc. Cell produces a resistant structure called endospore. Only one endospore is produced per cell. The endospore formation begins with the invagination of cell wall followed by invagination of cell membrane. It encloses part of protoplasm. Outside this cell membrane, a region called cortex is formed. Outside the cortex spore coat consisting of several layers is formed. Cytoplasm, ribosomes and DNA are also found in the endospore. The endospores are smaller than their parent cell.

Under unfavourable conditions, endospores remain dormant. On the return of favourable conditions, the endospore coat breaks open and a new bacterium is produced. Thus endospores are organs of perennation which tide over the unfavourable conditions.

ii. **Conidia:** In some bacteria e.g., *Streptomyces* the filament divides transversally into small cells. These cells transform into a chain of conidia.

iii. **Zoospore:** This is a common method of asexual reproduction in *Rhizobium* which produces flagellated zoospores.

iv. **Cyst:** In *Azotobacter*, thick walled spores, similar to endospores, are formed. These are called cysts.

3. Sexual Reproduction or Genetic Recombination or Parasexuality:

Sexual reproduction in bacteria does not involve production of gametes and their subsequent fusion. The process of genetic recombination in bacteria includes transformation, transduction and conjugation.

1. Transformations:

This process in bacteria was demonstrated by Griffith, a British medical officer in 1928. In this process, the donor and recipient bacterial cells do not come in contact. Griffith while working on Pneumonia causing bacterium *Diplococcus pneumoniae* came across two strains rough or R – cells and smooth or S – cells. The R-cells were avirulent and had no capsule whereas S-cells were virulent and capsulated. He injected a mouse with living R-cells and non-living S-cells. The mouse died within a few days. Blood analysis of dead mouse showed the presence of living cells, besides R-cells. He therefore, concluded that dead S-cells had released a factor (called transforming factor) which resulted in the transformation of R-cells into virulent forms, thereby killing the host. This transforming factor was later identified as DNA by Avery, Macleod and McCarty in 1944.



2. **Transduction:**

It is the process in which the genetic material is transferred from donor to the recipient bacterium by a bacteriophage (a virus that infects bacteria is known as bacteriophage). The process was discovered in the bacterium *Salmonella* by Zinder and Lederberg (1952).

3. **Conjugation:**

Transfer of DNA by the process of conjugation occurs between two sexually different strains of the bacteria (*E. coli*) – one acts as a donor of genes (male) and the other as recipient of genes (female). Both are haploid. During the rest of conjugation the genetic material is transferred from donor to the recipient through a bridge formed between the two.

Economic Importance of Bacteria:

Useful Activities:

1. Decay of Organic Waster:

Many saprotrophic bacteria act as scavengers by continuously removing the harmful organic waste (dead remains of animals and plants) from man's environment. The simple compounds released as a result of decomposition and decay (CO_2 , CO , nitrates, sulphates, phosphates, ammonia etc) are either released back into the environment for recycling or absorbed by plants as food.

2. Sewage disposal:

Ability of anaerobic bacteria to purify the organic matter is used in the sewage disposal system of cities. The faeces are stored in covered reservoirs and allowed to purify. The solid matter is decomposed into liquidy sludge which is passed through coarse filters. The effluent is finally purified and drained out into the river or used as fertilizer in the fields. e.g. *Streptococi*, *E.coli* etc.

3. Role in Nitrogen Cycle:

Bacteria participate most actively in nitrogen fixation. They increase soil fertility by converting molecular nitrogen of the atmosphere into nitrogenous compound. These bacteria are placed into following groups.

- i. Free living or symbiotic bacteria which occur in the soil and fix nitrogen directly e.g., *Clostridium*, *Azotobacter* etc.
- ii. Symbiotic bacteria which occur in roots of leguminous plants e.g., *Rhizobium leguminosarum*.
- iii. **Nitrifying Bacteria:** These bacteria convert ammonia to nitrate. This process involves two steps. In the first step ammonia is converted into nitrite (NO_2) by *Nitrosomonas*. While in the second step the nitrite is converted into nitrate (NO_3) by *Nitrobacter*.



- iv. **Ammonifying Bacteria:** Ammonifying bacteria convert protein into ammonia. The proteins are generally dead remains of plants and animals. Such bacteria are therefore, also called bacteria of decay or Putrefying bacteria, e.g., *Bacillus mycoides*, *B. vulgaris*.
4. **In Food Chain:** Bacteria act as decomposers and convert the organic substances to simple substances. Thus, they play an important role in the recycling of materials. The activity is largely responsible for accumulations of nutrients in the soil.
5. **In Dairy:** Various types of bacteria are found in milk. These convert lactose sugar of the milk into lactic acid which causes the milk protein Casein to Curdle. The preparation of cheese and curd is based on this principle. The bacteria in above fermentation process are *Streptococcus lactis*, *Lactobacillus Casei*, *L. Acidophilous* etc.
- i. **Antibiotics:** These are metabolic products of one microorganism which are determined or inhibitory to other microorganism in very small amount. Antibiotic cure diseases by competitive inhibition and are obtained mostly from bacteria. Some of the antibiotics are specific (narrow spectrum antibiotics) while others are broad spectrum i.e., they act on a variety of Pathogenic micro-organisms. Some of the common and important ones are: Polymyxin B → *Bacillus polymyxa*, Streptomycin → *B. griesus*, Chloromycetin - *Streptomyces venezuelae*, Neomycin - *Streptomyces. fradiae*.
6. **Symbiosis in Human Intestine:** *E.coli* is a common colon bacterium found in human beings and many vertebrates. This bacterium is helpful in digestion.
7. **In Ruminant Animals:** In these animals rumen is inhabited by cellulose digesting bacteria like *Ruminococcus albus*. Ruminant animals eat grass but the cellulose is digested only by the ruminant bacteria present in them.
8. **Sewage Disposal:** Fecal matter collected in sewage links is digested by a number of aerobic bacteria. In this process methane and CO_2 is used are produced. Of, these methane is used as biogas, and CO_2 is used by some algae present in tank for photosynthesis. Oxygen released by algae during photosynthesis is used in oxidation of sewage. Thus sewage tank or pond is an example of algae – bacteria symbiosis.
9. **Genetic Engineering:** One of the best materials for work on genetic engineering and molecular biology is *E.coli*. Genetic engineering is associated with direct manipulation of individual genes.

The transfer of human insulin gene into bacteria has been one of the great feats of genetic engineering. Diabetic mellitus is caused due to shortage of human insulin and the sufferers are forced to use insulin extracted from slaughtered animals. Insulin is a protein and it was thought that if the genes for the protein could be inserted into a bacterium there could be cultured to serve as a cheap commercial source.



Another useful human protein is the antiviral agent called interferon, normally produced in response to viral infection. Transfer of interferon gene into bacterium has been accomplished.

Harmful Activities of Bacteria:

Following are some of the harmful activities of bacteria.

1. **Food Poising:** Some saprotrophic bacteria cause decay of our food. Some produce powerful toxins in food to cause 'food poisoning'. Some of them are:

- a. **Botulism:** is caused by *Clostridium botulinum*. The main symptoms are vomiting, paralysis followed by death.
- b. **Staphylococcal Food Poising:** is caused by *Staphylococcus aureus*. Common symptoms are nausea, vomiting & diarrhoea.
- c. **Perfringes Poising:** *Clostridium perfringes*. Diarrhoea & acute abdominal pain.

2. **Human diseases:** Many bacteria are parasites which infect the human body and cause various diseases.

e.g. Cholera	<i>Vibrio cholera</i>
Diarrhoea	<i>Bacillus coli</i>
Tuberculosis	<i>Mycobacterium tuberculosis</i>
Typhoid	<i>Salmonella typhi</i>

3. **Plant Diseases:** Many serious plant diseases are caused by bacteria.

e.g. i. Angular leaf spot	<i>Gossypium sp</i>	<i>Xanthomonas malvace</i>
ii. Blight of Paddy	<i>Oryza sativa</i>	<i>X. Oryzae</i>

4. **Pollution of Water:** Many Pathogenic bacteria such as *Vibria cholera*, *Salmonella typhi* etc pollute water and make it unfit for drinking.

Actinomycetes (Actinobacteria)

General Characters of Actinomycetes:

1. *Actinomycetes* are a group of unicellular, branched, filamentous bacteria which resemble fungal mycelia. They grow in the form of radiating colonies in culture, and therefore, commonly called ray fungi.
2. They occur commonly in soil, fresh – water, manure, food products and other substrata rich in dead organic matter.
3. The filaments are aseptate (non-septate), branched and very thin but sometimes break off into rod – shaped structures.



4. They are Gram positive saprotrophic bacteria which constitute an important component of decomposers.
5. Some Pathogenic species cause skin diseases in human beings.
6. Most of the species are facultative anaerobic. A few species are mobile.
7. Asexual reproduction occurs by fragmentation, conidia formation. The endospores are not formed.
8. Many species of *actinomycetes* produce important antibiotics such as streptomycin.

Mycoplasma

General Characters of Mycoplasma:

1. Mycoplasmas are the smallest known prokaryotic organisms, characterised by the absence of cell wall. These organisms were discovered in 1843 by Pasteur in the pleural – fluids of cattles suffering from Pleuro – Pneumonia and were therefore, called Pleuro-Pneumonia like organism (PPLO). The credit for growing these organisms in culture medium goes to Nocard and Roux (1898). They also demonstrated that if healthy cattles were injected with these microorganisms the symptoms of disease appear. Later, Nowak (1929) placed them in the genus *Mycoplasma*.
2. In nature they occur in soil, sewage water and in decaying organic matter. They are anaerobes. Some *Mycoplasma* occurs parasitically and pathogenically in plants, animals and in human beings. Pathogenic *Mycoplasma* cause diseases.
3. *Mycoplasma* varies in size mostly from 0.125 to 0.150 μm in diameter. They are the smallest free living organisms and can pass through bacterial proof filters.
4. They are highly polymorphic varying in shape from spherical to branched filamentous structure. Since these organisms do not have definite shape. Therefore, they are called jokers of plant kingdom.
5. Mycoplasmas are unicellular, non – mobile, gram negative prokaryotes which lack a distinct cell wall and do not produce spores.
6. *Mycoplasma laidlawii* has been listed as the smallest of all the free living organisms with a diameter of 0.1 μm to 0.3 μm .
7. The cell membrane is made up of Proteins and lipids. It also contains cholesterol. The cell membrane encloses the dense cytoplasm, which contains numerous 70s ribosome's, a network of fibril or DNA, soluble RNA and soluble proteins. The amount of RNA and DNA in these organisms is less than half that is usually present in other Prokaryotes.
8. Cells of Mycoplasmas divide unevenly into very minute bodies called minimal reproductive units. They are commonly found inside the mature cells.



9. Mycoplasma are insensitive to Penicillin, but sensitive to other antibiotics like streptomycin, erythromycin etc. Their insensitivity to Penicillin is perhaps due to the absence of cell wall. This antibiotic interferes in the synthesis of bacterial cell wall components like Peptidoglycon.

10. Mycoplasma cause various plant diseases like aster yellow, potato witch's broom, mulberry dwarf etc.

11. Diseases like rheumatism, arthritis are caused by Mycoplasma in animals.

Cyanobacteria (Blue Green Algae)

General Characters:

1. Occurrence:

(GK-Cyano = blue, bact= rod) or blue green algae are one of the most successful groups of prokaryotic, Gram negative photoautotrophic bacteria distributed all over the world.

i. They occur a wide range of habitats and grow almost everywhere when get suitable moisture and temperature. They are mostly aquatic and occur in fresh water habitats such as ponds, lakes and other fresh water reservoirs. Many species are terrestrial and grow on moist rocks, moist soils and tree trunks. A few species are marine.

ii. A few species grow in hot water springs having a temperature range of 70° – 75° (*Phormidium*, *Mastigocladus*) and other grow a very low temperature in polar regions e.g., *Nostoc*, *Schizothrix* etc.

iii. *Trichodesmium*: imparts red colour to sea, hence called red sea.

iv. Some species form Symbiotic association with other organisms like algae partner in Lichen, in *Cycas* caroloid roots, in water fern *Azolla*, in *Anthoceros* (a bryophyte) etc.

2. Organisation of Thallus:

In organisation of thallus cyanobacteria range from unicellular to branched heterotrichous forms.

i. Unicellular forms e.g., *Chroococcus* etc.

ii. Unicellular Polar-thallie with a definite base and apex e.g., *Dermocarpa*, etc.

iii. Multicellular Colonial forms. E.g., *Gloeocapsa*, *Trichodesmium*.

iv. Simple branched filamentous forms without heterocysts and akinetes e.g., *Oscillatoria*.

v. Simple unbranched filamentous with heterocyst e.g., *Nostoc*, *Anabaena*.

vi. Unbranched heterocystous filaments with heterocysts filaments with base and apex. E.g., *Rivularia*.

vii. Heterotrichous filamentous with false branching e.g., *Scytonema*, *Plectonema*.



viii. Heterotrichous filamentous with true branching e.g., *Haplosiphon*, *stigonema* etc.

3. Flagella

Flagella are completely absent but the movement occurs in some genera by special gliding motion. Such movements are connected with the secretion of mucilage.

4. Cell Structure:

Each cell has a definite cell wall surrounded by a mucilaginous sheath. The sheath is made up of reticulately arranged microfibrils within an amorphous matrix. The fibrils may be composed of pectic acid and mucopolysaccharides. The cell wall is firm and rigid. The cell wall is followed by Plasma membrane made up of lipid and protein.

Inner content of the cell can be distinguished into outer pigment region called chromatoplasm and central hyaline centropiasm. The membrane bound organelles are absent.

The photosynthetic pigments are located on broad sheet like lamellae, called thylakoids. The photosynthetic pigments present in the cell are chlorophyll a, β - carotene, myxoxanthophyll, myxoxanthin, C-phycoerythrin and C-Phycocyanin.

True nucleus is absent. The central nucleoid has irregularly arranged fine strands of DNA. Other cellular inclusions are gas vacuoles, Cyanophycin granules, volutin granules, 70s ribosomes.

Some cyanobacteria possess special type of cells called heterocysts to perform special functions e.g., *Nostoc*, *Anabaena*, *Scytonema*. There is no mitotic cell division in cyanobacteria. The cell divides by fission or amitotic division.

5. Nutrition:

Cyanobacteria contain chlorophyll – a and other photosynthetic pigments. They synthesize their own carbohydrates by the process of photosynthesis.

6. Reproduction:

Cyanobacteria reproduce by vegetative and asexual methods. Vegetative reproduction occurs by.

- i. Fragmentation and hormogonia formation. Unicellular forms multiply by binary fission. Filamentous forms reproduce by breaking of filaments into short pieces.
- ii. Asexual reproduction occurs by the formation of akinetes, endospore, exospores and nanospores.
- iii. There is no sexual reproduction, but genetic recombination equivalent to sexual reproduction has been reported in some genera e.g., *Cylindrospermum majus*, *Anabaena* etc.



Economic Importance of Cyanobacteria:

Useful Activities:

1. Cyanobacteria are used as green manure by farmers because of their ability to fix atmospheric nitrogen.
2. *Spirulina* is used as source of protein. It is cultured, powdered and then supplied in the form of tablets. This process is known as single cell protein (SCP).
3. *Nostoc commune* is used as source of food by Chinese and South Americans.
4. Cyanobacteria, growing symbiotically in Lichens act as pioneers of plant succession. On barren rock and help soil formation.
5. Some cyanobacteria like *Anabaena*, *Lyngbya*, *Tolypothrix* etc prevent soil erosion and help in conservation.

Harmful Activities:

1. Harmful toxins released by *Microcystis*, *Anabaena* affect fish and other aquatic fauna.
2. Some Cyanobacteria cause discolouration and severe damage to plaster and brick work by growing on buildings and historical monuments.
3. *Lyngbya* may cause some skin infections.

Archaeobacteria

Archaeobacteria (Gk. archae=ancient, and bact=rod) are unique type of Prokaryotic microorganism that live in extreme environmental conditions such as in Dead sea, Great salt lake, Volcanic walls, hot sulphur springs etc.

1. Archaeobacteria are characterised by the absence of Peptidoglycan in their cell walls. In most of them, the wall is composed of non-cellulosic Polysaccharides.
2. The cell membrane lipids of archaeobacteria contain glycerol linked to branched hydrocarbon chains.

Archaeobacteria have been classified into three groups:

- I. Methanogenic or Methanogenic Archaeobacteria
- II. Halophiles or Halophilic Archaeobacteria
- III. Thermoacidophiles or Thermoacidophilic archaeobacteria

I. Methanogenic or Methanogenic Archaeobacteria:

General Characters:

- i. Methanogens are obligate anaerobes. They live anaerobically in swamps, marshes, and gut of animals where they produce cellulose enzyme for digestion of cellulose.
- ii. They produce methane by anaerobically decomposing organic matter.



- iii. The fermentation of cattle dung by methanogens in specially designed plants produce cooking gas (fuel gas) and slurry. The latter is used as organic manure for growing crops.
- iv. Methanogens added to animal wastes produces a biogas that can be used to run generators that produce electricity.

II. Halophiles or Halophilic Archaeobacteria:

- i. These are anaerobic archaeobacteria that live in salty habitats like salt lakes, salt marches etc.
- ii. Some halophiles occur in deep sea volcanic vents at 118⁰C.
- iii. In strong light halophiles develop a pigment called bacteriorhodopsin, which helps to produce ATP chemiosynthetically from light energy. E.g., *Halobacterium*, *Halococcus*.

III. Thermoacidophiles or Thermoacidophilic archaeobacteria:

- i. These bacteria live in hot and acidic conditions e.g., hot sulphur springs at PH of 2.
- ii. They oxidise sulphur to sulphuric acid under aerobic conditions. E.g., *Thermoplasma Sulfobolus*.

Kingdom Protista

Kingdom Protista includes all unicellular eukaryotic microorganisms except some unicellular algae e.g., *Chlamydomonas*, *Chlorella* etc, fungi e.g., yeasts and animals, which are placed in their respective kingdoms along with their closely related multicellular organisms. The Protists are regarded as ancestors of all multicellular eukaryotic organisms. The kingdom Protista is made up of eukaryotic organisms. Most tend to be unicellular, although there are some multicellular Protists.

General Characters:

1. Habitat:

Protists are aquatic organisms. Some live as parasites within animal bodies.

2. Structure:

Protists are microscopic unicellular organisms. The cell structure is typically eukaryotic. Protoplasm is surrounded by a distinct Plasma membrane. Photosynthetic forms have a distinct cell wall made up of cellulose. Internally, the cells have distinct membrane bound organelles like Endoplasmic reticulum, nucleus with chromosomes, Golgi apparatus, mitochondria, 80s ribosomes. The Photosynthetic Protists possess chloroplasts with internal thylakoids. Cytoplasm shows cytoplasmic streaming. Mobile Protists have cilia or flagella, which have fibrils arranged in the form of 9+2 arrangement. Fibrils are made up of Protein tubulin.

3. Locomotion:

In Protista mobile forms move from one plane to another with the help of:

- I. Pseudopodia.
- II. Flagella.
- III. Cilia.

I. Locomotion by Pseudopodia:

Pseudopodia are blunt finger like Protoplasmic extension. They give irregular shape to the organisms. This type of locomotion occurs in several protozoans like *Amoeba* etc. Pseudopodia are of four types:

- i. Lobopodia: Lobe like with broad and blunt ends e.g., *Amoeba*.
- ii. Filopodia: Fine thread like often with rounded ends e.g., *Euglypha*.
- iii. Axopodia: Long and stiff with hard axial filament e.g., *Actinophrys*.
- iv. Reticulopodia: Long and branched forming network e.g.,

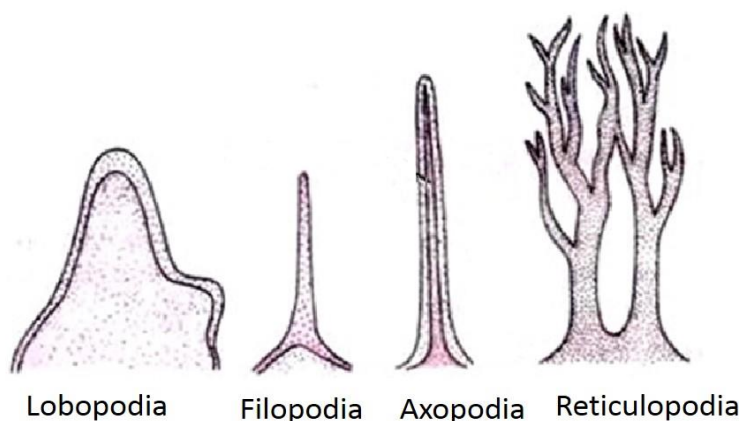


Figure: Locomotion by Pseudopodia in *Globigerina* (Source:infovisual.info)

II. Locomotion by Flagella:

Flagella are hair like appendages which project from the free surface the free surface of the cells. The external long and whip like part of the flagellum is called shaft. Internally each flagellum consists of 9+2 fibrillar arrangement. Most flagella exhibit undulating movements which propel the organism in the direction opposite to that of a beat locomotion by flagella occurs in Dinoflagellates, Euglenoids and Zooflagellates.

III. Locomotion by Cilia:

The cilia bearing Protists are called ciliates. Cilia are short, fine, hair like structures present all over the body surface. E.g. *Paramecium*.



- i. **Wriggling Locomotion:** It is a kind of slow worm like movement of non-flagellated Protists performed with the help of wave of contraction and expansion of body. E.g., Sporozoans.
- ii. **Locomotion by Mucilage Propulsion:** Some Protists like diatoms exhibit creeping or rolling type of movement by secreting soft mucilage in the direction opposite to the direction of movement.

4. Nutrition in Protists:

Kingdom Protista includes diverse type of unicellular organisms. They perform following type of nutrition.

- i. **Photosynthetic (autotrophic or Holophytic):** Many Protists possess chlorophyll and prepare their own food by the process of photosynthesis e.g., Dinoflagellates (*Gymnodinium*), Diatoms (*Pinnularia*), *Euglena* etc.
- ii. **Holozoic:** Nutrition where the individual eats other animals and plants e.g., *Amoeba*, *Paramecium*.
- iii. **Saprobic:** Protists feed on decaying organic matter e.g., Slime moulds.
- iv. **Parasitic:** Protists obtain their nutrition from other living organisms e.g., *Monocystis*, *Entamoeba*, *Plasmodium*.
- v. **Mixotrophic:** In this type, Protists obtain their nutrition in more than one method at the same or different times due to change in external conditions e.g., *Euglena*.

5. Reproduction:

In Protists reproduction occurs by both asexual and sexual methods.

I. Asexual Reproduction:

It is a type of reproduction where genetic constitution remains the same as that of its parent. It is most common type. It takes place by the following methods:

- i. **Binary Fission:** In this method the parent cell divides into two almost equal daughter cells either transversally as in *Paramecium*, longitudinally as in *Euglena* or axially as in *Amoeba*.
- ii. **Multiple Fission:** When parent cell divided into number of daughter cells it is called multiple fission. It occurs in *Paramecium*.
- iii. **Plasmotomy:** Fission of multinucleate Protists into two or more multinucleate off-springs by division of cytoplasm without nuclear division is called Plasmotomy. It occurs in *Opalina*.
- iv. **Budding:** In this type of asexual reproduction, a small bud is formed from the parent body which separates and develops into new individual e.g., *Arcella* etc.
- v. **Spore Formation:** Sessile or stalked sporangia are formed in slime moulds. They liberate the spores which can withstand a prolonged period of desiccation. On germination each spore gives rise to new individual e.g., Slime moulds.



II. Sexual Reproduction:

Sexual reproduction involves meiosis and fusion of gametes (syngamy). The latter results in the formation of zygote. In protists sexual reproduction occurs in three ways.

- i. **Isogamy:** When fusing gametes are structurally and physiologically alike. The gametes may be motile or non – motile.
- ii. **Anisogamy:** In anisogamy the motile or non-motile gametes are morphologically dissimilar. The larger gamete is the female and the smaller one is the male. These structurally different gametes are known as anisogametes or heterogametes.
- iii. **Oogamy:** In Oogamy, there is a fusion of large non-motile egg or Ovum with a small motile sperm.

Major Groups of Protista:

The kingdom Protista has been grouped into three categories:

1. Photosynthetic Protists.
2. Slime moulds (Decomposer protists).
3. Protozoan Protists.

1. Photosynthetic Protists:

The major groups of algae that have been included in Photosynthetic Protists are:

- I. Dinoflagellates.
- II. Euglenoids.
- III. Diatoms etc.

Photosynthetic algae are mostly Planktonic i.e. they grow and cover the surface of water body. The photosynthetic algae are the major producers of aquatic ecosystems accounting for more than 80% of the total CO_2 fixed in the biosphere.

I. Dinoflagellates

General Characters:

1. Dinoflagellates are well defined group of unicellular, photosynthetic organisms. Majority of them are motile and few are non-motile.
2. Majority of Dinoflagellates are Planktonic and cover the surface of water body imparting them characteristic colour. Some of them like *Gonyaulax*.
3. Nutrition of Dinoflagellates is mainly photosynthetic. However, some forms are saprobic, parasitic, symbiotic or holozoic.
4. Some Dinoflagellates release poisonous toxins into the water which kills large number of marine animals. E.g., *Gonyaulax*.

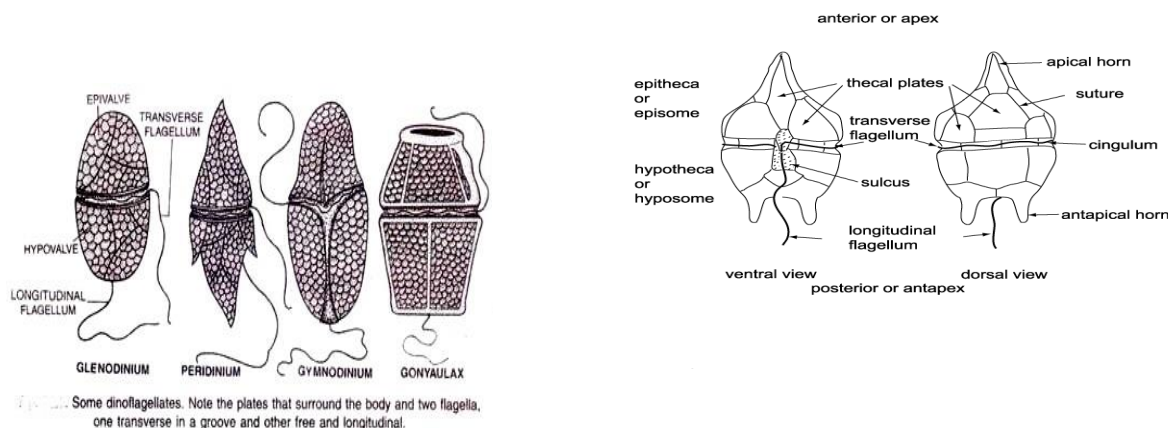
5. Some dinoflagellates show bioluminescence. This process in dinoflagellates is associated with a cytoplasmic particle called a scintilon. The compound responsible for bioluminescence is luciferin which is oxidised by enzyme Luciferase resulting in the emission of light.

6. Structure:

The cell wall of dinoflagellates is called theca or lorica. It is composed of plates made up of cellulose. The theca contains two narrow cuts – longitudinal (vertical) and transverse. The former is called sulcus and the latter girdle or annulus (cingulum). The cells possess two flagella which are of different sizes (Heterokont). One flagellum is transverse, and another arises from vertical furrow (sulcus). Cells possess a relatively large and prominent nucleus known as mesokaryon. Photosynthetic pigments include chlorophyll a and c together several xanthophylls (peridinin, dinoxanthin, neoperidinin). The reserve food material is starch or oil. The cells possess an osmoregulatory organelle called Pusule, which looks like contractile vacuole. Cells possess mitochondria, ribosomes and Golgi bodies. They also possess mucilage bodies or mucilage bodies or vesicles below the cell membrane.

7. Reproduction:

Dinoflagellates reproduce sexually as well as asexually. Sexual reproduction is of isogamous or anisogamous type. Asexual reproduction occurs through cell division or by the formation of zoospores and cysts.

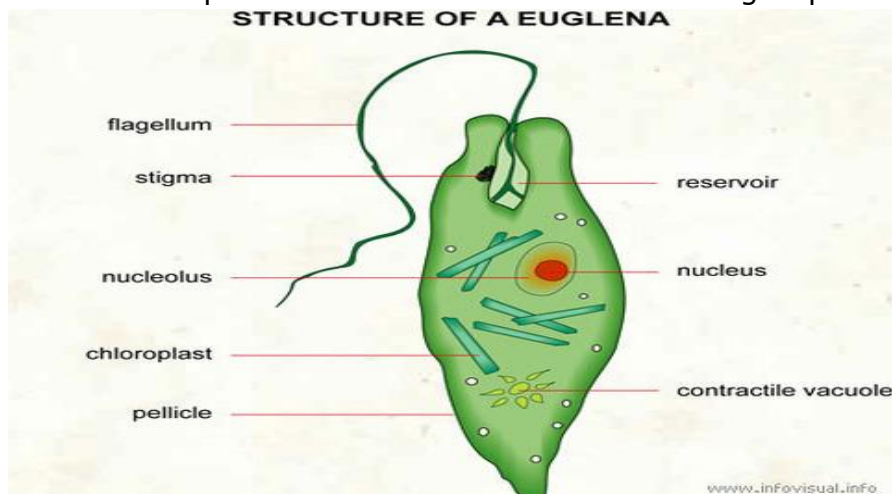


II. Euglenophyta:

General Characters

1. Members of Euglenophyta exhibit both Plants like and animal like features.
2. Euglenoids are unicellular, flagellate and motile. A few forms are non-mobile. They are commonly found in fresh-water habitats. Some members occur in brackish and muddy soils. The most common euglenoid flagellate is *Euglena viridis*.
3. These lack a definite cell wall (cellulose), instead, cells are covered with a thin membrane known as the pellicle or periplast.

4. The number of flagella in each euglenoid cell may be one or two. Out of the two flagella, one is long and the other is short.
 5. Cells at the anterior end possess a mouth (cytostome) which leads into flask shaped cavity gullet or cytopharynx which opens into a large basal reservoir.
 6. In biflagellate form, the two flagella arise from two basal granules inserted into the cavity of cytopharynx. The two flagella join with each other at a swelling, called Paraflagellar body, but only one flagellum emerges out through the cytostome.
 7. An orange red eye spot also called stigma (a collection of 20 to 50 orange sec lipid droplets) is located at the base of flagellum attached to the membrane of reservoir at the level of Paroaflagellae body. They contain a red pigment astaxanthin. Eye spot and paraflagellar body act as photoreceptors and direct the organism towards the optimum light.
 8. Large contractile vacuole occurs at the anterior end which serves the function of osmoregulation.
 9. Each cell possesses a single large nucleus. The nuclear envelope persists during cell division. Nucleolus also persists and divides into two.
 10. The mode of nutrition in euglenoids is photoautotrophic. Some forms are saprobic (*Rhabdomonas*) or holozoic (*Peranema*).
 11. The photoautotrophic form possesses long radiating chloroplasts. These chloroplasts contain chlorophyll a and b, together with carotenoids.
1. The reserve food in Paramylon which is stored in the form of Paramylon granules.
 2. Reproduction: Reproduction in this group occurs by mitotic cell division. The nuclear envelope remains intact throughout the process of mitosis. No
 3. sexual reproduction is known to occur in this group.



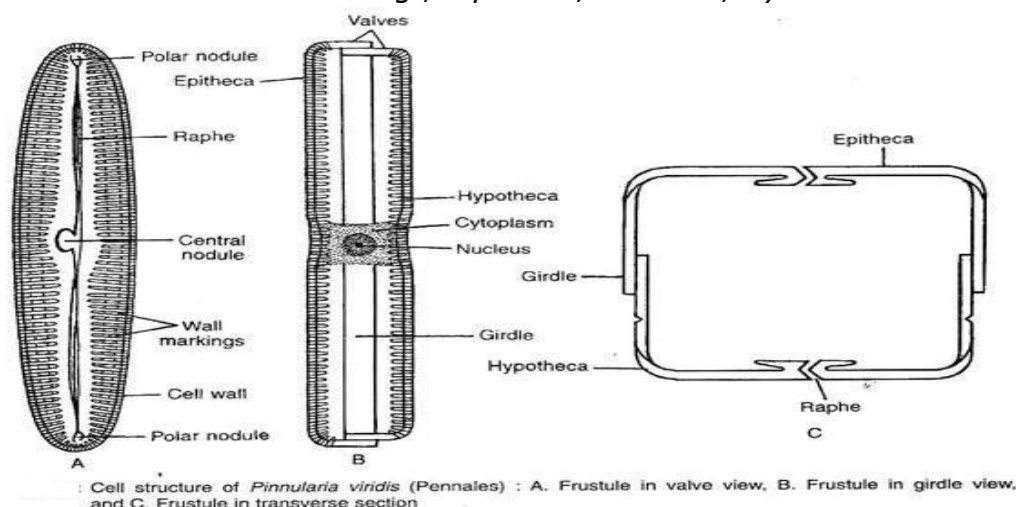


III. Diatoms (Division – Bacillariophyta):

General Characters:

1. The members of Bacillariophyceae are generally referred to as diatoms. These are mainly unicellular but occasionally may be colonial also.
2. The cells are surrounded by a two – part like cell wall the frustule.
3. Most of the diatoms occur as phytoplanktons both in fresh and marine waters. Some grow on moist soils.
4. Diatoms are photosynthetic. They may be circular rectangular, triangular, elongated or filamentous.
5. They exhibit mainly two types of symmetry – radial symmetry as in centric diatoms and isobilateral symmetry as in pennate diatoms.
6. The cell wall is chiefly composed of cellulose impregnated with glass like silica. It shows sculpturing and ornamentation.
7. The cell wall is composed of two overlapping halves (or theca) that fit together. The upper half (lid) is called epitheca and the lower half (case) is called hypotheca.
8. Diatoms do not possess flagella except in the reproductive stage. They float freely on the water surface due to presence of light weight lipids.
9. The cells are diploid. Each cell has a large central vacuole in which a prominent nucleus is suspended by means of cytoplasmic strands.
10. The cell possesses plate like chloroplasts. They contain chlorophyll a, chlorophyll c, carotene, diadinoxanthin and fucoxanthin. Chlorophyll b is absent.
11. The reserve food material is oil and a polysaccharide chrysolaminarin (or leucosin).
12. Reproduction: Asexual reproduction takes place by binary fission. In this process each daughter individual retains its one-half of the parent cell and the other half is synthesized i.e., epitheca is retained and hypotheca is synthesized.
13. Sexual reproduction takes place the union of haploid gametes formed after meiosis. The zygote formed develops into auxospore (large size a big cell zygote).

14. The cell walls of diatoms do not decay easily. They form diatomic or diatomaceous earth on the sea floors e.g., *Diploneis*, *Navicula*, *Cyclotella* etc.



Economic Importance:

1. Diatoms constitute main producers in the aquatic ecosystems and thus form the main source of food to aquatic animals.
2. Diatomaceous earth obtained from sea floors is used in industrial filtration of sugars, oils, alcohols and antibiotics.
3. Diatomite is used as a cleaning agent in toothpastes and metal polishes, added to paints for enhancing night visibility.
4. Diatomite is used as insulating material in refrigerators and furnaces and employed as a source of water glass or sodium silicate.

2. Slime Moulds (Fungi Like Protists or Decomposer Protists):

General Characters:

1. Slime moulds are organisms which share the characters of both plants and animals.
2. Mycologists included them in the division Myxomycota (GK myxa=slime mykes=fungus), of the kingdom Mycota.
3. Modern biologists include slime moulds under the kingdom Protista and are called Protistan fungi.
4. Slime moulds are terrestrial and occur in shady moist areas.
5. The vegetative parts do not possess cell wall. They either occur as Plasmodium or Pseudoplasmodium. However, the reproductive structures possess cell walls.
6. The organisms occur as slimy mass during the vegetative phase, thus called slime-moulds.
7. The Protoplasm is differentiated into outer enucleated (hyaloplasm) and central nucleated portions. At maturity, it may contain several hundred to several thousand nuclei.



8. Chlorophyll is absent. The mode of nutrition is saprotrophic, a few are parasitic on algae.
9. Slime moulds show amoeboid movement, and move by the formation of pseudopodia.
10. A large number of pigmented granules are present within the central nucleated portion which imparts various colourations due to the presence of pigment called anthracene.
11. Asexual reproduction occurs by fragmentation, sclerotia and by the formation of sporangia.
12. Sporangia produces spores. Each spore possesses a cellulose cell wall.

Sexual reproduction occurs by the fusion of gametes (biflagellate swimmers or myxamoeba). The mode of sexual reproduction is isogamous or anisogamous.

3. Protozoan Protists (Animal like Protists):

This group includes four Phyla:

- I. Zooflagellata (zooflagellates)
- II. Sarcodina (sarcodines)
- III. Sporozoa (sporozoans).
- IV. Ciliata (ciliates)

General Characters:

1. Distribution:

Protozoan protists have worldwide distribution. They may be aquatic (fresh as well as marine), terrestrial or Parasitic.

2. Form and Structure:

They are small microscopic, unicellular and colourless organisms with varied shapes viz, spherical, oval, bell-shaped etc. The body is naked consists of uninucleate and multinucleate protoplasm, bound by a delicate membrane or a firm pellicle, lorica.

3. Locomotion:

The Protozoan protists move with the help of Pseudopodia, flagella or cilia. Some parasite forms are non-motile.

4. Nutrition:

The mode of nutrition is mainly holozoic. Some forms are saprobic.

5. Respiration:

Exchange of gases takes place through the general body surface. However, some excretion may occur through contractile vacuoles.



6. Osmoregulation:

The contractile vacuole maintains the water balance in the body, by removing the excess of water.

7. Reproduction:

Asexual reproduction occurs by

- i. Binary fission.
- ii. Multiple fission or
- iii. Budding.

Sexual reproduction occurs by

- i. Syngamy.
- ii. Conjugation.

During unfavourable conditions some Protists form cysts, which help in perennation and reproduction of organisms. Example includes, *Trypanosoma gambiense*, *Trichonympha*, etc.

I. Zooflagellates (Phylum Zooflagella)

General Characters:

Zooflagellates show following characteristic features.

1. They occur as free living aquatic, parasitic commensals or symbiotic organisms. Some of them cause human diseases.
2. They are generally uninucleate organisms bounded by a firm pellicle.
3. The body of zooflagellates possesses one to several flagella for locomotion and capture of food.
4. The mode of nutrition is holozoic, saprobic and parasitic. Food is stored in the form of glycogen.
5. Asexual reproduction occurs by binary fission and cyst formation.
6. Sexual reproduction has been reported only in few forms.

II. Sarcodina (Phylum – Sarcodina):

General Characters:

The main characteristic features of Sarcodines are as under:

1. Sarcodines grow as free floating in fresh and sea waters.
2. They develop different types of Pseudopodia for locomotion.
3. Mouth is absent. The sarcodines are uninucleate, binucleate or multinucleate.
4. Flagella are absent. However, they are present in some development stages.
5. Nutrition is holozoic.
6. Asexual reproduction occurs by binary fission, multiple fission, swarm spores and budding.
7. Sexual reproduction occurs by syngamy.

**Classification of Scordina:**

Sarcodines are further classified into four types.

i. Amoebids:

These protists have irregular body shape due to formation of Pseudopodia. The cytoplasm is differentiated into ectoplasm and endoplasm. Examples, *Amoeba*, *Entamoeba*, *Pelomyxa*.

ii. Radiolarians:

They are marine, giant free floating Sarcodines having a central perforated capsule and a skeleton of silica. The protoplasm that occurs inside the capsule is called intracapsular and that occurs outside the capsule is called extracapsular. The intracapsular protoplasm contains nuclei, small vacuoles and reserve food material. The intracapsular protoplasm is pigmented, vacuolated and develops fine thread like radiating Pseudopodia. Reproduction occurs by the formation of swarm spores. E.g., *Acanthometra*, *Collozoum* etc.

iii. Foraminiferans:

They are marine or fresh water bottom dwellers having chambered and perforated shells. They develop reticulopodia for creeping and ingestion. Reproduction occurs by fission and syngamy. Examples – *Elthidium*, *Globigerina*.

iv. Heliozoans:

Majority of helizoans are shelled but a few are shell less. Shelled forms have skeleton with siliceous scales or spines. They develop axopodia which helps in locomotion and capture of Prey. Examples: *Entamoeba histolytica*

III. Sporozoans (Phylum–Sporozoa)**General characteristics:**

1. All sporozoans are endoparasites and cause diseases.
2. Their mode of nutrition is parasitic.
3. They are non-motile.
4. The outer covering of the body is Pellicle or cuticle. It has single nucleus.
5. Asexual reproduction occurs by multiple fission.
6. Sexual reproduction takes place by Syngamy, which is followed by formation of haploid spores.
7. Life cycle includes two different hosts.
Examples – *Plasmodium* (malarial parasite).

IV. Ciliates (Phylum – Ciliata):**General Characters:**

Ciliates are characterised by the following features:



1. Most of the ciliates are free living and are found in fresh and marine waters (*Paramecium*). A few are parasitic (*Balantidium*). Some are colonial and sedentary.
2. The body of ciliates is covered with flexible pellicle which possesses cilia all over the body.
3. They possess specialised organelles to perform various functions equivalent mouth, digestive tract, anus, kidney muscle, skin and sense organs of higher plants.
4. They move and capture food with the help of cilia.
5. Nutrition is holozoic, a few have absorptive.
6. Fresh water forms have contractile vacuole for locomotion.
7. Ciliates show nuclear dimorphism. The larger nucleus controls vegetative and metabolic activities and growth. The small micronucleus takes part in sexual reproduction.
8. Ciliates eject minute trichocysts with force to stun the prey and defend themselves.
9. Asexual reproduction is by binary fission and sexual reproduction by conjugation. Under unfavourable conditions they form cysts.

Examples: *Paramecium*, *Opalina*, *Podophyra*.

Kingdom Fungi

Fungi are achlorophyllous eukaryotic thallophytes. These form a large group which includes more than 1, 00, 000 species. The branch of botany dealing with study of fungi is known as mycology (mykes – mushroom, logos – discourse). The first systematic description of fungi was given by an Italian botanist 'Pier' Antonia Micheli (1729). He is called the founder of Mycology.

General Characters

1. Habit:

Thallus is called mycelium. It is made up of thread-like filaments known as hyphae. The hyphae are septate or aseptate. The cell wall is mostly made up of chitin.

8. Habitat:

Fungi occur almost everywhere in nature. They grow in water, soil, air, on food, leather, cloth etc. They can also be seen on our hair, mouth, eyes. The economic losses they cause are out of all proportions to their size and importance as plants.

9. Nutrition:

All fungi are characterised by the absence of chlorophyll. Hence they lack the ability to manufacture their own food. They depend on dead decaying organic matter for their food. They store food in the form of glycogen and oil. On the basis of food habits fungi can be grouped into following three classes:



I. Parasites

II. Saprophytes

III. Symbionts

I. Parasites:

Those fungi which obtain their food from other living organisms (plants or animals) are called Parasites. The organisms on which parasite lives are called host. The parasites can be ectoparasites in which they grow only on host surface and send out specialised absorbing organs called haustoria within the host tissue for absorption e.g., *Erysiphe*, *Mucor*.

Some Parasitic fungi which grow inside host tissue are called endoparasites e.g., *Pythium*, *Puccinia* etc.

II. Saprophytes:

Fungi which obtain their food from dead decaying organic matter are called saprophytes e.g., *Mucor*, *Pestalotia*.

III. Symbionts:

It is an organic relationship between two organisms, where both of them get benefitted. Two common examples are:

- i. **Lichens:** It is a composed plant formed by the association of algae and fungi. The algae partner belongs to chlorophyceal or cyanophyceal and the fungal partner is member of Ascomycetes or Basidiomycetes.
- ii. **Mycorrhize:** It is an association between fungal hyphae and roots of higher plants such as *Pinus*.

10. Vegetative Structure:

On the basis of thallus structure fungi can be placed into following two groups:

- i. **UnicellularFungi:** In lower groups of fungi, the thallus consists of only a single cell. In case of slime moulds, the thallus is naked and multinucleate amoeboid mass of protoplasm called Plasmodium e.g., *Plasmodiophora*.
- ii. **FilamentousFungi:** In majority of fungi, the thallus is made up of long and slender filaments called hyphae. The network of hyphae is called mycelium. The hyphae are hyaline or coloured and may be aseptate or septate. Aseptate hyphae are long, branched and acellular with many nuclei embedded in the common protoplasm. Such type of thallus is known as coenocytic and is characterised of Phycomycetes. E.g., *Mucor*.

The hyphae in Ascomycetes, Basidiomycetes and Deuteromycetes are septate, septa in most cases possess a central pore or are non-porous.

The Septum of higher fungi (Basidiomycetes except uredinales) is more complex called dolipore septum (Latindolium – a large jar). The dolipore is a barrel shaped – pore with open ends. The edges of the septa around the pore are swollen. The opening of the pore on both the sides is guarded by cap-like thickenings called Parenthosome. The septal pore may however, remain partially plugged by woronin bodies (some membrane bound bodies & crystalline structures). The Septate hyphae cells are either multinucleate or uninucleate. The uninucleate type of Basidiomycetes is known as monokaryotic or homokaryotic. Sometimes monokaryotic cells of two different strains fuse and thus each cell of the hyphae may have two nuclei. Such a pair of nuclei is called dikaryon. These nuclei remain together without fusing and divide independently and simultaneously as new cells are formed. Such hyphae are termed as dikaryotic or heterokaryotic.

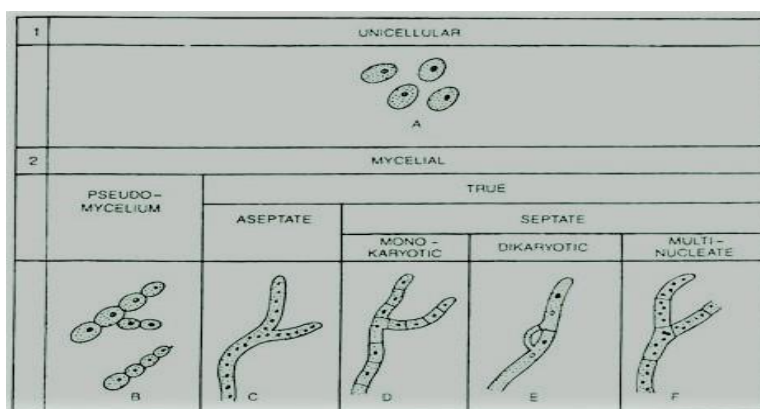


Figure: Different Types of Thallus in Fungi

11. Reproduction:

Fungi reproduce by three methods, vegetative, asexual and sexual.

I. Vegetative Reproduction:

Vegetative reproduction occurs by following three ways:

- Fragmentation:** Thallus or hyphae breaks into number of segments. Each segment grows into new individual.
- Fission:** In fission a cell simply breaks into two daughter cells by constriction. It is common in unicellular fungi.
- Budding:** In this process a 'bud' or an outgrowth is produced by the parent cell. The nucleus divides and one of the two daughter nuclei migrate into the bud. The bud separates and develops into a new individual. E.g., yeast.

II. Asexual Reproduction:

It occurs practically in all fungi by means of wide variety of unicellular or multicellular spores. It occurs during unfavourable environmental conditions. Some common types of spores are as under:



- i. **Zoospores:** These are motile uninucleate and naked flagellate spores. Zoospores are formed endogenously within a sac like structure called zoosporangium. E.g., *Albugo Synchytrium*.
- ii. **Conidium (Pl. Conidia):** Conidia are non – motile spores born either singly (e.g., *Phytophthora*) or in chain (e.g., *Penicillium*, *Aspergillus*) at the tip of the hyphae. The hyphae bearing Conidia at its tip is called Conidiophore. Conidia are usually unicellular but septate Conidia are formed in some fungi e.g., *Alternaria*.
- iii. **Oidium (pl = oidia):** These are small, thin walled free cells formed due to the fragmentation of a somatic hyphae into cells. The hyphal branch forming oidia is called oidophore. It cuts off oidia apically in succession. Each oidium behaves as a spore: *Coprinus*, *Mucor*.
- iv. **Chlamydospore:** These are unicellular, thick walled, non-mobile resting spores formed by rounding off the contents of the hyphal cells. Chlamydospores may be terminal or intercalary in position e.g., *Mucor*, *Peziza*, *Ustilago*.
- v. **Aplanspores or Sporangiospores:** These are non-mobile unicellular spores which are formed within a Sac like Sporangium. The hypha bearing terminal Sporangium is called Sporangiphore. E.g., *Mucor*.
In some fungi the entire thallus is converted into one or more reproductive structures (sexual or asexual). Therefore, the reproductive and vegetative phases do not occur together at the same time in the same individual. Such fungi are called holocarpic e.g., *Synchytrium*.
However, in majority of fungi only a part of the thallus produces the reproductive structure and the rest of the thallus remains vegetative. Such fungi are called eucarpic e.g., *Mucor*.

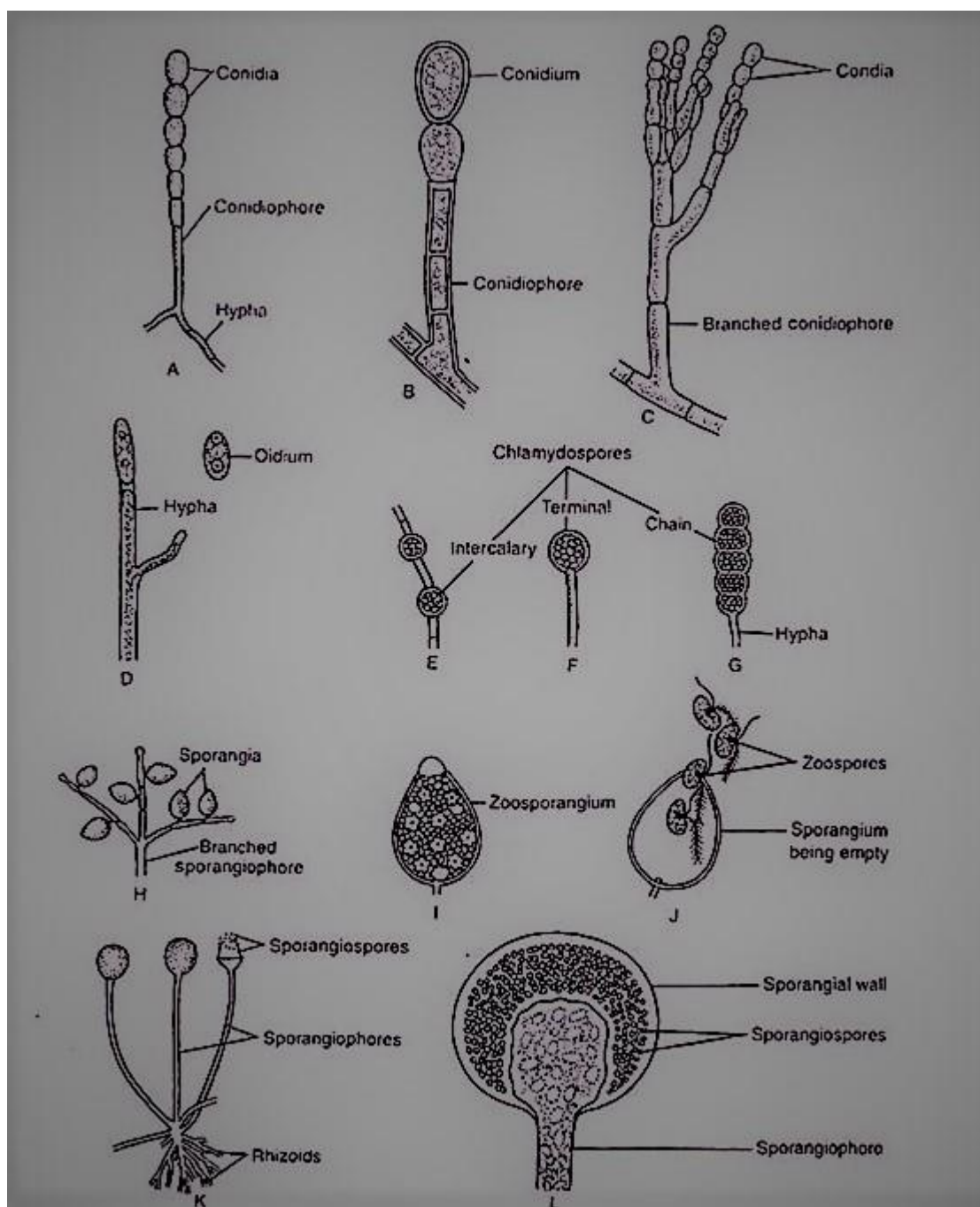


Figure: Asexual Reproduction in Fungi

III. Sexual Reproduction:

Sexual reproduction in fungi involves fusion of two compatible nuclei. Some fungi develop distinct male and female sex organs whereas others (advanced forms) do not develop them. In such forms the somatic hyphae take part in sexual reproduction. The sexual reproduction involves following three steps:



i. **Plasmogamy:** This is the fusion of Protoplasm of two sexually compatible elements such as the spores, gametes or vegetative cells. In this process the haploid nuclei come to lie in a single cell but they do not fuse.

ii. **Karyogamy:** This is the fusion of two nuclei brought together by Plasmogamy. The nuclei are haploid and fuse to form a diploid nucleus. Karyogamy may take place either immediately after Plasmogamy or there is a sufficient interval between these two steps.

iii. **Meiosis:** Karyogamy is followed by meiosis resulting in the formation of haploid nuclei.

There are various methods of sexual fusion in fungi. These are:

I. **Gametic Copulation (Planogametic Copulation):**

The motile gametes are called Plamogametes. It may be any of the following three types:

i. **Isogamy:** It involves fusion of two morphologically similar and mobile gametes.

ii. **Anisogamy:** Here both the fusing gametes are mobile but the male gamete is smaller than the female gamete.

iii. **Oogamy:** In this type of couplation, female gamete is larger and non – mobile while the male gamete is smaller and mobile due to flagella.

Primitive fungi have isogamous planogametes whereas advanced forms the fusing gametes are anisogamous e.g. *Synchytrium*.

II. **Gametangial Contact:**

In this process gametes are not released from the gametangia, instead the two gametangia of opposite sex come in contact and the gametes are directly transferred from one gametangium to other through a tube called fertilization tube. E.g. *Albugo*, *Pythium*.

III. **Gametangial Copulation:**

It involves fusion of the entire contents of two gametangia. Two gametangia of different sex come close together and the common wall between the two gametangia dissolves. As a result a common cell is formed where the protoplasm and the nuclei of the gametangia fuse. E.g., *Mucor*.

IV. **Spermatization:** Some fungi (Basidiomycetes and Ascomycetes) produce numerous minute, uninuecleate, spore-like male gametes called Spermatia (sing = spermatium).

These are not mobile and are carried by wind, insects or water to respective female hypa through which nucleus of the spermatium is transferred to the receptive hypa. E.g., *Puccinia*.

V. **Somatogamy:** In some fungi sex organs are not produced and instead somatic cells directly function as gametes e.g., *Peniopora*.

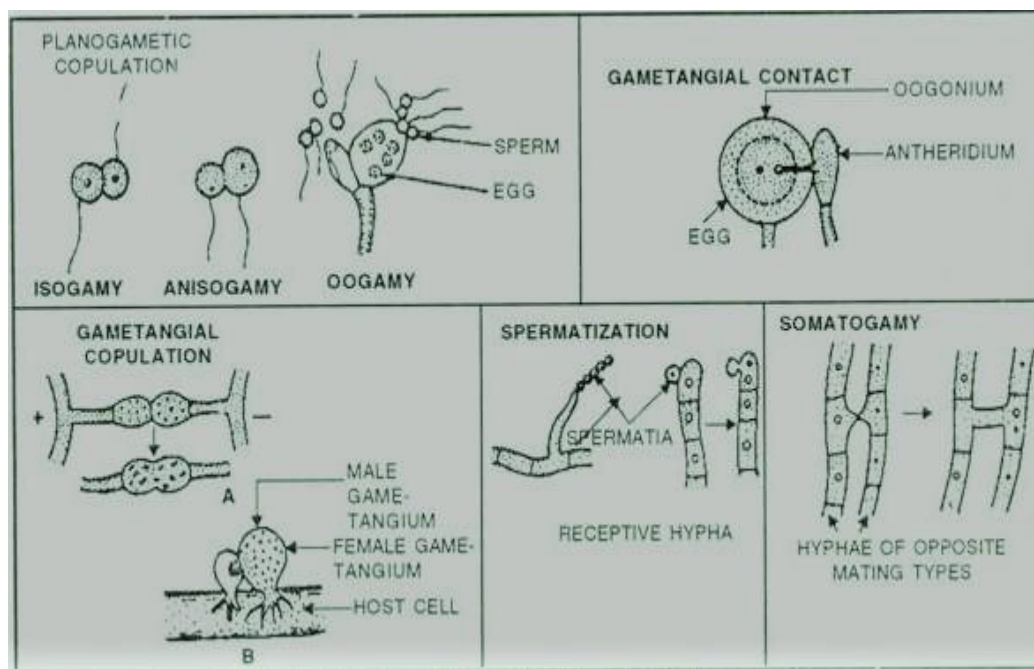


Figure: Sexual reproduction in Fungi

Classification of Fungi

On the basis of thallus structure and types of sexual reproduction fungi are classified into five divisions.

1. Mastigomycotina.
2. Zygomycotina.
3. Ascomycotina.
4. Basidiomycotina.
5. Deuteromycotina.

1. Division-Mastigomycotina, class-Oomycetes:

General Characters:

The main characteristics features are:

- i. Thallus is mycellial. The hypae are coenocytic (i.e., aseptate and multinucleate). Septa occur during the formation of sex-organs.
- ii. Asexual reproduction occurs by the formation of spores produced inside the sac-like Sporangia. Terrestrial species produce aplanospores and aquatic species produce zoospores.
- iii. The zoospores may be unflagellate or Biflagellate. Biflagellate zoospores have heterokont flagellation.



- iv. Sexual reproduction may be isogamous or oogamous (Male-anthridia, female-oogonia).
- v. The mode of sexual fusion is gametangial contact type. plasmogamy is immediately followed by karyogamy.
- vi. Sexual reproduction leads to formation of resting oospores.

Examples include *Phytophthora*, *Plasmopara viticola*.

2. Division Zygomycotina Class Zygomycetes (Conjugation Funji):

General Characters:

Main characteristic features are:

- i. The thallus is mycellial, hypae are coenocytic. Septa occur during the formation of sex – organs.
- ii. Cell wall is made up of Chitin or fungal cellulose.
- iii. Motile stage is totally absent.
- iv. Asexual reproduction occurs by the formation of sporangiospores formed inside sporangia.
- v. Sexual reproduction occurs by gametangial copulation, also called conjugation. Therefore, zygomycetes are also called conjugation fungi.
- vi. Gametes are non – motile and multinucleate, called coenogametes.
- vii. Sexual reproduction occurs by the formation of diploid zygospore.
- viii. The diploid nuclei of zygospore divide by meiosis before it enters the resting stage. During germination the zygospore gives rise to a Promycellium that bears a germ sporangium at its tip. The germ sporangium produces meiospores, called germ spores.

Example: *Rhizopus stolonifer*.

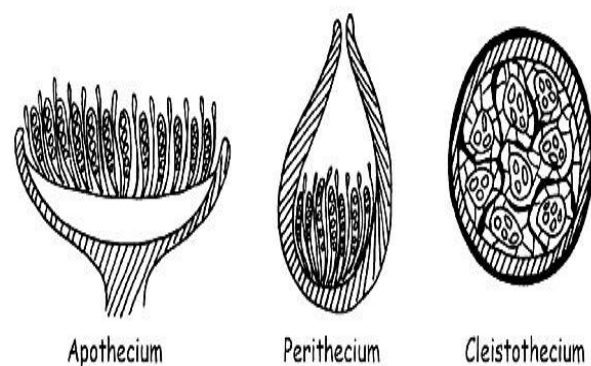
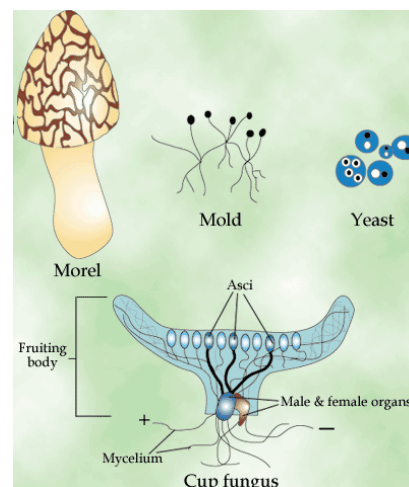
3. Division Ascomycotina Class : Ascomycetes. (The Sac Fungi):

General Characters:

- i. The Ascomycetes (GK askos = sac, mycete = fungus) includes diverse type of fungi such as brown, green, blue and pink moulds, powdery mildews, cup fungi, yeast morels and truffles. Majority of them are terrestrial and occur as saprotrophs or as parasites.
- ii. The yeasts include forms that are unicellular and are among the simplest of sac fungi. Except yeast, all ascomycetes are mycelial. The hypae are septate and multicellular.



- iii. The septa bear simple septal pores.
- iv. The Ascomycetes are characterised by complete absence of motile structures in their life cycle.
- v. Yeasts reproduce asexually by budding and fission.
- vi. Majority of Ascomycetes reproduce asexually by the formation of conidia. Conidia are formed on special hyphae, called conidiophores.
- vii. Sexual reproduction occurs by gametic copulation (e.g., yeast), gametangial contact (e.g., *Pyronema*), spermatization e.g., *Ascobolus* and Somatogamy (*Peziza*).
- viii. Sexual reproduces take place in three stages – Plasmogamy, karyogamy and meiosis.
- ix. Some specialized dikaryotic cells of dikaryophase function as ascus mother cells. In this cells the two nuclei opposite mating type fuse to form a diploid nucleus. The diploid nucleus divides first by meiosis and then by mitosis to form 8 (sometimes 4) haploid nuclei which form 8 ascospores. They remain inside the ascus. Half the number of ascospores in an ascus belongs to one mating type and remaining half belonging to second mating type.
- ix. The ascospores are liberated from ascus and germinate to produce new mycelia.
- x. The asci are produced inside the fruiting body called ascocarp. However, in some cases ascocarp is not produced e.g., (yeast). The ascocarps are of three types:
- Apothecium:** These are cup-shaped or disc-shaped fruiting bodies. The club-shaped asci are intermingled with sterile Paraphysis in the upper fertile layer, called hymenium. Just below the hymenium is sub-hymenium and fleshy-part hypothecium. E.g., *Peziza*, *Morchella*.
 - Perithecium:** It is flask-shaped fruiting body which has a definite apical pore, called ostiole. E.g., *Claviceps*.
 - Cleistothecium:** It is a small spherical or ovoid indehiscent fruiting body which is completely closed from all the sides. E.g., *Erysiphe*.
Examples: yeast, *Aspergillus*, *Penicillium*, *Morchella*.



4. Basidiomycotina, class: Basidiomycetes (the club fungi):

General Characters:

- i. Basidiomycetes include mushrooms, toadstools, puffballs, jelly-fungi, shelf-fungi, plant pathogens, including rusts and smuts.
- ii. Basidiomycetes are named for their characteristic structure, the club-shaped basidium (Pl. Basidia).
- iii. The mycelium of basidiomycetes is composed of septate and perforated hyphae. Each septum is perforated centrally by a dolipore.
- iv. The mycelia are of three types: Primary, secondary and tertiary.
- v. The Primary mycelium develops from uninucleate haploid basidiospores. It multiplies by conidia or idia formation.
- vi. The specialized sex – organs such as antheridia, oogonia etc. are not formed. Sexual reproduction occurs in primary mycelium by somatogamy and spermatization.
- vii. Sexual reproduction involves Plasmogamy, karyogamy and meiosis. Plasmogamy results in the formation of dikaryon. Karyogamy is delayed and the intervening phase develops from the dikaryon.
- viii. The secondary mycelium consists of dikaryotic or binucleate cells. It grows by cell division.
- ix. The secondary mycelium multiplies by the formation of different types of spores such as chlamydospores, uredospores, teleutospores, aeciospores etc.
- xi. Some of the reproductive cells of secondary mycelium become club – shaped basidia. Karyogamy and meiosis takes place in these basidia.

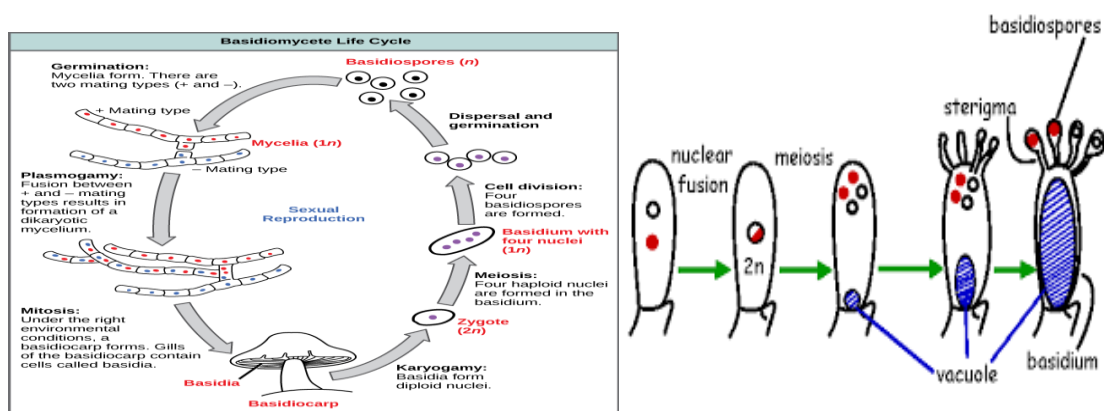
xii. Each basidium produces four haploid basidiospores exogenously at the tips of tubular outgrowths, called sterigmata. The basidiospores get detached and germinate to give rise primary mycelia.

xiii. Motile structures are completely absent in the life cycle.

xiv. Some higher forms produce fruiting bodies called basidiocarps (e.g., mushrooms). The body of basidiocarp comprise of complex secondary mycelium, called tertiary mycelium.

Examples:

- Agaricus compestris* (field mushroom, gelled mushroom)
- Amanita* (toad stools). They are deadly poisonous. They contain a substance Phallin which dissolves corpuscles.



5. Division Deuteromycotina (Class Deuteromycetes) (*The fungi imperfecti*):

General Characters:

- Deuteromycetes include all those fungi in which perfect stage or sexual stage is not known.
- They are Sprotrophs. Most of them are parasites and cause serious diseases in plants, animals.
- The mycelium consists of well developed branched and septate hyphae.
- Reproduction occurs only by asexual methods by the formation of Conidia.
- Sexual reproduction is absent.

Examples: *Alternaria*, *Fusarium* etc.



Status of Virus:

Viruses:

Viruses are the most primitive acellular and non-cytoplasmic microscopic infectious agents that replicate inside the body of a host. They were discovered by D. J Ivanowski (1892). The term virus was coined by the Dutch microbiologist, Martinus Willem Beijerinck in the year 1897. It is derived from Latin, which means poison or venomous substance. W. M Stanley in 1935 isolated pure crystals of Tobacco Mosaic virus and concluded that viruses are made up of nucleoproteins.

Viruses are called as living chemicals as they are inert once outside the host and become alive once they enter the host's body. They can be crystallised and purified. The study of viruses is called as virology.

General Properties of Viruses:

1. They are non-cellular organisms, which is enclosed in a protective envelope.
2. The presence of spikes helps in attaching the viruses to the host cell.
3. These viruses do not grow, neither respire nor metabolize, but they reproduce.
4. They are surrounded with a protein coat – capsid and have a nucleic acid core comprising of DNA or RNA.
5. They are considered both as living and non-living things. These viruses are inactive when they are present outside of host cells but become active within host cells. These viruses cause several infections and reproduce within the host cell by using the enzymes and raw materials.

General Structure of Viruses:

1. Shape and Size:

The viruses are of different shapes. They may be spherical, rod – shaped (TMV) tadpole – like (Bacteriophage), helical (influenza) or Polyhedral. Viruses are smaller than bacteria. The size ranges from 10nm (virus of foot and mouth disease) to 300nm (smallpox virus).

2. Chemical Structure and Composition:

A virus is made up of a nucleic acid core and protein coat called capsid which surrounds the core.

- i. **Nucleic Acid:** A virus always contains only a single kind of nucleic acid i.e., either DNA or RNA. The nucleic acid may occur as single or doubled stranded. The infectious property of virus is due to its nucleic acid injected into host cell.
- ii. **Capsid or Protein Coat:** The protein coat is called capsid. It is made up of many identical protein sub units called capsomers. The capsomers are composed of either one or several types of proteins. Some larger viruses have an additional covering outside the capsid. Such viruses are called enveloped viruses e.g., Influenza virus.

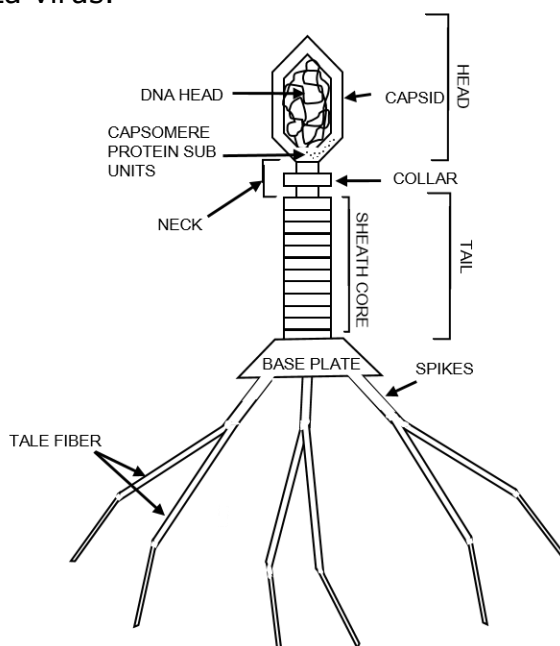


Figure: Structure of T-even Bacteriophage

Classification of Viruses:

Viruses can be classified primarily on their phenotypic characteristics, core content, chemical composition, capsid structure, size, shape, genome structure and modes of replication.

The Baltimore classification is the most commonly used for studying the system of virus classification. This system was developed by an American biologist David Baltimore in the 1970s, for which he was awarded Nobel Prize.

The below flowchart describes the classification of viruses based on their different criteria.

Classification based on the presence of nucleic acid:

DNA virus:

The virus, having DNA as its genetic material is called DNA Virus. There are two different types of DNA viruses:

- i. Single-stranded (Ss) DNA virus: e.g. Picornaviruses, Parvovirus, etc.
- ii. Double-stranded (Ds) DNA virus: e.g. Adenovirus, Herpesvirus, etc.

RNA virus:



The virus, having RNA as its genetic material is called RNA Virus. There are two different types of RNA viruses:

- i. Double-stranded (Ds) RNA virus: e.g. Reovirus, etc.
- ii. Single-stranded (Ss) RNA virus.

Single-stranded (Ss) RNA virus is further classified into two groups:

- i. Positive sense RNA (+RNA)
- ii. Negative sense RNA (-RNA).

Poliovirus, Hepatitis A, Rabies virus, Influenza virus are examples of single-stranded RNA virus.

Classification based on the structure or symmetry:

1. Complex virus. E.g Poxvirus
2. Radial symmetry virus. E.g. Bacteriophage
3. Cubical or icosahedral symmetry shaped virus. E.g. Reovirus, Picornavirus
4. Rod or Spiral shaped or helical symmetry virus. E.g. Paramyxovirus, orthomyxovirus

Classification based on the replication properties and site of replication:

Here, viruses invade into the host cell, where it replicates and assembly within the cell organelles:

1. Replication within the cytoplasm of the host cell.
E.g. All RNA virus except the Influenza virus.
2. Replication within the nucleus and the cytoplasm of the host cell.
E.g. Influenza virus, Poxvirus, etc.
3. Replication within the nucleus of the host cell.
All DNA viruses except Pox virus.
4. Replication of the virus through the double-stranded DNA intermediate.
E.g. All DNA virus, Retrovirus and some tumour causing RNA virus.
5. Replication of the virus through a single-stranded RNA intermediate.
E.g. All RNA virus except Reovirus and tumour-causing RNA viruses.

Classification based on the host range:

Based on the type of host, there are four different types of viruses:

1. Animal viruses
2. Plant viruses
3. Bacteriophage
4. Insect virus

1. Animal viruses:

These viruses infect by invading the cells of animals, including humans. Prominent examples of animal viruses include the influenza virus, mumps virus, rabies virus, poliovirus, Herpes virus, etc.



2. Plant viruses:

These viruses infect plants by invading the plant cells. Well-known examples of plant virus include potato virus, tobacco mosaic virus, beet yellow virus, and turnip yellow virus, cauliflower mosaic virus, etc.

3. Bacteriophage:

The virus which infects bacterial cells is known as bacteriophage. There are many varieties of bacteriophages, such as DNA virus, MV-11, RNA virus, λ phage, etc.

4. Insect virus:

The virus which infects insects is known as Insect virus also called as the viral pathogen of insects. These viruses are considered as a powerful biocontrol agent in the landscape of modern agriculture. Ascovirus virions and Entomopox virus, are best examples for insect virus.

Classification based on the mode of transmission:

1. Airborne infections – Transmission of the virus through the air into the respiratory tract. E.g., Swine flu, and Rhinovirus.
2. Faecal oral route – Transmission of the virus through the contaminated water or food.
E.g. Hepatitis A virus, Poliovirus, Rotavirus.
3. Sexually transmitted diseases – Transmission of the virus through sexual contacts with the infected person. E.g. Retrovirus, human papillomavirus, etc.
4. Transfusion-transmitted infections- Transmission of the virus through the blood transfusion.
E.g. Hepatitis B virus, Human Immunodeficiency Virus, etc.
5. Zoonoses -Transmission of the virus through the biting of infected animals, birds, and insects to human. E.g. Rabies virus, Alphavirus, Flavivirus, Ebola virus, etc.

Diseases Caused By Virus:

Following are the diseases caused by viruses. These diseases have made a significant socio-economic impact in the last few decades:

1. AIDS (Acquired Immunodeficiency Syndrome)
2. Ebola
3. Influenza
4. SARS (Severe Acute Respiratory Syndrome)
5. Chikungunya
6. Small Pox (Now eradicated)
7. Covid-19 (Severe and Acute Respiratory Disorder with High Fever)

Reproduction in Viruses:



Viruses multiply only within the host cell. During multiplication nucleic acid of virus is replicated and also the proteins required for the viral coat are formed. The process of multiplication is best understood by bacteriophage.

1. The phage attaches itself to the wall surface of the bacterium with the help of tail fibres and end plate.
2. The tail sheath contracts and the phage DNA is injected into the bacterial cell.
3. The phage DNA takes over the protein synthesizing machinery of bacterial host and inactivates the DNA of the bacterium.
4. Phage DNA replicates and also synthesizes new proteins for its capsid. The protein coats are assembled around phage DNA. The process continues till large number of phage particles is formed.
5. Ultimately the bacterial cell bursts (the process is called lysis) and new phage particles are liberated. These particles are capable of infecting other bacteria of the same type. The entire process of multiplication takes about 30 minutes. It is called latent period.

Biological Status of Viruses:

Viruses are non-cellular, microscopic infectious agents that can only replicate inside a host cell. From a biological perspective, viruses cannot be classified either as living organism nor non-living. This is due to the fact that they possess certain defining characteristic features of living organisms and non-living entities. Thus, a virus is a non-cellular, infectious entity made up of genetic material and protein that can invade and reproduce only within the living cells of bacteria, plants and animals.

For instance, a virus cannot replicate itself outside the host cell. This is because viruses lack the required cellular machinery. Therefore, it enters and attaches itself to a specific host cell, injects its genetic material, reproduces by using the host genetic material and finally the host cell splits open, releasing the new viruses.

Viruses can also be crystallized, which no other living organisms can do. It is these factors that lead to viruses being classified in the grey area – between the living and non-living.

Viruses as non-living:

1. Viruses have no complete cellular structure.
2. They do not have cellular metabolism.
3. Viruses are active only within the living host.
4. Viruses can be precipitated like chemical substances.

Viruses as living organisms:

1. They have definite shape and morphology.
2. They possess genetic material DNA or RNA.
3. They are obligate parasites and are host specific.
4. They show property of mutation.



5. They can multiply within the living host thus showing one of the important properties of living organisms.

Examples:

Plant Viruses:

- i. Tobacco Mosaic Virus (TMV): RNA virus, rod shaped.
- ii. Bacterial Virus (Bacteriophages): Tadpole shaped, a DNA virus.

Animal Viruses:

- i. Influenza Virus: Round or oval in shape contains RNA.
- ii. Coronavirus: Round in shape contains RNA.

AIDS (Acquired Immunodeficiency Syndrome):

It is caused by HIV (Human Immunodeficiency Virus), a retrovirus (RNA virus) that transcribes its genes into DNA. Infected persons have little resistance to infection and nearly all of them die of disease that non-infected individuals easily ward off.

HIV attacks WBC and destroys human immune system. One special kind of white blood cell called CD4⁺ cell raises the defending cells to action. But in AIDS patients' virus attacks these CD4⁺ cells and kills them.

Status of Lichens:

Lichens are curious plants formed by the close association of algae and fungi. The algal component is known as phycobiont and the fungal partner as mycobiont.

- i. **Phycobiont:** The phycobiont mostly belongs to green algae chlorophyceae e.g., *Protococcus*, *Cystococcus*, *Trebouxia* etc or to blue green algae.e.g. *Nostoc*, *Rivularia*, *Stigonema*.
- ii. **Mycobiont:** Mycobiont or the fungal component mostly belongs to Ascomycetes, and a few belong to Basidiomycetes e.g, *Cora*, *Corella*, *Dictyonema*.

General characters of Lichens:

1. Occurrence:

Lichens are cosmopolitan in distribution. They are slow growing plants found in wide variety of habitats. They are found in extreme climatic conditions such as dry exposed rocks and also in snow covered Arctic or Antarctic regions. Due to this property they are pioneers of plant communities.

2. Structure:



Lichens are thalloid plants of green and bluish-green colour. They are usually dull in appearance. Many Lichens have additional pigments, such as yellow, orange, brown, black etc.



I. External Form:

On the bases of external form Lichens are of following three types:

- i. **Crustose Lichens:** Lichens forming crusts closely appressed to the substrate are called crustose Lichens. Their thallus is inconspicuous and flat, and without lobes e.g., *Rhizocarpon*, *Graphis*, *Strigula* etc.
- ii. **Foliose Lichens:** These are leaf-like with well branched and lobed thalli. They remain attached to the substratum with the help of thin rhizoid-like structures called rhizines, e.g., *Parmelia*, *Collema* etc.
- iii. **Fruticose Lichens:** These Lichens have well developed branched erect or pendulous thallus which gives them a shrub like appearance. They remain attached to the substratum by a basal mucilaginous disc e.g., *Alectoria*, *Usnea*, *Cladonia* etc.

II. Internal Structure: Vertical section of a well developed foliose lichen shows following structures.

- i. **Upper Cortex:** It is outer most tough protective covering made of compactly interwoven hyphae. In some foliose lichens, upper cortex has pores known as breathing pores, through which gaseous exchange takes place. Other structures that help in gaseous exchange are *Cyphellae*.
- ii. **Algal Layer:** Inner to upper cortex is a distinct region of loose fungal tissue in which many algal cells are embedded, e.g. *Parmellia*. In some lichens the algal cells are uniformly distributed throughout the thallus.
- iii. **Medulla:** The medulla forms the bulk of the thallus. It is made up of loose mass of irregularly interwoven hyphal threads. In crustose lichens the lower cortex is absent and fungal hyphae of medulla region penetrate the substrate to fix the thallus.
- iv. **Lower Cortex:** Like upper cortex it is also made up of compactly arranged hyphae. Some of the hyphae of lower cortex extend beyond the surface of the thallus and form rhizines. These serve as organs of attachment.

3. Reproduction: The algal partner reproduces asexually only, while the fungal partner carries its normal sexual reproduction.

I. Asexual Reproduction:

1. **Fragmentation:** The adult thallus breakdown accidental into pieces and each of them grows into new thallus. E.g., Foliose and fruticose forms.
2. **Soredium:** It is a small specialised part of lichen thallus which consist few cells of alga surrounded by a thin layer of mycelium. They become detached, and form new thallus on germination.
3. **Isidia:** These are small finger like projections which develop on upper surface of thallus, having general structure of thallus, after detachment they develop into new thallus.



II. Sexual Reproduction: In lichens sexual reproduction occurs only in fungal partner mostly belonging to Ascomycetes.

i. Male Reproductive Structures:

They are flask shaped structures called spermatogonia having an opening called ostiole. Each spermatogonium produces male cells called spermatia.

ii. Female Reproductive Structures:

They are known as carpogonia. Each carpogonium has two parts-the basal ascogonium and upper long tube called trichogyne.

iii. Fertilization:

Spermatia get attached to trichogyne, the wall between them dissolves and nucleus of spermatium enters into trichogyne and reaches ascogonium and fuses with female nucleus. The ascogonium develops into ascocarp, containing eight ascospores which are formed by meiotic division of diploid nucleus. The ascospore after liberation, form new mycelium which comes in contact with algae and form lichen.

4. Relationship:

i. Symbiosis (Consortium):

The relationship between algal and fungal partner of lichens is usually considered as symbiotic, in which alga provides organic food to fungus and in turn fungal partner makes water and mineral available to algae. Fungus also protects alga from desiccation.

ii. Helotism (Master and Slave Relationship):

Some believe that it to be a master (fungi) and slave (algae) relationship rather than symbiotic. This view based on the fact that the algae found in the thallus of lichen can and does live in Free State. The fungus on the other hand, is unable to survive in the absence of an algal partner. Besides, fungus sometimes produces haustoria which penetrates and kill some of algae cells.

Economic Importance of Lichens:

- 1. Pioneers in Plant Succession:** Lichens are pioneers in plant succession as they are the earliest settlers on barren rock.
- 2. Lichens as Food:** Lichens contain a substance called lichenin which is similar to carbohydrate. It is nutritive and thus edible e.g., *Evernia*, *Cetraria islandica*.
- 3. Lichens as Fodder:** Lichens form favourite food for reindeers, cattle, etc. *Cladonia rangiferina*, (reindeer moss), *Lobaria pulmonaria* etc.
- 4. Lichens as Medicine:** Usnic acid obtained from *Usnea* and *Cladonia* is used as broad spectrum antibiotic. It is effective against Gram⁺ bacteria. *Parmelia perlata* is used in the treatment of snake bite.

5. **Lichens as Source of Dyes:** Litmus paper is prepared by soaking the paper in the extract of *Roccella tinctoria*.
6. **Lichen in Tanning Industry:** *Cetraria islandica* and *Lobaria pulmonaria* have two colouring substances lecanoric acid and erythrin which are used in tanning industry.
7. **In Perfumery:** Species of *Evernia* and *Ramalina* are the sources of essential oils which are used in soaps and other cosmetics.
8. **Indicators of Air Pollution:** Lichens are very sensitive to air pollution particularly SO_2 concentration in atmosphere. Thus, decrease in lichen population in an area indicates air pollution.
9. Species of *Roccella* and *Lacanora* yield 'Orchill' which is used in dyeing of woollen and silk fabrics.

Status of Viroids:

Viroids are tiny, naked molecules of RNA, only a few hundred nucleotides long that are important infectious disease agents in plants. They are infectious pathogens that affect only plants, therefore are also called as the plant pathogens. Viroids were first discovered by T.O. Diener in the year 1971. It was first examined in the potato spindle tuber viroid that caused a huge loss to the potato industry.

A recent viroid outbreak killed over ten million coconut Palms in Philippines. It is not clear how viroid cause disease. One clue is that viroid nucleotide sequence resembles the sequence of introns with ribosomal RNA genes. These sequences are capable of catalysing the destruction of chromosomal integrity.

Structure of Viroids:

Structurally, viroids are smaller than viruses and possess circular and single strands of Ribonucleic Acids (RNA's) with no protein coating. These entities hijack the cellular machinery present in plant cells to replicate new copies of itself. It primarily affects all forms of higher plants.

The plants that are infected by viroids are responsible for the crop failures and also cause loss of millions of dollars in the agricultural revenue every year. Some of the plants that are affected by these pathogens are potatoes, tomatoes, cucumbers, chrysanthemums, coconut palms, avocados, etc.



Figure: Structure of Viroid (Source; google.com)



Characteristic Features of Viroids

Some of the characteristic features of viroids are given below-

1. Viroids are formed only on the RNA.
2. These are known to be smaller in size and infect only the plants.
3. These are among the smallest known agents causing infectious disease.
4. Viroids are the species of nucleic acid with relatively low molecular weight and a unique structure.
5. They reproduce within the host cell which they affect in and cause variations in them causing death.
6. Viroids are mainly classified into two families namely Pospiviroidae- nuclear viroids and Avsunviroidae- chloroplastic viroids.
7. Viroids are said to move in an intracellular manner, cell to cell through the plasmodesmata, and a long-distance through the phloem.

Diseases Caused by Viroid:

Viroids are the plant parasites like transcriptional machinery of the cell organelles such as the nucleus or the chloroplast since they are known to be non-coding. These replicate by the process of RNA–RNA transcription. They mainly infect the epidermis of the hosts after causing mechanical damage to the cell wall of the plant.

Some of the diseases that are caused by the infection of viroid in plants are:

- i. *Citrus exocortis*
- ii. Cucumber pale fruit
- iii. *Chrysanthemum* stunt.

These infectious diseases are spread by the propagation of seeds in plants by cutting, tubers, etc. and also by mishandling the contaminated implements.
The only disease that is caused by viroids in humans is Hepatitis- D.

The symptoms that are caused by the infection of viroid in plants include:

- i. stunting of growth
- ii. stem necrosis
- iii. deformation of the leaves and fruits
- iv. At last causing the death of the plant.

Most of the viroids are said to infect the plants, including coconut and the apple trees. The (PSTV) potato spindle tuber viroid causes significant crop damage to the potato yields causing the tubers to elongate and then crack. The other common type of viroid infection symptoms includes stunting and leaf epinasty.



Taxonomic Aids:

Taxonomical aids are the collections of samples or preserved organisms which help in extensive research for the identification of various taxonomic hierarchies. Classifying organisms into various categories needs a lot of field and laboratory study. This is so important because taxonomic categorization helps in identifying many organisms necessary in various fields like agriculture, industries, bio resources, etc.

The taxonomical Aids are the main source which helps us in studying the relative level of a group of organisms, their taxonomic hierarchy and the taxonomic rank.

Taxonomical Aids are required for the taxonomic studies of various species of plants, animals, and other organisms, which require correct classifications and identification. Various taxonomic aids are discussed as under:

1. Botanical Gardens:

These are gardens in which specific plants are grown and are labelled according to their taxonomy. Thus, the labels carry their scientific names and family. The main purpose of botanical gardens is to identify the plant species under consideration.

Botanical gardens are places where plant from various groups are grown for scientific study, conservation, public education, aesthetic and research purposes. A botanical garden is supported by a library, laboratory, herbarium and museum.

Botanical gardens are maintained by government, semi government or private organisations. Botanical garden also has green houses for cacti and succulents. The famous botanical gardens are:

1. New York Botanical Garden U.S.A.
2. Royal Botanical Garden, Kew England.
3. Indian Botanical Garden Kolkata.
4. National Botanical Garden Lucknow.

Role of Botanical Gardens:

1. Botanical gardens provide a ready material for research.
2. Botanical gardens play an important role in conservation of endangered species.
3. Many major botanical gardens of world have herbaria and libraries to facilitate taxonomic research at a single place.
4. Botanical gardens help in identifying the nature and exotic species.
5. Botanical gardens have aesthetic and recreational value.



2. Herbarium:

Herbarium is a store house of collected plant specimens that are dried, pressed and preserved on sheets. These sheets are arranged according to universally accepted system of classification. These specimens along with their description on herbarium sheets become a store house for future studies. The herbarium sheets carry information about the local name, botanical name, English name, etc. Herbarium also serves a quick referral system in taxonomic studies, e.g., Central National Herbarium of Indian Botanical Garden Kolkata.

Role of Herbaria:

The herbaria play following important roles:

1. The specimens preserved in herbaria offers study when needed.
2. Type specimens, on the description of which the species names are established, are kept in safe rooms with limited access.
3. Herbaria offer a facility for identification of plant specimens on site as well as by post.
4. Herbaria have become centres for research in plant taxonomy, morphology etc.
5. Knowledge of plant taxonomy and distribution is gained from herbarium specimens.

3. Museum:

Biological museums are found in schools and colleges; like the biology laboratory that we find in our schools. In these museums, plants and animal species are preserved in jars and containers with the help of appropriate preservatives. They may also be dried and preserved. Birds and larger animals are usually stuffed before preserving and insects are killed and pinned in boxes. We sometimes find skeletons of various animals too.

Role of Museums:

- i. **Acquisition of materials.** Museum acquire object in several ways, of which field collection is one of the most useful.
- ii. **Recording of Materials.** Each acquisition is listed carefully by specialist staff.
- iii. **Preservation of Materials.** The primary purpose of museum is to preserve selected objects.
- iv. **Research:** Many museums published scholarly journals, series of papers and books to make available result of research on collections.
- v. **Exhibitions of Materials:** Various members of museum staff prepare acquisitions for exhibitions. The specimens selected for exhibition are put on a view in numerous ways. The choice of approach and techniques depends on the purpose of exhibits.
- vi. **Education.** Museums help in spreading education.



4. Zoological park:

These are places where animals and birds are kept in protected boundaries. An attempt is made to provide them with a habitat closest to their natural habitats. Thus, we get a chance to learn about their natural habits and behaviour. Zoological parks are open for human visits.

Role of Zoological Parks:

Zoological parks contribute in conserving biodiversity by:

- i. Providing natural environment and open space to animals, i.e., wild life species.
- ii. Keeping them safe from their predators ensuring protection, food and shelter.
- iii. Providing home to different native and exotic wild animals.
- iv. Involving in the rescue of endangered species.
- v. Facilitating breeding of animals and releasing them free.

5. Keys:

Key is another taxonomic aid used for identification of plants and animals based on the similarities or dissimilarities. The keys are based on contrasting characters generally in a pair called couplet. It represents the choice made between two opposite options. This results in acceptance of only one and rejection of the other. Each statement in the key is called a lead. Separate taxonomic keys are required for each taxonomic category such as family, genus and species for identification purposes. Keys are generally analytical in nature. Taxonomic keys are of two types:

- i. **Yorked or Indented Key:** It provides sequence of choice between two or more statements of characters of a species. The job of the taxonomist is to make the correct choice for identification.
- ii. **Bracketed Key:** In this key pairs of contrasting characters are used for identification of the specimens. The major difference between indented key and Bracketed key is that, Bracketed key uses contrasting characters but they are not separated by intervening subdividing characters.

Other Taxonomic Aids:

Besides the above mentioned taxonomic aids, flora, manuals, monographs and catalogues also serve as taxonomic aids for correct identification.

1. Flora:

These contain the actual account of habitat and distribution of plant species of a given area. It provides the index to plants occurring in a particular area. Hooker compiled first complete flora of India.



2. 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.

3. Manuals:

These provide information for identification of names of species occurring in an area. They also help in correct identification.

4. Catalogue:

These provide the list of publications. The publications publish the books, periodicals, and dictionaries which provide new information for taxonomic studies.

Further readings:

1. Biology, Textbook for Class XI, NCERT
2. www.easybiologyclass.com
3. www.biologydiscussion.com
4. www.botanystudies.com
5. www.britannica.com



UNIT III: ANATOMY OF FLOWERING PLANTS

Syllabus

Tissue and Tissue System:

Types of Tissues- Meristematic and Permanent, and their Classification and functions.

Anatomy of Dicot and Monocot Root, Stem and leaves.

Secondary Growth in Dicot Stems and Roots.

Introduction:

Anatomy is the branch of biology concerned with the study of internal structures or an organ system of an organism. Anatomy of flowering plants is the study of the structure of organisms and their parts.

Plant Anatomy also called as the *phytotomy*. It is the study of the internal structure of plant including the tissues, [root system](#), stem, leaves, flower, fruit and seeds. Thus it is the study of the gross internal structure of plant organs as observed after section cutting.

Tissue:

Tissues may be defined as a group or collection of similar or dis-similar cells that perform or help to perform a common function and have a common origin. The term "Tissue" in plant anatomy was coined by N. Grew in (1682).

Plant Tissue Systems:

The plant tissue system comprises of three major types. They are:

- I. Dermal tissue system,
- II. Ground tissue system, and
- III. Vascular tissue system.

I. Dermal Tissue System:

Dermal tissue system, also called as *Tegumentary* tissue system, covers the outside of a plant in a single layer of cells called the epidermis. It mediates most of the interactions between a plant and its environment. Epidermal cells secrete a waxy substance called cuticle, which coats, waterproofs, and protects the above-ground parts of plants. Cuticle helps prevent water loss, abrasions, infections, and damage from toxins.

This tissue includes several types of specialized cells. Pavement cells, large, irregularly shaped parenchymal cells which lack chloroplasts, make up the majority of the epidermis. Within the epidermis, thousands of pairs of bean-shaped schlerenchymal guard cells swell and shrink by osmosis to open and close stomata, tiny pores which control the exchange of oxygen and carbon dioxide gases and the release of water vapour. The lower surfaces of some leaves contain as many as 100,000 stomata per square centimetre.

Functions of Epidermis:

1. The exchange of matter between the plant and the environment.
2. The epidermis on above ground organs (leaves and stems) is involved with gas exchange
3. The epidermis on below ground organs (roots) is involved with water and ion uptake.

II. Ground Tissue System:

Ground tissue system also called as *fundamental* tissue system makes up much of the interior of a plant and carries out basic metabolic functions. Ground tissue in stems provides support and may store food or water. Ground tissues in roots may also store food.

Functions of Ground Tissue System:

1. The ground tissue of the leaf (called mesophyll) uses the energy in sunlight to synthesize sugars in a process known as photosynthesis
2. The ground tissue of the stem (called pith and cortex) develops support cells to hold the young plant upright
3. The ground tissue of the root (also called cortex) often stores energy- rich carbohydrates

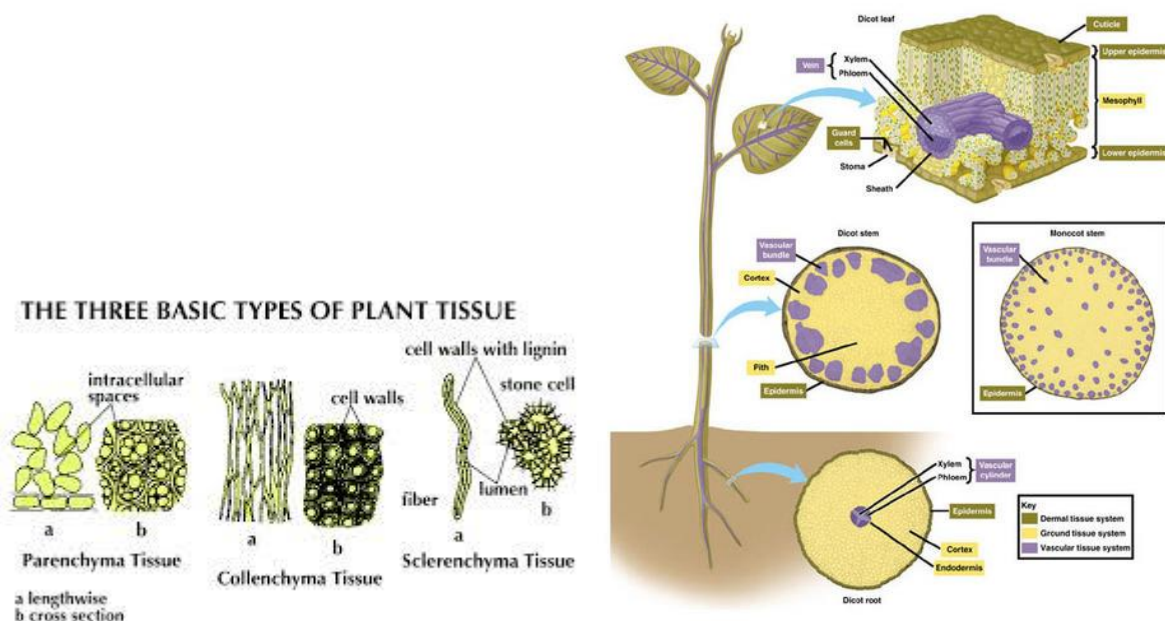


Figure: Tissue System in Plants(Source: Britannica.com)



III. Vascular Tissue System:

Vascular tissue system also called as *fascicular* tissue system runs through the ground tissue inside a plant. Plants have vessels that transport water, minerals, and nutrients. These vessels are the vascular tissue, and consist of xylem and phloem. Xylem and phloem are packaged together in bundles, as shown in figure below.

Functions of Vascular Tissue System:

1. Vascular tissues transport of water and dissolved substances inside the plant
2. The xylem carries water and dissolved ions from the roots to stems and leaves
3. The phloem carries dissolved sugars from the leaves to all other parts of the plant

Summary of plant tissue Systems:

Tissue System	Components	Functions
Dermal Tissue System	Epidermis Periderm (in older stems and roots)	1. Protection 2. Prevention of water loss
Ground Tissue System	Parenchyma tissue Collenchyma tissue Sclerenchyma tissue	1. Photosynthesis 2. Food storage 3. Regeneration 4. Support
vascular Tissue System	Vascular bundles -Xylem -Phloem	1. Transport of water and minerals. 2. Transport of food Protection

Types of Plant Tissues:

There are two types of tissues in the flowering plants:

- I. Meristematic Tissues
- II. Permanent Tissues

I. Meristematic Tissues:

(GK. Meristos = Divisible).

Meristematic tissues are a group or cluster of cells which remain in continuous state of division or retain their power of division. Meristematic tissue is a simple plant tissue of thin walled embryonic cells which undergo forming new cells and tissues. The term, "meristem" was coined by Naegeli (Carl Wilhem von Nageli) in 1858.



Characteristics of Meristematic Tissues:

1. Cells of meristematic tissues may be rounded, oval, polygonal or rectangular in shape and are compactly arranged without intercellular spaces.
2. They have thin and elastic primary wall made up of cellulose, dense protoplasm with many small vacuoles and large nuclei.
3. Meristematic cells do not store reserve food materials.
4. The plastids are present in the form of proto-plastids. The crystals are absent and the endoplasmic reticulum is poorly developed.
5. Meristematic cells usually divide in a particular plane.

Types of Meristematic Tissues:

Depending upon the location, meristematic tissues are of three types;

1. **Apical meristems**
2. **Intercalary Meristems**
3. **Lateral Meristems**

1. Apical meristems:

The apical meristems are located at the growing points of stem, root and their branches the apical meristems are responsible for the linear growth of an organ, thus help the plant to grow in length.

2. Intercalary meristems:

The intercalary meristems are actually part of the apical meristem which gets separated from it during the growth of stem and root in the length. They are located in between the regions of permanent tissue. They may lie above the node (as in grasses and cereals), below the node (as in *Mentha* or mint) and base of leaves (*Pinus*). The intercalary meristems give rise to permanent tissues.

3. Lateral meristem:

These meristems are present along the lateral side of root and stem, thus they occur parallel to the circumference of the organ in which they develop. The cells of lateral meristem undergo periclinal divisions producing secondary tissues on the outer and inner side. They increase the girth of the plant organs. Examples of lateral meristems are cambium, cork cambium etc.

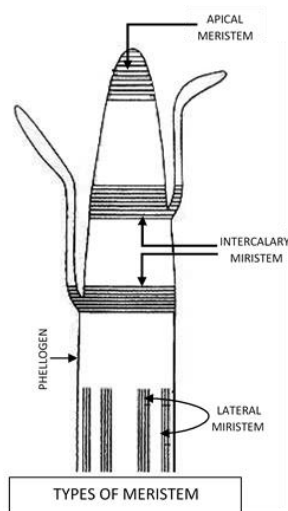


Figure: Meristematic Tissues

II. Permanent Tissues:

Permanent tissues are derived from the meristematic tissues that have lost their ability to divide after attaining their mature form. The permanent tissues form the major portion of the plant.

Characteristics of Permanent tissues:

1. These are derived from meristematic tissue and are composed of cells that have lost the ability to divide.
2. They are divided into simple and complex tissues, which are further divided.
3. The simple tissues constitute the parenchyma which is thin-walled cells with cellulose in the cell wall and performs [photosynthesis](#), storage and secretion. The collenchymas which are formed of closely packed isodiametric cells, providing mechanical support and the sclerenchyma which are formed of dead cells also meant for mechanical support, having two types of cells, fibres, and sclereids.
4. The complex tissues consist of the xylem, which conducts water and minerals to other parts of the plant and the phloem which transports food material to various parts of the plant.

Types of permanent Tissues:

Permanent tissues are of two types:

1. Simple Permanent Tissues and
2. Complex Permanent Tissues.

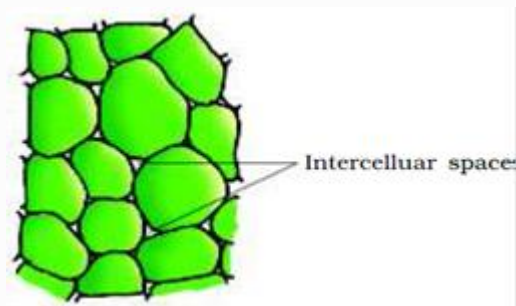
1. Simple Permanent tissues

Simple Permanent Tissues consist of:

- i. Parenchyma
- ii. Collenchyma
- iii. Sclerenchyma

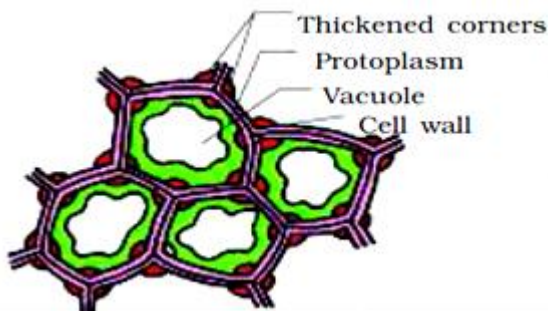
i. Parenchyma:

Parenchyma is a simple permanent living tissue which is made up of thin-walled isodiametric cells. Each cell encloses a large central vacuole and peripheral cytoplasm containing nucleus. They are found in non-woody and soft areas of stem, root, leaves, fruits and flowers. They store the food and provide turgidity to softer parts of plant.



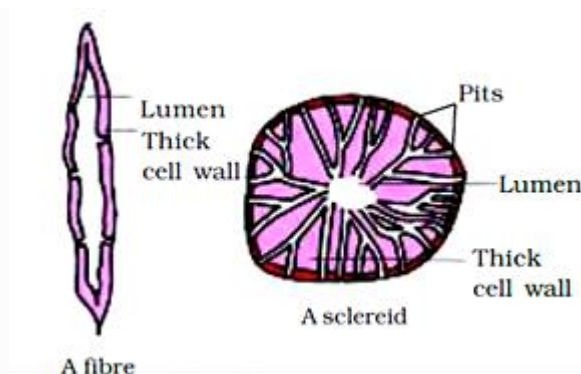
ii. Collenchyma:

Collenchyma consists of cells which are much thickened at corner due to cellulose, hemicellulose and pectin. Oval, spherical or polygonal often contain chlorophyll. They provide mechanical support to the growing parts of the plants like young stem.



iii. Sclerenchyma:

Sclerenchyma are supportive tissue having highly thick walled cells with little or no protoplasm due to deposition of cellulose or lignin. They are of two types: fibres and sclereids. They provide mechanical support to mature plant organs to tolerate bending, shearing, compression etc.



Summary of Simple permanent Tissues:

Parameters	Parenchyma	Collenchyma	Sclerenchyma
Location	Major component	Layers below the epidermis (dicotyledonous plants). Either as patches or a homogeneous layer	Fruit walls of nuts, seed coats, Leaves of tea
Structure Of cells/Cell wall	Isodiametric, Round, Oval, Elongated. Thin cell wall made of cellulose.	Contain chloroplasts, are spherical, oval, polygonal. Thick cornered cells due to cellulose, pectin and hemicellulose deposits.	Long, narrow cells with thick cell wall having pits. Usually dead without chloroplasts. They can be fibres(pointed, thick-walled, elongated, occur in groups) or sclereids(Oval, a spherical thick dead cell with lumen)

2. Complex Permanent Tissue:

Unlike simple permanent cells which look the same and are made up of one type of cells, complex permanent tissues are made up of more than one type of cells. These different types of cells coordinate to perform a function. Xylem and Phloem are complex permanent tissues and are found in the vascular bundles in the plants.

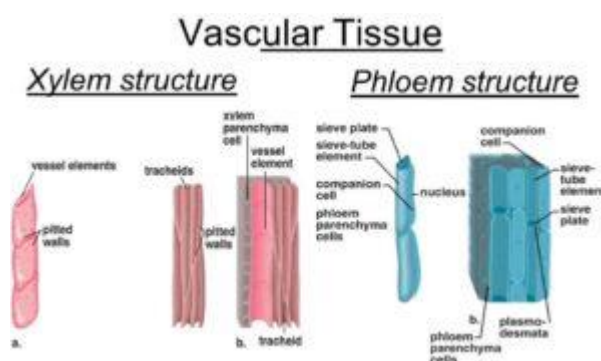
Types of Complex permanent Tissues:

They are of two types:

- Xylem
- Phloem

i. Xylem: It consists of tracheids, vessels, xylem parenchyma and xylem fibres. Tracheids and vessels are hollow tube-like structures that help in conducting water and minerals. The xylem conducts only in one direction i.e vertically. The xylem parenchyma is responsible for storing the prepared food and assists in the conduction of water. Xylem fibres are supportive in function.

ii. Phloem: It consists of four of elements: sieve tubes, companion cells, phloem fibres and the phloem parenchyma. Unlike the xylem, phloem conducts in both directions. It is responsible for transporting food from the leaves to the other parts of the plant. Phloem contains living tissues except for fibres that are dead tissues.



Difference between Xylem and phloem:

Xylem	Phloem
1. It conducts water or sap.	1. Phloem conducts organic food.
2. Xylem is found deep in the plant.	2. It is situated towards the outer side.
3. Xylem provides mechanical strength.	3. It has no mechanical functions.
4. It is made up of vessels, tracheid, xylem fibre and xylem parenchyma.	5. Phloem is made up of sieve tube, companion cells, phloem parenchyma and phloem fibres.

Functions of plant tissues:

Plant tissues have different functions depending upon their structure and location

1. They help provide mechanical strength to organs.
2. They help in providing the elasticity and flexibility to the organs.
3. They help the tissues to bend easily in various parts of a plant like- leaf, stem, and branches without damaging the plant
4. The xylem and phloem tissues help in transportation of material throughout the plants

5. They divide to produce new cells and help in the growth of the plants.
6. They help in various cellular metabolisms like photosynthesis, regeneration, respiration, etc.

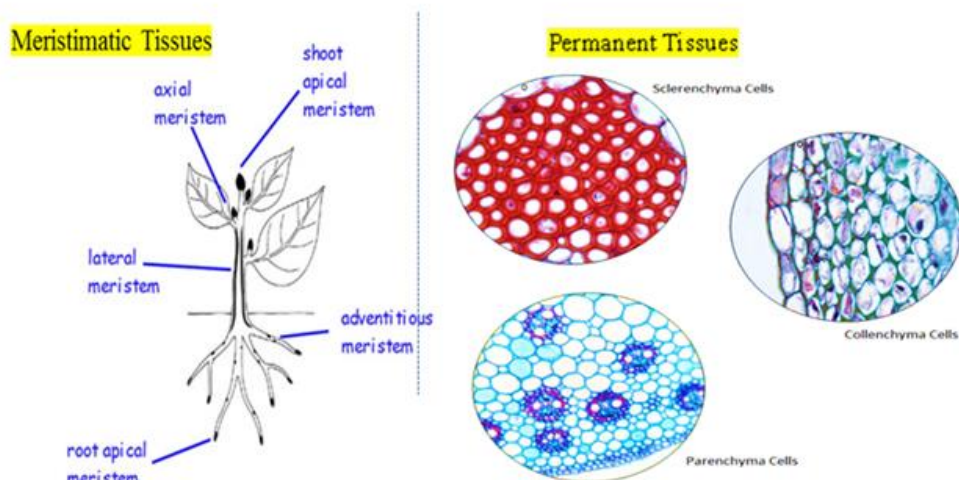


Figure: Meristematic and Permanent Tissues (Source: toppr.com).

Difference between Meristematic and Permanent Tissues:

Meristematic Tissue	Permanent Tissue
1. Capable of cell division	1. Lost power of cell division
2. Undifferentiated Cells	2. Differentiated cells
3. Have not attained definite form and size	3. Have attained definite form and size
4. Dense and abundant cytoplasm	4. Thin layer of cytoplasm around vacuole (if living)
5. Always living	5. May be living or dead



Anatomy of Dicot and Monocot plants

Angiosperms are the most diversified group in the plant kingdom, consisting of around 2,00,000 species. This includes herbs, shrubs, and trees, all of which reproduce sexually through seeds. Depending on the number of cotyledons in the seed, angiosperms are of two types-

- i. Monocotyledonous Plants
- ii. Dicotyledonous Plants.

The differences between the plants arising from a monocotyledonous seed and from a dicotyledonous seed are very evident.

Anatomy is the study of internal structure of organism. Study of plant anatomy includes histology- study of organization and structure of tissues. Anatomy helps in knowing the structural peculiarities of different group of plants and indicates the structural adaptation to diverse environments.

Anatomy of Dicot root:

Dicot roots of gram shows following distinct region in its Transverse section with following features:

1. Epiblema
2. Cortex
3. Endodermis
4. Pericycle
5. Vascular bundles
6. Pith

1. Epiblema or Epidermis:

It is the outermost unilayered with several unicellular root hairs. It consists of thin walled, compactly arranged living parenchymatous cells. Usually epiblema is characterised by absence of stomata and cuticle. Sometimes the epiblema may be less cuticularised. It provides protection to the roots due to presence of unicellular root hairs it also helps in absorption of water and minerals from soil.

2. Cortex:

It is thin walled, multilayered region made from circular or polygonal parenchymatous cells. they usually have intercellular spaces. The cortical cells have no chloroplast but



may contain leucoplast for storage of starch grains. The cortex is responsible for transportation of *water and salts* from the root hairs to the centre of the root.

3. Endodermis:

It is the innermost layer of cortex and covers the stele. It consists of compactly arranged barrel shaped parenchyma without intercellular spaces. Most of the cells are characterised by the presence of special thickening of suberin and lignin on their radial and tangential walls called **casparian strips**. Some endodermal cell near protoxylem has no casparian strips and called **passage cells** or transfusion cells. These cells allow radial diffusion of water and minerals through the endodermis.

4. Pericycle:

It is the outermost layer of stele and composed of uniseriate layer of parenchymatous cells without intercellular spaces. Some dicots and hydrophytes do not bear pericycle. Several lateral roots and lateral meristem arise from pericycle region (hence lateral roots are endogenous in origin). At the time of secondary growth, it produces secondary cambium or phellogens.

5. Vascular bundles:

They are 2-8 in number, radial and arranged in ring. Xylem and phloem bundles are separated from each other by parenchymatous cells called conjunctive or complementary tissue.

- i. **Xylem** is exarch (i.e. protoxylem towards the periphery and metaxylem towards the centre) and consists of tracheids, vessels, xylem parenchyma and xylem fibres.
- ii. The **phloem** forms oval masses beneath the pericycle, alternating with xylem bundles. Phloem consists of sieve tubes, companion cells and phloem parenchyma. Usually phloem fibres are absent or reduced.

6. Pith:

It is feebly developed and centrally located. It consists of thin walled, polygonal parenchyma cells with intercellular spaces. In dicots roots, it may be reduced or absent. It helps in storage of food materials.

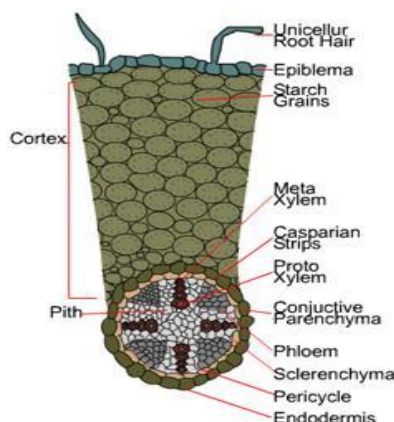


Figure: T.S. of dicot root (gram) (Source: youtube.com)

Anatomy of Monocot roots (Zea mays)

Plants whose seed contains only one cotyledon or embryonic leaf is known as monocotyledon or simply monocot.

Primary Structure of Monocot roots

Monocot roots of maize shows following distinct regions:

1. Epiblema
2. Cortex
3. Endodermis
4. Pericycle
5. Vascular bundles
6. Pith

Salient features of Different Regions of Monocot Root:

1. Epiblema:

Epiblema is the outermost single layer made from compactly arranged parenchymatous cells without intercellular space. Usually Epiblema has no stomata but bears unicellular epidermal root hairs and less amount of cutin. It contains more cuticle than dicot roots. The root hairs and thin walled epidermal cells take part in the absorption of water and minerals from the soil.

The epiphytes have several layered hygroscopic epidermis, called *velamen tissues*. It is made from spongy dead cells which helps in absorption of water from atmosphere. It also checks excessive loss of water from cortex. Usually the wall of velamen has spiral or reticulate secondary thickening of cellulose, pectin and lignin.

**2. Cortex:**

Cortex is a multi-layered well developed and made from oval parenchymatous cells with intercellular spaces. The intercellular spaces usually help in gaseous exchanges, storage of starch, etc. In monocots and several old roots, few layers of cortex just below epiblema give rise to a single or multilayered cuticularised sclerenchymatous region called exodermis. Cortex helps in mechanical support to the roots (like hypodermis to stem).

3. Endodermis:

Endodermis is innermost layer of cortex made from barrel shaped parenchyma. It forms a definite ring around the stele. These cells are characterized by the presence of casparian stripes. It is deposition of suberin and lignin, and their radial and tangential walls. Usually passage cells are absent in monocot roots.

Due to presence of casparian stripes, endodermis forms water tight jacket around the vascular tissues, hence it is also called biological barrier. It regulates the inward and outward flow of water and minerals and prevents diffusion of air into xylem elements.

4. Pericycle:

Pericycle is uniseriate (multiseriate in *Smilax*) and made from thin walled parenchymatous cells. It is outermost layer of stellar system. Usually it is made from parenchymatous cells but it may become sclerenchymatous in older roots. Several lateral roots arise from this layer. Hence, lateral roots are endogenous in origin.

5. Vascular bundle:

Vascular bundle: is radial, arranged in a ring (except mangrove, which also contains lenticels), polyarch (presence of many alternating xylem and phloem bundles). Xylem and phloem are found at different radii alternating with each other (radial). The number of xylem and phloem vary from, 8 to 46 (100 in *pandanus*).

Xylem is exarch, i.e. the protoxylem lies towards periphery and metaxylem toward center. The protoxylem has smaller vessels with spiral or annular thickening, whereas the walls of metaxylem contains pitted thickening.

Phloem consists of seive tubes, companion cells and phloem parenchyma. Usually phloem sclerenchyma or fibers are absent. The phloem is also exarch (protophloem towards the periphery and metaphloem towards the center). Secondary growth is absent in monocot roots due to lack of vascular and cork cambium.

Conjunctive tissue is parenchymatous tissues which separates xylem and phloem bundles. It may become sclerenchymatous in older roots.

6. Pith:

Pith is large, well developed portion of monocot root. It occupies the central portion and made from thin walled parenchymatous tissue with intercellular spaces. It contains abundant amount of starch grains.

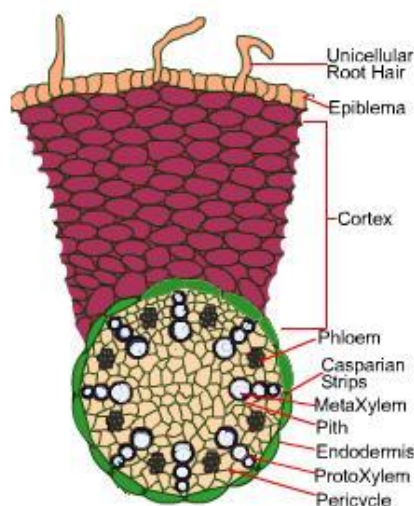


Figure: T.S of Monocot Root (Maize) (Source: youtube.com)

Dicotyledonous and Monocotyledonous Stem

Dicot stem:

Plants whose seed contains two cotyledon or embryonic leaf are known as dicotyledonous or simply dicots.

Anatomy of Dicot Stem:

The microscopic structure of T.S. of sunflower (*Helianthus annus*) stem shows following distinct regions:

1. Epidermis
2. Cortex (hypodermis, general cortex, endodermis)
3. Pericycle
4. Medullary rays
5. Vascular bundles
6. Pith

1. Epidermis:

Epidermis is the outermost layer of (dicot) stem with multicellular epidermal stem hairs. The cells are living, barrel shaped and compactly arranged without intercellular spaces and chloroplasts. They may contain stomata for gaseous exchange. The



epidermis is externally covered by thick cuticle. The epidermal multicellular stem hairs help in protection and heat loss.

2. Cortex:

Cortex is present below the epidermis in several layers. It can be differentiated into:

- i. **Hypodermis** consists of 3-5 layers of collenchyma without spaces. It contains thickenings by the deposition of extra cellulose with pectin and gives mechanical support. Due to the presence of chloroplast, it also helps in photosynthesis.
- ii. **General cortex** encloses intercellular spaces with resin ducts, each surrounded by a layer of small thin walled spherical or oval cells. It is made from loosely arranged parenchymatous. The cortical cells may contain chloroplast and perform photosynthesis. Some oil ducts line with epithelial cells. It also helps in gaseous exchange and storage of food materials.
- iii. **Endodermis** is unilayered innermost cortex made from more or less barrel shaped compactly arranged parenchymatous tissues. It stores starch and is often called **starch sheath**. Casparian stripes are clearly visible in the endodermis region. It is the deposition of lignin and suberin. Several dicot stem may not bear distinct endodermis.

3. Pericycle:

Pericycle consists of several cells in thickness, with sclerenchyma and intervening masses of parenchyma. It is heterogeneous. They have thick wall sclerenchymatous tissue found on patches above the phloem or bast, hence also termed as **hard bast** or **bundle cap**. The hard bast helps in mechanical support and parenchyma helps in storage of food materials.

4. Medullary Rays:

Medullary rays are parenchymatous, radially elongated or polygonal cells lying between vascular bundles. It helps for the radial conduction of water and food materials. It is an extension of pith, hence also called pith rays.

5. Vascular Bundles:

Vascular bundles are conjoint, collateral, open and arranged in a ring (**eustele**). Each bundle is composed of outer phloem and inner xylem on the same radius with a strip of cambium in between them (open type).

- i. **Phloem** lies outside of the vascular bundle and is composed of sieve tubes, companion cells and phloem parenchyma (all are living) and few bast fibers. Companion cells are associated with sieve tubes.
- ii. **Xylem** lies toward the pith or center and is composed of xylem vessels, tracheids, xylem fibres (wood fibres) and xylem parenchyma (wood parenchyma). The xylem is

endarch (i.e. protoxylem lie towards the **pith**, while **metaxylem** lies towards periphery). Protoxylem is smaller with annular, reticulate or spiral thickenings, while metaxylem is wider with pitted vessels. The xylem parenchyma is mostly found around the protoxylem.

- iii. **Cambium** is a thin strip of two or three layered cells which are radially arranged. It lies between xylem and phloem. The cells appear almost rectangular in a transverse section and have thin wall. Due to its position, it is also called **intrafascicular cambium**. Cambium is a type of lateral meristematic tissues which increases the thickness of the plant through secondary growth.

6. Pith:

Pith is extensively developed and occupies the central portion of the ground tissue. It is made from rounded or oval, thin walled parenchymatous cell with large amount of intercellular spaces. Pith helps in the storage of food materials.

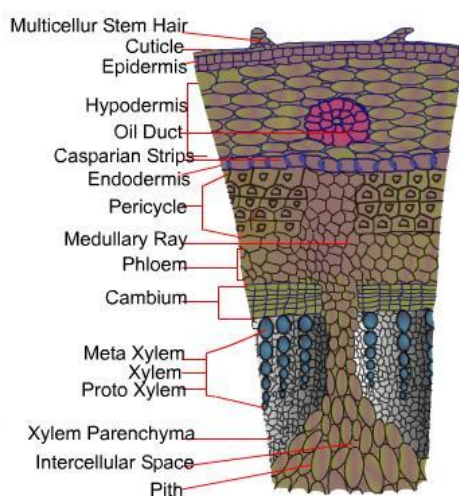


Figure: T.S. of Dicot Stem (Sunflower)

Characteristics of Dicot Stem:

Typical dicot stem shows following characteristics:

1. Presence of well-defined epidermis with cuticle and multicellular stem hairs.
2. Cortex has collenchymatous hypodermis regularly or as discontinuous patches.
3. Endodermis is distinct as the innermost layer of the cortex.
4. Pericycle composed of parenchyma and sclerenchyma alternately as irregular patches (heterogenous).
5. Vascular bundles are conjoint, collateral, endarch, open and arranged in a ring surrounding pith (eustele).



6. The centre of pith is made from thin walled parenchyma cells with distinct intercellular spaces. Pith rays or medullary rays are found as separator of two vascular bundles.

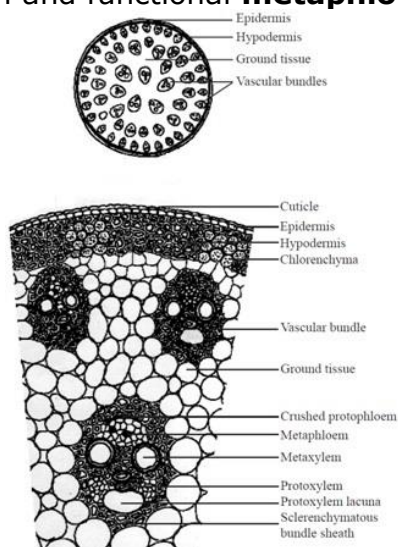
Anatomy of Monocot stem

The transverse section of stem of maize (which is a monocot plant) contains following regions:

1. Epidermis
2. Hypodermis
3. Ground tissues
4. Vascular bundles

1. **Epidermis** is the outermost uniseriate cuticularised layer of parenchyma with stomata. It is made from arranged barrel shaped cells usually without epidermal stem hairs.
2. **Hypodermis** is just internal to epidermis, made from compactly arranged sclerenchyma without intercellular spaces. It provides mechanical strength to the plant.
3. **Ground tissue** is parenchymatous and not differentiated into cortex, endodermis, pericycle and pith as in dicot. These cells are smaller, polygonal, compactly arranged (toward center) or loosely arranged (toward peripheral). The scatter vascular bundles are imbedded in these tissues. These cells contain reserve materials.
4. **Vascular bundles** are conjoint, collateral and closed. It has two types: larger and smaller and scattered in ground tissue without any order (**atactostele**). The large vascular bundles lie towards the center (less in number) and smaller towards and periphery (more in number). Each vascular bundles has oval outline and surrounded by a sclerenchymatous bundle sheath which encloses Xylem and Phloem.
 - i. **Xylem** consists of vessels, tracheids, xylem parenchyma and limited xylem fibres. Vessel is **Y-shaped** with larger two round pitted metaxylem vessels forming the arms and smaller annual or spiral protoxylem vessels, forming the base. A large water cavity (schizolysigenous cavity, i.e. formed from disintegration of some protoxylem) is present in the inner side of the protoxylem. It stores water and also called lacuna or water cavity. The xylems are endarch with outer metaxylem and inner protoxylem.

ii. **Phloem** lies outside the xylem in the vascular bundle. It consists of sieve tubes, companion cells and phloem fibers, but lacks phloem parenchyma. The outer phloem is protophloem and functional **metaphloem** lie inner portion.



Characteristics of Monocot Stem:

Typical monocotyledonous stems shows following characteristics:

1. Circular stem, may have depressed structures due to the presence of lateral branches
2. Have thick cuticle, single layered epidermis and epidermal hairs are absent
3. Single layered cuticularised epidermis may contain multicellular trichomes
4. Ground tissues are not differentiated into cortex and pith
5. Hypodermis is generally sclerenchymatous
6. It has no distinct endodermis and pericycle
7. Epidermis contains stomata with guard cells.
8. Scattered vascular bundles are surrounded by sclerenchymatous bundle sheath cells and called atactostele
9. Each vascular bundle is oval, conjoint, collateral and closed
10. There is no distinction between pith and pith rays
11. Xylem is endarch, phloem is represented only by companion cells, sieve tubes and little phloem fibers

Anatomy of Dicotyledonous and Monocotyledonous Leaves

Leaves are extremely significant vegetative organs since they are largely concerned with transpiration and photosynthesis. Like stem and roots, leaves also comprise of the three



tissue systems - ground, dermal, and vascular. The dermal tissue system contains a lower epidermis and an upper epidermis. Stomata take place in both the epidermis but more often in the lower epidermis. The ground tissue system which takes place among the epidermal layers of leaf is termed as mesophyll tissue. Frequently it is distinguished into spongy parenchyma on the abaxial that lower side and palisade parenchyma on the adaxial that is upper side.

Based on the manner of orientation to the main axis of plant and direction of sunlight, leaves in angiosperms can be divided into two types:

1. Dorsiventral (Dicotyledonous) Leaves
2. Isobilateral (Monocotyledonous) Leaves

1. Dorsiventral (Dicotyledonous) Leaves:

Dorsiventral leaves orient themselves at an angle to the main axis and perpendicular to the direction of sunlight. Most dicots have dorsi-ventral leaves that are net-veined, including most trees, bushes, garden plants and wildflowers.

2. Isobilateral (Monocotyledonous) Leaves:

Isobilateral leaves orient themselves parallel to the main axis and parallel to the direction of sunlight. Most monocots possess parallel-veined isobilateral leaves, including grasses and grass like plants like, lilies, irises, amaryllises etc.

Most leaves have certain common features like a covering of an epidermal layer on each surface. The ground tissue that occurs between the two epidermal layers is called mesophyll. Vascular bundles, commonly known as veins, are embedded in the mesophyll. The structure and characteristics of each of these layers differ greatly for dorsiventral and isobilateral leaves.

Anatomy of dorsiventral (Dicotyledonous) leaf of Mango (*mangifera indica*)

The internal structure of the dorsiventral leaf shows these regions with following features:

1. Epidermis
2. Mesophylls
3. Vascular bundles

1. Epidermis:

It is the outermost covering of the leaf that forms the boundary between the atmosphere and underlying mesophyll. It is present on both ventral or adaxial (upper epidermis) and dorsal or abaxial (lower epidermis) surface. Both the upper and lower epidermis are covered by a cuticular layer. It consists of uniseriate, compactly arranged thin walled parenchymatous tissue without chloroplast (but present in upper epidermis).



Usually upper epidermis is thickly cuticularised. Lower epidermis contains numerous stomata without chloroplast; while upper epidermis contains high amount of chloroplast and no stomata, thus the leaf is hypostomatic (some exceptions exist).

2. Mesophyll:

It is the ground tissue between the upper and lower epidermis. In dorsiventral leaf, it is differentiated into palisade parenchyma and spongy parenchyma.

i. Palisade parenchyma lies towards the upper epidermis and consists of one, two or three layers of elongated cells, densely packed with profuse intercellular spaces and chloroplasts. Due to large intercellular spaces and chloroplast it helps in gaseous exchange and photosynthesis.

ii. Spongy parenchyma lies towards the lower epidermis and made from loosely arranged, irregular, thin walled cells parenchymatous tissues with large intercellular spaces, air cavities and few chloroplasts, Hence, it helps in gaseous exchange in transpiration and photosynthesis.

3. Vascular bundles:

Numerous vascular bundles are scattered in spongy parenchyma. Each bundle is conjoint, collateral and closed. Vascular bundle is surrounded by large parenchymatous bundle sheath or border parenchyma. Collenchyma may also be associated with bundle sheath cells. Xylem lies toward the upper epidermis and phloem toward lower epidermis. Single mid-vein vascular bundle is larger and several smaller veinlet vascular bundles are smaller. Smaller vascular bundles are freely scattered in mesophyll cells of leaf.

- i. **Xylem** consists of vessels, tracheids, wood fibres and wood parenchyma (lies toward the upper epidermis). The xylem tracheids and vessels help in conduction of water and minerals and mechanical supports while parenchyma helps in lateral transport. At maturity, the protoxylem lies towards upper epidermis and metaxylem toward lower epidermis.
- ii. **Phloem** consists of sieve tubes, companion cells and some cells of phloem parenchyma (lies towards lower epidermis). The phloem companion cells and sieve tubes help in conduction of food materials and phloem parenchyma helps in lateral conduction and storage of food materials.

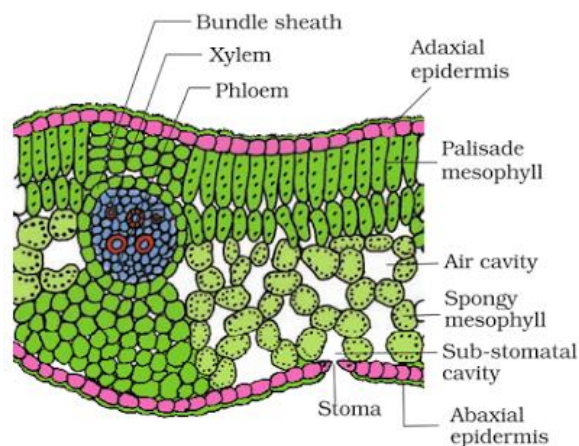


Figure: T.S. of dorsiventral leaf (mango leaf)

Diagnostic characteristics of Dorsiventral Leaf:

1. Hypostomatic stomata are present only on lower epidermis
2. Differentiated Mesophyll into upper palisade parenchyma and lower spongy parenchyma
3. Hypodermal Collenchyma between bundle sheath of midrib vein and the upper and lower epidermal layers
4. Conjoint, collateral Vascular bundles with endarch xylem
5. Vessels and tracheids differentiated into metaxylem and protoxylem

Anatomy of Isobilateral (Monocotyledonous) Leaf

The internal structure of isobilateral or monocotyledonous leaf (maize) shows distinct layers of epidermis, mesophylls cells and vascular bundles with following features:

1. Epidermis
2. Mesophyll
3. Vascular Bundles

1. Epidermis:

Epidermis is single layered, present on both surfaces and has cuticles (cuticularized) and stomata on both surfaces (amphistomatic). It is composed of compactly arranged oval or barrel shaped thin walled parenchymatous cells. A few cells in the Upper epidermis may become larger, less cuticularised; lens shaped and found on groups called motor cells or bulliform cells. These cells

becomes empty and large and regulate the curling and uncurling (rolling up) of the leaves during dry conditions.

2. **Mesophyll:**

Mesophyll is the ground tissue that is present between the two epidermal layers. It is not differentiated into palisade and spongy parenchyma and contains chloroplasts. It is composed of cells that are almost spherical, oval or angular with irregular intercellular spaces.

Mesophyll tissues are not found in the mid-vein region. In mid vein region, sclerenchymatous cells extend from the vascular bundle to the lower and upper epidermis. This extension of sclerenchyma is called bundle sheath extension.

3. **Vascular Bundles:**

Vascular bundles are of two types- small bundles are abundant and larger bundles are found in between them. The bundles are conjoint, collateral, closed and each covered by parenchymatous bundle sheath cells containing starch grains. Sclerenchymatous cells may be present on both sides of the large bundles. The larger bundles have distinct phloem towards the lower epidermis and xylem toward upper surface.

i. **Xylem** consists of two pitted oval metaxylem; in between them, tracheids are also found. Xylem parenchyma are less numerous. Protoxylem is represented by a lysigenous cavity.

ii. **Phloem** has sieve tubes and companion cells. The small bundles are surrounded by individual sheaths and contain not distinct and less developed phloem and xylem.

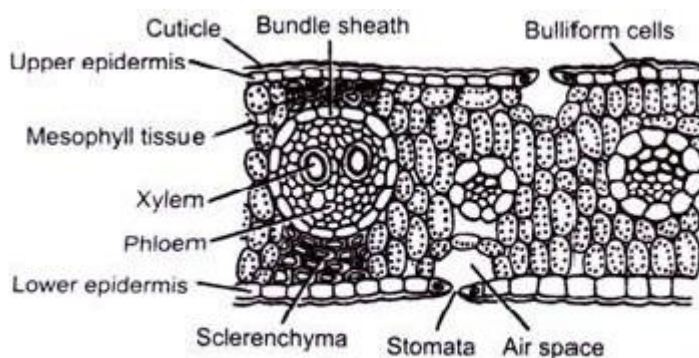


Figure: T. S. of Monocot leaf (*Zea mays*)

**Diagnostic Features of Isobilateral Leaf:**

1. Epidermis composed of two layers.
2. Amphistomatic stomata on both layers
3. Cuticularized Cuticle is present on both epidermal layers
4. Motor Cells present in upper epidermis
5. Undifferentiated mesophyll - tissue not differentiated into palisade and spongy parenchyma
6. Bundle sheath formed by sclerenchymatous cells that extend from the vascular bundle towards upper and lower epidermis
7. Conjoint, collateral, closed - vascular bundles
8. Two protoxylem and two xylem present in each vascular bundle
9. Hypodermal sclerenchyma present on both sides of vascular bundle

Difference between Dorsiventral (Dicotyledonous) Leaves and Isobilateral (Monocotyledonous) Leaves:

Dorsiventral (Dicot) Leaves	Isobilateral (Monocot) Leaves
The symmetry of dicot leaf is "Dorsiventral".	The symmetry of monocot leaf is "Isobilateral".
Stomata are absent or less abundant on the upper side.	Stomata are equally distributed on both sides
Mesophyll is differentiated into two parts- upper palisade parenchyma and lower spongy parenchyma.	Mesophyll is undifferentiated.
Bundle sheath is single layered and formed of colourless cells.	Bundle sheath may be single or double layered.
Hypodermis of the mid-region is collenchymatous.	Hypodermis of the mid-region is sclerenchymatous.

Secondary Growth in Dicot Stems and Roots

Introduction

Some plant parts, such as stems and roots, continue to grow throughout a plant's life: a phenomenon called indeterminate growth. Other plant parts, such as leaves and flowers, exhibit determinate growth, which ceases when a plant part reaches a particular size.

Growth in plants occurs in two ways:

i. Primary Growth

ii. Secondary Growth

i. Primary Growth:

Primary growth causes the plant to grow in length, both below and above the ground. Mostly, primary growth occurs at the apices, or tips, of stems and roots. Primary growth is a result of rapidly-dividing cells in the apical meristems at the shoot tip and root tip. Subsequent cell elongation also contributes to primary growth. The growth of shoots and roots during primary growth enables plants to continuously seek water (roots) or sunlight (shoots).

ii. Secondary Growth:

Secondary growth causes the plant to grow in width due to the presence of lateral meristems or cambium layer which actively divides to bring about this kind of growth. Secondary growth occurs due to the lateral meristems that divide similar to the apical meristems. The cells of the lateral meristems divide rapidly and grow outwards laterally rather than apically as in case of primary growth. The lateral meristems that cause secondary growth are known as cambium. This layer of cambium is present in dicots but absent in monocots.

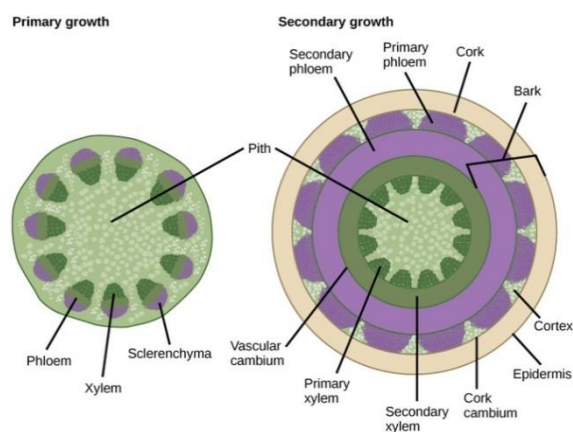


Figure: Primary and secondary growth in woody plants (Source: brainkart.com)



Secondary Growth in Dicot Stem:

The growth in length of main axis by the activity of apical meristem is called primary growth. Increase in thickness or girth of the axis due to the formation of secondary tissue is called secondary growth. The secondary tissue is formed by the activity of cambium and cork-cambium. The cambium forms secondary tissues in the stelar region and cork-cambium forms secondary tissues into cortical regions. Secondary growth occurs only in dicot stem and root. It is usually absent in monocot root and stem.

In dicot stem, secondary growth takes place through the following steps:

1. Formation of Cambium Ring:

Formation of the cambium ring is the first step of secondary growth. The cambium of vascular bundles becomes meristematic. At the same time some of the medullary ray cells lying at the level of cambium also become meristematic and form a strip of interfascicular cambium to form a complete circular ring, which is called cambium ring. The cambium ring forms the secondary tissues in the stelar region.

The vascular cambium consists of two types of cells:

i. Fusiform Initials

ii. Ray Initials.

i. **Fusiform initials:** Fusiform initials are vertically oriented and divide to form the elements of xylem and phloem.

ii. **Ray initials:** The cells of ray initials are smaller and isodiametric which give rise to vascular rays of parenchymatous cells.

2. Formation of Secondary Vascular Tissues:

The cambium ring cuts off new cells, both on outer and inner sides. The new cells formed on the outer side gradually modify into the elements of secondary phloem. The cells formed on the inner side gradually modify into secondary xylem.

Secondary Phloem: They consist of sieve tubes, companion cells, phloem parenchyma and phloem fibres. The primary phloem present on the outside gets crushed and is represented by small patches.

Secondary Xylem: Secondary xylem consists of vessels, tracheids, wood fibres and wood parenchyma. The vessels or trachea are most abundant in secondary xylem and are usually shorter than that of the primary xylem. The cambium ring forms more tissue on the inner side than on the outer side. As a result, secondary xylem forms the main bulk of the plant body and is generally called the wood. Its width increases with age. The primary xylem persists as conical projections towards the pith.



3. Vascular Rays:

Ray initials of the cambium ring form some narrow bands of parenchymatous cells. These cells extend radially from the pith to the phloem. These are called secondary medullary rays or vascular rays. The rays present in xylem are xylem rays and the rays present in phloem are called phloem rays.

4. Annual Rings:

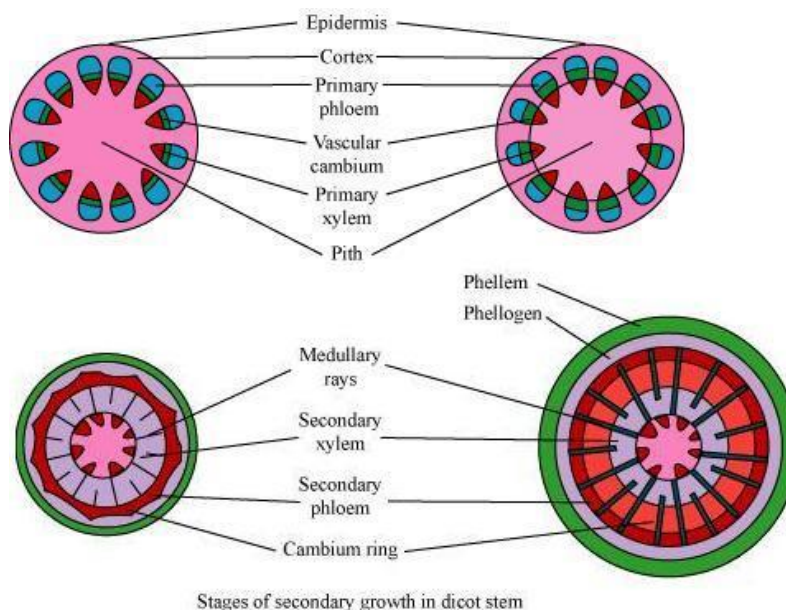
The activity of vascular cambium is greatly affected by the variations in the climate. It is more pronounced in temperate regions. The cambium stops dividing in winter. In the spring season or early summer, the cambium becomes more active and produces a large number of vessels with wider lumen. These are called spring wood or early wood.

During the autumn or winter season, the cambium becomes less active and produces vessels with narrow lumens. Tracheids and wood fibres are formed in large numbers. These woods are called autumn wood or late wood. Hence, the annual rings are formed year after year. In the oldest part of the tree, annual rings can be used in determining the age of a tree.

In tropical regions, the climate is more or less uniform. Therefore, the annual rings are not well developed and do not correlate with the age of tree.

5. Sapwood and Heartwood:

In older stems, the woody trunk is differentiated into two regions. The outer light coloured region is called sap wood or alburnum and central dark coloured region is called heart wood or duramen. The cells of sapwood are living and functional. They take part in conduction of water and storage of food. The heartwood consists of dead cells. During the growth process, the rings of sap wood gradually process, the rings of sap wood gradually convert into heartwood. The living cells of sap wood lose their protoplast and water content. The lumen of the xylem vessels get blocked by the ingrowth of the parenchyma cells. The adjacent parenchyma tissue enters through the pits of vessels and gradually enlarges to form a balloon like structure, which is called tyloses. The heartwood is stronger and more durable than sapwood. The heartwood becomes resistant to the attacks of bacteria and fungi due to the presence of antiseptic oils.



Secondary Growth in Dicot root

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

1. Formation of Cambium:

The dicotyledonous roots possess a limited number of radial vascular bundles with exarch xylem. Normally the pith is very little or altogether absent. On the initiation of secondary growth, a few parenchyma cells beneath each group of phloem become meristematic and thus as many cambial strips are formed as the number of phloem groups.

The cambial cells divide tangentially again and again and produce secondary tissues. Thereafter some of the cells of single layered pericycle become meristematic lying against the protoxylem groups, which divide and form a few layers of cells. The first formed cambium now extends towards both of its edges and reaches the inner most derivatives of the pericycle, thus giving rise to a complete ring of cambium. The cambium ring is wavy in outline, as it passes internal to phloem and external to xylem groups. The cambial cells produce more xylem elements than phloem. The first formed cambium produces secondary xylem much earlier, and the wavy cambium ring ultimately becomes circular.

Now whole of the cambium ring becomes actively meristematic, and behaves in the similar way as in the stem, giving rise to secondary xylem on its inner side and secondary phloem towards outside.

2. Development of Secondary Tissues:

The secondary vascular tissues form a continuous cylinder and usually the primary xylem gets embedded in it. At this stage distinction can be made only by exarch primary xylem located in the centre. The primary phloem elements are generally seen in crushed condition.

The cambial cells that originate from the pericycle lying against the groups of protoxylem function as ray initials and produce broad vascular rays. These rays are traversed in the xylem and phloem through cambium; this is characteristic feature of the roots. Normally, such rays are called medullary rays.

3. Development of Periderm:

Simultaneously the periderm develops in the outer region of the root. The single layered pericycle becomes meristematic and divides, giving rise to cork cambium or phellogen. It produces a few brownish layers of cork cells or phellem towards outside, and the phelloderm on the inside.

4. Lenticels:

The phelloderm does not contain chloroplasts. The pressure caused by secondary tissues ruptures the cortex with endodermis, which is ultimately sloughed off. The Epiblema dies out earlier. Lenticels may also be formed.

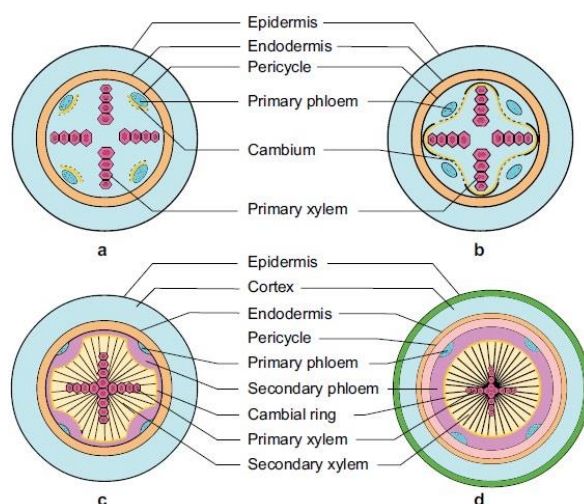


Figure: Different stages of the secondary growth in a Dicot Root (Source: brainkart.com)



Salient Features of Secondary Growth in Dicot Roots:

1. Vascular cambium is formed secondarily from conjunctive parenchyma cells lying just below each phloem strand.
2. The number of cambium rings forms is equal to the number of phloem present.
3. The cells of pericycle lying outside the protoxylem also become meristematic to form part of strips of cambium.
4. These strips join with the former cambium to form a wavy ring of vascular cambium.
5. This cambium ring produces secondary xylem on the inner side and secondary phloem on the outer side.
6. In roots, growth rings are not distinct because there is no seasonal variation under the soil.
7. From the outer region of pericycle arises the phellogen which cuts phellem (cork) on the outer side and secondary cortex or phelloderm toward the inner side.

Significance of Secondary Growth:

1. Secondary growth is a means of replacement of old non-functional tissues with new active tissues.
2. The plants showing secondary growth can grow and live longer as compared to other plants.
3. Secondary growth adds to the girth of the plant. It provides support to increasing weight of the aerial growth.
4. Secondary growth produces a corky bark around the tree trunk that protects the interior from abrasion, heat, cold and infection.
5. It adds new conducting tissues for replacing old non-functioning ones as well as for meeting increased demand for long distance transport of sap and organic nutrients.
6. It provides a fire proof, insect proof and insulating cover around the older plant parts.
7. Commercial cork is a product of secondary growth. It is obtained from *Quercus suber* (Cork Oak).
8. Wood is a very important product of secondary growth. It represents secondary xylem.

**Differences Between Secondary Growth in Dicot Stem and Root:**

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



Plant Physiology

Stephan Hales is regarded as the father of plant physiology

J.C. Bose is regarded as the father of Indian Plant physiology

Transport and Plant Water Relations

Syllabus

Transport in Plants: Means of transport, (diffusion, facilitated diffusion, Passive symports and antiports, Active transport).

Plant Water Relations: Water potential, osmosis, plasmolysis, imbibition, long distance transport of water- apoplast, symplast, pathways ascent of sap, Root pressure theory and transpirational pull theory (cohesion - tension theory).

Transpiration: types & significance, mechanism of opening and closing of stomata, guttation, Phloem transport, flow from source to sink, (mass flow hypothesis)

In plants, various substances like water, minerals, organic substances and plant growth regulators need to be transported. Water and minerals are transported unidirectional through xylem from roots to shoot system. However, translocation of organic and inorganic nutrients is multi directional and occurs through phloem. Organic compounds synthesized in the leaves are transported to all parts including storage organs.

From storage organs the stored food is export to the developing plant parts as and when required. Important nutrients are also withdrawn from plant parts undergoing senescence and are supplied to the growing parts by the process of nutrient remobilization. Plant growth regulators, present in very minute quantities, are often transported in polarized (unidirectional) manner.

Means of Transport

Transport in plant is an important phenomenon. It can be either short distance or long distance.

Short distance transport

If transport occurs within the cell or from one cell to another cell, then it is considered as short distance transport. It can further be of two types viz., passive and active transport.

Passive Transport

If transport occurs along the concentration gradient, i.e., from high concentration to low concentration without the expenditure of energy (ATP). It occurs by following methods:

Diffusion

It is a physical process in which passive transport of solvent molecules or solute ions occur without the expenditure of energy. It is a slow process and is independent of living system. During the process, the molecules or ions flow in a random fashion from the region of higher concentration to region of lower concentration be it a gas, liquid or solids. Rate of diffusion is mainly affected by

- i. Concentration gradient of diffusing substance.

- ii. Permeability of the membrane separating them.
- iii. Temperature
- iv. Pressure
- v. Density

Diffusion rate is inversely related to square root of relative density of the diffusing substance. This is known as Graham's law of diffusion.

$$D \propto \frac{1}{\sqrt{d}}$$

Where D is diffusion and d is density

Diffusion is a very important phenomenon in plants as it is the only means of transport of gases in them.

Tendency of different substances to diffuse according to their own partial pressures or concentration is called independent diffusion.

Facilitated Diffusion

It occurs along the concentration gradient. Thus a favorable concentration gradient of molecules is essential for diffusion. The rate of diffusion depends on the size of the substances, i.e., smaller the substance, the faster it will diffuse and on its solubility in lipids (major constituents of membrane), i.e., more the substance is soluble in lipid, faster it will diffuse through the membrane. Transport of substances (having hydrophilic moiety) is facilitated by transport proteins. These proteins do not create any concentration gradient by themselves; a concentration gradient is already present.

This process is called facilitated diffusion. Facilitated diffusion does not allow net movement of molecules from low to high concentration because it will require input of energy. The rate of transport finally reaches the maximum when all transporters of proteins are utilized.

Facilitated diffusion is very specific, i.e., allows uptake of only selected substances.

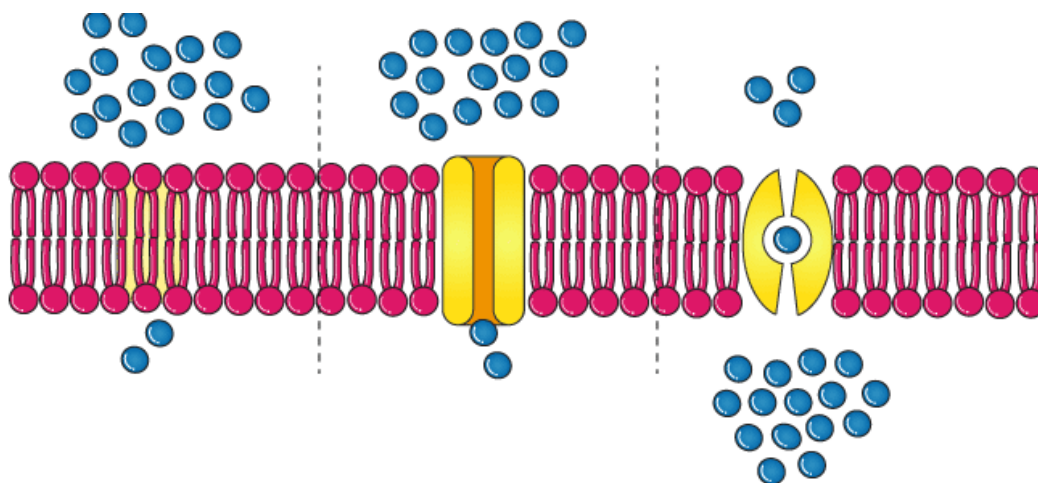


Image courtesy: www.byjus.com/biology

There are two different types of transport proteins, i.e., carrier proteins and channel proteins. Carrier proteins bind the particular solute to be transported and deliver the same to the other side of the membrane.

The channel proteins form channels in the cell membrane so that molecules can easily get transported. This is called channel mediated facilitated diffusion. Out of these channels, some always remain open while, the others are controlled. The large transporter proteins, which create huge pores in the outer membranes of the plastids, mitochondria and bacteria to cross a variety of molecules up to the size of small proteins are called porins.

During transportation, the extracellular molecule binds to the transport protein which then rotates towards the intracellular matrix and releases the molecule inside the cell, e.g., Water channels made up of eight different types of aquaporins.

Note: Aquaporin are membrane proteins for passive transport of water. They enhance the rate of transport of water across the membrane without altering the direction of transport.

Passive Symports and Antiports

In relation to facilitated diffusion, some carrier or transport proteins allow the movement of molecules only if two molecules move together. This type of movement is known as co-transport.

It can be of following three types:

- Symport:** In this both molecules cross the membrane in the same direction.
- Antiport:** In this both molecules cross membrane in opposite directions.
- Uniport:** In this type, the molecules move across a membrane independent of any other molecules

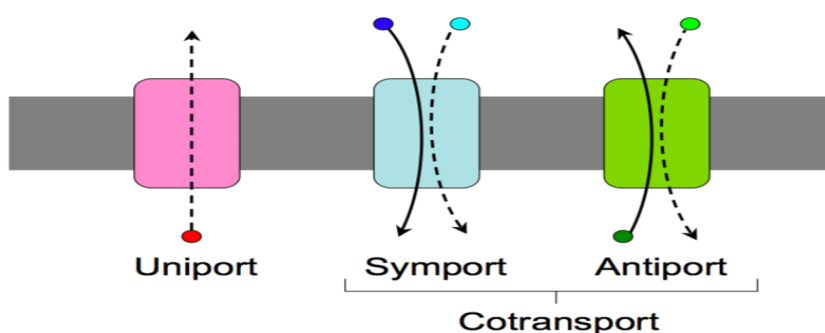


Image courtesy: [researchgate.com](https://www.researchgate.com)

Active Transport

Active transport uses energy in the form of ATP to pump molecules or ions against a concentration gradient (i.e., uphill transport low concentration to high concentration). This is carried out by the carrier proteins in the plasma membrane. "When the transporters become saturated or are used up the rate of transport reaches its maximum level.



These carrier proteins are very specific in carrying protein across the membrane. The ions once transported inside the membrane cannot return back to the outer space. While the carrier protein returns back to its original state in order to pick new ion or a molecule. These carrier proteins are very sensitive to inhibitors or other substances, which have the property of reacting with side chains of the proteins.

Out of the transport mechanisms discussed above, diffusion (whether facilitated or not) takes place along a concentration gradient without the utilization of energy. However, both facilitated diffusion and active transport are mediated through membrane proteins.

Protein transporters are highly selective in nature, liable to get saturated, respond to inhibitors and are under hormonal regulation.

Table 1.1 ► Comparison of Membrane Transport Mechanisms

Transport Mechanism	Electrochemical Gradient	Energy	Carrier-mediated	Classification
Simple diffusion	Downhill	None	No	Passive
Facilitated diffusion	Downhill	None	Yes	Passive
Primary active transport	Uphill	ATP hydrolysis	Yes	Active
Secondary active transport	Substrate uphill Cosubstrate downhill	Energy exchange	Yes	Active

Abbreviation: ATP, adenosine triphosphate.

Image courtesy: www.doctorlib.info/physiology

Plant Water Relations

Before discussing how absorption and transportation of water takes place in plants. It is necessary to understand some basic facts about water. Without the constant supply of water, the plant could not carry on any of its physiological activities.

Some useful functions of water are given below

- Water carries the nutrients from the soil to the plants.
- Water acts as a major component of all living cells, i.e., a medium in which all substances are dissolved and undergo various types of reaction, e.g., protoplasm of cells is nothing but water containing several different molecules or suspended particles.
- It acts as an excellent solvent and also acts as cooling system in plants.
- Every plant whether herbaceous or woody consists of water but its amount varies, e.g., Herbaceous plant has 10-15% of its fresh weight as dry matter watermelon has 92% of water while woody plants has relatively very little water.
- It also acts as a major component of seeds (for their survival and respiration) although they appear dry.
- It acts as a limiting factor for growth and productivity of plant in both agricultural and natural environments because of high demands of water by plants.

Note: A mature corn plant absorbs almost three liters of water in a day, while a mustard plant absorbs water equal to its own weight in about 5 hrs.



Terrestrial plants take up huge amount water daily but most of it is loss to the air through transpiration (i.e., evaporation from the leaves).

To understand plant water relation an understanding of action standard terms like water potential, solute potential, pressure potential etc.

Water Potential

Potential is the way of representing free energy. All living organisms require free energy to grow, maintain metabolism and reproduce. As water molecules possess kinetic energy, they are in random motion (in both liquid and gaseous form) which is rapid and constant.

Thus, water potential is the difference between the free energy of water molecules in pure water and the energy of water in any other system. It is denoted by (Ψ_w) and expressed in pressure unit i.e., pascals (Pa). Greater the concentration of water in a system, greater will be its kinetic energy or water potential, i.e., pure water will have greatest water potential.

The best way to express spontaneous movement of water from one region to another is in terms of differences in the free energy of water between two regions, i.e., one with the higher energy to one with the lower energy.

Thus, water will move from the system containing water with higher potential to the one having lower potential (down the gradient). Hence, this movement of water is called diffusion.

Note:

The term water potential was first used by Slatyer and Taylor.

By convention, the water potential of pure water at standard temperatures, which is not under any pressure, is taken to be zero.

Water potential is always regarded as the tendency of water to leave a system.

Solute Potential:

The magnitude by which water potential is reduced due, to the presence of a solute in pure water is known as solute potential. When solute or some substance is dissolved in pure water, the concentration of water decreases and solution will have fewer free water. It infers that the presence of solute particles in water reduces the free energy of water due to which water potential also decreases.

Solute potential is denoted by Ψ_s and is always negative (or has value less than zero). Hence, a greater number of solute molecules = Lower solute potential (more negative).

Pressure Potential:

If a pressure more than atmospheric pressure is applied to pure water or a solution (containing solute), the water potential increases. This is equal to pumping water from one place to another such as our heart buildup pressure for the circulation of blood in the body.

When water enters a plant cell through diffusion, it becomes turgid due to building up of pressure against the cell wall in a plant system. This leads to increase in the pressure potential. It is usually positive known a turgor pressure and is denoted by fp . Loss of

water during transpiration produces a negative hydrostatic pressure or tension in the xylem. This is very important in transport (Ascent of sap) over long distances in plants. Water potential is affected by both solute and pressure potential.

$$\Psi_w = \Psi_s + \Psi_p$$

At atmospheric pressure for a solution

$$\Psi_w = \Psi_s$$

Osmosis

A plant cell is surrounded by both cell wall and cell membrane. The cell wall is freely permeable, i.e., it does not act like a barrier to the movement of water and other substances. The cell membrane and membrane of vacuole, the tonoplast is responsible for determination of water or other molecules in or out of the cell.

The large central vacuole and its contents (vacuolar sap) contributes to the solute potential of the cell.

Osmosis may be defined as the net movement of solvent molecules (water molecules) across a differentially or semipermeable membrane.

Osmosis takes place very spontaneously in response to a driving force. The movement of solvent, in osmosis occurs due to the differences of water potential on two sides, i.e., water will move from a region of higher chemical potential to a region of lower chemical potential until the state of equilibrium is reached.

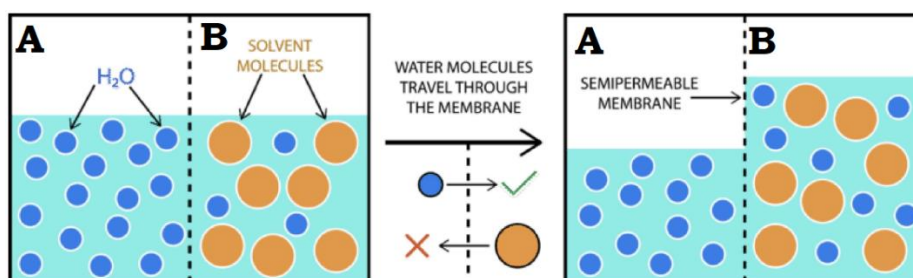
The net direction of molecules and rate of osmosis depends on two factors

- Pressure gradient
- Concentration gradient.

Osmosis is a passive process and does not require any input of energy. Discovery of osmosis was made by Pfeffer.

Illustration of Osmosis

Phenomenon of osmosis can be easily understood on the basis of the diagram given below:



On the basis of this following observations are made:

- Solution in chamber B has a lower water potential (as it contains more solute particles than A).
- Solution in chamber A has a lower solute potential (as solutes are absent) and B chamber has higher solute potential (as it contains high solute particles and less solvent, i.e., water).

iii. Osmosis will take place from chamber A to B because as explained earlier osmosis always occurs from its region of higher chemical potential to a region of lower chemical potential. One must not be confused with the movement of solvent (water) and movement of solute (water + solute particles) as solute always moves from a region of lower concentration to higher concentration and vice-versa in the case with solvent

Endosmosis: The inflow of solvent (water) into a cell from outside when placed in distilled water, is called endosmosis in which cells swell up due to the entry of water and become turgid.

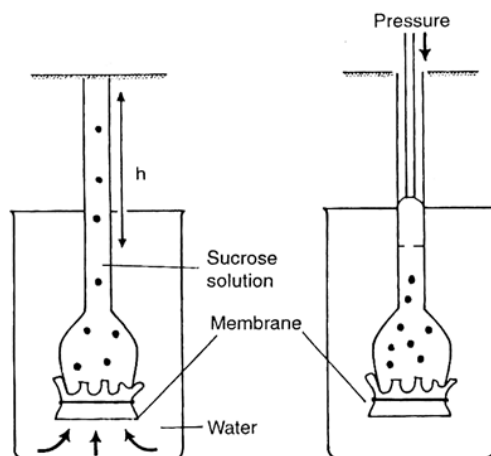
Exosmosis: The outward flow of water from cell when placed in hypertonic solution like sugar solution, the cell tends to shrink and becomes flaccid. This outward flow of water in solution is called exosmosis.

The Funnel Experiment

This is another experiment, which is performed in the laboratory through which phenomenon of osmosis can be easily demonstrated.

Following steps are performed during this experiment

1. A beaker is taken and filled with pure water.
2. A thistle funnel is filled with sucrose solution and kept inverted in a beaker containing water (level is noted).
3. The inverted funnel is separated from a pure water through a semi-permeable membrane.
4. Level of the sucrose solution will rise into the funnel as water will move into the funnel.
5. Water will continue moving till an equilibrium state is achieved.
6. If sucrose will diffuse out through the membrane, the equilibrium will not be reached ever, because for the state of equilibrium the concentration or gradient potential should be equal in both the chambers, i.e., funnel and beaker.
7. External pressure is applied from the upper part of the funnel to stop the water movement into the funnel through the membrane.





Significance of Osmosis

- It helps in maintenance of cell turgidity.
- Plays a vital role in stomatal movement during transpiration.
- It helps in the movement of liquids across biological membranes.
- It also has effects on absorption of water by roots.

Osmotic Pressure:

It is that pressure of a solution, which must be applied to the solution in order to allow passage of solvent due to osmosis. This is also the function of solute concentration; i.e., more the concentration of a solute, greater will be the amount of pressure applied in order to prevent water from diffusing. Osmotic pressure is numerically equal to the osmotic or solute potential but osmotic potential has a negative sign, while osmotic pressure is always a positive pressure.

$$\Psi_s = -\pi$$

Where Ψ_s is the solute potential and π is the osmotic pressure

The osmotic pressure of a solution largely depends upon the ratio between the number of solute and solvent particles present in a given solution.

Instrument used for measuring osmotic pressure is called osmometer, eg., Berkeley and Hartleys osmometer.

Reverse osmosis is expulsion of pure water from solution through a semipermeable membrane under the influence of external pressure, higher than osmotic pressure of solution.

Differences between Osmotic Pressure and Osmotic Potential

Osmotic Pressure	Osmotic Potential
It is the pressure that must be applied in order to prevent the passage of solvent due to osmosis	It is the amount by which potential is reduced as a result of presence of solutes
Its unit is bars with positive sign	Its unit is bars with negative sign
Osmotic pressure of pure solvent (water) is zero. The value increases due to addition of solute particles	The value of osmotic potential for pure water is also zero. Addition of solute particles makes the value of osmotic potential more negative
During osmosis, water molecules move from a solution with less osmotic pressure to solution with more osmotic pressure	During osmosis, water molecules move from a solution with more osmotic potential to solution with less osmotic potential



Types of Solutions

The plant cells or tissues behave according to the movement of water depending upon the surrounding solution. Thus, on the basis of concentration of cell sap (cellular solution found in large central vacuole of a living plant cells).

The solutions are of following three types

- i. **Isotonic solution:** It is a type of solution, which has a similar concentration as the cell sap of the cells, i.e., No change occurs in a cell after placing it in isotonic solution.
- ii. **Hypotonic solution:** It is a type of solution which has lower concentration (more diluted) than the cell sap. The cell swells up when placed in this solution.
- iii. **Hypertonic solution:** It is a type of solution which has higher concentration than the cell sap of cells. The cells shrink, when placed in hypertonic solution.

Note: The term 'Diffusion Pressure Deficit' (DPD) was coined by BS Meyer in 1938. The amount by which diffusion pressure of a solution is lower than that of its pure solvent is known as diffusion pressure deficit.

$$\text{DPD} = \text{OP} - \text{TP (WP)}$$

For fully turgid cell

$$\text{DPD} = \text{Zero (as OP} = \text{TP)}$$

For Flaccid cell

$$\text{DPD} = \text{OP (as TP} = \text{Zero)}$$

Plasmolysis

This phenomenon occurs when water moves out of the cells and the cell membrane of a plant cell shrinks away from its cell wall when placed in a hypertonic solution (having more concentration). During the process the hypertonic solution causes exosmosis (outward movement of water).

The water first moves out from the cytoplasm and then from the central vacuole. This withdrawal of water through diffusion into the extracellular fluid causes the cell to shrink in size, due to which cell moves away from the walls. The cells is said to be plasmolyzed.

The space between the cell wall and the shrunken protoplast is occupied or filled by the external solution.

At limiting plasmolysis, the pressure of external solution balances the osmotic pressure of the cytoplasm. Thus, during this state of equilibrium when flow of water into and out of the cell is same, the cells are called flaccid.

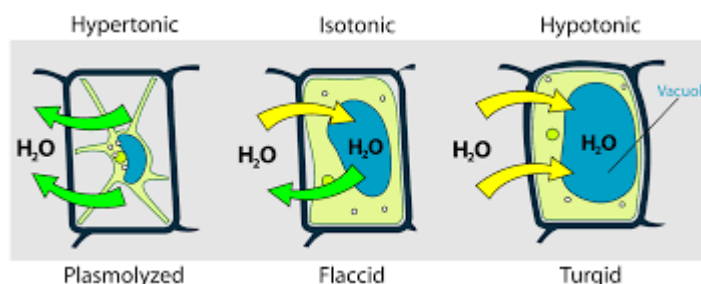


Image courtesy: Wikipedia

Deplasmolysis:

The process in which the plasmolyzed cell when placed in pure water or hypotonic solution, builds up a turgor pressure (in which water enters the cell and cause the cytoplasm to build up a pressure against the wall). It is mainly responsible for enlargement and extensive growth of the cells. During this stage, water enters due to endosmosis and cell again becomes turgid when protoplast attains its original shape and size. As cell wall is rigid, the cell does not rupture. The pressure exerted against rigid wall due to the entry of water by the protoplasts is called pressure potential, i.e.,

- Deplasmolysis should be followed immediately after plasmolysis otherwise the cell protoplast becomes damaged permanently.
- Pressure potential of a flaccid cell is zero because there is no net movement of water in and out of the cell.
- Cell wall is found in bacteria, fungi, algae some archaea and plant cells (animals and protozoans do not have cell wall).

Differences between Plasmolysis and Deplasmolysis

Plasmolysis	Deplasmolysis
It occurs when a tissue is placed in hypertonic solution	It occurs when a plasmolyzed cell is placed in hypotonic solution
It is a result of exosmosis	It is a result of endosmosis
It involves shrinkage of protoplasm from cell wall	It results in the swelling of shrunken protoplast so as to come in contact with the cell wall
It is not reversible after a long interval of time	It is reversible even after a long interval of time

Significance of Plasmolysis

- It allows a plant cell to lose water without dying, it can shrink or increase in size as water is available within the constraints of the cell wall.



2. It is shown by living cells. By this we can determine whether a cell is living or dead.
3. It helps in determining osmotic pressure of plants.
4. It proves that cell wall is elastic and permeable.

Imbibition

It is a special phenomenon in which water or any other liquid is absorbed by the solid particles (colloids) of a substance. This leads them to increase enormously in volume. The solid particles which imbibe water or any other liquid are called imbibants. The liquid, which is imbibed is known as imbibate. It is also a type of diffusion because movement of water occurs along concentration gradient as in diffusion. During imbibition, water molecules get tightly adsorbed and become immobilized.

During imbibition water molecules lose most of their kinetic energy in the form of heat. This is called heat of hydration or heat of wetting.

Imbibition can be best explained and seen in absorption of water by seeds and dry wood which acts as absorbents to imbibe water and swell.

Imbibition Pressure

The pressure developed by solid particles, which adsorb water or any other liquid when submerged in pure imbibing liquid is called imbibition pressure. It is due to this pressure in plants that seedlings emerge out of the soil and establish themselves.

Conditions necessary for imbibition to take place are

- i. Affinity between the adsorbent and the liquid imbibed is essential.
- ii. Water potential gradient between the absorbent and the liquid imbibed.

The phenomenon of imbibition is also influenced by several factors like temperature (increases with rise in temperature), pressure (decreases if pressure is against imbibant), pH (depends on change of imbibant) electrolytes (decreases) and texture of imbibant (increases if it is loose, decreases if it is compact in nature).

Importance of Imbibition

Helps seedlings to come out of soil.

Acts at the initial stage in germination of the seeds.

In older times, the imbibition pressure was used in breaking the rocks and stones.

It is dominant in the initial stage of water absorption by roots.

Differences between Imbibition and Diffusion

Imbibition	Diffusion
The absorption of solvent takes place by a solid substance	It is the movement of substances from the region of their higher concentration to the region of their lower concentration



It always results in the release of heat (Heat of wetting or heat of hydration)	It does not involve the release of heat
The molecules of water are adsorbed to the surface of hydrophilic colloid e.g., cellulose, starch, proteins etc.	The diffusing molecules distributed uniformly through the available space
The imbibant swells up but the swelling is less than the volume of the imbibate	No overall change in the volume is seen
It occurs only when adsorbent (imbibant) is present	There is no requirement of adsorbent
It develops a very high pressure (up to 1000 atm)	It develops less pressure comparatively (up to 100 atm)

Note:

Adsorption is property of colloids. Hence, material which have high proportion of colloids are good imbibants. eg., wood, is good imbibant as it contains proteins, cellulose and starch as colloidal substances.

Long Distance Transport of Water:

Long distance transport of substances cannot take place by the process of diffusion alone. Diffusion accounts for only those molecules that move for short distance and it is a very slow process. For instance, the movement of a molecule across a typical plant cell (about 50 μm) takes approximately 2.5 second. At this rate, the movement of molecules over a distance of 1 m would take approximately 32 years by diffusion alone.

In large and complex organisms, sites of production or absorption and sites of storage are far away from one another thus, the substances to be transferred have to follow a long path and move across very large distances. Hence, some special long distance transport systems are necessary in order to transfer substances across long distances at much faster rate.

The movement of water, minerals and food across long distances is generally done by a mass or bulk flow system, which operates due to difference between the pressure of two points, i.e., the source and the sink. The substances whether dissolved or suspended in solution, are carried at a same speed. Such a movement is different from diffusion where different substances move independent of each other depending upon concentration gradients of their own. Mass or bulk flow movement occurs through vascular tissues, xylem and phloem of plants. The bulk movement of substances through conducting or vascular tissues of plant is called translocation.

There are generally two types of vascular tissues in plants which are responsible for translocation

- i. **Xylem:** It is responsible for translocation of water with mineral salts, some organic nitrogen and hormones mainly from roots to aerial parts of plants.
- ii. **Phloem:** It is responsible for translocation of organic and inorganic substances from leaves to other parts of the plant. Bulk flow can operate either due to positive

hydrostatic pressure gradient (like a garden hose) as in phloem or a negative hydrostatic pressure gradient (like suction through a straw) as in xylem.

Absorption of Water by Plants

Plants absorb water through roots. However, the area of young roots where most absorption of water and minerals takes place is root hair zone. Root hairs are thin walled, slender extension of root epidermal cell present at the tip of the roots in millions. These are very delicate structure, which do not last for more than days or a week. They have very sticky walls that help in tight adhesion to the soil particles. Tracheids and trachea of xylem transport water in plants. Water once absorbed by file root hairs enter epidermis from where, it moves deeper into the root layers and finally reaches xylem following two pathways, i.e., apoplast and symplast.

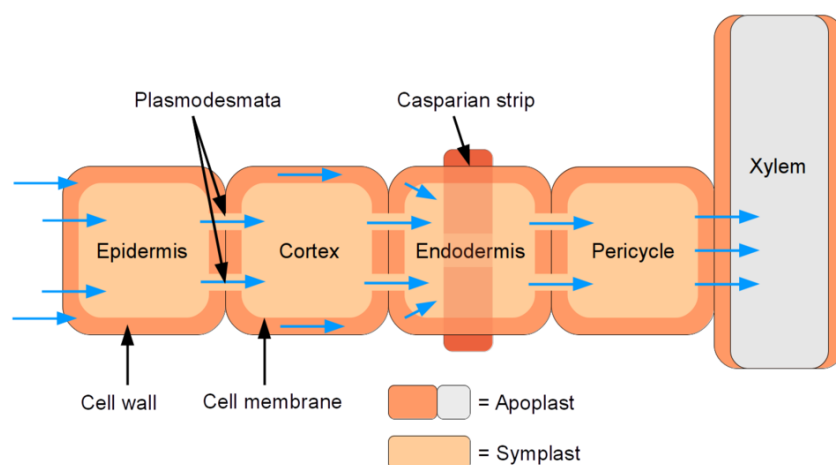


Image courtesy: www.linkedin.com

Apoplast Pathway

Apoplast is the system of adjacent cell walls (i.e., interconnecting cell walls, intercellular spaces, cell wall of endodermis) that occur continuously throughout the plant, except at the casparian strips of endodermis in roots. In this pathway, the movement of water molecules takes place through intercellular spaces and the walls of the cells only. The water movement takes place along the gradient" from root hairs to xylem through the walls of intervening cells without crossing any membrane or cytoplasm. Thus, it does not provide any barrier to the movement of water, which occur through mass flow, due to adhesion and cohesion of water molecules. There is no involvement of osmosis in the apoplast pathway.

Symplast Pathway

This system includes the living part of the plant cells made up of interconnected protoplasts of neighboring cells and connected through cytoplasmic strands extending through plasmodesmata.



The water that enters into the cell sap of root hair as a result of active absorption, moves into the underlying cortex cells bounded by a continuous selectively permeable membrane through plasmodesmata.

The movement is relatively slower as water enters the cells through the cell membrane.

The movement is again down the potential gradient. This pathway is aided by cytoplasmic streaming, which helps in quicker movement across individual cells. Thus, facilitating transport.

Cytoplasmic Streaming is an autonomous vital movement that occurs in eukaryotic cells continuously, e.g., around the central vacuole. Also known as cyclosis. It can be easily observed in the cells of Hydrilla leaf. The movement of chloroplast due to streaming is easily seen under microscope.

It is generally believed that both apoplast and symplast pathways are operative in plants but apoplast pathway offers less or no resistance. Thus, water continue to move through apoplast in the roots.

As the apoplast pathway is blocked by the bond of a suberized matrix called the casparian strip in the inner boundary of the cortex, the endodermis is imperious to water.

Therefore, the movement of water by and the endodermis occurs by the symplast pathway, i.e., water from the cell walls enter the cell cytoplasm and moves from one cell cytoplasm to another cell cytoplasm crossing the cell membrane through plasmodesmata and finally reaches the xylem elements.

Mycorrhizal Absorption:

Instead of using root hairs for absorption many plants use mycorrhiza for water absorption. Mycorrhiza is a symbiotic association between a fungus and a young root system of a plant. Fungal hyphae have a very large surface area and extend into soil for sufficient distance, where a root cannot reach.

They absorb both mineral ions and water from the soil and provide these substances to the roots. The roots in turn provides sugar and N-containing compound to the mycorrhizae. The mycorrhizal association is obligate in many cases, e.g., seeds of Pinus and many orchids cannot germinate properly without the development of mycorrhizal association.

Water Movement up a Plant (Ascent of sap)

Translocation of water or ascent of sap is usually upwards from the roots toward the top of the plant via stem, i.e., to the leaves and growing points or apical meristems and other aerial plant parts. It occurs through the tracheary elements of xylem. Many theories have been put forward to explain the upward movement of water.

Two of them are given below



Root Pressure Theory

It is believed that all plants absorb excess of water by an active process and tends to build up a positive hydrostatic pressure within the root system known as root pressure. Due to this activity the water is pushed upward along the length of the stem to a small height. The pressure inside the xylem is caused due to the diffusion pressure gradient and is maintained by the activity of living cells.

Demonstration of Root Pressure Theory in Plants

At the start of the experiment, choose a plant having soft stem on a day when there is plenty of moisture in the atmosphere. Early in the morning cut the stem horizontally near the base, i.e., just above the soil with a sharp blade. The moment cut is made, few drops of solution start oozing out of the cut stem, which is due to the positive root pressure. Now in order to determine the rate of exudation (substances that oozes out) and the composition of the exudates (like sap, germs, latex, etc.), fix a vertical glass tube filled with water, with the help of a rubber tube to the cut end the stem. A column of sap is seen to rise in the tube, which will be the measure of the root pressure.

Root pressure is inhibited or reduced during reduced aeration, low or high temperature, drought, etc. Root pressure is maximum during early morning of spring and – rainy season when the level of evaporation is low or minimum and decreases with the advancement of day. The magnitude of root pressure is about two bars or atmospheres.

Guttation

When the amount of root pressure is high and rate of transpiration is low, many herbaceous plants tend to lose small quantities of water or liquid in the form of drops from the hydathodes (small pores) or water glands. These are present on the margins of the leaves or where the main vein ends and near the tips of blades of some vascular plants like grasses and small herbaceous plants (rose, strawberry, tomato, etc.). This phenomenon water loss in its liquid phase is called guttation. It takes place usually in early morning. The water that oozes out contains organic-and inorganic substances.

Contribution of Root Pressure

As root pressure contribute a modest push in the overall water transport. The enormous tension developed by transpiration, breaks the continuous chains of water molecules in the xylem which gets re-establish by the root pressure. In this way root pressure provides a great contribution in the transport of water.

Limitations to Root Pressure theory

Root pressure theory cannot account for the translocation of water or ascent of sap due to the following reasons:

- i. It cannot lift sufficient amount of water upward to meet the requirement of water.
- ii. It fails to play a role in water movement in tall trees like gymnosperms, etc.
- iii. The amount of the fluid transported by the root pressure is not enough in measuring the movement of water in xylem in many trees.



- iv. Root pressure seems to be absent in summer when the requirements of water are high.

Although it plays a major role in the transport of water through xylem in some plants and some seasons but it does not account for majority of water transport due to which most plants fulfil their needs by transpirational pull.

Transpiration Pull Theory

Plants have a continuous water column in their xylem channels that starts at the base, i.e., roots and continues up to leaves from where water is lost through the process of transpiration. Thus, despite the absence of a circulatory system in plants, the flow of water upward through the xylem in plants achieve fairly high rates up to 15 meters per hour.

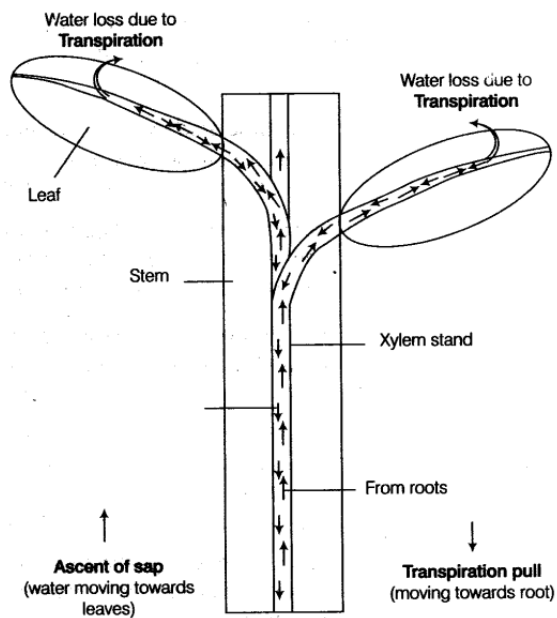
The water molecules in the water column remain attracted by the cohesive force and cannot be separated easily from one another. Thus, there is attraction between water molecules and the inner wall of xylem ducts. Hence, water column cannot be pulled away from the walls of xylem ducts due to strong adhesive and cohesive forces. This maintains the continuity of water column from roots to leaves.

Water is lost from mesophyll cells to the inter cellular spaces as a result of transpiration and develops a strong negative water potential. There are very large number of leaves and each leaf has thousands of transpiring mesophyll cells, which withdraw water from the xylem. This leads to a negative pressure in the water column, which exerts an upward pull over the water column. This pull is known as transpirational pull.

This tension or pull is transmitted up to the roots in search for more water. The water column (formed in the xylem elements of roots) now moves upward under the influence of transpirational pull.

Thus, the cohesive, adhesive forces and transpiration pull all help in lifting up of water through xylem elements and because of the critical role of cohesion the transpiration pull is also called cohesion-tension transpiration pull model of water transport.

Cohesion-tension theory was originally proposed by Dixon and Jolly in 1894 and further improved by Jolly in 1914.

**Further readings:**

6. Biology, Textbook for Class XI, NCERT
7. www.easybiologyclass.com
8. www.biologydiscussion.com
9. www.botanystudies.com
10. www.britannica.com



UNIT-II: KINGDOM PLANTAE

Syllabus

Salient features of various plant groups for identification and their classes: (Algae, Bryophytes, Pteridophytes, Gymnosperms and Angiosperms).

Morphology of Flowering Plants and Their Functions: morphology of Root, stem, Leaves, Inflorescence, Flowers, Fruits and seeds.

Description of Flowering Plants of families: Fabaceae, Solanaceae and Liliaceae

Introduction:

Robert H. Whittaker (1969) organized the organisms into five kingdoms. He classified organisms on the basis of cell structure, mode and the source of nutrition and body design.

Plant kingdom classification has changed a number of times over the years. For instance, blue-green algae were once considered to be part of the plant kingdom, but today, they are classified under Kingdom Eubacteria. Similarly, lichen was once considered a plant; however, they are composite organisms. In other words, lichens are comprised of two individual organisms – a fungus and an alga. Historically, organisms that could not be classified under animals were grouped under plants.

Kingdom Plantae or the plant kingdom is the taxonomic rank that includes algae, bryophytes, pteridophytes, gymnosperms and angiosperms. The very first land plants appeared roughly 470 million years ago, and over the aeons, a spectacular number of plant biodiversity has evolved.

Characteristics of Kingdom Plantae:

The plant kingdom has the following characteristic features:

1. They are non-motile.
2. They usually reproduce sexually.
3. They follow the autotrophic mode of nutrition.
4. These are multicellular eukaryotes with cell wall and vacuoles.
5. These contain photosynthetic pigments called chlorophyll in the plastids.
6. They are different organelles for anchorage, reproduction, support and photosynthesis.



Classification of Kingdom Plantae:

Plant kingdom is a vast group; therefore, the kingdom is further classified into subgroups. Levels of classification are based on the following three criteria:

1. **Plant body:** Whether the body has well-differentiated structures or not.
2. **Vascular system:** Whether the plant has a vascular system for the transportation of substances or not.
3. **Seed formation:** Whether the plant bears flowers and seeds or not; if it does, then whether it is enclosed within fruits or not.

Considering all these factors, the plant kingdom has been classified into two subgroups. They are:

I. Cryptogams

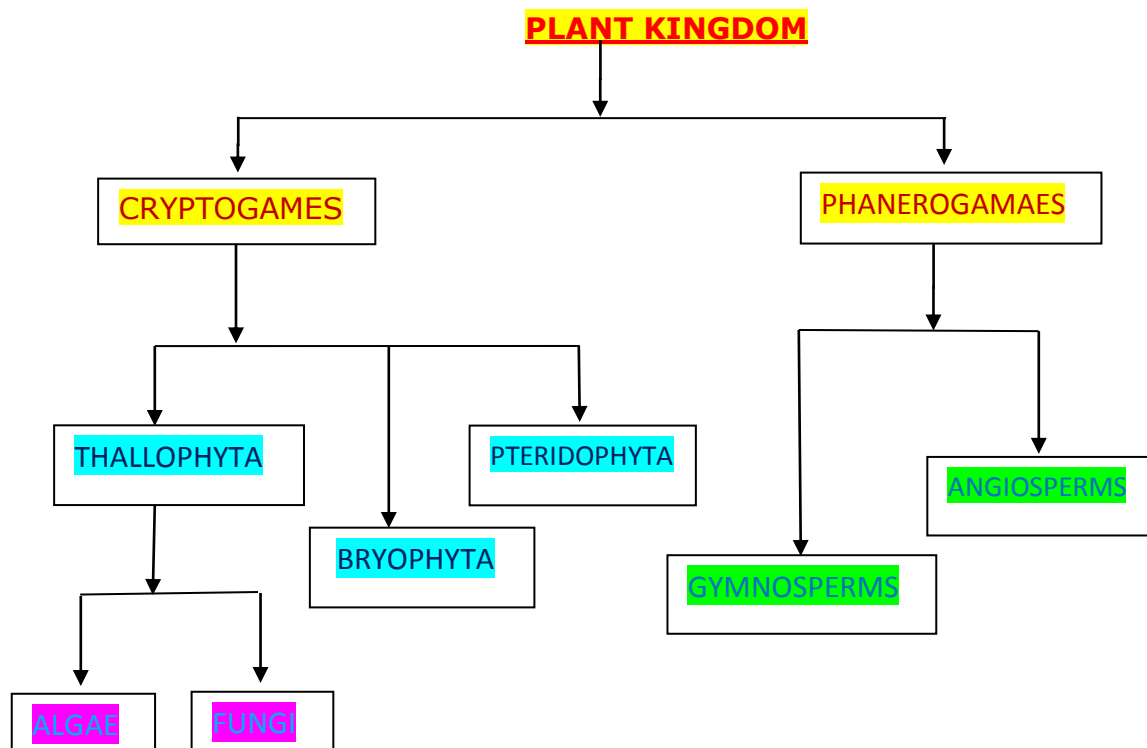
II. Phanerogams

I. Cryptogams:

Cryptogams are plants that do not have well-developed or conspicuous reproductive organs. They have hidden reproductive organs and don't produce seeds. The thallophytes, the bryophytes and the pteridophytes are 'cryptogams'. Reproduction in all three groups occurs through spore formation.

II. Phanerogams:

Plants that have conspicuous reproductive organs and produce seeds are called Phanerogams. Gymnosperms and Angiosperms belong to the group Phanerogams. A. W. Eichler (1839 – 1887) classified plant kingdom as under:





Characteristic features of various plant groups:

I. Cryptogams:

1. Thallophyta
2. Bryophyta
3. Pteridophyta

1. Thallophyta:

Thallophytes are a polyphyletic group of non-motile organisms that are grouped together on the basis of similarity of characteristics, but do not share a common ancestor. They are the primitive plants where the body is not differentiated into stem, roots and leaves. These include lichens, algae, fungi, bacteria and slime moulds.

Characteristics of Thallophyta:

1. They are usually found in moist or wet places.
2. This is due to the absence of "true roots" and vascular tissue that is needed to transport water and minerals. Hence they are found in moist or wet places.
3. They are autotrophic in nature.
4. Most members in this group manufacture their own food. But a few members like fungi are dependent on other sources of food.,
5. Reserve food is generally starch.
6. After photosynthesis, glucose is produced and consumed almost immediately; the remaining glucose is converted into complex compounds called starch.
7. They have a cell wall composed of cellulose around their cells.
8. Absence of vascular tissue.
9. Unlike other plants, xylem and phloem are absent. etc.
10. Sex organs are simple, single-celled; there is no embryo formation after fertilization.

Division of Thallophyta:

The division Thallophyta is classified into two subdivisions:

- I. Algae
- II. Fungi.

I. Algae:

They are chlorophyll-bearing thalloids. They are autotrophic and largely aquatic plants. On a side note, it has been observed that green algae form a symbiotic relationship with sloths that are native to the lush tropical rainforests of South America and Central America. Sloth fur is very coarse and readily absorbs water. As a result, sloth fur forms a moist and damp environment for the algae to flourish. The algae in return, provide the sloth with extra nutrition and camouflage from predators. Example: Spirogyra.



II. Fungi:

They are achlorophyllous (meaning: they do not produce chlorophyll) heterotrophic thallophytes. Sometimes, to overcome this handicap, fungi may develop a symbiotic relationship with an algae or a cyanobacterium. The algae can produce food as it has chlorophyll and the fungi in return provide a safe environment that shields the algae from UV rays. Lichen is an example where two organisms act as a single unit.

2. Bryophyta:

Bryophyta, the division of green plants, refers to embryophytes which in literal terms are land plants. They are Small, non-vascular plants that prefer moist environments. They have differentiated plant body like stem and leaf structures. But they lack a vascular system for the transportation of substances across the plant body. Bryophytes are found in both land and aquatic habitats, hence are known as amphibians of the plant kingdom. The only prime feature of bryophytes is that they do not have true vascular tissue. Some do have specialized tissues which are used to transport water but are not considered to be a true vascular tissue due to the lack of lignin.

Bryophytes are believed to have evolved from Charophytes and are considered to have been the first true plants to have ever evolved.

This division includes:

1. **Mosses:** Class Bryopsida
2. **Liverworts:** Class Marchantiopsida
3. **Hornworts:** Class Anthoceropsida.

3. Pteridophyta:

It is speculated that life began in the oceans, and through millions of years of evolution, life slowly adapted on to dry land. And among the first of the plants to live on land were the Pteridophytes. Pteridophytes have well-differentiated structures such as stem, root, leaves as well as a vascular system. They are seedless, and procreate through spores. They don't have conducting tissues for transportation of water and minerals. Instead, the water and minerals flow from the surface of the plant- cell to cell in the plant's body. This is also one of the reasons why these plants need a constantly moist environment to survive. Unlike most other members of the Plant Kingdom, pteridophytes don't reproduce through seeds; they reproduce through spores instead.

Ferns, horsetails, Marsilea are some common examples of Pteridophytes.

II. Phanerogams:

- I. Gymnosperms
- II. Angiosperms

I. Gymnosperms:

Gymnosperms are the vascular plants that possess "exposed" seeds. The gymnosperms have well-differentiated plant body and vascular system. They bear seeds. The term, "Gymnosperm" has been derived from Greek words, '*gymno*', meaning 'naked' and '*sperma*', meaning seed. The seeds of gymnosperms are naked which means they



are not enclosed within a fruit. The perennial, evergreen woody trees belong to this group. Pines, deodar, redwood, etc. are a few examples.

II. Angiosperms:

Angiosperms are vascular plants with the body characterised as stems, roots, and leaves. They also possess special structures such as flowers and fruits. The term, "Angiosperm" has been derived from Greek words: *angio*, 'covered' and *sperma*, meaning 'seed'. Seeds of angiosperms are enclosed inside the fruits. Angiosperms are the most advanced and beneficial group of plants, commonly known as flowering plants. They can grow in various habitats as trees, herbs, shrubs, and bushes. Depending on the number of cotyledons present in seeds, angiosperms are divided into two: monocotyledons or monocots and dicotyledons or dicots.

Examples include the Mango tree, pomegranate plant, etc. Seeds germinate from embryonic leaves called cotyledons.

Detailed study of Various Plant Groups:

Algae:

Algae are chlorophyll bearing thalloids. They are autotrophic. The study of algae is called phycology or algology.

General Characters/ Silent Features:

1. Habitat:

Algae are mostly aquatic but are also found in other habitats. Some of the examples are given below.

- i. **Planktons:** These are passively floating masses of plants (Phytoplankton). They mostly consist diatoms.
- ii. **Red Sea:** It is a part of Mediterranean Sea, where a Blue green alga *Trichodesmium erythrae* grows on surface and imparts red-colour.
- iii. Some algae grow under very special environmental conditions such as hot water springs (thermal algae), on ice or snow (cryophytes), on surface of other plants (epiphytes) and animals (epizophytes) in symbiotic association.

2. Thallus Organisation:

The vegetative structure of algae varies considerably in shape and size. Some important types are:

- I. Unicellular Algae
- II. Multicellular Algae
- III. Colonial Algae

I. Unicellular Algae:

The thallus consists of a single cell. They may be of the following types:



- i. **Motile:** These possess flagella and are capable movement e.g., *Chlamydomonas*.
- ii. **Non-motile:** These lack flagella, hence non-motile e.g., *Chlorella*.

II. Multicellular Algae:

The thallus is made up of many cells either in the form of colonies or filamentous.

III. Colonial Algae:

In these algae many cells are grouped together to form a colony. The colony may be motile or non-motile.

- i. **Motile:** In some of these colonies, the number of cells remains constant throughout the life. They are called Coenobium e.g., *Volvox*.
- ii. **Non-motile:** These are non-motile colonies in which number of cells is not definite. These are called coccoid, e.g., *Hydrodictyon*.

3. Filamentous Stage:

In these multicellular forms the cells are arranged in series, one over the other to form the filament. The filaments may be branched e.g., *Polysiphonia* or unbranched *Ulothrix*. In some filamentous algae the thallus has two distinct systems – Prostrate or creeping that helps in attachment and erect or projecting which is green and hence photosynthetic. Such a thallus is known as heterotrichous, e.g., *Fritschiella*.

- i. **Siphonaceous:** In many algae, thalli are aseptate and thus nuclei remains scattered throughout the tabular thallus, such a structure is known as coenocytic, e.g., *Vaucheria* etc.
- ii. **Pseudo parenchymatous Algae:** It is a thallus where the filaments are repeatedly branched, giving an appearance of a Parenchymatous organisation, e.g., *Batrachospermum*.
- iii. **Parenchymatous Algae:** In brown algae parenchymatous thallus is formed due to extensive cell division, e.g., *Fucus*, *Laminaria*.

4. Reproduction:

Reproduction in algae is of three types:

- I. Vegetative Reproduction
- II. Asexual Reproduction
- III. Sexual Reproduction

I. Vegetative Reproduction:

The most common method of vegetative reproduction is fragmentation. In BGA pieces of trichomes are called hormogonia.

II. Asexual Reproduction:

Asexual reproduction takes place by following methods.



10. **Zoospores:** These are uni- or multi flagellate asexual spores formed within zoosporangium e.g., *Ulothrix*, *Oedogonium*.
11. **Aplanospores:** These are non-motile spores formed within the sporangium, e.g., *Ulothrix*.
12. **Hypnospores:** Type of aplanospores with a very thick wall. This enables it to remain dormant during unfavourable conditions, e.g., *Vaucheria* etc.
13. **Palmella Stage:** It is a structure consisting large mucilage in which many non-motile cells are embedded. It develops as a result of repeated divisions of the cells and concurrent dissolution of parent cell wall forming mucilage, e.g., *Chlamydomonas*.
14. **Autospore:** These are formed due to the division of the contents of the parent plant into many segments, each of them resembling the parent cell e.g., *Chorella* etc.
15. **Akinete:** These are non-motile spores with a very thick wall which remains fused with the wall of the parent cell. It contains large amount of reserve food material e.g., *Anabaena*, *Nostoc* etc.

III. Sexual Reproduction:

It involves formation of haploid gametes which fuse to form a diploid zygote. Meiosis occurs during germination of zygote and the resultant new plant is a haploid gametophyte. Sexual reproduction occurs in following ways:

10. **Isogamy:** Both the mating gametes are similar in shape, size and structure, e.g., *Ulothrix*.
11. **Anisogamy:** Both the gametes are motile. Male gamete is smaller in size than female gamete, e.g., *Caulerpa*.
12. **Oogamy:** The male gamete is smaller and motile while the female gamete is larger and non – motile, e.g., *Oedogonium*.

Classification of Algae

The three main classes of algae are:

- IV. Chlorophyceae.
- V. Phaeophyceae.
- VI. Rhodophyceae.

I. Chlorophyceae: (Green – Algae)

General Characters:

- IV. The plant body may be unicellular, colonial or filamentous.
- V. They are grass green due to dominance of chlorophyll a & b which are located in definite chloroplast.
- VI. Most of the members have one or more storage bodies called Pyrenoids located in the chloroplast. Pyrenoids contain proteins besides starch.



- VII. Some forms may store food in the form of oil droplets.
- VIII. They have a rigid cell wall made of inner layer of cellulose and outer layer of Pectose.
- IX. Vegetative reproduction takes place by fragmentation; asexual reproduction takes place by the formation of zoospores.
- X. The sexual reproduction may be isogamous, anisogamous or oogamous type.
- XI. Examples are *Chlamydomonas*, *Volvox*, *Ulothrix*, *Spirogyra* and *Chara*.

II. Phaeophyceae (Brown – Algae)

General Characters:

- 1. They are found in marine habitats.
- 2. They range from simple branched, filamentous forms (*Ectocarpus*) to profusely branched forms as represented by Kelps, which may reach a height of 100 meters.
- 3. A large number of brown algae are popularly known as sea-weeds. Some of them are the largest sea plants. The giant brown algae are called Kelps. The largest kelps are *Nereocystis* (20 – 30m) and *Macrocystis* (40 – 60mts).
- 4. They possess chlorophyll a, c, carotenoids and xanthophylls. They vary in colour from olive green to various shades of brown depending upon the amount of xanthophylls pigment; fucoxanthin is also present in them.
- 5. Food is stored as complex carbohydrate, in the form of Laminarin or Mannitol.
- 6. Many species of brown algae possess air bladders which keep them afloat by providing buoyancy.
- 7. Phaeophycean cell wall is made up of inner layer of cellulose and outer by a mixture of polysaccharides collectively called as Phycocolloids (algin).
- 8. The protoplast contains, in addition to plastids, a centrally located vacuole and nucleus.
- 9. Plant body is usually attached to substratum by a holdfast, and has a stalk, the stipe and leaf like photosynthetic organ, the frond.
- 10. Vegetative reproduction takes place by fragmentation.
- 11. Asexual reproduction mostly takes place by biflagellate zoospores.
- 12. Sexual reproduction may be isogamous, oogamous or anisogamous.
- 13. Examples are *Ectocarpus*, *Dictyota*, *Laminaria*, *Sargassum* and *Fucus*.

III. Rhodophyceae (Red – Algae)

General Characters:

- vi. Members of Rhodophyceae are commonly called red-algae due to the dominance of red pigment, r-phycoerythrin in their body.
- vii. Majority of the red-algae are marine with greater concentration found in warmer areas.
- viii. The cell wall is made up of cellulose, Pectic compounds and certain mucopolysaccharides called phycocolloids such as, agar, carrageenin and funori.



- ix. The thalli of most of the red-algae are multicellular.
- x. Food is stored in the form of floridean starch which is very similar to amylopectin and glycogen in structure.
- xi. Vegetative reproduction occurs by fragmentation.
- xii. Asexual reproduction occurs by non-motile spores, carpospores, tetraspores, neutral spores etc.
- xiii. Sexual reproduction is advanced type of oogamy.
- xiv. Common members are *Porphyra*, *Gelidium*.

Economic Importance of Algae:

1. **Food:** Many green algae such as *Chlorella*, *Ulva* etc. are used as food.
2. **Antibiotics:** Antibiotic chlorellin is obtained from *Chlorella*, which is used against Gram +ve and Gram -ve bacteria.
3. **Sewage Disposal:** Green alga such as *Chlorella*, *Chlamydomonas*, remove CO_2 and restores O_2 by the process of photosynthesis and make sewage water habitable to aquatic animals.
4. **In Space Research:** In recent years, it has been realised that *Chlorella* could be used to provide O_2 during space flight trips. The algae can reuse CO_2 during the process of photosynthesis and release O_2 for the use by Astronauts.
5. *Chlorella* and *Spirulina* are rich in proteins and are used as food supplement by space travellers.
6. Agar obtained from *Gelidium* and *Gracillaria* are used to grow microbes and in preparations of ice-creams and jellies.

Bryophyta:

Bryophyta (Bryon = moss, phytes = plants) is a group of simplest and primitive plants. These occupy position between the algae and the Pteridophyta. They are worldwide in distribution, occurring in all climates of earth, wherever there is sufficient moisture to sustain plant life.

The life cycle of bryophytes has two distinct phases, the gametophytic and the sporophytic. The gametophytic phase, which bears reproductive structures, is green, freely branched, independent and long lived. The sporophyte, on the other hand, is completely dependent upon the gametophyte and short lived.

General Characters of Bryophyta:

1. Habitat and habit:

Bryophytes are terrestrial plants generally restricted to moist and shady places such as moist walls, damp rocks, moist soil and decaying logs on forests. Bryophytes also occur in other habitats:



d. **Aquatic:** *Riccia fluitans*, *Riella* etc.

e. **Epiphytes:** *Frullania*.

f. **Saprophytes:** *Buxbaumia aphylla* (moss) and *Cryptothallus mirabilis* (a liverwort).

2. Gametophyte:

Gametophyte plant body is either thalloid as in liverworts or foliose and erect with stem (axis) and lateral appendages (leaves) as in mosses.

Plant body is generally small (Zoopsis 0.5 – 4cm). However, some aquatic mosses e.g. *Fontinalis*, *Dawsonia* are reported to be 50 – 70 cm long.

True roots are absent. The function of roots is performed by rhizoids and scales. Rhizoids are unicellular and unbranched in liverworts but multicellular and branched in mosses.

True vascular tissue is absent. However, a conducting strand of few thick walled cells is present in mosses. Mostly water and food materials are transported from cell to cell.

3. Reproduction:

Bryophytes reproduce through:

- I. Vegetative
- II. Sexual reproduction.

I. Vegetative Reproduction:

Vegetative reproduction takes place by.

6. Fragmentation,
7. Formation of tubers and adventitious branches,
8. Formation of special structures like gemmae and protonema.

II. Sexual Reproduction:

Sexual reproduction is oogamous. The sex organs are multicellular and considerably more complicated. The male as well as female sex organs are surrounded by a sterile jacket layer. The male sex organ, known as antheridium, is stalked, pear shaped or oblong. It has an outer one cell thick jacket which surrounds mass of fertile cells called, the androcytes. Each androcyte produces a flagellated male gamete called the sperm or antherozoid.

The female sex organ, known as archegonium, is a stalked and flask shaped structure. It has a venter and long neck. The neck is filled with neck canal cells and venter has a large egg cell and a small venter canal cell.

The male gametes are released from antheridia, swim through a thin film of water and are attracted towards the archegonium. They enter into the archegonium and fertilize the egg.



The diploid zygote formed as a result of fertilization, remains within the venter of the archegonium and is the mother cell of sporophytic generation. Zygote develops into multicellular embryo.

4. Sporophyte:

The sporophyte (also known Sporogonium) is a simple structure, without leaf, stem and roots. It is differentiated into foot, seta and capsule. In some bryophytes, however, sporophyte is reduced and simple being made of capsule only (e.g. *Riccia*) or foot and capsule e.g. *Corsinia*.

The sporogenous cells present in the capsule form spore mother cells (SMC) after repeated divisions. Each spore mother cell undergoes meiosis to form four haploid spores. All the spores are similar in shape and size. They are non-motile and dispersed by wind. Spore is the mother cell of the gametophytic generation. In liverworts spores germinate to form a young gametophyte but in mosses the spores give rise to gametophytic structure called Protonema. The Protonema later forms erect gametophores.

Classification of Bryophytes:

According to the latest recommendations of ICBN (International Code of Botanical Nomenclature), bryophytes have been divided into three classes.

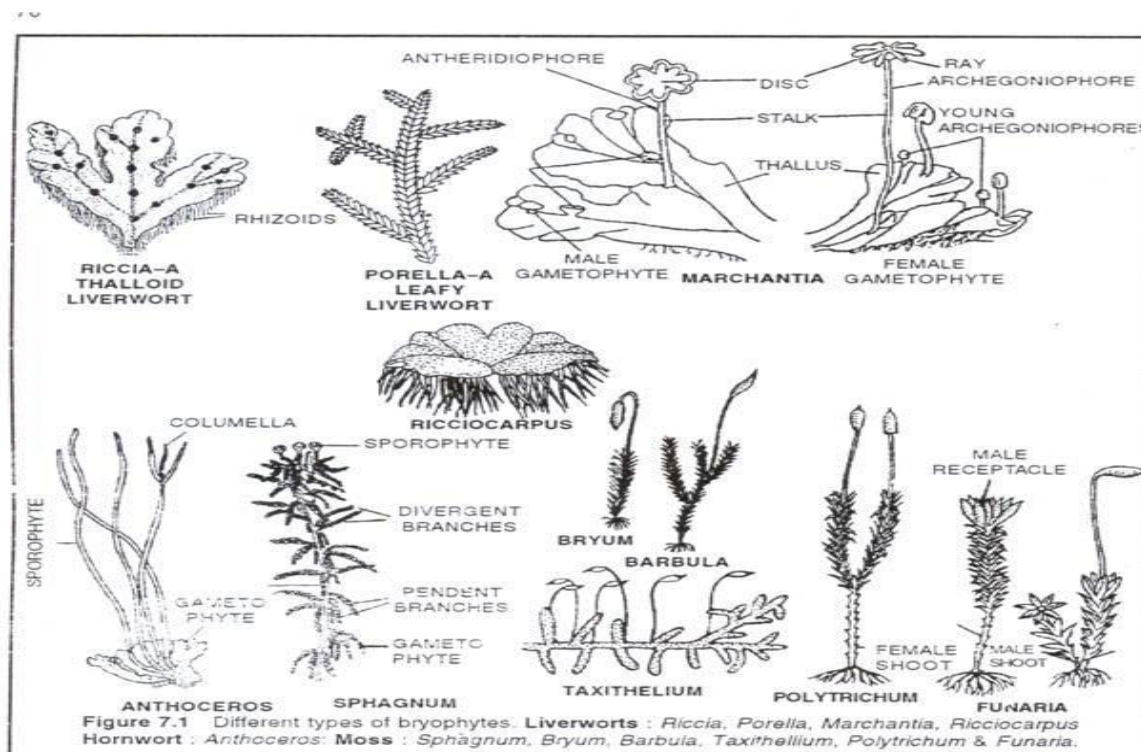
1. Hepaticae (Hepaticopsida - Liverworts)
2. Anthocerotae (Anthocertopsida- Hornworts)
3. Musci (Bryopsida- Mosses)

Class I. Hepaticae or Hepaticopsida:

1. Gametophytic plant body is either thalloid or foliose. If foliose, the lateral appendages (leaves) are without mid-rib. Always dorsiventral.
2. Rhizoids without septa.
3. Each cell in the thallus contains many chloroplasts; the chloroplasts are without pyrenoids.
4. Sex organs are embedded in the dorsal surface.
5. Sporophyte may be simple (e.g., *Riccia*) having only a capsule, or differentiated into root, seta and capsule (e.g., *Marchantia*, *Pallia* and *Porella* etc.)
6. Capsule lacks columella.

Class II. Anthocerotae or Anthocertopsida (Hornworts):

1. Gametophytic plant body is simple, thalloid; thallus dorsiventral without air chambers, shows no internal differentiation of tissues.
2. Scales are absent in the thallus.
3. Each cell of the thallus possesses a single large chloroplast with a pyrenoid.
4. Sporophyte is cylindrical, only partly dependent upon gametophyte for its nourishment. It is differentiated into bulbous foot and cylindrical capsule. Seta is meristematic.
5. Endothecium forms the sterile central column (i.e., columella) in the capsule (i.e. columella is present).



Class III. Musci or Bryopsida:

1. Gametophyte is differentiated into prostrate protonema and erect gametophores
2. Gametophore is foliose, differentiated into an axis (=stem) and lateral appendages like leaves but without midrib.
3. Rhizoids multi-cellular with oblique septa.
4. Elaters are absent in the capsule of sporangium.



5. The sex organs are produced in separate branches immersed in a group of leaves.

Sporophyte Characteristics of the three groups of Bryophytes:

Characteristic feature	Liverworts	Mosses	Hornworts
Capsule form	Simple	Differentiated (operculum, peristome)	Elongated
Columella	Absent	Present	Present
Dehiscence	Longitudinal or irregular	Transverse	Longitudinal
Dispersion of spores	Elaters	Peristome teeth	Pseudo-elaters
Growth	Defined	Defined	Continuous
Maturation of spores	Simultaneous	Simultaneous	Graduate
Persistence	Ephemeral	Persistent	Persistent
Seta	Present	Present	Absent
Stomata	Absent	Present	Present
Structure	Small, without chlorophyll	Large, with chlorophyll	Large, with chlorophyll

Pteridophyta

Introduction

Pteridophytes are vascular cryptogams. They occupy the position between bryophytes and Spermatophytes. They are chlorophyllous, autotrophic, archegoniate, embryophytic and tracheophytic. Pteridophytes show diplohaplontic life cycle.

The term, "Pteridophyta" has been derived from Greek words, *Pteron* meaning 'Feather' and *Phyton* meaning 'Plants'. The name 'Pteridophyta' was given to this group owing to their pinnate or feather like fronds. Vascular cryptogams are, therefore, an assemblage of seedless vascular plants that have successfully flourished on land and reproduce by means of spores. It is believed that pteridophytes flourished during Devonian and Carboniferous periods of Paleozoic Era. The group constitutes the largest living group of primitive plants with more than 10,000 species.

General characters of Pteridophytes:

- v. These are the first true land plants in the evolution of the plant kingdom.



- vi. Pteridophytes exhibit a well-defined heteromorphic alternation of generations. Diploid sporophyte is the dominant phase in life cycle.
- vii. Sporophyte is an independent plant and is free from gametophyte at maturity.
- viii. Gametophyte is either fully or partially dependent on sporophyte for its nutrition.
- ix. Sporophyte is differentiated into stem, root and leaves.
- x. Pteridophytes have an internal conducting system consisting of xylem and phloem. They are the only vascular cryptogams.
- xi. The roots of Pteridophytes are adventitious type.
- xii. The stem of Pteridophytes is usually a rhizome. But in Lycopodials and horse tails the stem is aerial.
- xiii. The leaves are small (microphyllous) in several groups of plants and in higher forms they are large (Macrophyllous) and simple with well-developed petiole.

Reproduction in Pteridophytes:

I. Asexual Reproduction:

Asexual reproduction is by spores. The spores germinate to produce a haploid gametophyte called prothallus. Sporophyte produces meiospores inside a capsule called sporangia. The sporangia are borne on the lower surface or in the axils of fertile leaves called sporophylls. Sporophylls may be of two types:

- i. **Homosporous:** Spores produced are of only one type. Homosporous species usually produces bisexual (monoecious) gametophytes
- ii. **Heterosporous:** Spores produced are of two types. Heterosporous species produce unisexual (dioecious) gametophytes.

II. Sexual Reproduction:

The microspore germinates to produce male gametophyte and the megaspore germinates to produce female gametophyte. Gametophyte performs sexual reproduction by zooidogamous type of oogamy.

The sexuality of pteridophytic gametophytes can be classified as follows:



- a. **Dioicous:** The individual gametophyte is either a male producing antheridia and sperm, or a female producing archegonia and egg cells.
- b. **Monoicous:** Every individual gametophyte may produce both antheridia and archegonia and it can function both as a male as well as a female.
- c. **Protandrous:** The antheridia matures before the archegonia.
- d. **Protogynous:** The archegonia matures before the antheridia.
- i. Sex organs (both antheridia and archegonia) are multicellular with a sterile jacket but without stalks.
- ii. Fertilization takes place in the venter of archegonium. Water is necessary for it.
- iii. The diploid zygote develops into embryo in the archegonial venter. The embryo grows into sporophyte.

Life Cycle in Pteridophytes:

The life cycle of Pteridophytes is diplohaplontic with heteromorphic alternation of sporophyte and gametophyte. Sporophyte and gametophyte are independent of each other.

Development of sporangium:

Development of sporangium may be of two types namely,

1. **Leptosporangiate:** Sporangium develops from a single superficial cell
2. **Eusporangiate:** Sporangium develops from a group of superficial cells

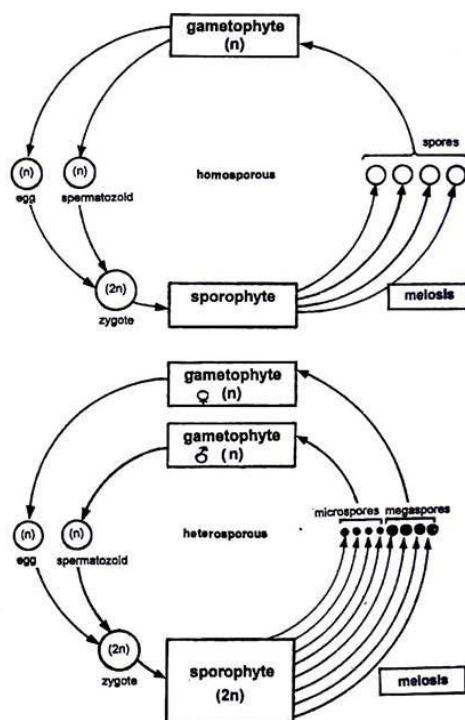


Fig. 4. Life Cycles of Homosporous and Heterosporous Pteridophytes

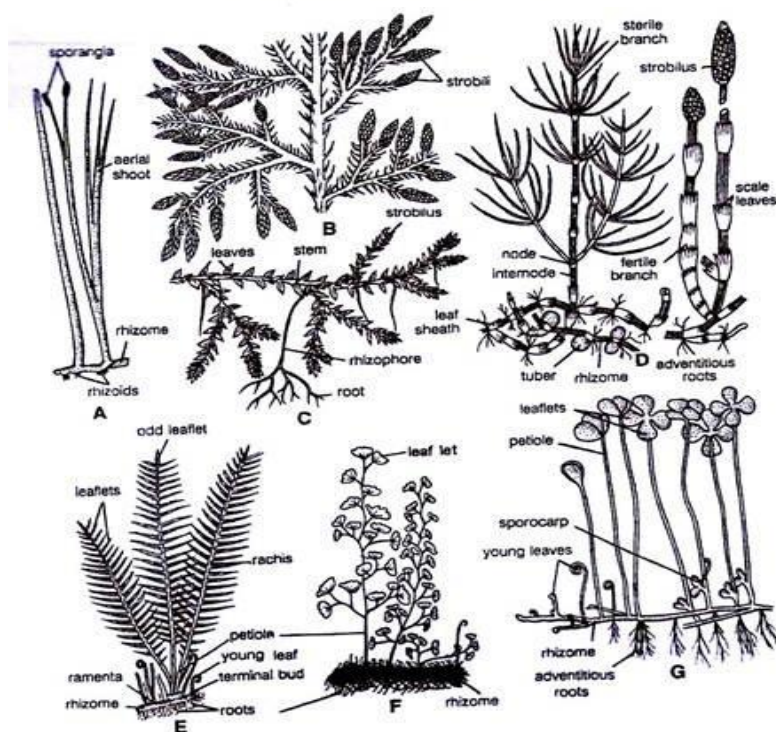


Fig 1 (A-G). Different forms of Pteridophytes A. *Rhynia*, B. *Lycopodium*, C. *Selaginella*, D. *Equisetum*, E. *Pteris*, F. *Adiantum*, G. *Marsilea*

Classification of Pteridophytes:

Pteridophyta were classified into following four sub-phyla by Oswald Tippo (1942).

I. Psilopsida.



- II. Lycopsidea.
- III. Sphenopsida.
- IV. Pteropsida.

I. Psilopsida:

1. These are oldest known vascular plants, most of them except *Psilotum* and *Tmesipteris* are fossils.
2. Plant body is relatively less differentiated.
3. Roots are absent; instead dichotomously branched rhizome is present.
4. Aerial axis is either naked or have small spirally arranged leaves.
5. Sporangia are cauline (i.e., directly born on the axis or stem), example *Psilotum*, *Tmesipteris*.

II. Lycopsidea:

- iv. The plant body is differentiated into root, stem and leaves.
- v. Leaves are small (i.e., microphyllous) with a single unbranched vein.
- vi. Sporangia develop in the axil of the sporophyll.
- vii. Sporophylls generally form compact strobili. Examples; *Lycopodium*, *Selaginella* etc.

III. Sphenopsida:

6. Stem is differentiated into nodes and internodes.
7. Leaves are microphyllous, present in whorls at each node.
8. Sporangia are borne on sporangiophores which form compact cones at the apex of the fertile branches, examples; *Equisetum*.

IV. Pteropsida:

- iii. Plant body is well differentiated into root, stem and leaves.
- iv. Leaves are megaphyllous, pinnately compound.
- v. Sporangia develop on ventral surface of the sporophylls, usually aggregated into sori. Examples; *Dryopteris*, *Pteris*, *Polypodium* etc.

Economic Importance of Pteridophytes:

Pteridophytes are little economic value. Some of their uses are as follows.

6. Soil Conservation:

Plants like *seleginella* are useful in soil conservation.

7. Ornamentals:

Many species of *Selaginella* (*S. willdenovii*, *S. caesia*) are used as ornamentals, as they have metallic tinge.

8. Medicines:



Lycopodin a homoeopathic medicine is obtained from *Lycopodium*. *Equisetum arvense* has diuretic (promoting urine discharge) properties.

Pteridophyta Examples:

Following are the important examples of Pteridophyta:

1. Whisk Fern
2. Flying Spider
3. *Dicksonia sellowiana*
4. *Salvinia natans*
5. *Lophosoria quadripinnata*
6. Equisetidae
7. Man fern
8. Silver fern

Difference between Bryophytes and Pteridophytes:

Bryophytes	Pteridophytes
Bryophytes are non-vascular plants.	Pteridophytes are vascular plants.
The plant body is leafy or thalloid.	The plant body is differentiated into roots, stem and leaves.
No vascular tissues.	Vascular tissues are present.
Rhizoids are present for anchorage.	Roots are present for anchoring.
Gametophyte is dominating.	Sporophyte is dominating.
Anthredium is stalked.	Anthredium is sessile.
Cells are haploid.	Cells are diploid.
Eg., Mosses, Liverworts, Hornworts	Eg., Spike mosses, Ferns, Club mosses

Gymnosperms:

Gymnosperms are the plants with naked seeds or ovules freely exposed before and after fertilization. They are the most ancient seed plants believed to have originated during the late Palaeozoic Era about 265 million years ago and flourished well during the Mesozoic era, the age of Dinosaurs. Gradually they have been replaced by Angiosperms with changing time and climatic conditions.

The term, "Gymnosperm" has been derived from Greek words, *gymnos*, meaning 'naked' and *sperma* meaning 'seeds'. It was first used by Theophrastus, (pupil of Aristotle) in 300 B.C. in his book *Enquiry into Plants*.

Most of the members of gymnosperms have now become extinct and only a few living forms are known today. Some gymnosperms like *Ginkgo biloba*, *Cycas* and *Metasequoia* are called living fossils as these plants are found both in living and fossil form.



General Characters of Gymnosperms:

1. Habit and Habitat:

Most of the gymnosperms are evergreen perennial trees or shrubs. Herbs are rare (e.g. *Zamia pygmaea*). Plants vary in their size from small herbs to large gigantic trees. *Sequoia sempervirens*, a gymnosperm, is the tallest living plant in the world reaching a height of 366 feet. It is also known as coast red wood of California. *Zamia pygmaea*, is the smallest gymnosperm about 35cm in height.

2. External Structure:

The plant body is Sporophyte and is differentiated into root, stem and leaves. Plants possess well developed tap root system. Roots often show symbiotic association with algae (e.g. *Cycas*) or fungi (e.g. *Pinus*). Stem is mostly erect, aerial, solid, cylindrical and branched or unbranched as in *Cycas*. Leaves are dimorphic:

- i. **Foliage Leaves:** Foliage leaves are green, simple, needle like or pinnately compound and
- ii. **Scaly Leaves:** Scaly leaves are minute, membranous, brown and deciduous.

3. Internal Structure:

Xylem consists of tracheids and xylem parenchyma only, vessels are absent. Phloem is made up of sieve tubes and phloem parenchyma; companion cells are absent. Like dicotyledonous angiosperms, the gymnosperms also show secondary growth. Resin and mucilage canals are usually present.

4. Reproduction in Gymnosperms:

Reproduction in Gymnosperms is of two types:

- I. Vegetative Reproduction
- II. Sexual Reproduction.

I. Vegetative Reproduction:

Vegetative reproduction takes place by the formation of bulbils or adventitious buds which develop on the stem in the axil of the scale leaves e.g., *Cycas*.

II. Sexual Reproduction:

i. Gymnosperms are heterosporous and sexual reproduction is oogamous type. In living gymnosperms the reproductive structures are arranged in the form of strobili or cones (except the ovulate structures of *Cycas*).

ii. Plants may be monoecious (e.g., *Pinus*) or dioecious (e.g., *Cycas*).



iii. Usually the cones are monosporangiate (unisexual) but in certain members e.g., *Ephedra* bisporangiate (bisexual) cones have been reported.

Male Cones:

- i. Male cone consists of many microsporophylls (stamens) arranged on central axis.
- ii. Microsporophylls bear microsporangia (pollen sacs) on the abaxial (lower) side.
- iii. Sporangial development is eusporangiate (develop from a group of cells).
- iv. Meiosis occurs in microspore mother cells and haploid pollen grains (male gametophytes) are developed.
- v. During the development of male gametophyte only one (e.g., *Cycas*) or two (e.g. *Pinus*) prothallial cells are formed.
- vi. Pollen tubes act as sperm carrier only in higher forms (e.g., *Pinus*, *Ephedra*) whereas in the lower forms it acts as haustorium (e.g., *Cycas*).
- vii. Pollen grains may be smooth (e.g., *Cycas*) or winged (e.g., *Pinus*).

Female Cones:

- i. Female cone is the aggregation of megasporophylls (carpels) which bear megasporangia (ovules).
- ii. Ovules are naked or not enclosed inside the ovary because ovary wall is absent.
- iii. Ovules are orthotropus and are covered by a single integument (unitegmic e.g., *Cycas*) or two integuments (bitegmic e.g.. *Ephedra*). An additional covering in the form of aril or cupule is also present outside the integument.
- iv. The single integument is differentiated into three layers: outer fleshy (outer sarcotesta), middle stony sclerotesta) and inner fleshy layer (inner sarcotesta).
- v. In young ovules meiosis occurs and 4 haploid megaspores are produced.
- vi. Three mgaspores degenerate and one functional megaspore forms female gametophyte (monosporic) or endosperm.
- vii. Endosperm is haploid because it develops before fertilization.
- viii. Female gametophytes bear archegonia.
- ix. The number of archegonia is variable. In *Gnetum* only one, in *Pinus* two and in *Cycas* more archegonia develop. The archegonium in *Gnetum* is represented by ovum only.

x. Each archegonium has a single egg and a ventral canal cell. Neck canal cells are absent. In some members e.g. *Cycas* venter canal cell is also absent.

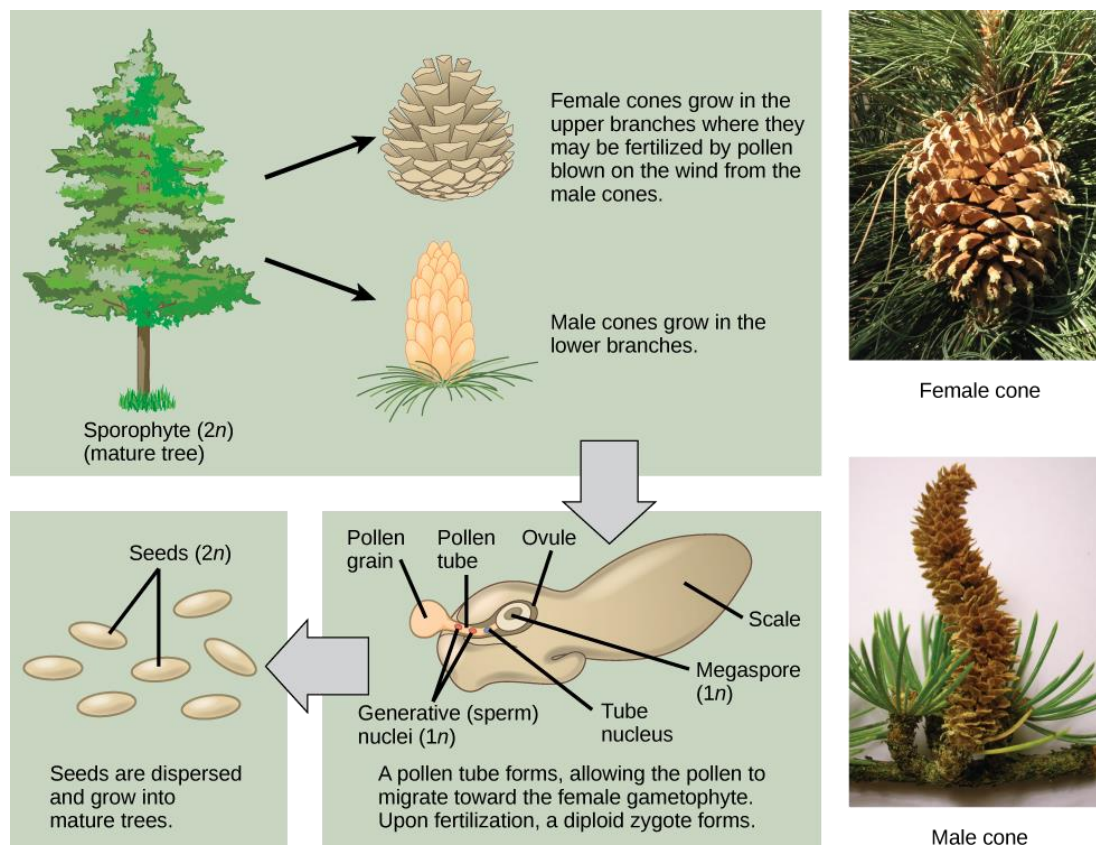


Figure: Reproduction in Gymnosperms (Source: google.com)

Pollination:

Gymnosperms are wind pollinated.

i. The microspores are liberated in various stages of development of male gametophyte e.g., they are liberated at 3-celled stage in *Cycas*. 4-celled stage in *Pinus* and 5-celled stage in *Ephedra*. Except in *Cycas* and *Ephedra* the male gametes are non-motile.

ii. Pollination is anemophilous i.e., brought about by wind.

iii. Pollen grains come in direct contact with the ovule. They are deposited in the pollen chamber where they germinate.

Fertilization in Gymnosperms:

Fertilization occurs by siphogamy, i.e. the male gamete is carried to the archegonium through pollen tube. Double fertilization is absent in gymnosperms. Endosperms develop before fertilization and hence it is haploid. Most gymnosperms show polyembryony.



Embryogeny in Gymnosperms:

The development of embryo is meroblastic i.e., only a part of the zygote (basal) develops into an embryo. There are free nuclear divisions in the early stages of development of embryo (except *Gnetum* and *Welwitschia*). Later it gets differentiated into upper (haustorial), middle (supensorial) and basal (embryonal) cells. Polarity is endoscopic with the shoot end directed away from the micropyle.

Polyembryony is observed in some members of gymnosperms e.g. *Pinus*. Several embryos develop due to fertilization of more than one egg or by the division of the zygote (cleavage polyembryony) but only one embryo attains maturity. A true fruit like that of angiosperms is absent in gymnosperms. It is because of the absence of ovary. The ovule after embryo formation turns into the seed. The integuments of the ovule act as seed coat. Number of cotyledons varies in different members; they are two in *Cycas* and many in *Pinus*. These become green while still enclosed within the seed.

Seed:

The seeds remain attached to the megasporophyll. The ripe and dry seeds are shed. Each seed contains a young sporophyte in the form of dormant or inactive state of embryo embedded in the food laden endosperm. The seeds are protected in the seed coat.

- i. Integuments and nucellus represent the parent sporophytic phase.
- ii. Endosperm represents the gametophytic phase.
- iii. Embryo represents the new sporophytic phase.

Alternation of Generation:

Gymnosperms show distinct alternation of generation. The sporophytic or diploid phase is dominant, long lived and independent while the gametophytic or haploid phase is short lived and is dependent on gametophytic phase.

Classification of Gymnosperms:

Chamblain (1934), divided gymnosperms into two sub-classes.

- I. Cycadophyta
- II. Coniferophyta

I. Sub-class Cycadophyta:



The members of Cycadophytes are characterised by unbranched stem and large foliage leaves. It includes 3 orders.

Order 1: **Cycadofilicales:**

It is a group of fossil plants. E.g., *Lyginopteris*.

Order 2: **Bennettitales** or **Cycadeodales:**

It is also group fossil forms. E.g. *Cycadeodea*

Order 3: **Cycadales:**

It includes both living and fossil forms *Cycas*, *Zamia*.

II. Sub-class Coniferophyta:

The members of this group are characterised by long profusely branched stem and simple small leaves. It includes four orders:

Order1: **Cordaitales:**

All the members of this group are extinct. E.g., *Cordaites*.

Order 2: **Ginkgoales:**

All the members of this order, except for, *Ginkgo biloba* are extinct.

Order 3: **Coniferales:**

The order includes both fossils and present day forms. Example *Pinus*, *Cedrus*, *Sequoia*.

Order 4: **Gnetales:**

Gnetales are modern group consists of living forms. They differ from other gymnosperms in the presence of vessels in the xylem. Examples, *Ephedra*, *Gnetum*, *Welwitschia*.

Economic Importance of Gymnosperms:

5. Many gymnosperms produce good quality of timber, e.g., deodar (*Cedrus deodara*), Kail (*Pinus wallichiana*) and Chir, (*P. roxburghii*) are widely used as building material.
6. Turpentine Oil, an important material in paint industry, is obtained from the resin of *Pinus* species.
7. Cedar wood oil, extracted from the heartwood of *Juniperus virginiana* is used as a clearing agent and oil immersion lenses by biologist.
8. Canada balsam, used as a mounting medium for biological preparations, is the resin of *Abies balsamea*.
9. Sago, a type of starchy food, is extracted from the stem and seeds of *Cycas*. (Commercially, Sago is obtained from *Metroxylon rumphic*; an angiosperm).
10. Chilgoza, an important dry fruit, are the roasted seeds of *Pinus gerardiana* (Chilgoza Pine).
11. An important medicine, Ephedrine is obtained from *Ephedra*. It is used for curing Cough and Asthma.
12. Many gymnosperms like *Cycas*, *Pinus* etc are grown as ornamentals.



Angiosperms:

The angiosperms or flowering plants constitute the most dominant and ubiquitous vascular plants of the present day flora. They are called flowering plants because they produce their reproductive structures in the flower. The ovary develops into the fruit and the ovules present inside the ovary develop into the seeds. The term "angiosperm" means 'enclosed seed' because the seeds are enclosed within the ovary.

Angiosperms are vascular plants with body differentiated into roots, stems, and leaves. They constitute the most dominant vascular plants of the present day flora. These make up the majority of all plants on earth.

Angiosperms are the most dominant plant groups with more than 250,000 different species that occupy a wide range of ecological habitats. It is believed that angiosperms appeared on earth about 250 million years ago during the age of Jurassic-Cretaceous periods of Mesozoic Era, long before the evolution of man.

General Characteristic Features of Angiosperms:

Angiosperms have diverse characteristics. The important characteristics of angiosperms are mentioned below:

1. Occurrence:

The angiosperms originated about 250 million years ago and comprise 80% of the earth. They are a major source of food for humans and animals. Angiosperms can survive in a variety of habitats, including marine habitats.

2. Body Structure:

The sporophyte is differentiated into stems, roots, and leaves. The sporophytes are diploid. They can grow as trees, shrubs, bushes, as well as herbs. These plants have diploid (2n) sporophytes. Angiosperms have a distinctive underground root, as well as aerial shoot system.

3. Vascular System:

- i. Angiosperms have very well-developed conducting tissues. These tissues include the xylem and the phloem arranged in form of vascular bundles. The xylem contains vessels. Similarly, phloem consists of sieve tubes and companion cells.
- ii. The vascular bundles of monocotyledons are arranged in stems, in a cross-section. The dicotyledons have vascular bundles organized in form of a ring. A pith for storage, as well as cortex for strength and structure are found in the stem tissues. The outer part of the stem tissues is covered with a layer of epidermis.
- iii. The root system is very complex and consists of cortex, xylem, phloem, and epidermis. The vascular system has true vessels in the xylem and companion cells in the phloem.

4. Flower:

All plants have flowers at some stage in their life. The flowers are the reproductive organs for the plant, providing them with a means of exchanging genetic information.



5. Reproduction:

Reproduction in Angiosperms is of two types:

- A. Asexual Reproduction
- B. Sexual Reproduction

A. Asexual Reproduction:

Asexual reproduction in plants takes place in two ways:

- I. Naturally
- II. Artificially

I. Natural Methods:

Natural methods of asexual reproduction include self-propagation like:

i. Vegetative Propagation:

The most common techniques of vegetative propagation are:

Stems: Runners are the stems which usually grow in a horizontal form above the ground. They have the nodes where the buds are formed. These buds usually grow into a new plant.

Roots: A new plant is developed from around, inflated, modified roots called tubers. Example: Sweet Potato

Leaves: In some plants, detached leaves from the parent plant can be used to grow a new plant. They exhibit growth of small plants, called plantlets, on the edge of their leaves. Example: *Bryophyllum*.

ii. **Budding:** Plants such as ginger, onion, dahlia, potato, grow from the buds present on the surface of the stem. A stem tuber has several eyes on the surface. Under favourable conditions, these eyes sprout producing leafy shoots.

iii. **Fragmentation:** This mode is often used by nurseries and greenhouses to produce plants quickly.

iv. **Spore Formation:** Under favourable conditions, the spores germinate and grow into new plants.

II. Artificial Methods:

Following are the artificial methods of asexual reproduction in plants:

i. **Cutting:** In this method, a part of a plant is cut along with the node and is buried in the soil.

ii. **Grafting:** In this method, the parts of two different plants are joined together such that they continue to grow as a single plant.



iii. **Layering:** It is the method in which a stem attached to a plant is lowered in the ground and covered with soil. The stem grows roots while attached to the parent plant and then detaches as an independent plant.

iv. **Micropropagation:** This is the method of producing a large number of plants from an explant under laboratory conditions within a short time interval. This facilitates the growth of rare and endangered plant species that are difficult to grow under natural conditions.

B. Sexual Reproduction:

The stamens (microsporophyll) and the carpels (megasporeophyll) are organized into a structure called the flower.

- i. One megasporophyll (stamen) contains four pollen sacs (microsporangia).
- ii. The ovules are enclosed in the ovary at the base of the megasporophyll.
- iii. Angiosperms are heterosporous, i.e., produce two kinds of spores, microspore (pollen grains) and megaspores.
- iv. A single functional megaspore is permanently retained within the nucellus.
- v. The pollen grains transfer from the anther to stigma and reproduction takes place by pollination. They are responsible for the transfer of genetic information from one flower to the other. The pollen grains are much smaller than the gametophytes or reproductive cells present in the non-flowering plants.
- vi. The flowers undergo double and triple fusion which leads to the formation of a diploid zygote and triploid endosperm.
- vii. The process of fertilization is quicker in angiosperms. The seeds are also produced quickly due to the smaller female reproductive parts.
- viii. All angiosperms are comprised of stamens which are the reproductive structures of the flowers. They produce the pollen grains that carry the hereditary information.
- ix. The carpels enclose developing seeds that may turn into a fruit.

Stages of Sexual Reproduction:

Sexual reproduction in Flowering plants is divided into three stages:

- i. **Pollination:** The agents involved in transferring the pollen grains are birds, wind, animals, and water.
- ii. **Formation Zygote:** After the pollination, the male gamete is transferred down through the style of the pistil to the ovary and the male gametes are fused with female gamete to form a zygote.
- iii. **Formation of Fruits and seeds:** The ovules develop into seeds and ovary develops into a fruit. The ultimate product of sexual reproduction is seeds in angiosperms.



The production of the endosperm is one of the greatest advantages of angiosperms. The endosperm is formed after fertilization and is a source of food for the developing seed and seedling.

Classification of Angiosperms:

Angiosperms have been divided into two classes.

- I. Monocotyledons
- II. Dicotyledons

I. Monocotyledons:

Salient features of Class Monocotyledons:

1. Leaves are simple and show parallel venation. Examples are: Maize, Rice, Wheat etc.
2. Primary tap root is short lived and replaced by adventitious roots.
3. Each floral whorl has three members.
4. Seeds possess only one cotyledon.
5. Vascular bundles are closed and scattered.
6. Vascular cambium is absent.

II. Dicotyledons:

Salient features of Class Dicotyledons:

1. Leaves show reticulate venation. E.g. Peas, Apple etc.
2. Primary tap root is long lived. Adventitious roots also occur in some cases.
3. The flowers are tetramerous or pentamerous and the vascular bundles are organized in rings.
4. Seeds possess two cotyledons.
5. Vascular bundles are arranged in ring, vascular cambium is present.

Economic Importance of Angiosperms:

- iv. **Food:** Angiosperms are the major source of food. They produce cereals, pulses, vegetables, fruits, nuts etc.
- v. **Edible oils:** Flowering plants are the main source of edible oils used for cooking. These are obtained from groundnut (*Arachis hypogea*), mustard (*Brassica campestris*), sunflower (*Helianthus annuus*), coconut (*Cocos nucifera*) etc.
- vi. **Spices:** Angiosperms are source of spices, coriander (dhania), chillies (*Capsicum frutescens*) etc.
- vii. **Beverages:** Tea (*Camellia sinensis*), coffee (*Coffea arabica*) are the common beverages obtained from the flowering plants.



- viii. **Medicines:** The important medicinal plants include *Aconitum napellus*, *Atropa belladonna*, *Cinchona sp.* (quinine) etc.
- ix. **Timber:** Many angiospermic trees, particularly dicotyledons, yield valuable hard wood which is used as timber. E.g. Teak (*Tectona grandis*), Oak (*Quercus alba*), sandal wood (*Santalum album*) etc.
- x. **Fibres:** Fibres of different qualities are produced from various species of flowering plants. E.g. Textile fibres are obtained from cotton (*Gossypium barbadense*). Rough fibres are obtained from flax (*Linum ositatissimum*).
- xi. **Others:** There is a long list of useful articles such as paper, rubber, volatile oils, tobacco etc which we get from flowering plants. Sugar is obtained from sugar cane (*Saccharum officinarum*) and sugar beet (*Beta vulgaris*). A large number of plants are grown in gardens as ornamentals.

Morphology of Flowering Plants and Their Function:

Introduction:

Flowering plants also referred as angiosperms are a huge group of vascular plants in the plant kingdom. These plants show a great variety of form, shape and size. The size ranges from the *Lemna* and minute *Wolffia* (0.1cm) to the large-sized Banyan and tall Eucalyptus (up to 100 metres).

The Sub Unit, Morphology of Flowering plants, explains the complete features of flowering plants, its structure, functions, classifications, significances and other morphological features of roots, stem, leaves, flower, fruits and the seeds.

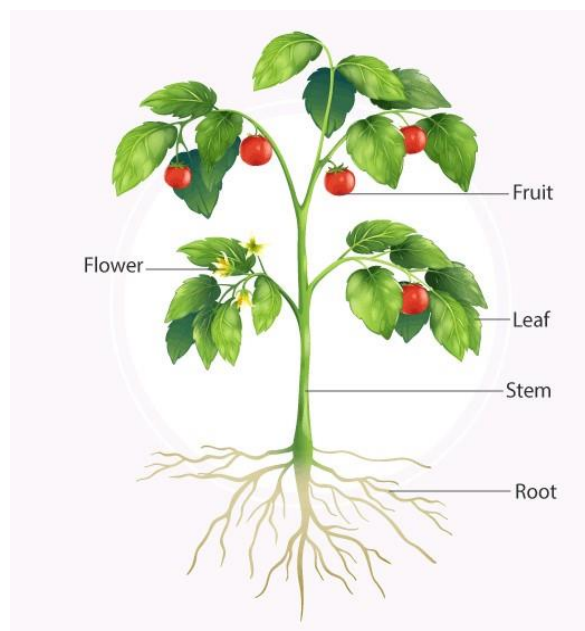


Figure: Different Parts of Plant

The term, morphology of flowering plants mainly refers to the study of morphological characteristics and relative positions of different parts of flowering plants. The two main external parts of a plant include:

- I. Root system
- II. Shoot system.

I. The Root system:

The root system is the underground part of the plant developed from the seed embryo. It is mainly involved in anchoring plants below the soil, provides support, stores food and nutrients, absorbs water and other essential nutrients required for the growth and development.



II. The Shoot System:

The shoot system is the aerial part of the plant, which is found above the root and ground level. The shoot system includes the stem, leaves, bud, flower, fruits and the seeds. Shoot system is one of the important systems of a plant.

Morphology of Root

Roots are the important underground part of all vascular plants. This part of the plant is mainly responsible for anchoring it down into the ground and absorbing the essential mineral elements, nutrients, and water from the soil. It is also used to store food.

However, not all plants have their roots underground; some plants have their roots growing above the ground. These are called aerial roots. Alike underground roots, these aerial roots are also responsible for absorbing nutrients, anchoring and affixing the plant by supporting them to the structures such as nearby walls, rocks, trellises, etc.

Few examples of plants with the aerial roots are: Bonsai, Banyan Tree, Mangroves, etc.

General Characteristics of Roots:

1. Roots are found in all the members of Phanerogams. It is important basic organ of the plants because of two important functions – absorption and fixation.
2. They form the descending organ of the plant axis, normally growing away from light. Grow towards gravity (Positively geotropic) except for breathing roots.
3. Normally roots lack chlorophyll and hence are non-green. However, roots of certain plants, which are exposed to light for long periods, turn green.
4. Roots do not bear buds, leaves and flowers. They lack nodes and internodes.
5. Root hairs are always unicellular.
6. The root apex is protected by root cap.
7. The branch roots are produced endogenously from Pericycle.
8. Roots are generally sub-cylindrical, tapering towards the tip.

Functions of Roots:

Roots perform various functions that are necessary for the survival of the plants. They are an integral or integrated system that helps the plant.

V. Primary Function:

1. Anchoring:

Roots are the reason plants remain attached to the ground. They support the plant body, ensuring that it stands erect.

2. Absorption:

Primary function of roots is to absorb water and dissolved minerals from the soil. This is crucial as it helps in the process of photosynthesis.

3. Translocation of organic nutrients:

Sugar produced in the leaves by photosynthesis, is transported downwards to the tissue of the root where it is metabolised.

4. Storage:



Plants prepare food and store in the form of starch in the leaves, shoots and roots. Prominent examples include carrots, radish, beetroot, etc.

5. **Reproduction:**

Even though roots are not the reproductive part of plants, they are vegetative parts. In some plants, roots are a means of reproduction. For instance, new plants arise from creeping horizontal stems called runners (stolons) in jasmine, grass, etc. This type of reproduction is called vegetative propagation.

6. **Ecological Function:**

They check soil erosion; provide sustenance and also habitat to various organisms.

VI. **Secondary Functions:**

1. **Food Storage:**

It occurs by fleshy roots, e.g., Carrot, Turnip.

2. **Additional Mechanical Support:**

In some plants roots are modified to provide additional mechanical support. E.g., Prop roots – Banyan tree. Stilt roots e.g. Maize.

3. **Haustorial Roots:**

Roots of some parasite plants act as haustoria e.g. *Cuscuta*. They penetrate up to phloem of host and absorb nourishment.

4. **Assimilation:**

Roots of some plants are photosynthetic. E.g., *Trapa*, *Tinospora*.

5. **Aeration:**

Roots of some plants help in exchange of gases e.g. *Rhizophora*.

6. **Symbiotic Nitrogen Fixation:**

Roots of leguminous plants have nodules containing nitrogen fixing bacteria.

7. **Floating and Balancing:**

Roots of some aquatic plants store air and help in floating and balancing. E.g. *Pistia*.

8. **Hygroscopic Roots:**

Aerial roots absorb moisture from the air e.g. epiphytic plants, Orchids, young Prop roots of Banyan etc.

9. **Climbing:**

Some weak stemmed plants develop climbing roots which help the plant to climb up the support. E.g., Betal, Money plant.

Structure of the Roots:

A typical root consists of following four regions. These merge into one another. The zones successively from apex to the base are follows:

1. Root cap:

The apex of each root is covered by a cushion of thin walled cells known as root cap. In aquatic plants (e.g. *Pistia*) the root apex is enclosed within a sac-like structure called root pocket. Root cap protects root apex since it is the main growing part of the root.

2. Zone of Cell Division or Root apical meristem:

It is just behind the root cap. It is the main growing region of the root where active cell division takes place. The region is about a few millimetres in length.

3. Zone of Elongation:

It is about 1-10mm in length. This region is characterised by the rapid elongation of cells. The division occurs in relatively small number of cells. This region is responsible for growth in length of the root.

4. Zone of Maturation:

It is usually one to several centimetres long. Here the cells, having fully expanded, mature into final form. Epidermal cells of this region give out root-hairs. These are main absorbing organs of root. Hence this, region is also called root-hair zone.

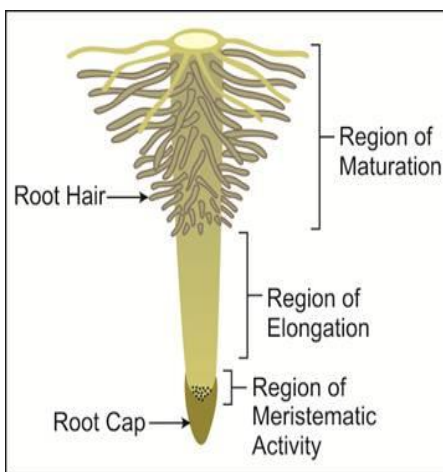


Figure: Structure of typical root.

Types of Roots:

All roots have similar functions, however, their structure varies. Hence, based on these criteria, the root system is classified into two types:

- I. Tap root system
- II. Adventitious Root System

I. Tap Root System:

The roots developing directly from the radical are known as Primary root. In most of the plants the primary root persists and becomes stronger to form tap root. Tap root usually produces lateral branches called secondary roots. Branches of secondary roots in turn are called tertiary roots. Taproots have a main central root upon which, small, lateral roots called root hairs are attached. Mustard, carrot, beetroot, parsley, China rose and all dicotyledons are examples of taproot system.

Modification of tap roots:

Tap roots are modified into number of forms to carry out specific functions. The important ones are;

1. Fusiform Roots:

The primary root is swollen in the middle and gradually tapers at both the ends. i.e., towards the apex and base *Rhapanus*, (reddish).

2. Napiform Roots:

The primary root becomes almost spherical at the base and tapers abruptly at the lower end. E.g., *Brassica rapa*, (turnip).

3. Conical Roots:

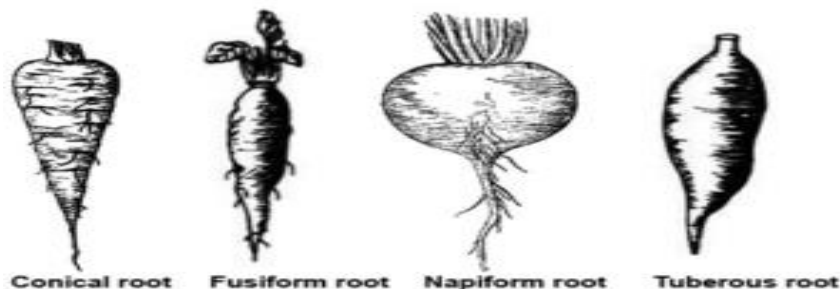
These roots are just like the cone, broad at the base and gradually taper towards the apex. e.g., *Daucas carota*, (Carrot).

4. Tuberous or Tubercular Root:

These roots are fleshy and do not maintain any specific shape. *Manihot esculenta* (Cassava from which the starch food Tapioca is obtained).

5. Pneumatophores or Respiratory Roots:

These develop in plants growing in saline waters. These roots grow vertically upwards. The air enters these roots through minute breathing pores called lenticels or Pneumathodes present on the tips of vertical roots. They are meant for exchange of gases. E.g., *Rhizophora*.



II. Adventitious Root System:

Roots developing from any part of the plant, other than radical, are known as adventitious roots. On the basis of nature of development, the adventitious roots are further classified into three types.

1. Fibrous Roots:



In this type the primary root does not persist for long time and is replaced with slender, thread like roots originating from base of the stem. E.g., *Triticum vulgare*, *Oryza sativa*, *Allium Cepa*.

2. **Foliar Roots:**

Roots developing from the leaf are known as foliar roots. They originate either from Petiole e.g. rubber plant (*Pogostemon*).

3. **True Adventitious Roots:**

These roots develop from the nodes and internodes of the stem e.g. Prop root of Banyan (*Ficus*), roots from the stem cuttings.

Modifications of Adventitious Roots:

1. **Tuberous Roots:**

Adventitious roots that store food, become swollen and do not attain a definite shape. E.g., Sweet Potato, *Ipomoea batata*.

2. **Fasiculated Roots:**

The swollen tuberous roots, when occur in clusters are called fasciculated roots e.g. *Dahlia*, *Asparagus*.

3. **Moniliform or Beaded Roots:**

These roots are alternatively swollen and constricted and giving a beaded appearance e.g. *Dioscorea alata*.

4. **Nodulose Roots:**

The adventitious roots swell only near their apices like single bead e.g. Mango-ginger, (*Curcuma Amada*).

5. **Annulated Roots:**

This type of root has many ring-like swellings placed at the top of other, Ipecac.

6. **Prop Roots (Columnar Roots):**

In banyan tree (*Ficus benghalensis*) and Indian rubber plant *Ficus elastic* many adventitious roots arise from the horizontal branches of the stem and grow vertically downward. They become thick Pillar-like and provide mechanical support to giant trees.

7. **Stilt Roots:**

These are small stout roots growing obliquely from the basal nodes of the main stem. They provide mechanical support e.g. *Zea mays*.

8. **Climbing Roots:**

These roots arise from nodes and internodes of many climbers. They help the plant in fixing themselves to their support. E.g., *Pothos*, (money plant), *Piper betal*, (betal), etc.

9. **Floating Roots:**

In Jussiaea (Family- Onagraceae), an aquatic plant, tufts of spongy, soft and light roots arise from the nodes in addition to ordinary adventitious roots. These roots have innumerable air spaces and thus help in maintaining buoyancy and facilitate respiration.

10. **Epiphytic Roots:**

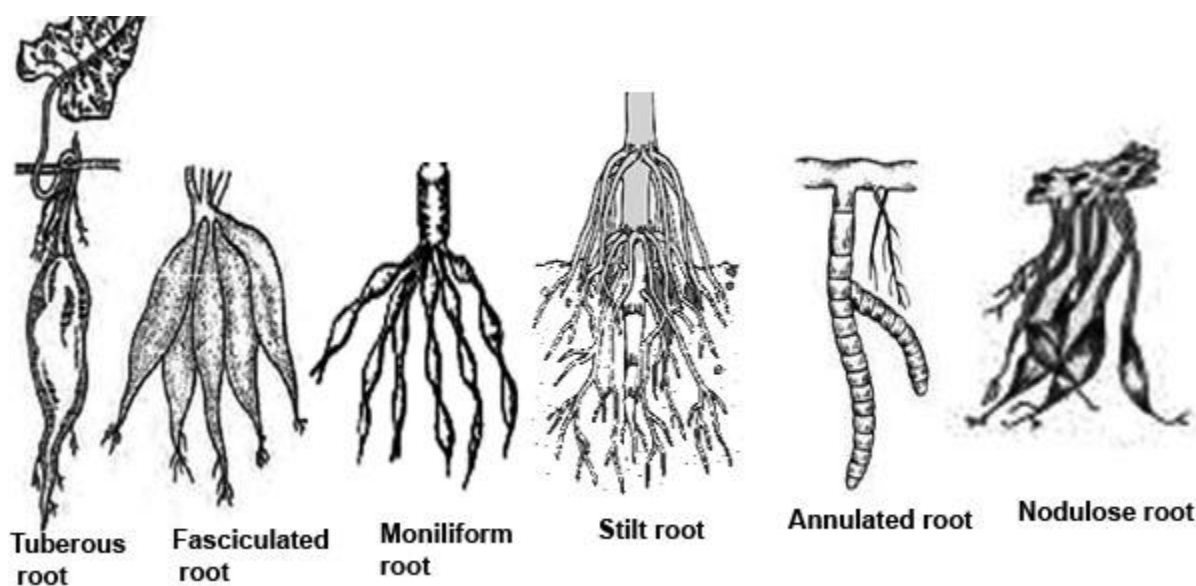
Epiphytes have two types of roots. Clinging roots which cling to the host for support and aerial roots which hang downwards. The latter are green in colour and have special outer covering called velamen. It helps in the absorption of moisture from air as the soil moisture is out of their reach e.g. *Vanda sp.*

11. **Assimilatory Roots:**

Aerial adventitious roots by some plants develop chlorophyll and become assimilatory in function i.e. synthesize food. E.g., *Trapa*, *Tinospora*, etc.

12. **Parasitic Roots or Sucking Roots:**

Parasite plants develop roots which penetrate into the tissue of the host plant to absorb nutrition. These roots function as haustoria e.g. *Cuscuta*.



Difference between Fibrous root and adventitious root:

Fibrous roots	Adventitious roots
The primary root is short-lived and is replaced by a large number of roots in monocotyledons	Roots arise from parts of the plants other the radicle.
Example: Wheat	Example: Banyan tree

Morphology of Stem:

The aerial part of the plant is called shoot system. It consists of stem, its branches and leaves. The shoot system develops from plumule (Tigellum).

The stem is the ascending part of the axis bearing branches, leaves, flowers and fruits. It develops from the plumule of the embryo of a germinating seed. It bears nodes and internodes. The stem bears buds, which may be terminal or axillary.



General Characteristics of Stem:

- v. The stem is an ascending axis of the plant and develops from the plumule and epicotyl of the embryo.
- vi. It is generally erect and grows away from the soil towards the light. Therefore, it is negatively geotropic and positively phototropic.
- vii. Stem is differentiated into node and internodes. It bears leaves and branches at the node.
- viii. The lateral organs of the stem (*i.e.*, leaves and branches) are exogenous in origin (*i.e.*, from the cortical region).
- ix. Shoot is usually green and photosynthetic.
- x. Trichomes (hairs) if present are either unicellular or multicellular.
- xi. Stem apex is always apical.
- xii. In mature plants, stem and its branches bear flowers and fruits.

Bud:

A bud is a condensed young shoot with underdeveloped leaves. In a bud internodes are short; hence nodes are situated very close to one another and the leaves become crowded. There are three types of buds.

1. Vegetative.
2. Floral and
3. Modified.

1. Vegetative Buds:



These buds develop into vegetative shoot. Vegetative buds are further classified into three sub-types.

i. **Normal Buds:**

Such buds are present at the tip of the branches and the main axis and are called terminal or apical buds. They also occur in the axil of the leaves and are called axillary buds or lateral buds.

ii. **Accessory Buds:**

Some plants produce extra some buds by the side of axillary buds. These are called accessory or supernumerary buds.

iii. **Adventitious Buds:**

These are the buds which develop from any part of the plant other than those of normal and accessory buds. These could be listed as

i. **Cauline Buds:** Buds that arise directly from stem e.g. rose.

ii. **Radical Buds:** Buds that develop from root e.g. sweet potato.

2. **Foliar Buds:**

Buds that develop on leaves e.g. *Bryophyllum*.

3. **Floral Buds:**

These buds always develop into flowers. They are of two types:

v. **Teendrils:** e.g. *Cardiospermum* (barren vine).

vi. **Bulbils:** e.g. specialised reproductive structures e.g., *Allium cepa* (Garlic).

4. **Modified Buds:** Vegetative and floral buds both may be modified for some specialised functions. These are

a. Tendrils e.g. *Passiflora*, vine etc.

b. Thorns e.g. *Citrus*.

c. Bulbils: These specialised reproductive structures are found in *Dioscorea* (Yam) etc.

Types of Stem:

Depending upon the size and woodiness, stems can be classified as: herbs, shrubs and trees.

1. **Herbacious:**

These are plants with small and soft stems. They are either unbranched or have a few branches. These include *Brassica*, *Triticum*, *Raphanus sativus* (raddish) etc.

2. **Shrubs:**

These are medium sized perennial plants with profusely branched woody stems. The branches arise from the base of the stem and the plants attain a bushy appearance. E.g., *Hibiscus rosa-sinensis*, *Camellia sinensis* (Tea plant).

3. **Trees:** These are Perennial plants with hard woody stems. They have a long trunk and branches arise from the upper part of the stem. E.g., *Magnifera indica*.



Branching in Stem:

A branch may be defined as a lateral appendage arising from the axil of the leaf, differentiated into nodes and internodes. There are two main types of branching.

5. Lateral.

6. Dichotomous.

1. **Lateral Branching:** The branches are produced laterally from lateral buds present on the main axis. It is of following two types.

I. Cymose Branching: The main axis terminates into a flower or a tendril and before its termination it gives off one or more lateral branches. Cymose branching is of three types.

- i. **Scorpioid Cyme:**

If successive branches develop or alternate side to side to form a zig – zag structure e.g. *Vitis vinifera*.

- ii. **Helicoid Cyme:** When the successive branches develop on one side only e.g., *Saraca indica*.

- iii. **Biparous Cyme:** This is a cymose branching in which at each point two lateral branches develop at a time e.g., *Plumeria*.

II. Racemose or Indefinite Branching:

In this branching the main axis grows indefinitely during the course of its development regularly produces lateral branches in an acropetal order. Since there is single axis supporting lateral branches, this type of branching is also called monopodial branching e.g. *Polyalthia*.

1. Dichotomous Branching:

The terminal bud divides into two each forming a branch likewise the tip of daughter branches also divide. Thus in dichotomous branching each branch bears two daughter branches. It is of following types.

- i. **Normal Dichotomy:**

In this type both the daughter branches are of equal dimension e.g., *Psilotum*, *Lycopodium*.

- ii. **Sympodial Dichotomy:**

In this type two branches of dichotomy show unequal growth. Here one of the branches grows more vigorously while the other is suppressed. It is of two types.

- **Scorpioid Dichotomy:** The suppression takes place on alternate sides of successive branching.
- **Helicoid Dichotomy:** In this type branch of the same side is suppressed each time.



Modifications of Stem:

In some plants, stems get modified to carry out some specific functions like storage of food Perennation, vegetative propagation etc. The various modifications of stem are:

- v. Underground modification of stem.
- vi. Sub – aerial modification of stem.
- vii. Aerial modification of stem.

iii. Underground Modification of Stem:

iv. Rhizome:

It is a thick, Prostrate and branched stem, growing horizontally beneath the soil surface. It has distinct nodes and internodes. The nodes bear small scale leaves with buds in their axil. These buds remain dormant and develop normal shoots during favourable conditions. The lower surface of node gives out adventitious roots e.g. *Zingiber officinale* (ginger), *Curcuma domestica* (turmeric).

v. Tuber:

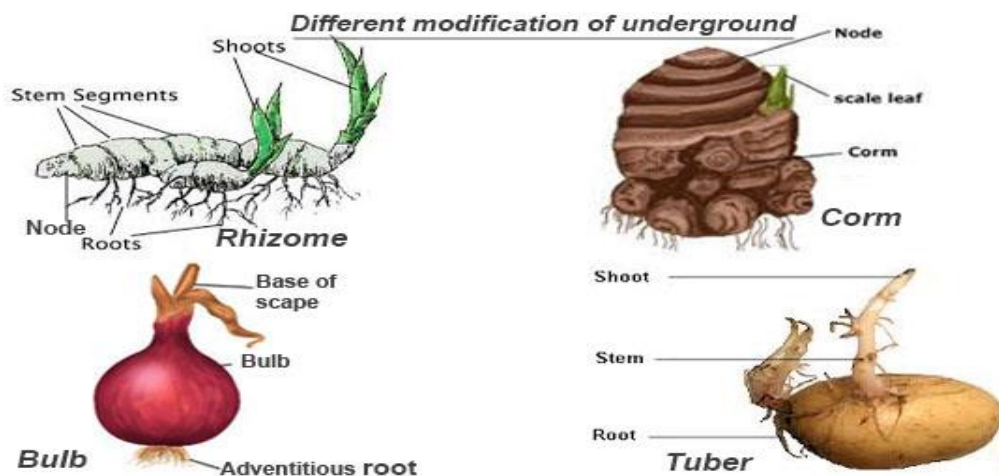
It is the swollen tip of underground branch. This branch arises from the axil of the leaf on the main stem. The tip of these branches becomes swollen due to accumulation of food material. The tubes are round or oval in shape. Each tuber has many notches on the surface called "eyes." Tubers do not give off adventitious roots e.g. *Solanum*.

vi. Corm:

Corm is condensed form of rhizome growing vertically down into soil. It is spherical to oval in shape and branched. Internodes are usually reduced and one or more axillary buds are present in the axil of the scale leaves. Some of these buds grow into daughter corms. Corms bear adventitious roots either at the base or throughout the surface e.g. *Crocus sativus* (saffron), *Gladiolus*, etc.

vii. Bulb:

It is highly condensed stem, represented by a short convex or highly conical disc. On its upper surface are present large numbers of fleshy scale leaves surround at terminal bud at the centre of the disc. The fleshy leaves of the bulb store food in the form of carbohydrates. A few outer leaves which become dry and scaly are protective in function. Large number of adventitious roots arise from lower surface e.g. *Allium cepa*, *A. sativum*.



iv. Sub – Aerial Modifications of Stem:

d. **Runner or Soble:**

It is a prostrate aerial stem creeping horizontally on the surface of the soil. It has long internodes. At each node axillary bud form aerial shoot and roots are given out at lower surface. E.g., *Cynodon*, *Oxalis*, etc.

e. **Sucker:**

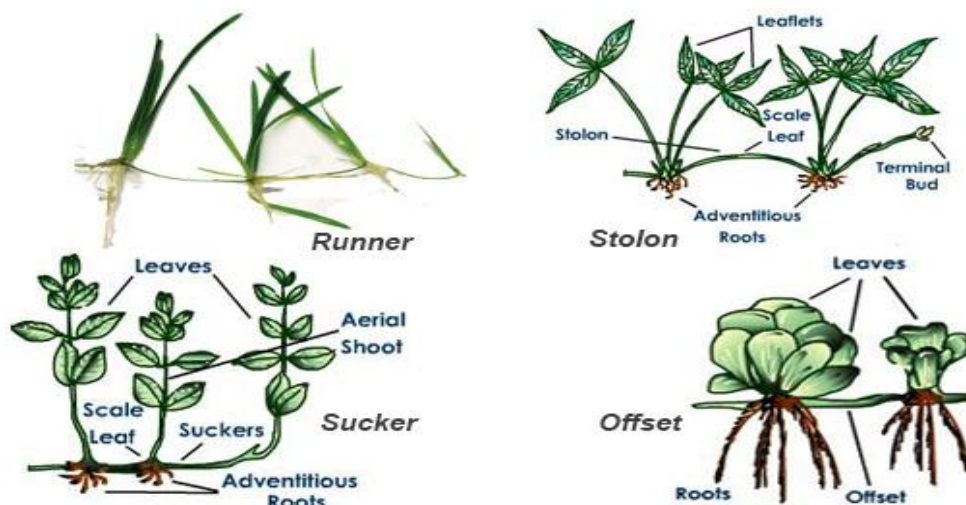
This is a sub – aerial branch arising from the basal underground portion of the main stem. Initially, it grows horizontally below the surface of the earth but soon grows obliquely upward forming a leafy shoot. Suckers are much shorter and stouter than runners. E.g., *Metha arvensis* (Podina).

f. **Stolon:**

It is similar to runner but is sub-terranean. Stolon is produced at the base of the stem under the soil. It gives out branches in different directions which bear a bud at their tips. Each of these bud develop into a new plant e.g. *Dracaena* (dragon plant).

g. **Offset:**

It is also similar to runner and originate from the axil of a leaf but has shorter and thicker internodes. It runs almost parallel to the surface, producing at its apex a tuft of leaves above and a cluster of small adventitious roots below e.g. *Pistia*, *Eichhorina* (water hyacinth).



v. Aerial Modification of Stem:

iv. Stem Tendril:

In plants with weak aerial stem, some axillary buds, instead of developing into branches, form tendrils. These are thin, wiry, leafless spirally coiled structures which help the plant in climbing. *Vitis* (vine) – terminal bud terminates into tendril.

v. Thorne:

It represents an auxiliary branch of limited growth. It is hard, often straight, pointed and may be branched. Thorns serve to be a defensive organ e.g. *Citrus* (lemon).

vi. Phylloclade:

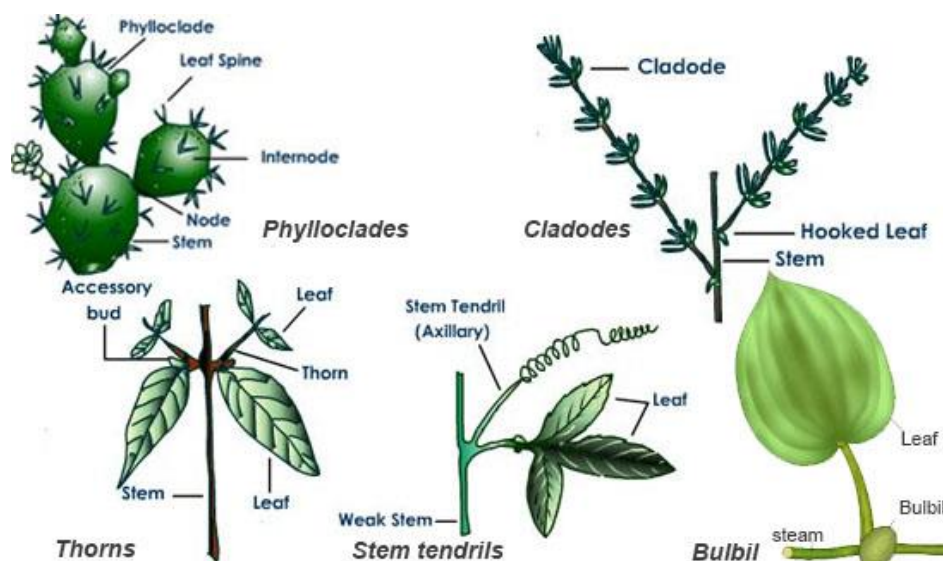
Plants of dry arid habitats shed their leaves to reduce water loss. In such plants, stem or its branch becomes modified into flat, fleshy and green leaf-like structure with distinct nodes and internodes. These are known as phylloclades or cladophylls. Some bear modified leaves into the form of scales or spines. Phylloclades serve as organs of photosynthesis and storage.

vii. Cladode:

These are phylloclades made of only one or two internodes of a branch. Cladodes are flat and leaf-like and perform the function of foliage leaves e.g. *Asparagus*.

viii. Bulbils:

These are modified vegetative or floral buds arising in the axil of scale or foliage leaves. They grow into a new plant while still attached to the parent plant or after their separation e.g. *Dioscorea* (wild yam), *Oxalis* etc.



Functions of Stem:

I. Primary Functions:

- iv. It bears leaves and holds them in such a position so as to provide maximum sunlight.
- v. The stem conducts water and mineral nutrients from the roots to the leaves, flowers and fruits.
- vi. The stem conducts organic food from the leaves to the roots and storage organs.
- vii. It holds flowers in such a position so as to facilitate pollination and fertilization.
- viii. The stem also bears fruits and seeds.

II. Secondary or Accessory Functions:

13. **Storage:** In many species, the stem acts as an organ of storage of food material (e.g. rhizome of Ginger, tuber of Potato, water – phylloclade).
14. **Synthesis of Food:** Some modified stems of xerophytic plants are green, flat and leaf – like. They perform photosynthesis e.g. *Opuntia*, *Asparagus*.
15. **Perennation:** Underground modified stems of many plants (e.g. Ginger) tide over the unfavourable conditions and help in perennation.
16. **Vegetative Propagation:** In many plants, stems serve as means of vegetative propagation e.g. tuber of Potato, corns etc.

Morphology of Leaf:

Leaf may be defined as a flattened lateral outgrowth developing at the nodes of the stem and or branches in acropetal succession. A typical angiospermic leaf consists of three parts viz. leaf base, petiole and lamina.

iii. Leaf Base (Hypopodium):

The basal part of leaf by which it is attached to the stem is called leaf base. Usually, it protects a small bud at its axil. In many species leaf base consists small outgrowths called stipules which protect the young leaves and the axillary bud. Stipules are usually found in dicotyledons.

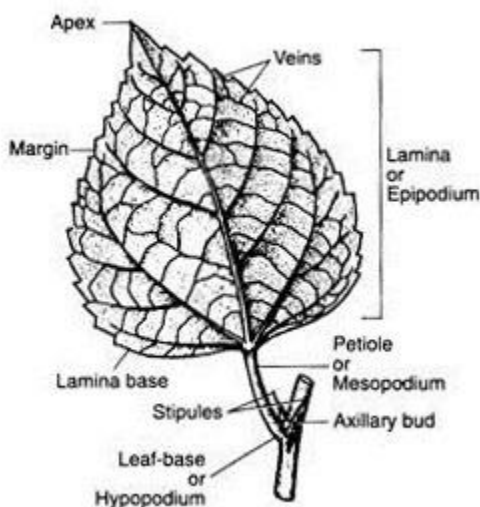
iv. Petiole (Mesopodium):

A petiole is a cylindrical or sub-cylindrical structure of a leaf which joins the lamina to the base. It raises the lamina above the level of stem so as to provide it with sufficient light exposure. A leaf with a petiole is called petiolate and the one without it is called sessile.

v. Lamina (Epipodium) or Leaf Blade:

The leaf lamina is normally a flat, thin, expanded and green structure where all the functions of leaf are carried on. It is a seat of photosynthesis, gaseous exchange, transpiration and most of the metabolic reactions of the plant. The shape, margin, apex, surface and extent of incision of lamina vary in different leaves.

A leaf is called dorsoventral if its upper surface differs in structure from its lower surface. It is called isobilateral when two surfaces are similar. However, some cylindrical leaves have no distinction of the two surfaces. They are called centric.



**Phyllotaxy:**

The arrangement of leaves on the stem and its branches is called Phyllotaxy. It is of following three types.

I. Alternate or Spiral:

When single leaf is born at each node and the leaves are arranged in such a way that a line drawn on a stem through the leaf bases takes a spiral course, the arrangement is called alternate or spiral or acyclic. E.g., Mango. A Phyllotaxy is written by taking the number of spirals (circles) as numerator and the number of leaves denominator. Thus spiral Phyllotaxy belong to following sub-types:

10. **Distichous**: Two ranked ($\frac{1}{2}$) or in two vertical rows e.g. Graminae (Poaceal)
11. **Tristichous**: Three ranked ($\frac{1}{3}$) or in two vertical rows e.g. Cyperaceae.
12. **Pentastichous**: Five ranked ($\frac{2}{5}$) or in five vertical rows. *Hibiscus rosa-sinensis*.
13. **Octostichous**: Eight ranked ($\frac{3}{8}$) or in eight vertical rows e.g. Papaya.

II. Opposite:

When pair of leaves arise at each node on opposite sides it is called opposite phyllotaxy. It is of two types.

6. **Opposite Superposed**: All the pairs of leaves of a branch arise in the same plane so that only two vertical rows of leaves are formed. E.g., Guava.
7. **Opposite decussate**: A pair of leaves at one node stands at right angles to the next upper or lower pair so that four vertical rows are formed on the stem. E.g. *Zinnia*, Tulsi, etc.

I. Whorled or Verticillate:

In this case more than two leaves arise at each node forming a circle or whorl. E.g., *Alistonia scholaris*.

Venation

The arrangement of principal Vein and veinlets in the lamina is termed as venation. The veins are chiefly made of vascular tissue, xylem and phloem. They have two important functions.

1. Mechanical support to lamina and
2. Supply of water and minerals (absorbed by roots) to all cells of the leaf and transport of organic food synthesized by green cells of the leaf to all non-green cells of the plant.



Types of Venation:

There are following two types of venation.

1. Parallel Venation.
2. Reticulate Venation.

1. Parallel Venation: In this type veins run parallel to each other from base to the tip of lamina. It is characteristic of monocotyledons leaves. Parallel venation is of two types.

- a. **Parallel Unicostate:** The leaf lamina possesses single main vein which gives rise to large number of lateral veins. All the lateral veins run parallel towards margins. E.g. Banana.
- b. **Parallel Multicostate:** The leaf lamina possess several main veins which run parallel to each other. It is of two types.
 13. **Convergent Type:** The main vein runs parallel to each other and converges at the apex. E.g., grasses, wheat, bamboo.
 14. **Divergent Type:** In this type, principal vein arising from the tip of petiole, diverge towards margins of leaf blade in a more or less parallel manner.

2. Reticulate Venation: The pattern of venation in which veinlets are repeatedly branched and form a network is called reticulate venation. It is characteristic of dicotyledons leaves. However, some monocotyledonous leaves also show reticulate venation. E.g. *Dioscorea*.

Reticulate venation is of following types.

- a. **Reticulate Unicostate:** In this type there is only one principal vein that gives off many lateral veins which run towards margins or apex of the leaf. E.g., mango.
- b. **Reticulate Multicostate:** In this type, there are two or more principal veins arising from the tip of petiole which run upward. It may be of two types.
 - i. **Convergent type:** The main veins converge towards the apex of the lamina. E.g. smilax.
 - ii. **Divergent type:** The main veins diverge towards the margins e.g. *Cucurbita*.

Types of Leaves:

On the basis of incision (cutting) of lamina, leaves are grouped into two categories:

1. Simple Leaf
2. Compound Leaf

1. **Simple Leaf:** A leaf is said to be simple as long as lamina is in one piece. The margins of the leaf may be entire or incised but incision do not extend down to the midrib or petiole e.g. mango, banyan, etc.



2. **Compound Leaf:** A leaf is said to be compound if the lamina is incised up to the midrib or petiole, thus dividing it into two or more segments. These segments are called leaflets.

Depending upon the position of leaflets, the compound leaves are divided into following two types.

5. Pinnately compound leaves.
6. Palmately compound leaves.

I. Pinnately Compound Leaves:

Here the incision reaches midrib of the lamina, and the leaflets are arranged in alternate or opposite manner along the midrib, now known as rachis. Pinnately compound leaves are of following types.

a. Unipinnate:

Here the leaflets are formed by single division of lamina. Unipinnate leaves are of two types:

- i. **Paripinnate:** This is a unipinnate leaf with even number of leaflets e.g. tamarind.
- ii. **Imparipinnate:** This unipinnate leaf bearing odd number of leaflets e.g. rose.

b. Bipinnate: In this case the leaflets of the first order divide again i.e. Acacia.

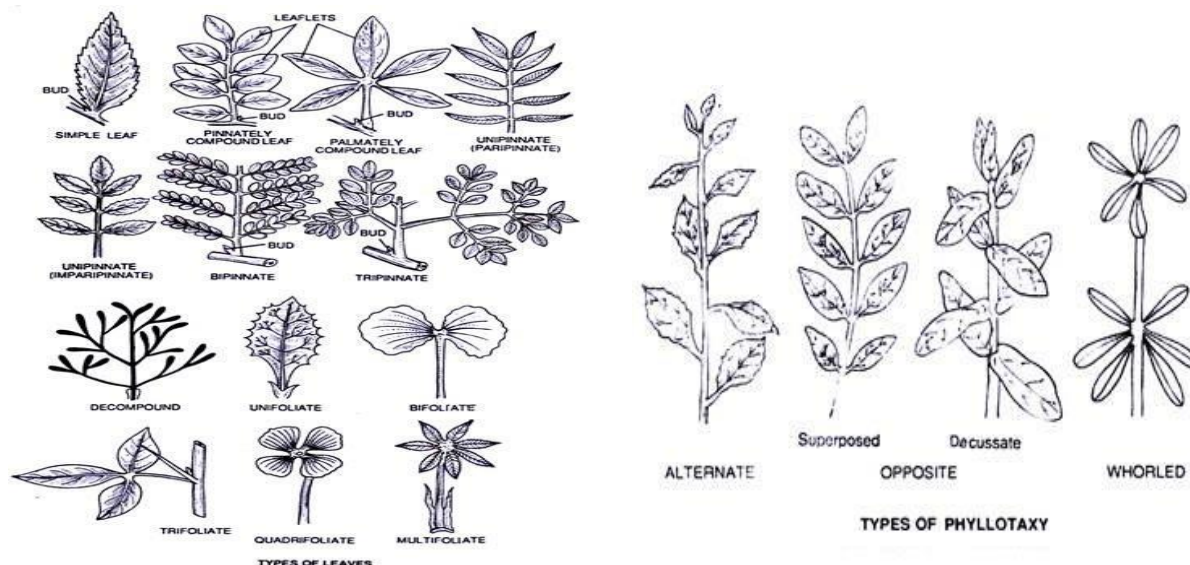
c. Tripinnate: It is a thrice pinnate compound leaf, i.e. the leaflets of the second order divide once more e.g., *Moringa*.

d. Decompound: This is a pinnately compound leaf where incision of lamina occurs more than three times e.g. carrot.

II. Palmately Compound Leaf:

In this type the incision of lamina is directed towards its base. The leaflets are attached to the tip of the petiole. Palmately Compound leaves are of following types:

- a. **Unifoliate:** This palmately compound leaf has a single leaflet articulated to the apex of a winged Petiole e.g. *Citrus*.
- b. **Bifoliate:** In this type two leaflets are articulated to the petiole e.g., *Bignonia grandiflora*.
- c. **Trifoliate:** Three leaflets are articulated to the tip of Petiole e.g., *oxalis*.
- d. **Quadrifoliate:** In this type, four leaflets are articulated to the tip of Petiole e.g., *Marsilea*.
- e. **Multifoliate (Digitate):** Four or more leaflets are articulated to the tip of the petiole, spreading like fingers from the palm e.g. *Bombax*.



Difference between Pinnately Compound leaf different from a Palmately Compound leaf:

Pinnately compound leaf	Palmately compound leaf
Many numbers of leaflets are present on a common axis	Several leaflets are attached to a common point.
Leaflets are attached to common axis called rachis	Leaflets are attached to a common point on the leaf stalk.
Leaflet bearing axis is the continuation of the petiole	Leaflet bearing axis is very short.
Ex: Neem leaves	Ex: Cotton leaves

Modification of Leaves:

10.Storage Leaves:

Some plants of dry habitats commonly have strongly thickened succulent leaves with water storage regions e.g., members of Crassulaceae.

11.Leaf Tendril:

In some plants leaves are modified into then wiry structures. The coil around the support and help the plant in climbing e.g. entire life modified as in wild pea.

12.Spines:

Leaves of certain plants are modified into spines as in cacti (e.g. opuntia), which is an adaptation to xerophytic conditions. Besides spines also protect plant from grazing.

13.Phyllode:



Here the leaflets fall and the petiole becomes modified into a flattened green leaf-like structure called the phyllode e.g. Australian acacia.

14. **Insect Catching Leaves:**

In some insectivores plants the leaves are adapted to catch and digest insects. In *Nepenthes*, lamina itself is modified into pitcher.

Functions of leaves:

The leaves perform the following functions:

1. **Photosynthesis:** Photosynthesis is the primary function of leaves. They convert carbon dioxide, water, and UV light into glucose through the process of photosynthesis.
2. **Transpiration:** Transpiration is the removal of excess water from the plants into the atmosphere. This occurs by the opening of stomata present in the leaves.
3. **Guttation:** Removal of excess water from the xylem at the edges of the leaves when the stomata are closed is known as guttation.
4. **Storage:** Leaves are a site of photosynthesis. Therefore, they store water and nutrients. The succulent and thick leaves particularly adapt to water storage.
5. **Defence:** Some leaves are modified into spines to protect them from being damaged or eaten by animals. For eg., *Opuntia*.
6. **Reproduction:** Leaves of some plants like *Bryophyllum* sprout new plants. The leaves of this plant begin the process of mitosis and asexually reproduce in the form of plantlets that cover the edges of the leaf.

Morphology of Inflorescence

Inflorescence is the mode of development and arrangement of flowers on the floral axis. The flowers are arranged with respect to a fixed floral axis. The primary stalk of the inflorescence is known as Peduncle. The stalk of individual flower is called Pedicel. Such flowers are called pedicillate. Flowers without pedicel are called sessile.

Types of Inflorescence:

Inflorescences are of two types.

- I. Racemose inflorescence (indeterminate).
- II. Cymose inflorescence (determinate).

I. Racemose Inflorescence:

In this type, the main axis continues to grow indefinitely and is not terminated into a flower. It is of following types.



1. **Raceme:** The inflorescence axis is simple, elongated bears stalked flowers e.g. *Brassica*.
2. **Panicle:** It is modified raceme. Here main inflorescence axis is branched and flowers are born acropetally on lateral branches, also called compound raceme e.g. *Yucca* (Gold mohur).
3. **Spike:** It is similar to raceme but the flowers are sessile e.g. *Piper longum* etc.
4. **Compound Spike (Spikelet or Locusta):** The inflorescence axis is branched and the flowers are arranged in a spike like manner e.g., *Amaranthus*. In grasses the unit of compound inflorescence is spikelet. Each spikelet is composed of a cluster of one or more flowers and their associated brackets.
5. **Strobile:** It is a spike in which each flower is borne in the axil of a persistent membranous bracket e.g. *Humulus lupulus*.
6. **Catkin (Amentum):** It is a spike consisting of unisexual flowers. The inflorescence is long and pendulous e.g. *Morus*, *Salix* etc.
7. **Spadix:** It is a spike with thick and fleshy inflorescence axis surrounding by one or several brightly coloured brackets, called spathe e.g. banana, maize.
8. **Corymb:** It is a racemose inflorescence with shortened main axis. The flowers have unequal stalks. The lower flower have much longer pedicel than the upper ones, bringing all the flowers to more or less same line e.g. *Prunus cerasus* (cherry).
9. **Compound Corymb:** In this case the central axis is branched and the flowers are born on these branches in Corymb like manner e.g. *Pyrus torminalis*.
10. **Umbel:** The inflorescence axis is shortened but the individual flowers are born on pedicels of about the same length. All the flowers arise from the single point, like the ribs of an umbrella. At the base of flower stalks, there is a whorl of brackets forming the involucre, e.g., *Allium Cepa*.
11. **Compound Umbel:** Compound umbel where inflorescence axis is branched, the branches arise from a single point in exactly umbel like manner. The branches bear umbels which are known as Umbellules, e.g. *Daucos carota*.
12. **Capitate:** In this case large number of sessile flowers arise from a suppressed axis forming a globose structure, e.g., *Mimosa*.
13. **Capitulum or Head (Anthodium):** The inflorescence axis is flattened forming a convex disc, called receptacle. A large number of sessile flower called florets are born on the receptacle e.g. sunflower.

II. Cymose Inflorescence:

In this type of inflorescence, the growth of the main axis is soon checked due to the development of a flower at the apex. Here, the main axis branches immediately below the terminal flower. These lateral branches also terminate into a flower. This is of following three types.

1. Uniparous or Monochasal Cyme:

This is an inflorescence where the main axis terminates into flower, and produces only one lateral branch which also terminates into flower. It can be:

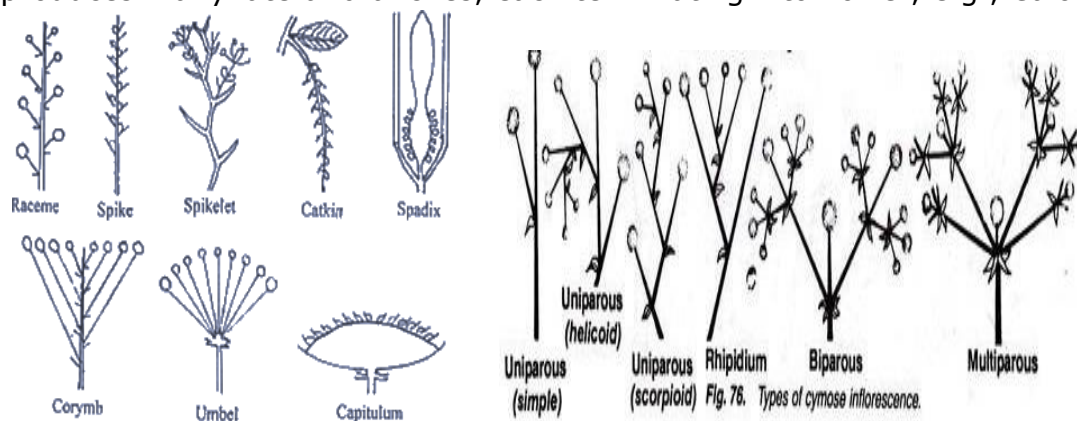
- vi. **Scorpioid Cyme (cincinnus):** When successive lateral branches develop on alternate sides in a zig-zag manner, e.g., *Ranunculus bulbosus*.
- vii. **Helicoid Cyme (Drepmium or Bostryx):** When lateral branches develop on the same side forming a sort of helix, e.g. *Juncus*.

2. Biparous or Dichasial Cyme:

In this type, the main axis terminates into flower and produces two lateral branches, e.g., *Ixora*.

3. Multiporous or Polychasial Cyme:

This is a Cymose inflorescence in which main axis is terminated by a flower and produces many lateral branches, each terminating into flower, e.g., *Calotropis*.



Difference between Racemose and Cymose inflorescence:

Racemose inflorescence	Cymose inflorescence
Inflorescence in which young flowers are present at the tip and older flowers are arranged at the base	Inflorescence in which old flowers are present at the tip and young flowers are arranged at the base
Main axis continues to grow and produce flowers laterally.	The main axis has limited growth which terminates into flower.

Special type of Inflorescences:

1. Cyathium:

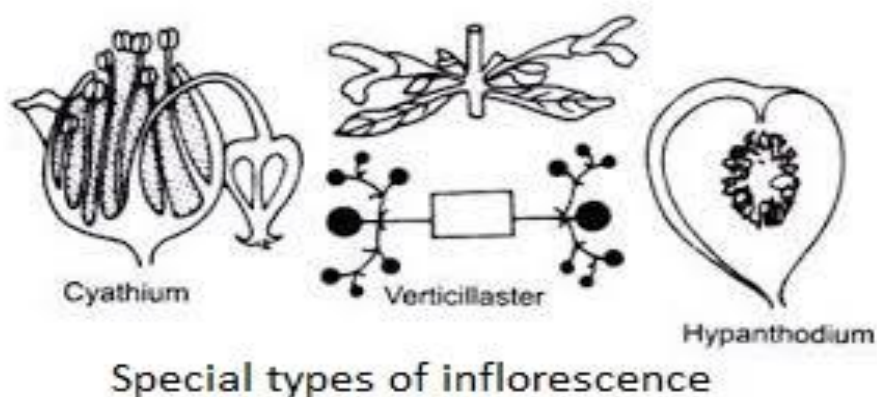
It is a compound inflorescence which looks like a single flower. The Peduncle terminates into a single flower, surrounded by a large number of male flowers. The female flower is represented by only a single pistil. The whole inflorescence is enclosed within cup-shaped involucre, e.g., *Euphorbia*.

2. Verticillaster:

It is characteristic feature of family Labiatae. In this case, the inflorescence axis consists of a series of nodes. At each node there are two opposite bract the main axis terminates into large flower and forms two lateral branches, which also terminate into flower. After this stage it changes into monochasial cyme. The flowers are sessile or sub – sessile e.g., *Salvia*, *Ocimum sanctum*.

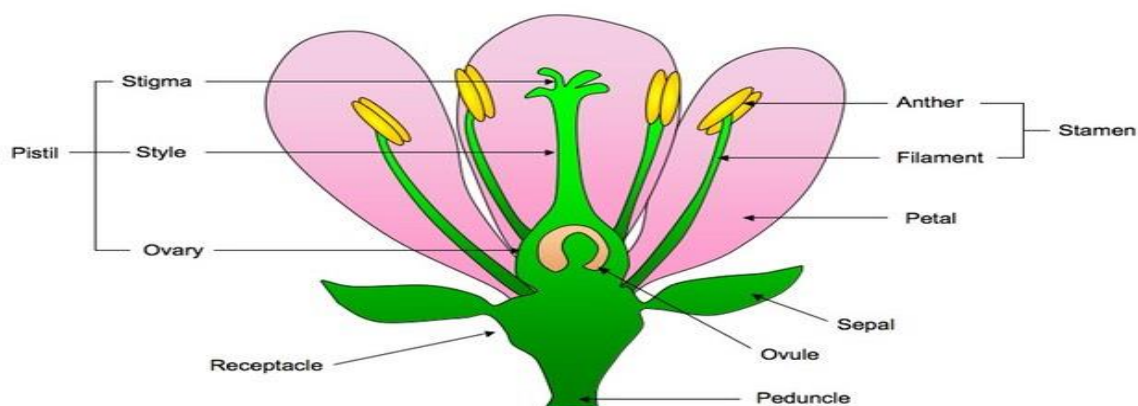
3. Hypanthodium:

In this type the main axis forms a fleshy cup-shaped receptacle. It is almost closed and has an apical opening guarded by scales. Flowers are born on the inner wall of the cup in cymose groups. They are unisexual, male flowers are near the ostiole and female flowers are at base of the cup, e.g., *Ficus*.



Morphology of Flower

Flower may be defined as modified shoot meant essentially for the reproduction of plant. The flower usually develops from a bud, growing axil of a small leaf like structure known as bract. The description of different parts of a flower is given below.



4. Pedicel:

This is a stalk to which flower is attached. The swollen tip of the Pedicel is called thalamus or receptacle, one which flower whorls are inserted.

5. **Calyx:**

It is the outer most floral whorl consisting of Sepals. Sepals are green and protective in function. If sepals are free, the condition is called Polysepalous, and if fused the condition is called gamosepalous, e.g, *Hibiscus*.

6. **Corolla:** It is the second floral whorl consisting of Petals. Like Sepals, Petals may be free (Polypetalous) or fused (gamopetalous). They are brightly coloured due to the presence of anthocyanin and anthoxanthin pigments. Petals are usually differentiated into a lower narrow stalk-like portion, the claw and the upper expanded portion the limb. The primary function of a corolla is to attract insects for Pollination.

Aestivation:

The arrangement of Petals (and also Sepals) in bud condition with respect to members of the same whorl is known as aestivation. It is of following types.

- vi. **Valvate:** The Petals meet by their edges and do not overlap each other, e.g., *Solanum*.

vii. **Twisted or Contorted:**

The Petals are arranged in such a way that one margin of a Petal overlaps that of next one and the other margin is overlapped by proceeding one. It gives a twisted appearance.

viii. **Imbricate:**

Out of five petals one is completely external one completely internal and in each of the remaining three, one margin is external one is external.

v. **Ascending Imbricate:**

The posterior petal is inner most i.e. it's both margins are overlapped, e.g., *Cassia*.

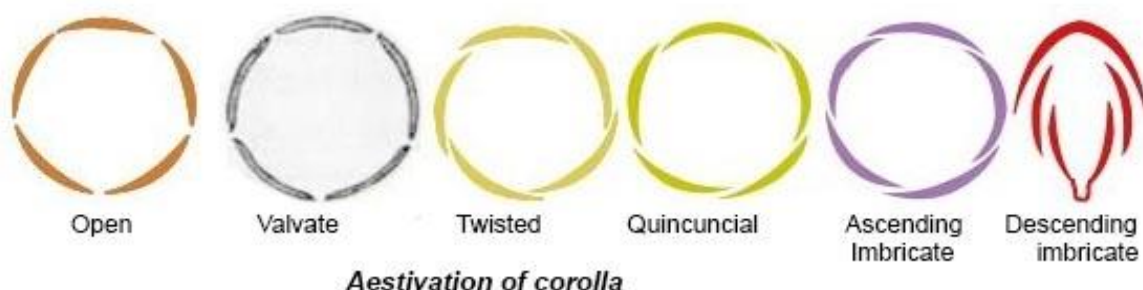
vi. **Descending Imbricate or Vexillary:**

The anterior petal is innermost and the posterior petal is largest and outermost e.g. Pea.

ix. **Quincuncial:**

It is modification of imbricate type. Out of five petals two completely external and in the remaining petal one margin is internal and the other is external.

In monocots, such as tulips, lily, etc. the accessory floral whorls are not distinguishable into calyx and corolla. These are collectively known as Perianth. Each member of the perianth is called tepal.



**x. Androecium:**

It is the male reproductive whorl of flower consisting of stamen. Each stamen, also called microsporophyll is made of three parts:

- i. Filament: Filament is a slender stalk, bearing at its tip sac like anther.
- ii. Anther: A typical anther is dithecous, because it has two elongate lobes which are united throughout their length by connective
- iii. Connective: The connection between two anther lobes is the connective.

Sometimes each anther has only one lobe, monothecous (e.g. *Hibiscus*). Each anther lobe is made up of two chambers, the pollen sacs or microsporangia, filled with pollen grains or microspores. Thus, a typical anther is tetrasporangiate. Non-functional stamens are called staminodes.

Most of the flowers have equal number of stamens, sepals and petals, and are arranged in one whorl, such flowers are called isostemonous.

In some flowers stamens are double the number of sepals and petals, and they are arranged in the whorls.

In such flowers if the outer whorl of stamens alternates with petals, the condition is called diplostemony (*Murraya*), and if the outer whorl is opposite the petals the condition is known as obdiplostemony.

Length of Filaments:

Depending upon the length, there are two types of stamens:

- vii. Tetradynamous Stamen
- viii. Didynamous Stamen

- I. Tetradynamous Stamen:** When out of six stamens four inner are long and two outer are short, the condition is known as tetradynamous, e.g., *Brassica*.
- II. Didynamous Stamen:** In this type, there are four stamens two are long and two outer are short, e.g., *Ocimum* (Labiatae).

Cohesion of Stamens:

Fusion amongst the members of same whorl is called cohesion. Following types of cohesion take place in stamens.

- I. Polyandrous:** The stamens are free from one another, e.g., *Ranunculus*, *Papaver* etc.
- II. Adelphous:**

Filaments are fused and anthers are free. Depending upon the number of groups into which filaments are fused, following types are given:

- 11. Monadelphous:** The stamens are united at one group by fusion of their filaments, anthers being free, e.g., *Hibiscus*. This is characteristic of family Malvaceae.
- 12. Diadelphous:** Stamens are fused in two bundles by fusion of their filaments, anthers being free, e.g., *Pisum* (Pea).
- 13. Polyadelphous:** Condition in which stamens form more than ten bundles.

III. Syngenesious:

This is a condition in which statements are united by their anthers only; filaments remain free, as in family compositae (e.g. sunflower).

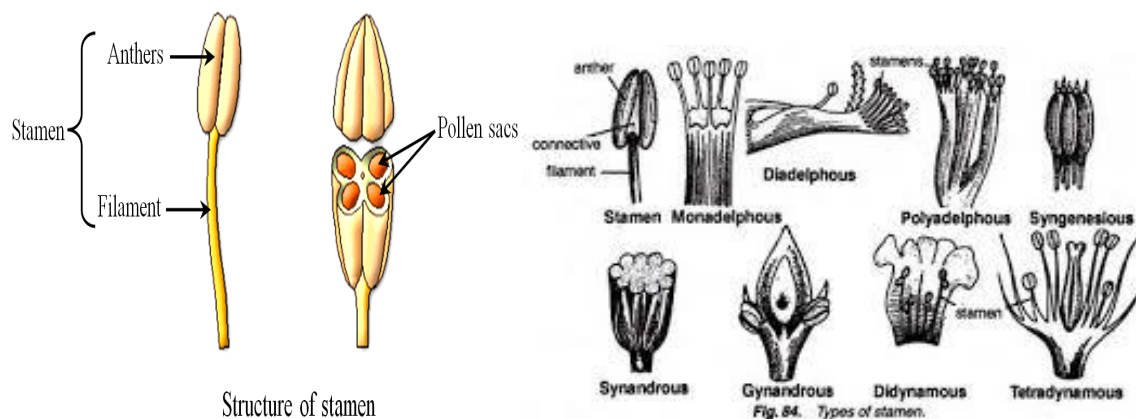
IV. Synandrous:

Stamens are united throughout their length, e.g., *Curcubita*.

Adhesion of Stamens:

Fusion of the members of two different whorls (e.g. Petals and Stamens etc) is known as adhesion. Following are some of the conditions.

3. **Epipetalous:** Stamen adhere to the Petals wholly or partially by their filaments (anthers remaining free), e.g., *Ocimum*, *Solanum*, etc.
4. **Epitepalous:** The stamens adhere to the tepals by their filaments only, e.g., *Asphodelus*.
5. **Gynandrous:** The Stamens adhere to the carpels either throughout their length or by their anthers only, e.g., *Calotropis* (madar).



Gynoecium or Pistil:

It is the innermost and female reproductive whorl of flower consisting of one or more carpels (megasporophyll). Gynoecia could be broadly classified into two types.

1. Simple or Monocarpellary:

This condition is found in pea and other legumes where gynoecium is made up of only one carpel.

2. Compound or Multicarpellary:

It is made up of more than one carpel. Such a gynoecium is found in large number of angiosperms. Multicarpellary gynoecium could be of following types.

- i. **Apocarpous:** Each carpel is free from the other forming a separate gynoecium, e.g., *Ranunculus* etc.
- ii. **Syncarpous:** All the carpels are fused with one another forming a compound gynoecium e.g. *Solanum*.

Number of Carpels:

Depending upon the number of Carpels a syncarpous gynoecium may be of following types.

- VI. **Bicarpellary** – with two carpel e.g. *Coriandrum* (Coriander).
- VII. **Tricarpellary** – with three carpels, e.g., *Allium cepa*.
- VIII. **Tetracarpellary** – with four carpels, e.g. *Berberis*.
- IX. **Pentacarpellary** – with five carpels e.g. *Hibiscus* (shoe flower).
- X. **Multicarpellary** – with many carpels e.g. *Papaver*.

The gynoecium consists of following parts.

- i. Enlarged basal portion is ovary.
- ii. A short or long stalk like extension of the ovary is the style and
- iii. The upper receptive end of the style is the stigma.

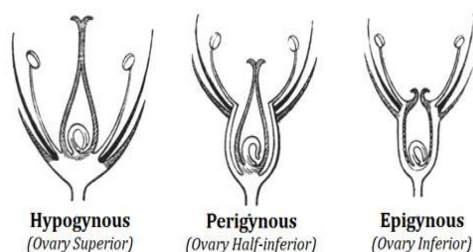
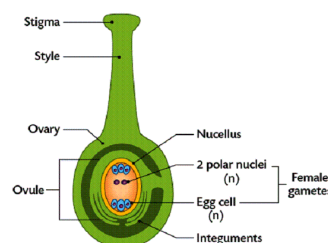
Ovary:

I. Position of Ovary:

With respect to other floral whorls, the ovary may occupy any of the following three positions.

8. **Superior (Hypogynous Flower):** Ovary occupies the highest position on thalamus, and sepals, petals and stamens are successively inserted below it, e.g., *Citrus*.
9. **Semi-Inferior:** The thalamus grows around the ovary to form a cup and bears sepals, petals and stamens on the rim of the cup, e.g., *Rosa*, etc (Perigynous flower).
10. **Inferior (Epigynous Condition):** The thalamus completely covers the ovary and fuses with it. Sepals, petals and stamens are born on the top of the ovary, e.g., *Cucurbita*.

Classification of Flower Based on Position of Ovary



II. Chambers in the Ovary:

In monocarpellary gynoecium the ovary has only one chamber or locule. In apocarpous gynoecium each carpel has one locule. In syncarpous gynoecium the ovary may either have one or many locules. Depending upon the number of locules, following types of ovaries can be recognised.

3. **Unicellular** – Ovary with one chamber, e.g., *Pea*.
4. **Bilocular** – Ovary with two chambers, e.g., *Solanum*.
5. **Trilocular** – Ovary with three chambers, e.g., *Musa*.
6. **Tetralocular** – Ovary with four chambers e.g., *Ocimum*.

7. **Pentalocular** – Ovary with five chambers e.g., *Hibiscus*.

8. **Multilocular**- Ovary with many chambers e.g., *Citrus*.

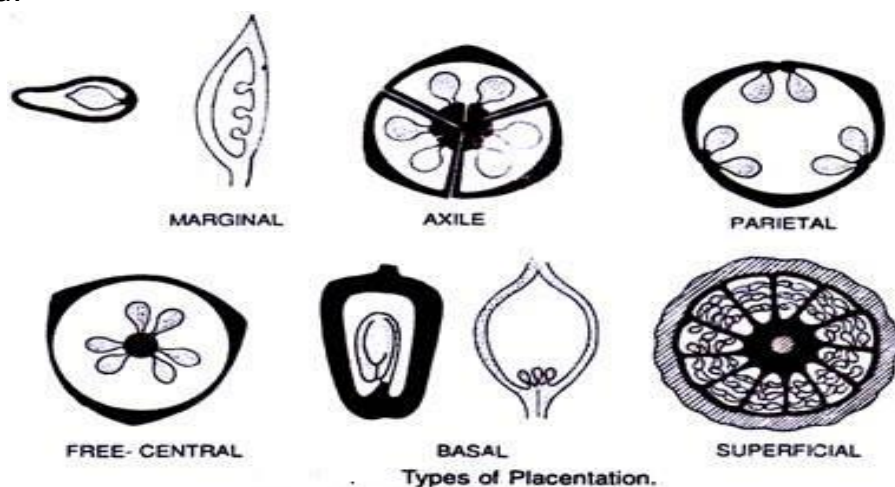
Difference between Apocarpous and Syncarpous ovary:

Apocarpous ovary	Syncarpous ovary
In apocarpous ovary, two or more carpels are free	In syncarpous ovary, two or more carpels are fused
Example: Lotus	Example : mustard

Placentation:

The arrangement of ovules within the ovary is known as placentation. It is of following types.

- iii. **Marginal:** In this case gynoecium is monocarpellary and the ovary is unicellular. The Placenta develops along the fused margins of the carpel, e.g., *Pisum*.
- iv. **Axile:** In syncarpous, multilocular ovules arise from the central axis, e.g., *Solanum*.
- v. **Parietal:** In parietal placentation, the ovules develop on the inner wall of the ovary or on the periphera part. Ovary is one chambered, but it becomes many chambered due to the formation of false septum, e.g., Mustard.
- vi. **Free-Central:** When the ovules are born on central axis and septa are absent the placentation is called free central, e.g., *Dianthes*.
- vii. **Basal:** In this case the placenta develops at the base of ovary and a single ovule is attached to it, as in sunflower.
- viii. **Superficial:** It is similar to axile placentation but the ovule bearing Placenta are born on the inner surface of the partition walls of multilocular ovary, e.g., *Nymphaea*.





Classification of Flowers:

Flowers may be classified as:

7. **Complete:**

A flower with all the four whorls, e.g., China rose.

8. **Incomplete:**

A flower that lacks one or more of these sets, e.g., *Luffa aegyptiaca*.

9. **Hermaphrodite** (Bisexual or Perfect):

A flower in which both male and female organs are present, e.g., China rose.

10. **Unisexual (Imperfect or Diclinous):**

A flower in which only one reproductive whorl is present. It may be

i. **Pistillate:** A flower with only gynoecium presents, e.g., *Luffa aegyptiaca*.

ii. **Staminate:** A flower with only androecium, male flower of *Luffa*.

11. **Monoecious:**

When both male and female flowers are present on the same plant, the plant is called monoecious, e.g., *Zea mays*.

12. **Dioecious:**

When male and female flowers occur on two different plants, the plant species is called dioecious, e.g., Mulberry.

13. **Neuter:**

A flower without androecium and gynoecium, e.g., ray florets of sunflower.

Symmetry of a Flower:

iii. **Actinomorphic or Regular Flower:**

Such a flower can be cut into two equal halves along more than one longitudinal planes, e.g., *Solanum*.

iv. **Zygomorphic or Irregular Flower:**

This flower can be cut into two equal halves only along one median longitudinal plane. In such flower members of some or all the floral whorls are unequal, e.g., *Pisum*.

v. **Asymmetrical Flower:**

These flowers cannot be cut into two equal halves along any vertical plane, e.g., *Canna*.



Floral Formula:

[I]	Bracts (Br)			
	Br	Bracteate	Ebr	Ebracteate
[II]	Bracteoles (Brl)			
	Brl	Bracteolate	Ebrl	Ebracteolate
[III]	Symmetry of the flower			
	⊕	Actinomorphic	⊖ or †	Zygomorphic
[IV]	Sex			
	♂	Staminate (male)	♀	Pistillate (female)
	♂ ♀	Hermaphrodite (Bisexual)		
[V]	Calyx (K)			
	K ₄	4 sepals, polysepalous	K ₍₄₎	4 sepals, gamosepalous
	K ₂₊₂	4 sepals in 2 whorls of 2 each		
[VI]	Corolla (C)			
	C ₄	4 petals, polypetalous	C ₍₄₎	4 petals, gamopetalous
	C ₂₊₂	4 petals in 2 whorls of, 2 each		
[VII]	Perianth (P)			
	P ₆	6 tepals, polytepalous/polyphyllous		
	P ₃₊₃	6 tepals, in 2 whorls of 3 each		
	P ₍₃₎₊₍₃₎	6 tepals, gamotepalous/gamophyllous		
[VIII]	Androecium (A)			
	A ₆	6 stamens, polyandrous		
	A ₂₊₄	6 stamens in 2 whorls of 2 and 4 each, Tetradynamous		
	A ₀	stamens absent	A _∞	stamens indefinite
	A ₍₂₎	monadelphous	A ₁₊₍₉₎	diadelphous
	A ₍₅₎	syngenesious	A ₍₅₎	synandrous
	C → A	epipetalous	PA	epitepalous/Epiphyllous

Functions of Flower:

The important functions of flowers are mentioned below:

1. Gametophytes develop in the flowers.
2. The flowers can produce diaspores without fertilization.
3. After fertilization, the ovary of the flower develops into a fruit containing a seed.
4. The most important function of flowers is a reproduction. They help in the union of male and female gametes.
5. Flowers provide nectar to certain birds and insects, which in turn help in the transfer of pollen from one flower to the other.
6. Flowers may promote selfing, i.e., the union of sperms and eggs from the same flower, or cross-fertilization, i.e., the union of sperms and eggs from different flowers.

Morphology of Fruit

Fruit may be defined as a ripened ovary containing one or more seeds. Fruits are the main features of a flowering plant. It is a matured ovary that develops after fertilisation. Some fruits are developed without fertilization and are known as Parthenocarp or parthenocarpic fruits. In some fruits, the edible portion is not derived from the ovary, but rather from the aril, such as the mangosteen or pomegranate, and the pineapple from which tissues of the flower and stem provide food. Depending upon the part of the flower, fruits are of two types:

I. True Fruit

II. False fruit

I. True Fruit: The fruits that are formed from the ovary, such fruits are known as true fruits.

II. False Fruits: when other floral parts such as thalamus as in apple, pear, fig, calyx (as in pine apple), etc., form a major part of the fruit, such fruits are described as false fruits, accessory fruits or spurious fruits.

Structure of the Fruit:

Fruit consists of two main parts:

i. **The Seeds:** developing from the ovules.

iii. **The Pericarp:** The pericarp (fruit wall) that develops from the wall of the ovary. Structure of pericarp, varies greatly in different kinds of fruits. In fruits such as Peaches, Plums and Cherries pericarp is clearly differentiated into three layers; the outer epicarp, the middle mesocarp and the inner endocarp. Of these, the epicarp and endocarp are usually one cell thick layers while the mesocarp may be very thin or may form a well-developed fleshy tissue, several centimetres thick.

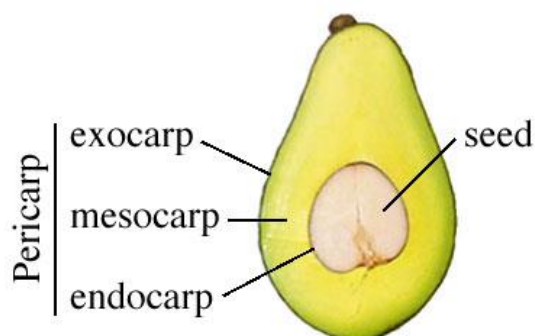


Figure: Structure of Fruit



Types of Fruits:

- III. Simple fruits.
- IV. Aggregate fruits.
- V. Composite fruits.

I. Simple Fruits:

A fruit that develops from a single ovary either monocarpellary or multicarpellary and syncarpous is said to be simple fruit. They may be sub-divided into dry fruits and fleshy fruits.

1. **Dry Fruits:** In these fruits the pericarp becomes more or less dry when ripe. Dry fruits are of three types – dehiscent, indehiscent and schizocarpic fruits.

- i. **Dehiscent fruits:** burst automatically on ripening, liberating seeds. *Pisum* (Papilionaceae).
- ii. **Indehiscent Fruits:** do not burst automatically on ripening. Their seeds are discharged after the decay of pericarp, e.g., *Zea mays*.
- iii. **Schizocarpic Fruits:** splits into number of indehiscent units called mericarps. Each mericarp contains one or more seeds. However, the pericarp does not burst and seeds are liberated only after the decomposition of Pericarp e.g. *Arachis hypogaea* (ground nut).

2. **Fleshy Fruits:** Fruits in which the entire pericarp or part of it and or accessory structures associated with it becomes fleshy and juicy at maturity, e.g., *Prunus amygdalis* (almond).

II. Aggregate Fruits:

Fruits developed from a flower having a number of free carpels, all of which ripe together and are aggregated as a unit on a common receptacle are known as aggregate fruits. The fruitlets of a group are collectively termed as aetio, e.g., blackberry (*Rubus*).

VI. Multiple or Composite Fruits:

These fruits are the products of the whole inflorescence together with its component parts. They are composed of a number of closely associated fruits derived from the entire inflorescence and forming one composite fruit at maturity. These are also known as infrutescence, e.g., *Morus indica* (Mulberry), *Ananas comosus* (Ananas).

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.

Morphology of Seed

Seed may be defined as a fertilized mature ovule with viable embryo which possesses an embryonic plant. It usually stores food material and has a protective coat. After fertilization, changes occur in various parts of the ovule and transforms into a seed.

Structure of Seed:

A mature seed consists of two essential parts:

- iii. The seed coat
- iv. The embryo.

I. The Seed Coat:

The outer covering of seed is called seed coat. In most of the seeds, the seed coat is made up of two layers. The outer layer is called testa and the inner layer is called tegmen. The testa is usually thick and leathery while tegmen is thin, papery and fused with the testa. The function of the seed coat is to protect the delicate embryo within.

The seed remains attached to the ovary wall or fruit wall (pericarp) by a short stalk called seed stalk or funiculus. In mature seeds the position of seed stalk is represented by a small oval depression called hilum. Just below the hilum is a small pore, the micropyle. In some seeds, the stalk is continuous with the seed coat and this fused part appears as small ridge just above the hilum. This ridge is known as raphe.

II. Embryo:

The embryo may be defined as the young or miniature plant, enclosed within the seed coat. It develops from a fertilized egg. The embryo of a mature seed consists of four distinct parts.

1. Cotyledons.
2. Plumule.
3. Hypocotyl
4. Radicle.

1. **Cotyledon:** The Cotyledons are also known as seed leaves are attached to embryonic axis. Dicotyledons have two cotyledons which are situated opposite to each other, while as monocotyledons have only one cotyledon.

2. **Plumule:** The part of the embryonal axis lying immediately above the point of attachment of the cotyledons is known as epicotyls and at the tip of epicotyl lies the plumule.

3. **Hypocotyl:** The part of the embryonic axis below the point of attachment of the cotyledon is known as hypocotyls. It represents the root stem transition region, i.e. the part where stem changes into root.

4. **Radicle:** The radicle is the basal tip of the hypocotyls. When seed germinates, the radical becomes the primary root of the seedling.

The radicle, plumule and hypocotyl together form the embryonic axis or tigellum.

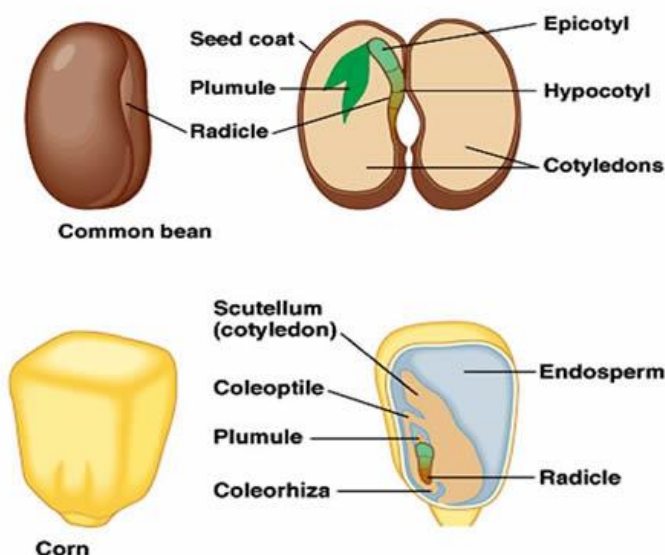


Figure: Structure of Seed

Classification of Seeds:

1. Based on the number of cotyledons present two types of seed are recognized.
 - i. **Dicotyledonous seed:** Seeds with two cotyledons.
 - ii. **Monocotyledonous seed:** Seeds with one cotyledon
2. Based on the presence ofr absence of the endosperm the seed is of two types:
 - i. Albuminous or Endospermous Seeds.
 - ii. Ex-albuminous or non-endospermous seeds.

i. **Albuminous or Endospermous Seeds:**

The cotyledons are thin, membranous and mature seeds have endosperm persistent and nourishes the seedling during its early development.

Examples are; Castor, Sunflower, maize

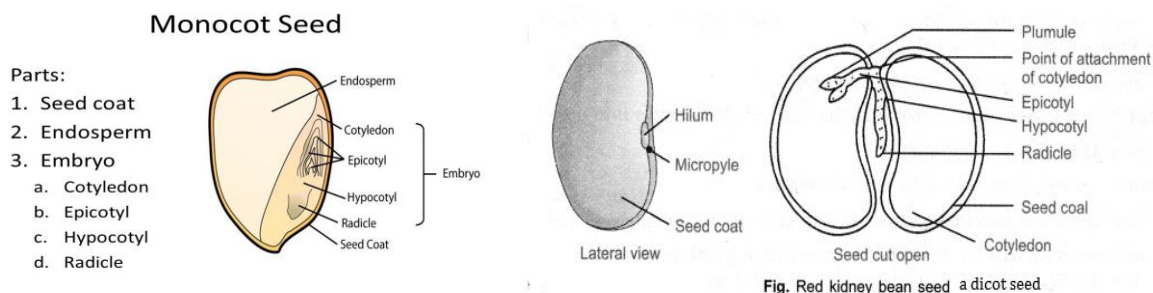
i. **Ex-albuminous or non-endospermous seeds:**

Food is utilised by the developing embryo and so the mature seeds are without endosperm. In such seeds, cotyledons store food and become thick and fleshy.

Examples are; Pea. Groundnut

Food Storage in Seeds:

1. In seeds food is stored in the cotyledons or in endosperm. In legumes food is stored chiefly in the cotyledons and there is no endosperm it is completely utilized by the developing embryo. Such seeds are known as non-endospermic or ex-albuminous.
2. In some seeds (e.g. cereals and grasses), the food is stored mainly in the endosperm. Such seeds are known as endospermic or albuminous.
3. Food material stored in seeds includes carbohydrates, proteins and fats. Seeds of wheat, rice, maize etc. are rich in carbohydrates. Seeds of castor, sunflower, soybean, peanut, etc. are rich in fats and seed of legumes are rich in proteins.



Functions of Seeds:

1. Seed encloses and protects the embryo for next generation.
2. It contains food for the development of embryo.
3. It is a means for the dispersal of new individuals of the species.
4. A seed is a means for the perpetuation of species. It may lie dormant during unfavourable conditions but germinates on getting suitable conditions.
5. Seeds of various plants are used as food, both for animals and men.
6. They are the basis of agriculture.
7. Seeds are the products of sexual reproduction, so they provide genetic variations and recombination in plants.



Description of Flowering plants of Families:

Family Fabaceae

This family was earlier called Papilionaceae, a sub-family of Leguminosae. It is distributed all over the world.

Vegetative Characters:

Habit:

Members of the Fabaceae show wide variety of habits. These are herbs, shrubs and trees. Roots are with root nodules.

Stem:

Erect or climbers, stem is herbaceous or woody.

Leaves:

Leaves are alternate, pinnately compound or simple; leaf base pulvinate, stipulate, venation reticulate.

Floral Characters:

Inflorescence: Racemose.

Flower: Bisexual, zygomorphic.

Calyx: Sepals five, gamosepalous, imbricate aestivation.

Corolla: Petals five, Polypetalous, Papilionaceous, consisting of a Posterior standard, two lateral wings, two anterior ones forming a keel (enclosing stamens and Pistil), vexillary aestivation.

Androecium: Stamens ten, diadelphous, anther dithecal.

Gynoecium: Ovary superior, monocarpellary, unilocular with, many ovules, style single.

Fruit: Legume, seed one to many, non-endospermic.

Floral Formula: $\text{Br}^{\%} \text{ } \overline{\text{K}}_{(5)} \text{C}_{1+2+(2)} \text{A}_{1+(9)} \underline{\text{G}}_1$

Floral diagram:

Figure: Floral diagram Family Fabaceae (Source: onlinesciencenotes.com)

Economic Importance:

All pulses belong to this family, which are rich in proteins. Besides pulses, the family also provides vegetables, oils, fodder, medicines and timber.

Pulses:

- iii. *Cajanus cajan* – Arhar
- iv. *Glycine max* – Soyabean.
- v. *Phascolus vulgaris* – Kidney bean.
- vi. *Pisum sativum* – Matar.

Vegetables:

- vii. *Trigonella foenum-graecum* (Fenugreek; Methi).
- viii. *Phascolus vulgaris* – kidney bean.

Oils:

- 1. *Arachis hypogea* (Ground nut).
- 2. *Glycine max* (Soyabean).

Dye:

- v. *Indigofera tinctoria*: Indigo dye was used for dyeing cotton & rayon.
- vi. *Butea monosperma* (Flame of the Forest): An orange-red dye obtained is used in holi and astringent.

Medicines:

Glycyrrhiza Glabra (E . Liquorice): A drug called liquorice is obtained from stem and root. It is used in cough syrups.

Timber:

- V. *Dalbergia sisso* (sisso, shisham).

Family Solanaceae

It is a large family, commonly called as the potato family. It is widely distributed in tropics, sub-tropics and even in temperature zones.

Vegetative Characters: Plants mostly herbs, shrubs and rarely small trees.

Stem: Herbaceous, rarely woody, aerial, erect, cylindrical, branched, solid or hollow, hairy or glabrous, underground stem in potato.

Leaves: Alternate, simple, rarely pinnately compound, exstipulate, venation reticulate.

Floral Characters:

Inflorescence: Solitary, axillary or cymose as in *solanum*.

Flower: Bisexual, actinomorphic.

Calyx: Sepals five, gamosepals, Persistent, valvate aestivation.

Androecium: Stamens five, epipetalous.

Gynoecium: Bicarpellary, Syncarpous, Ovary superior, bilocular, placenta swollen with many ovules, axile placentation.

Fruit: Berry or capsule.

Seeds: many endospermic.

Floral Formula: $\text{Br} \oplus \text{♂} \text{K}_5 \text{C}_{(5)} \text{A}_5 \text{G}_{(2)}$



Figure: Floral Diagram Solanaceae (Source: iitians.com)



Economic Importance of Family Solanaceae:

1. Edibles:

4. *Solanum tuberosum*.
5. *Solanum. melongena*.
6. *Lycopersicon esculentum* (Tomato).
7. *Capsicum annuum* (Chillis).

VI. Medicines:

I. *Datura metel* and *D. Stramonium*: A medicine stramonium is extracted from the dried leaves and fruits. It contains three alkaloids – atropine, hyoscyamine and hyocine.

- i. Atropine is used for dialating the pupil of the eye.
- ii. Hyoscyamine & hyocine have depressing effect on central nervous system.
- iii. Stramonium is used in the treatment of asthma.
- iv. Seeds of *Datura* are very poisonous if eaten may cause death.

II. *Atropa belladonna*: The toxin **atropine** cause delirium and hallucinations, and is **used** as pharmaceutical anticholinergics.

III. *Withania somnifera* (Aswagandh) aswagandh is extracted from roots used in treatment of cough and rheumatism.

VII. Use in industry:

- iv. *Nicotiana tabacum*

VIII. Ornamental Plants:

12. *Petunia nyctaginiflora*.
13. *Brunfelsia hopeana* (E. Yesterday, today, tomorrow)

Family Liliaceae

Distribution:

Commonly called lily family is a characteristic representative of monocotyledonous plants. It is distributed worldwide.

Vegetative Characters:

Perennial herbs with underground bulbs, corms and rhizomes.

Leaves: Mostly basal, alternate, linear, exstipulate with parallel venation.

Floral Characters:

Inflorescence: Solitary, cymose, often Umbellate clusters.

Flower: bisexual, actinomorphic.

Perianth: Tepals six (3 + 3), often united into tube; valvate aestivation.

Androecium: Stamens six (3 + 3)

Gynoecium: Tricarpellary, Syncarpous, ovary superior, trilobular with many ovules, axile placentation.

Fruit: Capsule, rarely berry.

Seed: Endospermic.

Floral Formula: $\text{Br} \oplus \text{P}_{3+3}, \text{A}_{3+3} \underline{\text{G}} (3)$

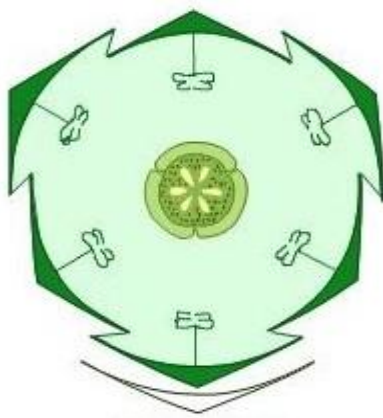


Figure: Floral Diagram Liliaceae (Source: askiitians.com)

Economic Importance:

- I. **Edibles.**
 - iii. *Allium cepa*.
 - iv. *Allium sativum*.
- II. **Medicines**
 - i. ***Smilax China*:** A drug sarsaparilla is extracted from roots of these plants and is used in the treatment of skin diseases.
 - ii. ***Colchicum autumnale*:** Colchicine extracted from corm is used for the treatment of rheumatism and to induce Polyploidy.
- III. **Fibres.**

***Yucca filamentosa*:** Fibres obtained from leaves are used for ropes.
- IV. **Ornamentals**
 - i. *Tulipa gesneriana* (Tulip).
 - ii. *Yucca gloriosa*.

Further readings:

1. Biology, Textbook for Class XI, NCERT
2. www.easybiologyclass.com
3. www.biologydiscussion.com
4. www.botanystudies.com
5. www.britannica.com



UNIT-IV MINERAL NUTRITION

Syllabus

Methods to study mineral requirement (Hydroponics). Essential mineral, elements criteria for essentiality of nutrients. Essential elements. Micro and Macro nutrients, their role and deficiency symptoms. Mechanism of absorption of elements, translocation of solutes, soil and reservoir of essential elements.

Nitrogen Metabolism: Nitrogen cycle- Biological nitrogen fixation, 'Photosynthesis, Historical background, site of photosynthesis. Various photosynthetic pigments, Mechanism, Light reaction including PS I, PS II and photophosphorylation (Cyclic and non-cyclic). Dark reaction or Biosynthetic phase, Calvin (C₃) cycle, C₄ cycle, factors effecting photosynthesis. Photorespiration.

Respiration: Introduction mechanism- glycolysis, Krebs's cycle. Electron transport system, Aerobic and anaerobic respiration. Respiratory quotient.

Growth and Development: Characteristics of plant growth, phases of growth, growth curve and its components- differentiation, dedifferentiation and redifferentiation, sequence of developmental processes in a plant cell, discovery and physiological effects (Auxins, Gibberellins, cytokinins, ethylene and IBA, Photoperiodism and vernalisation.

Mineral Nutrition

Minerals and Their Importance

The basic needs of all living organisms are essentially the same. They require macromolecules such as carbohydrates, proteins, fats, to grow and develop. In this chapter, we will focus on the inorganic plant nutrition. These inorganic substances or minerals provide nourishment to the living organisms or act as raw materials for body building and maintaining its normal functions.

Nutrients are basically divided into two main types:

- i) Organic nutrients
- ii) Inorganic nutrients

The product of photosynthesis (various sugars) are considered as organic nutrients, while as those absorbed by the roots via various methods are known as inorganic nutrients.

In this chapter we will concentrate mainly on inorganic nutrients and their various aspects related to the plant growth and development.

In 1860, Julius von Sachs, demonstrated for the first time that plants could be grown to maturity in a defined nutrient solution in complete absence of soil. This technique of growing plants in a nutrient solution is called hydroponics.

Hydroponics or Soilless Culture

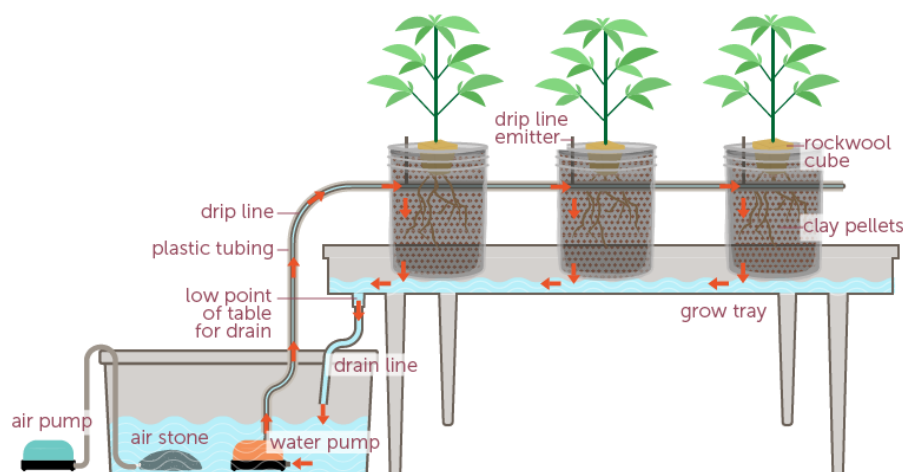
This technique was demonstrated from Julius von Sachs's experiments that plants could be grown to their maturity in a well-defined nutrient solution even in the absence of soil. This technique of growing plant in a nutrient solution without soil is well known and is also known as water culture.

The methods involved in hydroponics require a very careful purification of water and nutrient salts. This is essential in order to assess the role of a particular mineral.

Hydroponic Setup

- In hydroponic plant production, plants are grown in a tube or trough that are placed in slightly inclined position.
- A pump is used to circulate the nutrient solution from the reservoir to the elevated (upper) end of the tube. Funnel is used for adding solution (water and nutrients).
- Bent tube is used for aeration.

The nutrient solution flows down due to gravity and returns to the reservoir of the hydroponic setup. In this way, roots are bathed in aerated nutrient solution continuously.



A basic hydroponic setup (deep water culture) (Courtesy: www.leafy.com)

On conducting a series of experiments, in which roots of the plants were immersed in nutrient solution by eliminating or adding an element in varied concentration, the role of various minerals was ascertained.

Hydroponic revealed the identification of essential elements for plant growth and also helped in discovering their deficiency symptoms.



Criteria for Essentiality

In order to determine whether the particular element is essential or non-essential, the element must follow the criteria for essentiality given below

- i. The element must be absolutely necessary for supporting normal growth and development.
- ii. Requirement of the particular element in appropriate amount must be specific and it should not be replaced by any other element, i.e., if the deficiency of one element occurs, it should not be fulfilled by the addition of some other element.
- iii. The element must be involved directly in the functioning and metabolism of the plant.

Classification of Essential Mineral Elements

Essential elements occur in different proportions in plants. On the basis of the above mentioned criteria of essentiality some elements have been found to be absolutely essential for the normal and better growth, metabolism and development of plants.

These elements have been grouped into following two categories based on quantitative requirements

Macronutrients

These are the elements generally found in plant tissues in large amounts (in excess of around 10 m mole kg⁻¹ or 10 mg per gram of dry matter). They are also called as major elements. These elements are generally involved in the synthesis of organic molecules and development of osmotic potential. These are carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium and magnesium. Out of all these elements, carbon, hydrogen and oxygen are obtained from CO₂ and H₂O while, the others are obtained from the soil.

Micronutrients

These are the elements generally found in traces (very small amount only, i.e., less than 10 m mol kg⁻¹ or less than 0.1 mg per gram of dry matter). Micronutrients are generally eight in number and include iron, manganese, copper, molybdenum, zinc, boron, chlorine and nickel. These are mostly involved in the functioning of enzymes as co-factors or activators of metals.

**Differences between Macronutrients and Micronutrients**

Micronutrients	Macronutrients
Their quantities can be easily detected in plants as they occur in large amounts	They occur in very small amounts
They are needed for growth, metabolism and other body functions	These nutrients help in detoxifying the body and warding off human diseases
Their required concentration is at least 1 mg/g of dry matter	Their required concentration is equal to or less than 0.1 mg/g of dry matter
They have significant role in development of osmotic potential	They don't play any role in maintenance of osmotic potential
Compounds of macronutrients contain calories	Compounds of micronutrients don't contain calories
Their higher concentration doesn't cause toxicity	They cause toxicity even with slight increase from their maximal range

Based on the diverse functions of essential elements, these are also categorized into four other categories given below

- Essential elements as components of biomolecules and hence structural elements of cells. E.g., carbon, hydrogen, oxygen and nitrogen.
- Essential elements that are components of energy related chemical compounds in plants. e.g., Phosphorus is a component of ATP which functions as an energy currency of all the living systems; magnesium is a component of chlorophyll, which is involved in the conversion of light energy into chemical energy.
- Essential elements that activate or inhibit enzymes. They function as the activator or inhibitor of enzymes, e.g., Mg^{2+} acts as an activator of several enzymes in both photosynthesis (e.g., Ribulose biphosphate (RuBP) carboxylase, phospho-enol pyruvate (PEP) carboxylase) and respiration (e.g., hexokinase and phosphofructokinase). Zn^{2+} acts as an activator of alcohol dehydrogenase and Mo of nitrogenase during the course of fixation of nitrogen.
- Essential elements that can alter the osmotic potential of a cell. Most of the osmotic potential of cell is due to the inorganic salts. Potassium plays an important role in stomatal movement.

Role of Macro and Micronutrients

The essential elements perform several important roles, most important of them are given below:

- Regulation of permeability of cell membrane.



- ii). Maintenance of osmotic potential of cell sap.
- iii). Some of them takes part in an electron transport system.
- iv). Others function in buffering action, enzymatic activity and also function as a major constituent of macromolecules and co-enzymes.

Macronutrients

Various macronutrients with their sources, regions and numerous junctions are given below

a) Nitrogen (N)

It is a major constituent of amino acids, proteins, nucleic acids, hormones, vitamins, etc. It was the first macronutrient to be discovered and is required in very large amount by plants.

Nitrogen is not utilized by plants directly as such. It is mainly absorbed in the form of nitrates (NO_3^-), while others absorb, it in the form of nitrites (NO_2^-) or as ammonium ion (NH_4^+)

It is usually required by all parts of plants, mainly the meristematic tissues and by all the cells, which are metabolically active in nature

Functions:

Its main function is in growth, metabolic activities and also serves as enzymes in photosynthesis, etc.

It is present in porphyrins of chlorophylls and cytochromes, thus plays an active role in photosynthesis and electron transport chain.

Its deficiency causes chlorosis (yellowing) in older leaves (highly mobile) and anthocyanin formation in stem, petioles and leaves.

b) Phosphorus (P)

Most soils are phosphorus deficient. It is present in plants as both organic and inorganic forms. Organic form of phosphorus is not absorbed by plant as such, instead, it is either taken from the solid or the solution phase of soil. It is a constituent of certain proteins, all nucleic acid and cell membranes.

It is generally absorbed by roots from soil in the form of phosphate ions (either as H_2PO_4^- or HPO_4^{2-}).

It is required in all meristems or young tissues and in the regions of developing fruits and seeds. It generally gets withdrawn from the older tissues which becomes metabolically less active.

Functions:

It is mainly involved in phosphorylation reactions and also has its importance in energy transfer reactions.



Phosphorus is also present in high energy biomolecules such as adenosine triphosphate (ATP) and guanosine triphosphate (GTP). It also has its major role in ripening of grains and fruits.

It is an important constituent of nucleic acid (DNA/RNA), phospholipids, NADP etc.

The phosphorus deficiency results in premature leaf fall, necrosis and anthocyanin formation.

c) **Potassium (K)**

It does not act as a constituent of any organic substance, so potassium (K^+) is available to plants in its inorganic form such as potassium sulphate, potassium nitrate, etc. It is one of the major constituents of protoplasm.

It is found in all tissues of plants that has the property of differentiating themselves like meristematic tissues, bud, leaves and root tips.

Its amount is equal in whole plant except in seeds where it is found in lesser quantity.

Functions:

It helps in maintaining anion-cation balance in cells and is also involved in the synthesis of proteins.

It has its major role in opening and closing of stomata, in activation of enzymes, permeability of cells and also helps in maintaining the turgidity of cells.

Deficiency of potassium results in mottled chlorosis and also causes die-back disease.

d) **Calcium (Ca)**

It is an element which is always found in green plants and is absorbed by them in the form of calcium ions (Ca^{2+}) from the soil.

It is needed much in differentiating and meristematic tissues. It gets accumulated mostly in the older leaves.

Functions:

It functions in the synthesis of pectin (calcium pectate) found in middle lamella of the cell wall during cell division, thus important for providing mechanical strength.

It is also involved in the organization of mitotic spindle. It activates certain enzymes and plays an important role in the regulation of cellular activities.

Calcium deficiency causes disintegration of growing root/shoot/leaf apex. Its deficiency also causes irregular cell divisions and death of meristem.

e) **Magnesium (Mg)**

It is the major component of ring structure of chlorophyll, without which the formation of chlorophyll does not take place. It is absorbed by the plants in the form of a divalent magnesium ion (Mg^{2+}) from the soil.



During rainy season magnesium is leached out from the soil due to which its amount become deficient in plants.

It is required in growing areas of roots, stems, seeds.

Functions:

It helps in the activation of enzymes of photosynthesis and respiration, in the formation of chlorophylls, carotenoids and nucleic acids (DNA and RNA) and to in association of the ribosomal subunits.

Magnesium deficiency causes interveinal chlorosis on large scale and formation of anthocyanin in older leaves.

f) Sulphur (S)

It is found usually in the complex proteins of plants. The most abundant reservoir of sulphur in soil is in the organic form, such as lipids, amino acids, proteins, etc. It is absorbed by the plants in the form of sulphate ions (SO_4^{2-}) from mineral fraction of soil.

It is required mostly in young leaves and meristems.

Functions:

It acts as a major constituent in amino acids like cysteine and methionine and also of several co-enzymes, vitamin (like thiamin, biotin, coenzyme-A (Co-A) and ferredoxin).

It is due to the presence of sulphur constituent in Liliaceae family plants like onion, garlic, etc., that they have a characteristic odor. It also plays an important role in root nodule formation.

Micronutrients

Various micronutrients with their sources, regions and numerous functions are given below:

a) Iron (Fe)

It is required in huge amount by plants in comparison to other micronutrients. It occurs in the soil mainly in the form of hydroxides and oxides and is absorbed in the form of ferric ions (Fe^{3+}). It is required by every part of plant but is found abundantly along veins of the leaves. Excess amount of iron is stored as ferritin in plants.

Functions:

It is important for ferredoxin, biological N_2 fixation and electron transport chain. Plays an essential role in chlorophyll synthesis

Its deficiency causes rapid interveinal chlorosis in young leaves.

b) Manganese (Mn)

The oxides of manganese are common in soil. However, its highly oxidised form is not available to plants. It is absorbed by the plants in the form of manganous ions (Mn^{2+}).



It is required in leaves and seeds of plant.

Functions:

It is helpful in activating many enzymes like nitrate reductase, hydroxy amine reductase, decarboxylase and dehydrogenase that are involved in photosynthesis, respiration and nitrogen metabolism. It also functions in photolysis of water in order to liberate oxygen during light reaction of photosynthesis.

c) **Zinc (Zn)**

Zinc is absorbed in the form of Zn^{2+} ions. Zinc occurs in ferromagnesium minerals. These minerals are weathered in order to liberate bivalent form of Zn^{2+} . It is considered to be more soluble in soil than other heavy metals.

Zinc is required in every part of the plant.

Functions:

It helps in activation of various enzymes like carboxylases, oxidases, dehydrogenases, kinases, etc., and also in the formation of chlorophyll pigment. It is also needed in the synthesis of auxin.

Its deficiency causes khaira disease of paddy and little leaf disease.

d) **Copper (Cu)**

It is found in very low amount in soils. It is absorbed as cupric ions (Cu^{2+}). It acts as a component or activator of plastocyanin, cytochrome oxidase and many other enzymes.

It is also required in every part of plants like zinc.

Functions:

Like iron, it is also involved with enzymes that are required in redox reactions as it can be reversibly oxidized from Cu^+ to Cu^{2+} . It also plays a role in ascorbic acid formation.

Its deficiency causes die-back of citrus and other fruit trees. In cereals and legume crops copper deficiency causes reclamation disease.

e) **Boron (B)**

It is one of the most essential elements for the growth of nearly all plants, e.g., Tomato, lemon, mustard, cotton, etc. It is absorbed by the plants in the form of BO_3^{3-} or $\text{B}_4\text{O}_7^{2-}$ ions from the soil.

It is required mostly by leaves and seeds. If pH increases, availability of boron to plant gets decreases.

Functions:

It is essential in transportation of carbohydrate through phloem tissues. Boron is needed for uptake and utilization of calcium, in the germination of pollen tube. It is the only micronutrient that is not associated with enzymes.

Its deficiency causes brown heart rot of beets and stout axis.



f) **Molybdenum (Mo)**

The amount of this element in soil vary widely. Plants obtain it in the form of molybdate ions (MoO_4^{2-}).

It is required everywhere in plants but mostly utilized by roots.

Functions:

It is an essential component of several enzymes like nitrate reductase and nitrogenase involved in nitrogen fixation.

Its deficiency causes interveinal chlorosis in lemon and whip tail of cauliflower

g) **Chlorine (Cl)**

It is abundant in nature and is absorbed by the plants in the form of chloride ions (Cl^-).

It is also required everywhere like zinc and copper.

Functions:

Along with magnesium, it is essential for the water splitting in photosynthesis to liberate oxygen. It is also helpful in determining the concentration of solute with Na^+ and K^+ . It seems to be essential in balancing cationic and anionic ratio in cells.

h) **Nickel (Ni)**

It is also added as a micronutrient recently. It is found to be very mobile in plants and is absorbed by the plant in the form of Ni_2^+ ions.

It is required in whole plant.

Functions:

It acts as an essential part of enzyme urease. This enzyme is required to split urea in plant body to obtain nitrogen.

Its deficiency causes slow nitrogen metabolism and necrosis of leaf tips.

Deficiency Symptoms of Essential Elements

The deficiency symptoms vary from element to element and they tend to disappear when the particular deficient mineral nutrient is provided to the plant. Whenever the supply of an essential element becomes limited, growth of the plant gets retarded.

However, if the deprivation of the same nutrient continues for a long period of time, it may eventually lead to the death of the plant.

- (i) Critical Concentration is limited concentration of the essential element below which the growth of plant gets reduced, retarded or stops. Each essential element plays a vital role in structural and functional composition of plant. Thus, in the absence of any particular element, plants show various morphological changes, which are



indicative of certain element deficiencies and are called deficiency symptoms. The plant parts show symptoms of deficiency depending on the mobility of that element in the plant.

(ii) Accordingly, these can also be divided as

- a) **Mobile elements:** When the elements are actively mobile within the plants, the symptoms tend to appear first in older leaves and tissues. It is because the elements get mobilized from senescing regions to young tissues. For example, deficiency symptoms of N, K and Mg are visible in the senescent leaves first because these elements are actively mobile. In the older leaves, biomolecules containing these elements are broken down, making these elements available for mobilizing to younger leaves.
- b) **Immobile elements:** When the elements are immobile within the plants, the symptoms appear first in young leaves and tissues, because the elements are not transported out of the mature organs. For example, Elements like sulphur and calcium are not released out easily from the plant as they act as an important part of the structural component of the cell.

This aspect (mobility of elements) of mineral nutrition in plants play a very vital role in agriculture and horticulture.

Some Major Deficiencies in Plants

Various kinds of deficiency symptoms shown by the plants are given below:

- i. **Necrosis:** It is the phenomenon, which leads to the death of tissues, cell or organ mainly leaf tissue, while it is still a part of the living plant. It is caused due to the deficiency of elements like Ca, Mg, Cu, K, etc.
- ii. **Chlorosis:** It is the loss of chlorophyll which leads to the yellowing of leaves. This symptom is caused by the deficiency of elements like N, K, Mg, S, Fe, Mn, Zn and Mo in plants.
- iii. **Inhibition of cell division:** It occurs due to the lack or low levels of elements like N, S, Mo, K, etc.
- iv. **Delay flowering:** Deficiency of elements, like N, S, Mo leads to delay in flowering of plants.
- v. **Stunted plant growth:** If the low availability of element occurs, it may lead to inhibition of growth in plant and may eventually lead to the dwarfing (shortening) of whole plant, e.g., N, K, Ca, S, Zn, B, Mo and Cl.
- vi. **Premature fall of leaves and buds** It is another type of deficiency symptom that occurs due to the lack of different minerals like P, Mg, Cu, etc.

Mechanism of Absorption and Nitrogen Metabolism

Mineral Absorption

Absorption of mineral salts by plants from the soil occurs through the roots mainly from the root hairs and the zones of absorption. Hence, plants absorb the minerals from the soil for their translocation to other parts of the body through stream of xylem.



Minerals are not absorbed as such by the plants instead they are absorbed in their ionic forms.

For example, chlorine is not absorbed as such by the plant instead it gets accumulated in the form of chloride ions.

Mineral absorption by plants is done by two different phases

1. Initial Phase (Passive transport):

It is the pathway by which water or ions present in the free space or outer space of cells are up taken by roots of plants by taking apoplast pathway (avoid entry into cellular membranes and cytoplasm). In this phase, the plant absorbs mineral very rapidly and does not need any metabolic energy in the form of ATP. Thus, it is called passive process. The passive movement of ions occur through ion-channels and the transmembrane proteins that functions as selective pores into apoplast.

2. Metabolic Phase (Active transport):

It is the pathway which is dependent on metabolic energy in the form of ATP for the uptake of mineral ions by the roots into the inner spaces i.e., symplast of the cell. Hence, is called active process. The movement of ions from cell-to-cell is called flux. It can be further divided into two main types:

- i. Influx (inward movement of ions into the cells)
- ii. Efflux (outward movement of ions from the cells)

Translocation of Solutes

After absorption the mineral salts passes readily inward with the transport of water. The translocation of mineral elements to different parts of the body is done through tracheary elements of the xylem to reach upwardly to the leaves and other parts (ascent of sap). It is done through the plants by the transpirational pull.

The upward movement of water through stem is called ascent of sap. It occurs mainly through xylem. Minerals pass through xylem (not phloem) is proved by Stout and Hoaglan in 1939.

Metabolism of Nitrogen

Nitrogen exists as two nitrogen atoms joined by a very strong triple covalent bond. Nitrogen is needed by plants for the production of proteins, nucleic acids (DNA and RNA), chlorophyll and many other vitamins. It is also the most prevalent element apart from carbon, hydrogen and oxygen. It is absorbed as an inorganic compound which is changed into its organic form by plants and certain microbes. The ultimate source of nitrogen is the nitrogen gas present in the atmosphere. As nitrogen is limited in nature, plants compete with microbes for available nitrogen in the soil. Thus, nitrogen acts as a limiting nutrient for both natural and agricultural ecosystems.

Nitrogen Cycle:



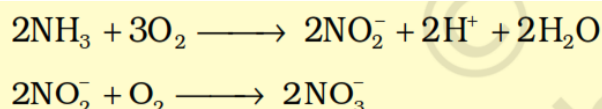
It is the process of cycle of events by which free atmospheric nitrogen is converted into its various chemical forms. The nitrogen cycle consists of four important processes, i.e., nitrogen-fixation, ammonification, nitrification and denitrification.

1. Nitrogen Fixation

In this process, atmospheric nitrogen is fixed which is to be used by the plants. In this step, the molecular nitrogen converted into inorganic nitrogenous compounds like nitrate, nitrite and ammonia. Nitrogen fixation is of two types viz., physical nitrogen-fixation and biological nitrogen-fixation.

Physical Nitrogen Fixation:

It is the conversion of N_2 to inorganic nitrogenous compounds without the involvement of microorganisms. Fixation occurs in nature by lightning and ultra violet radiations by which nitrogen gets converted into its oxides (as NO, NO_2 , N_2O etc.) on combining with O_2 . These oxides also get generated by forest fires, industrial combustions and by some power generating stations.



Biological Nitrogen Fixation:

The conversion of atmospheric nitrogen into inorganic nitrogenous compounds (nitrate, nitrite and ammonia) through microorganisms (bacteria, cyanobacteria, etc.) are called biological nitrogen-fixation.

Only few groups of prokaryotic organisms can fix atmospheric nitrogen. The prokaryotic organisms that reduce nitrogen have an enzyme called nitrogenase such microbes are called nitrogen fixers. These organisms that fix nitrogen can be of two types

- a) Free living bacteria: These are bacteria that are not present in close relationship with other bacteria or other organisms in order to convert nitrogen into ammonia, e.g., number of cyanobacteria like *Anabaena* and *Nostoc*. The free living bacteria can also further divided as:
 - ✚ Free living aerobic: These include microbes like *Azotobacter* and *Beijerinckia*.
 - ✚ Free living anaerobic: These include microbes like *Rhodospirillum* and *Clostridium*.
- b) Symbiotic bacteria: These are bacteria the fix nitrogen by forming close associations with each other or with another organism, e.g., relationship between *Rhizobium* bacteria with legumes. *Frankia* and *Rhizobium*, both are unable to fix nitrogen when present as free living (aerobes) in soil. But when present as symbionts they become anaerobes and are able to fix atmospheric nitrogen.

1) Symbiotic Biological Nitrogen Fixation:

The process of symbiosis involves two organisms living together in different associations. Several types of biological nitrogen fixing associations are known. The most familiar one



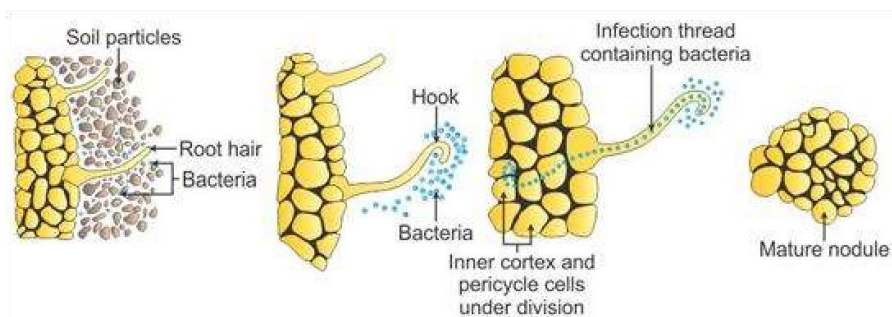
is the relationship of *Rhizobium* with the roots of several legumes belonging to class-Leguminosae like sweet pea, lentils, garden pea, alfalfa, sweet clover, broad bean, clover beans, etc. They get associated mostly on the root hair cells, the root hair curl and the bacteria invade it. An infection thread is produced carrying the bacteria into the cortex where they initiate root nodule formation. Root nodules are small, irregular outgrowth on the roots. They are internally pinkish in color due to the presence of leguminous hemoglobin or leghemoglobin (similar to the hemoglobin, the red pigment present in human blood).

Symbiotic nitrogen fixing bacteria are also known to occur in the roots of certain non-leguminous plants (both angiosperms and gymnosperms) i.e., *Alnus* and *Cycas* respectively.

2. Nodule Formation:

The process of formation of nodules is a series of multiple interactions that takes place between *Rhizobium* bacterium and the root system of legume plant (host). During the process, bacteria initially grow in soil near the roots of higher plants. They are unable to fix nitrogen there, but after coming in contact with the roots of leguminous plants, they interact chemically and enter into roots through root hairs. The process of nodule formation is as follows:

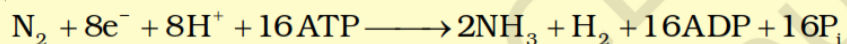
- i. *Rhizobium* multiply and colonize itself to the surrounding of the roots of host plant where it gets physically attached to the epidermal root hair cells.
- ii. After attachment, the root hair gets curled up at the tip due to which bacteria invade the root hair.
- iii. The enzymes from the bacteria degrade the parts of root hair cell wall which produces a thread-like structure called infection thread.
- iv. The bacteria invade the infection thread and reaches upto the inner cortex of the root.
- v. The bacteria after reaching cortex (mainly tetraploid cells) stimulate the initiation of formation of nodule.
- vi. Bacteria enlarges in size and become bacteroid (rod-shaped) thus, leaving the infection thread and enter the cells, i.e., inner cortical and pericycle cells to divide.
- vii. This growth and division of pericycle and cortical cells leads to the formation of a knob-like structure called mature root nodule.
- viii. The nodule, thus formed after division is finally responsible for the direct vascular connection with the host for the exchange of nutrients.



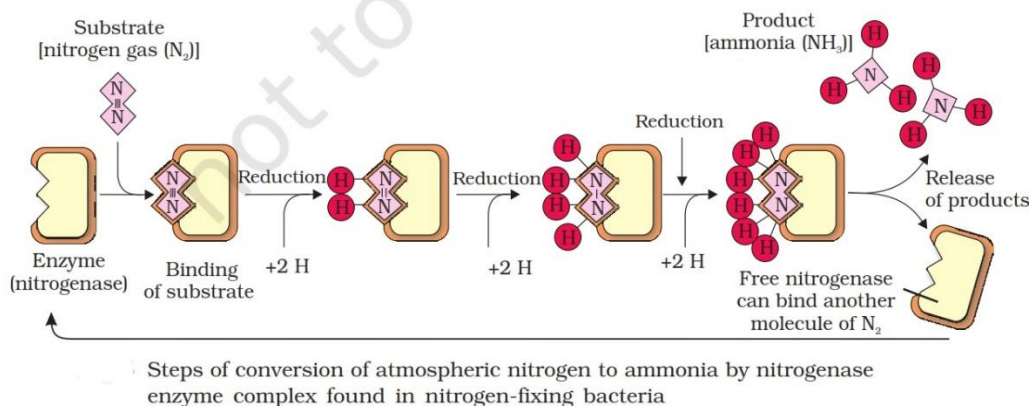
Development of root nodule in soybean (Image courtesy: [topperlearning.com](https://www.topperlearning.com))

Mature Nodule:

The mature nodule thus, formed after a series of events (as discussed above) and chemical changes contains all the essential biochemical components i.e., leghemoglobin and the enzyme nitrogenase. The enzyme nitrogenase catalysis the conversion of free nitrogen into ammonium, (first stable product). The enzyme nitrogenase has two subunits, i.e., Fe protein (non-heme iron protein) and Mo-Fe protein (iron molybdenum protein). The Fe protein component reacts with ATP and reduces Mo-Fe protein which then reduces 2 to ammonia.



Nitrogenase enzyme, cannot function in aerobic conditions as it is highly sensitive to molecular oxygen (O_2). Thus, for its activity it requires anaerobic conditions. Hence, in order to protect this enzyme from oxygen, the nodules produce a substance known as leghemoglobin (oxygen scavenger). Nitrogenase is not active when these microbes live in aerobic conditions, i.e., free-living but becomes active or functional in anaerobic conditions during events of nitrogen fixation.



The reaction involving NH_3 - synthesis by nitrogenase enzyme requires a very high input of energy (8 ATP for each NH_3 produced). The energy required, thus, is obtained from the respiration of the host cells.

ix. Ammonification

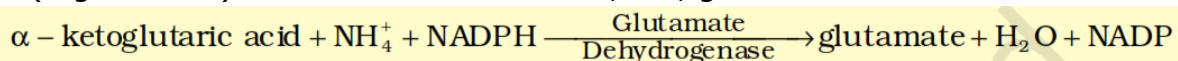
In next step, organic matter (proteins and nucleic acids) of the dead remains are decomposed in order to produce ammonia (NH_3) by microorganisms (like Actinomycetes, *Clostridium* etc.). Out of the ammonia product, some of the ammonia gets volatilized and re-enters into the atmosphere, while most of it undergo the process of nitrification by soil bacteria.

x. Fate of Ammonia

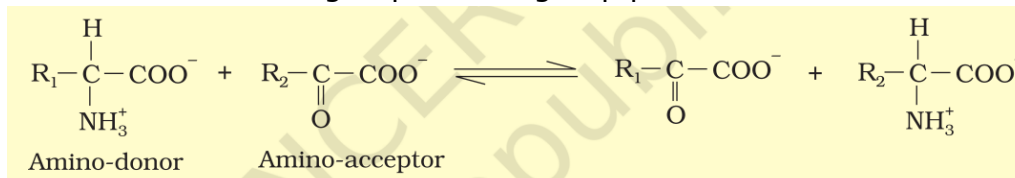
Nitrogen assimilation results in the formation of ammonia which is further used for the synthesis of amino acid. Most of the plants can assimilate both nitrate and ammonium ions (NH_4) (the ammonium ions are formed by the protonation of ammonia at

physiological pH). Ammonium ions are toxic to plants and cannot accumulate in them. Thus, these are used in the synthesis of amino acids in plants by following two methods

- a) Reductive animation: During this process, the ammonia reacts with α -ketoglutaric acid (organic acid) and forms an amino acid, i.e., glutamic acid.



- b) Transamination: It is the transfer of amino group ($-\text{NH}_2$) of one amino acid to keto group ($\text{C} = \text{O}$) of another keto acid. The enzyme responsible for this is transaminase or aminotransferase. Glutamic acid is the main amino acid involved in the synthesis of other amino acids through transamination. Glutamic acid is mainly responsible for making the transfer of amino group to keto group possible.



Amides

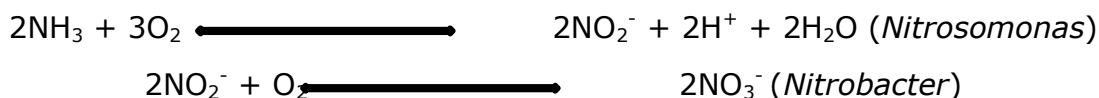
These are generally formed by the combination of amino acids and ammonia. Their formation takes place by replacement of hydroxyl ions of amino acid by NH_2 ion. The two most common amides formed in plants are asparagine and glutamine formed by the addition of another amino group to amino acids i. e., aspartic acid and glutamic acid respectively,

Uses of Amides:

- ✚ Both of the amides, i.e., asparagine and glutamine acts as metabolic reservoirs. They get accumulated in the tissue of healthy plants at the time of assimilation of ammonia (if assimilation occurs in excess amount).
- ✚ They are translocated to other parts of plant through xylem vessels in the form of nitrogen rich compounds because they contain more nitrogen than the amino acids.

xi. Nitrification:

It is the process in which ammonia produced by the degradation of manures may not be available to plants. So, it is first oxidized to nitrite by the soil bacterium *Nitrosomonas* or *Nitrococcus*. This nitrite is then further oxidized to nitrate by another soil bacterium i.e., *Nitrobacter*. The bacteria which helps in the process of nitrification are collectively known as chemoautotrophs.



The nitrate thus, formed are absorbed by plants and then transported to the leaves where it gets reduced to ammonia that finally forms amino-group of amino acids.

xii. Denitrification:



It is the process in which the nitrate present in the soil is reduced back to free nitrogen (N_2). The process of denitrification is carried out by gram negative denitrifying bacteria (*Thiobacillus denitrificans*, *Pseudomonas denitrificans* etc).

Denitrifying bacteria utilizes nitrate and nitrite ions as electron acceptors in place of oxygen.

Photosynthesis

Introduction

The energy required by all living organisms comes directly or indirectly from the sunlight.

Thus, sunlight plays an important role in fixation of CO_2 through which conversion of solar energy into chemical energy takes place. Water plays a significant role during this process.

Hence, photosynthesis is the process by which plants, some bacteria and some protists use the energy from sunlight to produce glucose, which through cellular respiration produce ATP, the fuel used by all living organisms.

Photosynthesis can also be defined as a physiochemical or photo-biochemical process (anabolic and endergonic) in which organic compounds (carbohydrates) are synthesized from the inorganic raw material (H_2O and CO_2) in presence of light and chlorophyll pigments. During this process, light energy is converted into chemical energy and oxygen is evolved as byproduct.

Photosynthesis is an important phenomenon due to the following two reasons

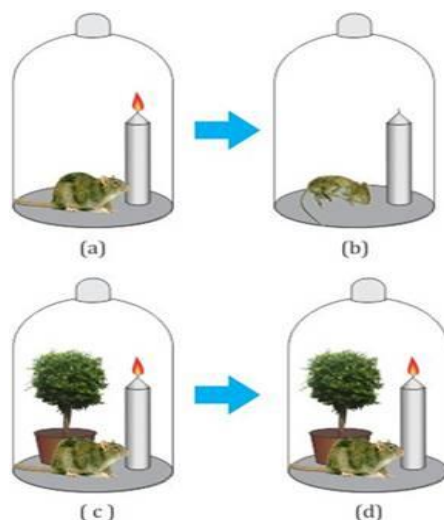
- i. It is the primary source of food on the earth.
- ii. It is also responsible for the release of oxygen into the atmosphere.
Photosynthesis is the only phenomenon of biological importance that can harvest the energy of sunlight.

Early Experiments

Study of photosynthesis started about hundreds of years ago. Prior to that researchers used to believe that plants get all of their nourishment from soil only by the means of roots. Thus, several simple experiments led to the development of understanding of the process involved. Some early experiments performed by different scholars are as follows.

Joseph Priestley

He performed a series of experiments in 1770s that revealed about the essentiality of air in the growth of green plants. He observed that a burning candle or a respiring mouse in a closed space, (i. e., bell jar) soon gets extinguished and died due to suffocation respectively, because burning candle and animal that breathe the air soon get damages. On the other hand after placing a mint plant in the bell jar along the burning candle and mouse, he observed that the mouse stayed alive and also the candle continue to burn for a longer time.



Priestley's experiment

Conclusion

Priestley hypothesized that the foul air produced by the burning of candles and mouse respiration could be purified by plant (mint plant in this case).

Jan Ingenhousz (1730-1799)

He performed his experiments by using same set-up used by Priestley. In his experiment with an aquatic plant, he showed that in bright sunlight, formation of small bubbles take place around the green parts, while in the dark, formation of those bubbles did not take place. He did this by placing the experimental set-up once in the dark and once in the sunlight. The bubbles that he observed were of oxygen and showed that only green parts of plants could release oxygen.

Conclusion

He thus, concluded that sunlight is essential for the plant that purifies the foul air produced by burning candles or by breathing of animals.

Julius von Sachs

He with his experiments in 1854 provided evidence that glucose is produced when plants grow, which is usually stored as starch. He later showed that a green substance, i. e., chlorophyll is found to be located in special bodies called chloroplast in plant cells.

Conclusion

He came to the conclusion that green parts are the place in the plants where production of glucose takes place and the same is stored in the form of starch.

The Engelmann (1843-1909)

He determined the action spectrum of photosynthesis by performing the interesting experiment with the help of a green alga, *Cladophora*. He splits light into its spectral components by using prism. He then illuminated the alga placed in a suspension of aerobic bacteria.

The bacteria were used to detect the sites of O₂ evolution. On doing so, he noticed that the accumulation of bacteria was mainly in the region of the blue and red light of the split spectrum.



Conclusion

By the work done by him at first, action spectrum of photosynthesis was thus described, which roughly resembles the absorption spectra of chlorophyll a and b.

Therefore, the key features of the process of photosynthesis were known by the middle of the nineteenth century, which detailed that plants acquire light energy harvested from sunlight for the formation of carbohydrates (food) from CO₂ and water.

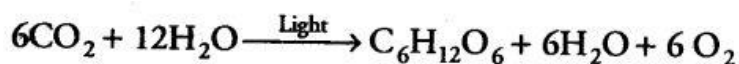
Cornelius Van Neil (1897-1985)

He was a microbiologist, who made a significant contribution on the basis of his studies of purple and green bacteria (photosynthetic bacteria) in understanding the photosynthesis. He demonstrated that during the process of photosynthesis, the hydrogen from a suitable oxidizable compound transferred, which reduces CO₂ to carbohydrates in the presence of sunlight.

With the help of this, he reached to the conclusion that, photosynthesis is a light dependent phenomenon.

Further, he states that in photosynthetic bacteria H₂S acts as a hydrogen donor, which gets oxidized to sulphur, i.e., they do not evolve O₂ during the process of photosynthesis. While in case of green plants H₂O acts as a hydrogen donor, which evolves O₂ as its oxidation product.

Thus, he inferred that O₂, which is evolved by the green plants comes from the water (H₂O) not from the CO₂ (later proved by the use of radioisotopic techniques). Thus, the overall reaction of the photosynthesis is represented as



It is also to be noted that it is not a single step reaction that determines the process of photosynthesis instead it is a multi-step process.

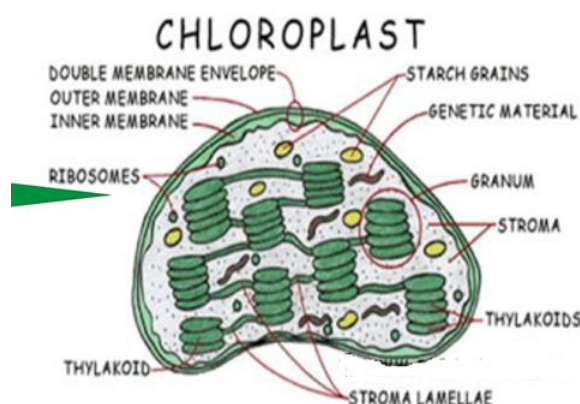
Conclusion

He concluded that the light is necessary to oxidize the photosynthetic substrate (H₂S – Photosynthetic bacteria) and (H₂O-Green plants) and release byproduct sulphur and O₂ in Bacteria and Green plants respectively. In absence of sunlight, this process does not occur.

Chloroplasts: The Site of Photosynthesis

These are the green plastids that function as the site of photosynthesis, i.e., helps in the synthesis of organic food.

The process of photosynthesis takes place in the green leaves of the plants because chloroplasts are abundantly present in the mesophyll cell of the leaves. Chloroplast aligned themselves with their flat surfaces parallel to the walls of the mesophyll cells under optimum light intensities and they would be perpendicular to the walls of the mesophyll cells when the intensity goes very high. Chloroplast is double membranous, DNA containing cell organelle. Internally, a chloroplast contains a proteinaceous matrix or fluid called stroma, the membrane system called lamellae or thylakoids. At some places, the thylakoid gets aggregated to form stacks of discs, called grana.



Chloroplast

The clear division of labor occurs within the chloroplasts, i.e., the membrane system is responsible for the synthesis of ATP and NADPH (photochemical phase), whereas the stroma has enzymes, which are responsible for the reduction of carbon dioxide into carbohydrates and formation of sugars.

As the former sets of reactions are dependent on light so are called light reactions while, the latter is dependent on the products of light reactions, i.e., ATP and NADPH (and independent from direct sunlight), thus are called dark reactions. It is to be noted that dark reactions does not rely that they occur in darkness or that they are not light dependent.

Pigments Involved in Photosynthesis

The pigments involved in the process of photosynthesis are called photosynthetic pigments. These pigments provide different shades of green in the leaves in different plants or in the leaves of same plant.

These pigments can easily be separated out by chromatographic technique (paper chromatography). On the basis of their significance, the photosynthetic pigments are of two types:

Primary pigments: The pigment forms the main molecule of photosystem, e.g., Chlorophyll a and b.

Accessory pigments: These support the function of primary pigments, e.g., Xanthophylls and carotenoids.

A chromatographic separation of the leaf pigments shows that it is not only the single pigment, which is responsible for the color in the leaves. Instead the different shades in leaf are due to four different pigments that have different ability to absorb light at specific wavelength.

Different pigments present in leaf are:

- i. Chlorophyll a ($C_{55}H_{72}O_5N_4Mg$):
This is bright or blue green in the chromatogram. It is known to be the chief plant pigment associated with photosynthesis.
- ii. Chlorophyll b ($C_{55}H_{70}O_6N_4Mg$):
This is yellow green in color.

iii. Xanthophylls:

This is yellow in color. These pigments are oxidized carotenoids.

iv. Carotenoids:

This is yellow to yellow-orange in color. They are also known as 'antenna pigment'.

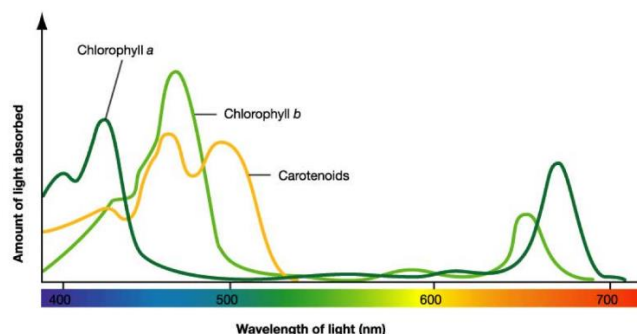
Chlorophyll a is the most abundant plant pigment found in the plants in the world. It contains magnesium (Mg^{+2}) metal as its constituents. Chlorophyll a and carotenes are universal pigments which are found in all O_2 liberating photosynthetic organisms.

The photosynthetic pigments are insoluble in water and are soluble in organic solvents only except phycobilins which are water soluble pigments.

Absorption Spectrum

It is the curve that shows the amount of different wavelength of lights absorbed by a substance. The graph given below shows the ability of chlorophyll-a to absorb lights of different wavelength.

Chlorophyll a shows maximum absorption peak at 450 nm and also shows another peak at 650 nm.

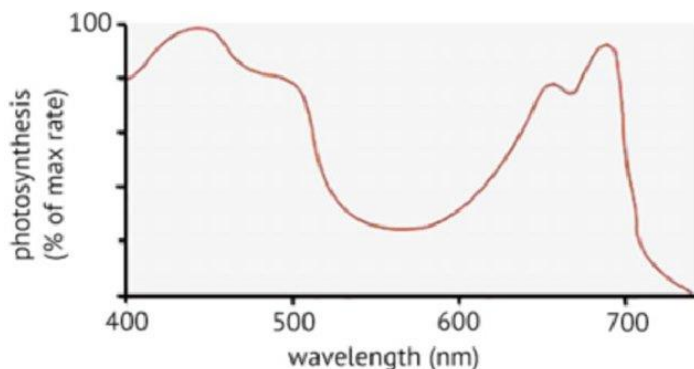


Absorption spectrum of Chlorophyll a, b and carotenoids

Absorption spectrum is constituted by the pigments like violet, blue, orange and red (400-500 and 600-700 nm). The Emission spectrum is constituted by yellow and yellow-green pigment (500-600 nm).

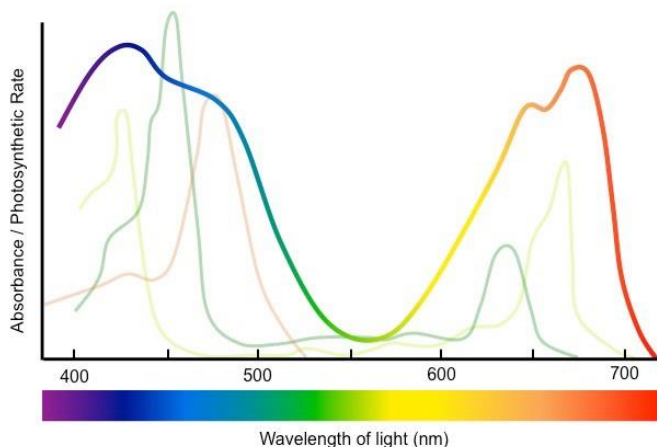
Action Spectrum

It is the curve that depicts the relative rates of photosynthesis at different wavelengths of light. Now another graph given below, shows the wavelength at which maximum photosynthesis occurs at blue, violet and red wavelength in a plant (which is shown by chlorophyll a).



Action spectrum of photosynthesis

Hence, this concludes that chlorophyll-a is the chief pigment, which is majority responsible for the photosynthesis. The another graph given below show the action spectrum of photosynthesis, which coincide closely to the absorption spectrum of chlorophyll.



Actin and Absorption spectrum of Chlorophyll a, b and carotenoids

Hence, all three graphs together shows that the major part of the photosynthesis takes place in the blue and red regions, while some of the photosynthesis takes place at other wavelengths also in the visible spectrum. Apart from chlorophyll-a (the major pigment,) which is mainly responsible for trapping of light, other thylakoid pigments such as chlorophyll-a, xanthophylls and carotenoids also absorb light, transferring energy to chlorophyll-a. These pigments are called accessory pigments.

These pigments enable a wider range of wavelength of incoming light to be utilized for photosynthesis and also provide protection to chlorophyll-a from photooxidation.

Photosynthetically Active Radiation (PAR)

The region of wavelength in which photosynthesis takes place normally. It ranges from 0.4 μ m to 0.7 μ m (400-700 nm).

Assimilatory Power

The chemicals (ATP and NADPH) synthesized in photosynthesis, termed as assimilatory power. They are used in the process to reduce CO₂ into carbohydrates.

Mechanism of Photosynthesis

It was observed that the rate of photosynthesis is directly proportional to the intensity of light, i.e., rate increases with the increase in intensity of light till the plant achieved the saturation point. The process of photosynthesis takes place in following two step viz., light reaction or the photochemical phase and dark reaction or the biosynthetic phase.

Light Reaction (The Photochemical Phase)

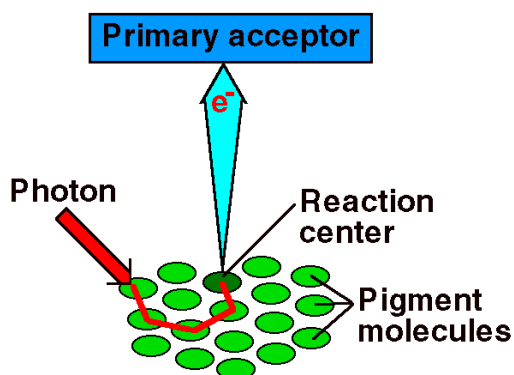
Light reaction includes the following steps, i. e., absorption of light, splitting of water, release of oxygen and finally the formation of high energy chemical intermediates, i.e., ATP and NADPH. `

During the course of light reaction, light is trapped by photosynthetic pigments present in the quantasomes of grana thylakoids. These photosynthetic pigments are organized

into two discrete photochemical Light Harvesting Complexes (LHCs) known as Photosystem-I (PS-I) and Photosystem-II (PS-II).

Photosystems

The light harvesting complexes or photosystems are made up of hundreds of pigment molecules bounded by proteins. Each photosystem has a photocenter or reaction center, where actual reaction takes place. This reaction center contains a special chlorophyll-molecule is fed by hundred other pigment molecules forms the light harvesting system called antennae. These antennae molecule absorb light of different wavelength, but shorter than reaction center in order to make photosynthesis more efficient. These photosystems are, named according to the sequence of their discoveries not in the sequence in which function during the light reaction.



Light harvesting Complex

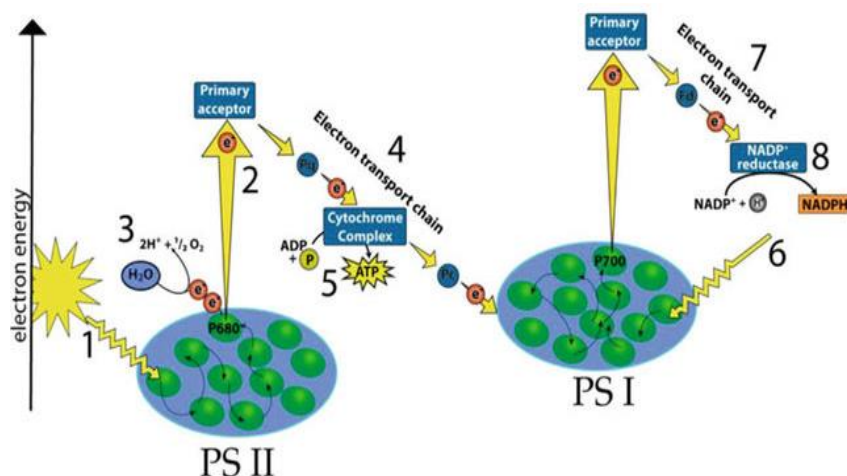
The reaction center is different in both the photosystem as given below

- In PS-I, the reaction center or chlorophyll-a has peak of absorption at 700 nm, known as P₇₀₀.
- In PS-II, the reaction center has absorption peak at 680 nm hence, called P₆₈₀.

Electron Transport

The photosynthetic electron transport chain initiates by the absorbance of light by the photosystem-II. The red light of wavelength 680 nm is absorbed by the reaction center of photosystem II due to which electrons becomes excited and jump into an orbit away from the atomic nucleus.

These electrons are then picked up by an electron acceptor, which passes them further to electron transport system consisting of cytochromes. It is to be noted that this movement of electrons is down-hill according to the redox potential scale (oxidation-reduction scale). The electrons of the electron transport chain are not used up in the chain instead they are further passed on to the pigments of PS-I.



Z-scheme/ Non-cyclic photophosphorylation

Now, like the PS-II, the electrons in the reaction center of PS-I also gets excited on receiving red light of wavelength 700 nm and gets transferred to another electron acceptor with higher redox potential. The electrons in this case also move downhill. But this time the electrons do not move to a reaction center or chlorophyll-a. Instead, they move to a molecule rich in energy and NADP^+ . On addition of these electrons the NADP^+ gets reduced to $\text{NADPH} + \text{H}^+$.

In 1960, Bendall and Hill discovered the Z-scheme of electron transport. It is a series of reactions that we have just studied above from the whole scheme of electron transfer initiating from PS-II, uphill to the acceptor molecule, down the electron transport chain to PS-I, excitation of electrons and then their transfer to another acceptor and finally downhill to NADP^+ in order to get reduced to NADPH and H^+ .

Splitting of Water

The electrons are continuously supplied to the photosystems-II by the available electrons, which get replaced due to the splitting of water. In this process the water splits into protons, electrons and oxygen. The complex for water splitting is associated with the photosystems-II that is located on the inner side of the thylakoid membrane.

These electrons thus, obtained by the splitting of water are needed to replace those electrons which are removed from the photosystem-I thus, are provided by photosystem-II.



While all the electrons formed, are replaced, the protons get accumulated in the lumen of the thylakoid and the oxygen gets into the atmosphere.

Photophosphorylation

Photophosphorylation is the process through which, ATP is synthesized from ADP and inorganic phosphate (P) by the cell organelles (like mitochondria and chloroplasts) with the help of energy from solar radiation.

Photophosphorylation in mitochondria is not light dependent, but it uses the energy by oxidation of nutrients to produce ATP, hence it is called oxidative phosphorylation. The process of photophosphorylation is of two types viz., non-cyclic photophosphorylation and cyclic photophosphorylation

Non-cyclic photophosphorylation:

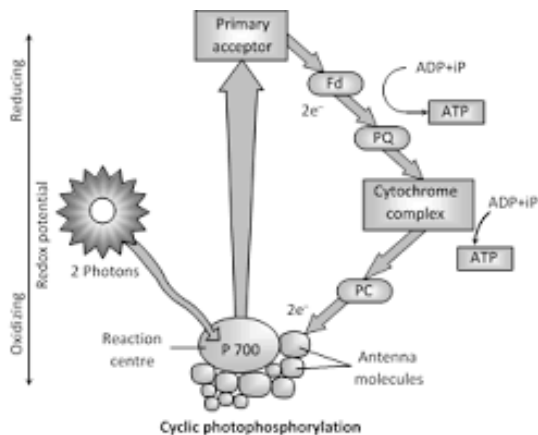
It is type of photophosphorylation in which both the photosystems (PS-I and PS-II) cooperate in light driven synthesis of ATP. During this cycle, the electron released from PS-II does not return to it hence, it is known as non-cyclic photophosphorylation. Both NADPH and ATP are formed during this reaction.

Cyclic Photophosphorylation

It is the type of photophosphorylation in which only PS-I is taking part and the electron released from the reaction center P_{700} returns to it after passing through a series of carrier i.e., circulation takes within the photosystem and the phosphorylation occurs due to cyclic flow of electrons.

When non-cyclic form of photophosphorylation gets stopped under certain conditions, the cyclic photophosphorylation occurs.

The cyclic photophosphorylation takes place in the stroma lamellae of the chloroplast. This happens because the stromal lamellae do not possess enzyme NADP reductase (essential for reducing $NADP^+$ to NADPH) and PS-II. Thus, the excited electrons in the cyclic photophosphorylation does not pass on to $NADP^+$ instead it gets cycled back to the PS-I complex. Hence, through the cyclic flow only the synthesis of ATP takes place.



Cyclic photophosphorylation

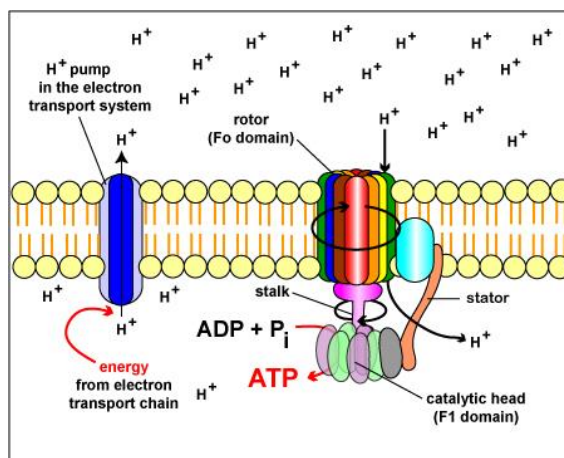
Chemiosmotic Hypothesis

This hypothesis was given by Peter Mitchell (1961) in order to explain the ATP synthesis in photosynthesis (also in respiration). The synthesis of ATP is directly linked to the development of a proton gradient across the thylakoid membranes of a chloroplast. The main difference that lies between the photosynthesis and respiration is the location where the accumulation of protons takes place. In chloroplast (photosynthesis), it occurs in thylakoid lumen while in mitochondria (respiration), it occurs in intermembrane space. Now, the point arises that what causes the proton gradient across the membrane?

The development of proton gradient results due to the reasons given below:

- As the water molecule splits into the inner side of the membrane the protons or hydrogen ions that are produced by the water splitting gets accumulate within the thylakoid lumen.
- Transportation of protons takes place across the membrane when the electron moves through the photosystems. The primary acceptor of electron is located towards the outer side of the membrane, which transfers electron to the proton (H^+) carrier and not to the electron carrier.

So, this molecule, while transporting an electron removes a proton from the stroma, thus, release of proton takes place into the inner side, i.e., on the lumen of the membrane.



Chemiosmotic synthesis of ATP

The enzyme NADP reductase is present on the stromal side of the membrane. Thus, along with the electrons that comes from the acceptor of electrons of PS-I, protons are also necessary to reduce NADP^+ to $\text{NADPH} + \text{H}^+$

Hence, protons in the stroma within the chloroplasts decreases in number, while accumulation of protons takes place in the lumen. Due to which the proton gradient is created across thylakoid membrane, which led to decrease in the pH at the side the lumen.

The gradient is broken down due to the movement of protons across the membrane to the stroma through the transmembrane channel of the F_0 portion of the ATPase enzyme.

Therefore, the proton gradient is important as it is the gradient whose breakdown leads to the release of energy (ATP).

ATP synthase enzyme

The enzyme ATPase consists of the following two parts F_0 particle and F_1 particle. F_0 particle remains embedded in the membrane and forms a transmembrane channel, which carries out facilitated diffusion of protons across the membrane. F_1 particle protrudes towards the outer surface of the thylakoid membrane which faces the stroma. Conformational change occurs in F_1 particle of ATPase, which caused due to the breakdown of the gradient, which allows the enzyme to synthesize several molecules of ATP.

Thus, the chemiosmosis, for its functioning, requires a membrane, a proton pump, a proton gradient and ATPase enzyme. The ATP thus, produced will be used immediately in the biosynthetic reaction (in stroma), responsible for the fixing of CO_2 and synthesis of sugar.

Dark reaction or Blackman's reaction or Path of carbon in photosynthesis

This is the second step in the mechanism of photosynthesis. The chemical processes of photosynthesis occurring independent of light is called *dark reaction*. It takes place in the stroma of chloroplast. The dark reaction is purely enzymatic and it is slower than the



light reaction. The dark reactions occur also in the presence of light. In dark reaction, the sugars are synthesized from CO_2 . The energy poor CO_2 is fixed to energy rich carbohydrates using the energy rich compound, ATP and the assimilatory power, NADPH_2 of light reaction. The process is called carbon fixation or carbon assimilation. Since Blackman demonstrated the existence of dark reaction, the reaction is also called as *Blackman's reaction*. In dark reaction two types of cyclic reactions occur

1. Calvin cycle or C3 cycle

It is a cyclic reaction occurring in the dark phase of photosynthesis. In this reaction, CO_2 is converted into sugars and hence it is a process of carbon fixation. The Calvin cycle was first observed by Melvin Calvin in chlorella, unicellular green algae. Calvin was awarded Nobel Prize for this work in 1961. Since the first stable compound in Calvin cycle is a 3 carbon compound (3 phosphoglyceric acid), the cycle is also called as C3 cycle. The reactions of Calvin's cycle occur in three phases.

I. Carboxylation phase

- i. Three molecules of CO_2 are accepted by 3 molecules of 5C compound viz., ribulose diphosphate to form three molecules of an unstable intermediate 6C compound. This reaction is catalyzed by the enzyme, carboxy dismutase
- ii. The three molecules of the unstable 6 carbon compound are converted by the addition of 3 molecules of water into six molecules of 3 phosphoglyceric acid. This reaction is also catalyzed by the enzyme carboxy mutase.

3 phosphoglyceric acid (PGA) is the first stable product of dark reaction of photosynthesis and since it is a 3 carbon compound, this cycle is known as C3 cycle

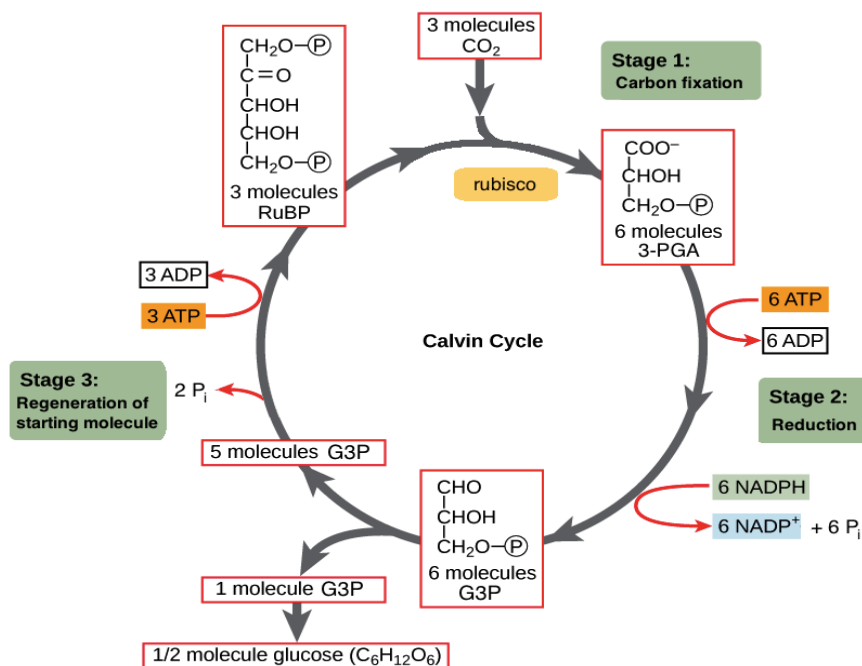
II. Reductive phase

- i. Six molecules of 3PGA are phosphorylated by 6 molecules of ATP (produced in the light reaction) to yield 6 molecules of 1-3 diphosphoglyceric acid and 6 molecules of ADP. This reaction is catalyzed by the enzyme kinase.
- ii. Six molecules of 1, 3 diphosphoglyceric acid are reduced with the use of 6 molecules of NADPH_2 (produced in light reaction) to form 6 molecules of 3 phosphoglyceraldehyde. This reaction is catalyzed by the enzyme, triose phosphate dehydrogenase.
- iii. Some of the molecules of 3 phosphoglyceraldehyde convert into dihydroxy acetone phosphate. Both 3 phosphoglyceraldehyde and dihydroxy acetone phosphate then unite in the presence of the enzyme, aldolase to form fructose, 1-6 diphosphate.
- iv. Fructose 1, 6 phosphate is converted into fructose 6 phosphate in the presence of phosphorylase.
- v. Some of the molecules of 3 phosphoglyceraldehyde instead of forming hexose sugars are diverted to regenerate ribulose 1-5 diphosphate.
- vi. One molecule of the fructose 6 phosphate gets converted into glucose 6 phosphate by the enzyme phosphohexose isomerase. This glucose 6 phosphate is then converted into one molecule of glucose by the enzyme phosphatase.

III. Regeneration phase:

During regeneration phase ribulose 1, 5 bisphosphate (RuBP) is resynthesized for continuation of the C₃ cycle.

- The remaining molecules of fructose 6 phosphate form xylulose 5 phosphate (5C sugar) in the presence of enzyme transketolase
- Xylulose 5 phosphate (5C sugar) then gets converted to ribose 5 phosphate by the epimerase.
- Ribose 5 phosphate finally gets phosphorylated to ribulose 1, 5 bisphosphate (RuBP) by the enzyme phosphorubilose kinase.



C4 cycle or Hatch and Slack pathway

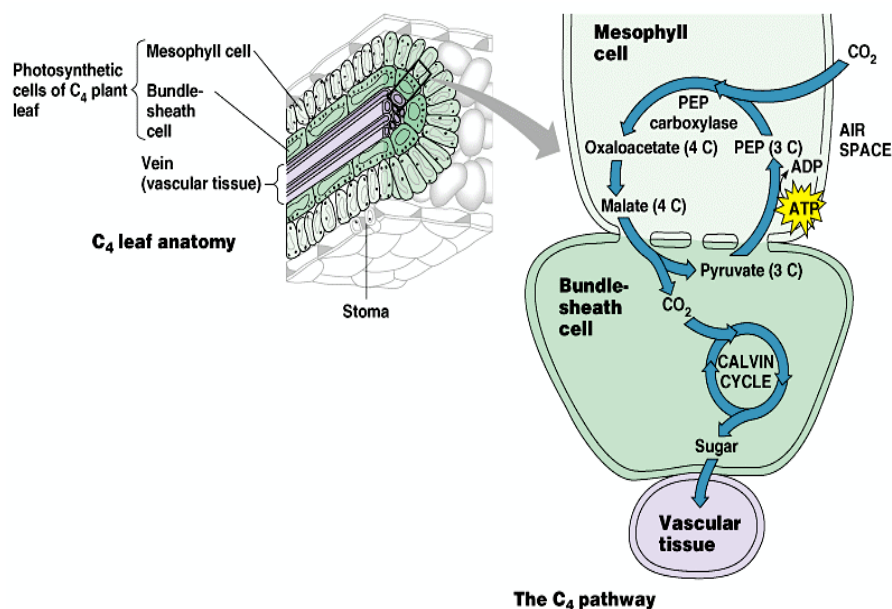
It is the alternate pathway of C₃ cycle to fix CO₂. In this cycle, the first formed stable compound is a 4 carbon compound viz., oxaloacetic acid. Hence it is called C₄ cycle. The path way is also called as Hatch and Slack as they worked out the pathway in 1966 and it is also called as C₄ dicarboxylic acid pathway. This pathway is commonly seen in many grasses, sugar cane, maize, sorghum and *Amaranthus*.

The C₄ plants show a different type of leaf anatomy. The chloroplasts are dimorphic in nature. In the leaves of these plants, the vascular bundles are surrounded by bundle sheath of larger parenchymatous cells. These bundle sheath cells have chloroplasts. These chloroplasts of bundle sheath are larger, lack grana and contain starch grains. The chloroplasts in mesophyll cells are smaller and always contain grana. This peculiar anatomy of leaves of C₄ plants is called Kranz anatomy. The bundle sheath cells are bigger and look like a ring or wreath. Kranz in German means wreath and hence it is called Kranz anatomy. The C₄ cycle involves two carboxylation reactions, one taking place in chloroplasts of mesophyll cells and another in chloroplasts of bundle sheath cells. The various steps in Hatch and Slack cycle are as:

- In the chloroplasts of mesophyll cells, phosphoenolpyruvate, a 3 carbon compound picks up CO₂ and changes into 4 carbon compound oxaloacetate in

- the presence of water. This reaction is catalyzed by the enzyme, phosphoenol pyruvate carboxylase.
- Oxaloacetate breaks down readily into 4 carbon malate and aspartate in the presence of the enzyme, transaminase and malate dehydrogenase
 - The malate gets transported to bundle sheath cells where it splits enzymatically to yield free CO_2 and 3 carbon pyruvate. The CO_2 is used in Calvin's cycle in the bundle sheath cell (second carboxylation).
 - This CO_2 is accepted by 5 carbon compound ribulose diphosphate to start C3 cycle in the bundle sheath cells of C4 plants. One molecule of glucose is produced as a C3 cycle in bundle sheath cells.
 - The pyruvate molecule is transferred to chloroplasts of mesophyll cells where, it is phosphorylated to regenerate Phosphoenol pyruvate in the presence of ATP. This reaction is catalyzed by pyruvate phosphate dikinase

The Phosphoenol pyruvate regenerated here again enter the C4 pathway. In Hatch and Slack pathway, the C3 and C4 cycles of carboxylation are linked and this is due to the Kranz anatomy of the leaves. The C4 plants are more efficient in photosynthesis than the C3 plants. The enzyme, Phosphoenol pyruvate carboxylase of the C4 cycle is found to have more affinity for CO_2 than the ribulose diphosphate carboxylase of the C3 cycle in fixing the molecular CO_2 in organic compound during carboxylation.



Crassulacean Acid Metabolism (CAM) cycle or the dark fixation of CO_2 in succulents

CAM is a cyclic reaction occurring in the dark phase of photosynthesis in the plants of Crassulaceae. It is a CO_2 fixation process wherein, the first product is malic acid. It is the third alternate pathway of Calvin cycle, occurring in mesophyll cells. The plants exhibiting CAM cycle are called CAM plants. Most of the CAM plants are succulents e.g.,



Bryophyllum, *Kalanchoe*, *Crassula*, etc. It is also seen in certain plants of Cactus e.g. *Opuntia*, Orchid and Pine apple families.

CAM plants are usually succulents and they grow under extremely xeric conditions. In these plants, the leaves are succulent or fleshy. The mesophyll cells have larger number of chloroplasts and the vascular bundles are not surrounded by well defined bundle sheath cells. In these plants, the stomata remain open during night and closed during day time. The CAM plants are adapted to photosynthesis and survival under adverse xeric conditions. CAM plants are not as efficient as C4 plants in photosynthesis. But they are better suited to conditions of extreme desiccation. CAM involves two steps:

Acidification

In darkness, the stored carbohydrates are converted into Phosphoenol pyruvic acid by the process of Glycolysis. The stomata in CAM plants are open in dark and they allow free diffusion of CO₂ from the atmosphere into the leaf. Now, the Phosphoenol pyruvic acid carboxylated by the enzyme Phosphoenol pyruvic acid carboxylase and is converted in to oxaloacetic acid.

The oxaloacetic acid is then reduced to malic acid in the presence of the enzyme malic dehydrogenase. The reaction requires NADPH₂.

The malic acid produced in dark is stored in the vacuole. The malic acid increases the acidity of the tissues.

Deacidification

During day time, when the stomata are closed, the malic acid is decarboxylated to produce pyruvic acid and evolve carbon dioxide in the presence of the malic enzyme. When the malic acid is removed, the acidity decreases the cells. This is called deacidification. One molecule of NADP⁺ is reduced in this reaction.

The pyruvic acid may be oxidized to CO₂ by the pathway of Krebs cycle or it may be reconverted to phosphoenol pyruvic acid and synthesize sugar by C3 cycle. The CO₂ released by deacidification of malic acid is accepted by ribulose diphosphate and is fixed to carbohydrate by C3 cycle.

CAM is a most significant pathway in succulent plants. The stomata are closed during day time to avoid transpiration loss of water. As the stomata are closed, CO₂ cannot enter into the leaves from the atmosphere. However, they can carry out photosynthesis during the day time with the help of CO₂ released from organic acids. During night time, organic acids are synthesized in plenty with the help of CO₂ released in respiration and the CO₂ entering from the atmosphere through the open stomata. Thus, the CO₂ in dark acts as survival value to these plants.

**Difference between C3 and C4 plants:**

	C3 Plant	C4 Plant
1.	Only C3 cycle is found	Both C4 and C3 cycles are found.
2.	The efficiency of CO ₂ absorption at low concentration is far less and hence, they are less	The efficiency of CO ₂ absorption at low concentration is quite high and hence, they are more efficient plants.
3.	The CO ₂ acceptor is Ribulose-1, 5-	The CO ₂ acceptor is Phosphoenol pyruvate.
4.	The first stable product is phosphoglyceric acid	Oxaloacetate (OAA) is the first stable product.
5.	Plants show one type of chloroplast (monomorphic type).	Plants show dimorphic type of chloroplast. The chloroplast of parenchymatous bundle sheath is different from that of mesophyll cells (dimorphic type). The chloroplasts in bundle sheath cell are centripetally arranged and lack grana. Leaves show Kranz anatomy
6.	In each chloroplast, two pigment systems (Photosystem I and II) are present.	In the chloroplasts of bundle sheath cells, the photosystem II is absent. Therefore, these are dependent on mesophyll chloroplasts for supply of NADPH + H ⁺ .
7.	The Calvin cycle enzymes are present in mesophyll chloroplast. Thus, the Calvin cycle occurs.	Calvin cycle enzymes are absent in mesophyll chloroplasts. The cycle occurs only in the chloroplasts of bundle sheath cells.
8.	The CO ₂ compensation point is 50-150 ppm CO ₂ .	The CO ₂ compensation point is 0-10 ppm CO ₂ .
9.	Photorespiration is present and easily	Photorespiration is present only to a slight degree or absent.
10.	The CO ₂ concentration inside leaf remains high	The CO ₂ concentration inside the leaf remains low (about 100 ppm).
13.	The light saturation intensity reaches in the	It is difficult to reach saturation even in full sunlight.
14.	Bundle sheath cells are unspecialized.	The bundle sheath cells are highly developed with unusual construction of organelles.
15.	The optimum temperature for the process is 10-25°C.	In these plants, it is 30-45°C and hence, they are warm climate plants. At this temperature, the rate of photosynthesis is double than that is in C3 plants.



16.	18 ATPs are required to synthesize one glucose molecule.	30 ATP molecules are required to synthesize one molecule of glucose
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Photorespiration

The excessive respiration that takes place in green cells in the presence of light is called as photorespiration. Decker (1955) discovered the process and it is also called as C₂ cycle as the 2 carbon compound glycolic acid acts as the substrate in photorespiration. In general, respiration takes place under both light and dark conditions. However, in some plants, the respiration is more in light than in dark. It is 3-5 times higher than the rate of respiration in dark. Photorespiration is carried out only in the presence of light. But the normal respiration is not light dependent and it is called dark respiration.

In photorespiration, temperature and oxygen concentration play an important role. Photorespiration is very high when the temperature is between 25 and 30°C. The rate of photorespiration increases with the increase in the concentration of oxygen. Three cell organelles namely chloroplast, peroxisome and mitochondria are involved in the photorespiration. This kind of respiration is seen in plants like cotton, pulses, capsicum, peas, tomato, petunia soybean, wheat, oats, paddy, chlorella etc and it is absent in grasses.

Mechanism

1. In the presence of excess oxygen and low CO₂, ribulose 1,5 diphosphate produced in the chloroplast during photosynthesis is split into 2 phosphoglycolic acid and 3 phosphoglyceric acid by the enzyme, ribulose 1,5 diphosphate oxygenase.
2. The 3 phosphoglyceric acid enters the Calvin cycle.
3. In the next step, phosphate group is removed from 2 phosphoglycolic acid to produce glycolic acid by the enzyme, phosphatase.
4. Glycolic acid then comes out of chloroplast and enter the peroxisome. Here, it combines with oxygen to form glyoxylic acid and hydrogen peroxide. This reaction is catalyzed by the enzyme, glycolic acid oxidase. Hydrogen peroxide is toxic and it is broken down into water and oxygen by the enzyme, Catalase. Photorespiration is an oxidation process. In this process, glycolic acid is converted into carbohydrate and CO₂ is released as the by product. As glycolic acid is oxidized in photorespiration, it is also called as glycolate metabolism.
5. The glyoxylic acid converted into glycine by the addition of one amino group with the help of the enzyme, amino transferase.
6. Now, the glycine is transported from the peroxisome into the mitochondria. In the mitochondria, two molecules of glycine condense to form serine and liberate carbon dioxide and ammonia.
7. Amino group is removed from serine to form hydroxyl pyruvic acid in the presence of the enzyme, transaminase.
8. Hydroxy pyruvic acid undergoes reduction with the help of NADH to form glyceric acid in the presence of enzyme alpha hydroxyl acid reductase.
9. Finally, regeneration of 3 phosphoglyceric acid occurs by the phosphorylation of glyceric acid with ATP. This reaction is catalyzed by the enzyme, Kinase.
10. The 3 phosphoglyceric acid is an intermediate product of Calvin cycle. If it enters the chloroplast, it is converted into carbohydrate by photosynthesis and it is suppressed.



Factors affecting photosynthesis

External factors

1. Light

It is the most important factor of photosynthesis. Any kind of artificial light such as electric light can induce photosynthesis. Out of the total solar energy, only 1-2 % is used for photosynthesis and the rest is used for other metabolic activities. The effect of light on photosynthesis can be studied under three categories.

i. Light intensity

Wolkoff (1966) found that the rate of photosynthesis is directly proportional to light intensity. But the extremely high light intensities do not favor for higher photosynthetic rates. The high light intensity which fails to accelerate photosynthesis is called light saturation intensity. Of the light falling on a leaf, about 80 per cent is absorbed, 10 per cent is reflected and 10 % is transmitted. The rate of photosynthesis is greater in intense light than in diffused light. The plants are grouped into two types on the basis of light requirement.

Heliophytes (Sun plants)

Sciophytes (Shade plants)

At a specific light intensity, the amount of CO₂ used in photosynthesis and the amount of CO₂ released in respiration are volumetrically equal. This specific light intensity is known as *light compensation point*.

At very high light intensity, beyond a certain point, the photosynthetic cells exhibit *photo oxidation*. This phenomenon is called *solarisation* and a result of this, inactivation of chlorophyll molecules, bleaching of chlorophyll molecules and even inactivation of some enzymes take place resulting in the destruction of whole photosynthetic apparatus. In general, low light intensity favours stomatal closure and in turn reduced rate of photosynthesis.

ii. Light quality (wavelength)

Photosynthesis occurs only in the visible part of the light spectrum i.e., between 400 and 700 nm. The maximum rate of photosynthesis occurs at red light followed by blue light.

The green light has minimum effect and photosynthesis cannot take place either in the infrared or in the ultraviolet light.

iii. Light duration

In general tropical plants get 10-12 hours of light per day and this longer period of light favours photosynthesis.

2. Carbon dioxide

CO₂ is one of the raw materials required for photosynthesis. If the CO₂ concentration is increased at optimum temperature and light intensity, the rate of photosynthesis increases. But, it is also reported that very high concentration of CO₂ is toxic to plants inhibiting photosynthesis.



3. Temperature

The rate of photosynthesis increases by increase in temperature up to 40 °C and after this, there is reduction in photosynthesis. High temperature results in the denaturation of enzymes and thus, the dark reaction is affected. The temperature requirement for optimum photosynthesis varies with the plant species. For example, photosynthesis stops in many plants at 0°C but in some conifers, it can occur even at -35°C. Similarly, photosynthesis stops beyond 40-50 °C in certain plants; but certain bacteria and blue green algae can perform photosynthesis even at 70 °C.

4. Water

Water has indirect effect on the rate of photosynthesis although it is one of the raw materials for the process. The amount of water utilized in photosynthesis is quite small and even less than 1 per cent of the water absorbed by a plant. Water rarely acts as a limiting factor for photosynthesis. During water scarcity, the cells become flaccid and the rate of photosynthesis might go down.

5. Oxygen

Oxygen is a byproduct of photosynthesis and an increase in the O₂ concentration in many plants results in a decrease in the rate of photosynthesis. The phenomenon of inhibition of photosynthesis by O₂ was first discovered by Warburg (1920) in green alga *Chlorella* and this effect is known as Warburg's effect. This is commonly observed in C₃ plants.

In plants, there is a close relationship between Warburg's effect and photorespiration. The substrate of photorespiration is glycolate and it is synthesized from some intermediates of Calvin's cycle. In plants that show Warburg's effect, increased O₂ concentration result in diversion of these intermediates of Calvin cycle into the synthesis of glycolate, thereby showing higher rate of photorespiration and lower photosynthetic productivity.

6. Mineral elements

The elements like Mg, Fe, Cu, Cl, Mn, P etc are involved in the key reactions of photosynthesis and hence, the deficiency of any of these nutrients caused reduction in photosynthesis.

7. Chlorophyll content

It is very much essential to trap the light energy. In 1929, Emerson found direct relationship between the chlorophyll content and rate of photosynthesis. In general, the chlorophyll sufficient plants are green in colour showing efficient photosynthesis. The chlorotic leaves due to irregular synthesis of chlorophyll or breakdown of chlorophyll pigment exhibit inefficient photosynthesis.

8. Leaf

The leaf characters such as leaf size, chlorophyll content, number of stomata. Leaf orientation and leaf age are some of the factors that are responsible for photosynthesis. The maximum photosynthetic activity is usually seen in the physiologically functional and full size leaves (usually third/fourth leaf from the tip of the shoot system).



9. Carbohydrates

If the accumulated carbohydrates are not translocated, the photosynthetic rate is reduced and respiration is increased. Sugar is converted into starch and gets accumulated in the chloroplasts. This reduces the effective surface in the chloroplast and the rate of photosynthesis is decreased.

10. Phytohormones

Treharne (1970) reported first that photosynthesis may be regulated by plant hormone system. He found that gibberellic acid and cytokinin increase the carboxylation activity and photosynthetic rates. Meidner (1967) also reported that kinetin @ 3µm causes 12 per cent increase in photosynthesis within one hour of the treatment.

Respiration in Plants

All living organisms require a continuous supply of energy for their survival. Energy is used to carry out various functions such as uptake of materials, absorption, growth, development, movement and even breathing. About 50% of the energy produced by the cell is utilized by these cellular activities and rest of it is changed into heat and get lost. Now, the question arises from where does this energy comes to carry out all these processes of life.

Introduction:

We eat food in order to obtain energy. The food we eat in the form of macro molecules is oxidized to fulfill energy requirement of body for carrying out all the basic life processes. As we have already studied in last chapter, that only green plants and cyanobacteria can prepare their own food by the process called photosynthesis. They use trapped energy in order to obtain their food by converting light energy into chemical energy, which thereby gets stored into the bonds of carbohydrates such as glucose, sucrose, starch, etc. But all cells, tissues and organs in plants do not photosynthesize instead, photosynthesis takes place in only some parts of plants, i.e., only cells that contain chloroplasts (mostly areas located in superficial layers).

Hence, all other organs, tissues and cells in green plant that are non-green are need food for oxidation. Hence, food has to be translocated from the green parts to the non-green parts for oxidation processes.

Need of Photosynthesis

Animals on the other hand are heterotrophic in nature, i.e., they either obtain their food directly from the plants (herbivores) or indirectly, dependent on herbivores for their food (carnivores). Saprophytes are dependent on dead and decaying matter for their food (e.g., Fungi). Thus, it can be concluded that all the food that is respired for life processes ultimately comes from photosynthesis.



Cellular Respiration

Cellular respiration or the mechanism of breakdown of food materials within-the cell to release energy and trapping the same energy for synthesis of ATP. Respiration is the process of breaking of the C-C bonds of complex compounds through oxidation within the cells, leading to release of considerable amount of energy. It is to be noted that site of breaking down of complex molecules to yield energy is cytoplasm and mitochondria (also only in eukaryotes) which is different from the site of photosynthesis, which is chloroplast in plants.

Respiratory Substrates

The compounds that are oxidized during the process of respiration are called respiratory substrates. Carbohydrates are used as major respiratory substrates are oxidized in high amounts, to release energy, but under some conditions in some plants, proteins, fats and organic acids are also used as respiratory substrates.

Differences between Respiration and Combustion

Respiration	Combustion
It is the breakdown of complex compounds through oxidation within the cells, leading to release of considerable amount of energy.	Combustion is the complete burning of glucose, which produces CO ₂ and H ₂ O and yield energy which is given out as heat.
It is a controlled biochemical process.	It is an uncontrolled physico-chemical process.
Many chemical bonds break simultaneously releasing large amount of energy.	Chemical bonds break one after another to release energy.
Enzymes are involved.	Enzymes are not involved.
Only a part of energy is lost as heat.	Most of the energy is liberated as heat.
A number of intermediates are formed for the synthesis of different organic compounds.	No intermediates are produced in this case.

ATP: Energy Currency of the Cell

During the process of oxidation of food within a cell, all the energy contained in the respiratory substrates are not released free into the cell, or in a single step. Instead it gets released in a series of step-wise reactions controlled by enzymes and is trapped as chemical energy in the form of ATP.

Hence, the energy released in respiration by the process of oxidation is not used directly but is used in synthesizing ATP (which is utilized whenever energy needs to be utilized). Thus, it is said that ATP acts as the energy currency of the cell. The energy trapped in



ATP is utilized in many energy requiring processes of the organisms, and the carbon skeleton produced during respiration is used as precursors for the biosynthesis of other molecules in a cell.

Do Plants Breathe: Exchange of Gases in Plants

For the process of respiration, plant takes O_2 and releases CO_2 . Plants have stomata and lenticels for gaseous exchange instead of specialized organs that are present in animals for exchange of gases.

Types of Respiration

We know that during the process of respiration, utilization of O_2 takes place with the release of CO_2 , water and energy as products. According to the dependence of cells on oxygen, cellular respiration may be classified into two types as given below

Aerobic Respiration

This is the type of respiration in which organism utilize oxygen for the complete oxidation of organic food into CO_2 and water. It occurs inside the mitochondria. Aerobic respiration yields more energy as the respiratory substrate gets completely oxidized in the presence of O_2 .

Anaerobic Respiration

This is the type of respiration in which organic food is oxidized incompletely without utilizing energy as oxidant. It occurs in cytoplasm and often releases small amount of energy.

It is believed that the first cells on this planet lived in an oxygen free environment, i.e., they were anaerobes. Even among present day living organisms, several are adapted to anaerobic conditions. Some of them are facultative anaerobes (organisms that have capability of switching from aerobic to anaerobic conditions according to the availability of oxygen) while others are obligate anaerobes (organisms that are killed by normal atmospheric concentration of oxygen of 21%).

Thus, in any case, all living organisms retain the enzymatic machinery for partial oxidation of glucose in the absence of oxygen. And this breakdown of glucose to pyruvic acid is called glycolysis.

Mechanism of respiration

Cellular respiration occurs inside the cell and proceeds with the help of enzymes. The first step in respiration (taking glucose as substrate) is the glycolysis (glucose oxidized to pyruvic acid). After which the pyruvic acid may enter the Krebs' cycle (aerobic respiration) or undergo fermentation (anaerobic respiration).



Glycolysis

Glycolysis (Greek. *Glycos* means sugar; *lysis* means splitting) is a step-wise process by which one molecule of glucose (6C) breaks down into two molecules of pyruvic acid (3C).

The scheme of glycolysis was given by Gustav Embden, Otto Meyerhof and J Parnas and is often referred as the EMP pathway. It is a common pathway in both aerobic and anaerobic modes of respiration. But in case of anaerobic organisms, it is the only process of respiration.

Glycolysis occurs in the cytoplasm of the cell. During the process glucose gets partially oxidised. In plants this glucose is derived from sucrose (end product of photosynthesis) or from storage carbohydrates. During the course of process in plant this sucrose is first converted into glucose and fructose by the action of invertase enzyme after this, these two monosaccharides enter the glycolytic pathway.

Steps Involved in Glycolysis

In glycolysis, a chain of following 10 biochemical reactions occur under the control of different enzymes.

Step I: Phosphorylation of glucose occur under the action of an enzyme hexokinase and Mg^{2+} that gives rise to glucose-6-phosphate by the utilization of ATP.

Step II: Isomerization of this phosphorylated glucose-6-phosphate takes place to form fructose-6-phosphate with the help of an enzyme phosphohexose isomerase (Reversible Reaction).

Step III: This fructose-6-phosphate is again phosphorylated by ATP in order to form fructose 1, 6-bisphosphate in the presence of an enzyme phosphofructokinase and Mg^{2+} . The steps of phosphorylation of glucose to fructose 1, 6-bisphosphate (i.e., from step 1 to 3) activates the sugar thus, preventing it from getting out of the cell.

Step IV: Splitting of fructose 1, 6-bisphosphate takes place into two triose phosphate molecules, i.e., dihydroxyacetone 3-phosphate and 3-phosphoglyceraldehyde (i.e., PGAL). This reaction is catalyzed by an enzyme aldolase.

Step V: Dihydroxyacetone 3-phosphate and 3-phosphoglyceraldehyde (i.e., PGAL) are isomers of each other. During glycolysis, all the dihydroxyacetone 3-phosphate is converted to 3-phosphoglyceraldehyde (i.e., PGAL) by the enzyme triose phosphate isomerase.

Step VI: Each molecule of PGAL removes two redox equivalents in the form of hydrogen atom and transfer them to a molecule of NAD^+ (This NAD^+ forms $NADH + H^+$) and accepts inorganic phosphate (Pi) from phosphoric acid. This reaction in turn leads to the conversion to PGAL (which gets oxidized) to 1, 3-bisphosphoglycerate (BPGA) (Reversible reaction).

Step VII: 1, 3-bisphosphoglycerate is converted to 3-phosphoglycerate with the formation of ATP. This reaction is catalyzed by an enzyme phosphoglycerate kinase. It is



also known as energy yielding process. The formation of ATP directly from metabolites constitutes substrate level phosphorylation (Reversible reaction).

Step VIII: In the next step, 3-phosphoglycerate is subsequently isomerized to form 2-phosphoglycerate, catalyzed by enzyme phosphoglyceromutase (Reversible reaction).

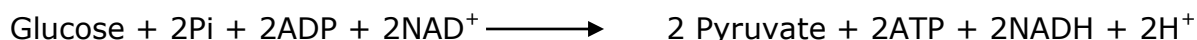
Step IX: In the presence of enzyme enolase and Mg^{2+} , with the loss of a water molecule, 2-phosphoglycerate is converted to Phosphoenol Pyruvate (PEP) (Reversible reaction).

Step X: High energy phosphate group of Phosphoenol Pyruvate (PEP) is transferred to a molecule of ADP, by the action of enzyme pyruvate kinase in the presence of Mg^{2+} and K^+ . This in turn produces two molecules of pyruvic acid (pyruvate) and a molecule of ATP by substrate level phosphorylation. The pyruvic acid thus, produced is the key product of glycolysis.

Metabolic Fate of Glycolysis

Glycolysis has two phases, i.e., preparatory (glucose is broken down to glyceraldehyde-3-phosphate) and pay off phase (the GAL-3-P is changed into pyruvate) producing NADH and ATP.

The overall reaction of glycolysis can be depicted as:



Two molecules of NADH on oxidation produce 6 molecules of ATP. Therefore, a net gain of 8ATP molecules occurs during glycolysis.

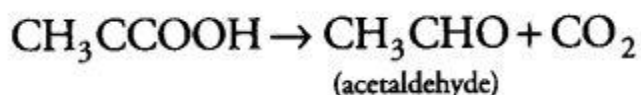
The fate of the end product of glycolysis (pyruvate) depends upon the availability of oxygen in the cell. In the presence of oxygen, pyruvic acid will enter the mitochondrion and undergo complete oxidation of glucose to CO_2 and H_2O in aerobic respiration (Krebs' cycle). On the other hand, in the absence of oxygen, the pyruvic acid will undergo anaerobic respiration (lactic acid fermentation or alcoholic fermentation).

Fermentation

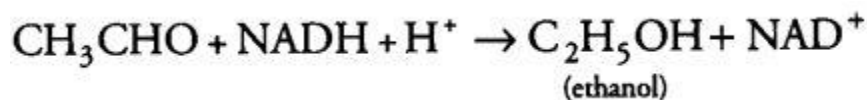
Various microorganisms like yeast & bacteria and even animals and plants are sometimes known to catabolize pyruvic acid incompletely into various organic compounds depending upon the specific enzymes they possess.

Types of anaerobic respiration:

- Alcoholic fermentation: In fungi (e.g., yeast), and some higher plants, the incomplete oxidation of glucose is achieved under anaerobic condition in which pyruvic acid is converted into CO_2 and ethanol. It is done under two steps. Initially pyruvic acid is first decarboxylated to acetaldehyde in the presence of enzyme pyruvic acid decarboxylase.



This acetaldehyde is then further reduced to ethyl alcohol or ethanol in the presence of enzyme, i.e., alcohol dehydrogenase.



- ii. Lactic acid fermentation: Organisms like bacteria produce lactic acid as an end product from pyruvic acid. During the reduction, the pyruvic acid produced in glycolysis is reduced by NADH_2 to form lactic acid, CO_2 is not produced and NADH_2 is oxidized to NAD^+ . This reaction is catalyzed by a lactic acid dehydrogenase, FMN proteins and Zn^{2+} ions.

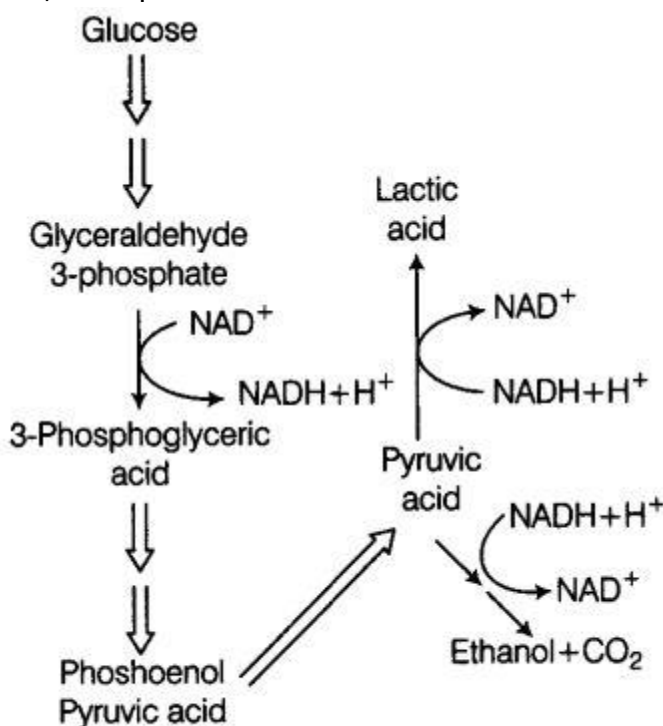


Fig 14.2 Major pathways of anaerobic respiration

Likewise, in case of animal cells also (such as muscles) during exercise, when there is inadequate amount of oxygen for cellular respiration, pyruvic acid is reduced to lactic acid by lactate dehydrogenase.

Thus, in both the processes reoxidation of reducing ($\text{NADH} + \text{H}^+$) agent takes place.

Energy Yield in Fermentation

In both alcoholic and lactic acid fermentation, the energy released is very less, i.e., not more than 7% of the energy is released from glucose and not all of it is trapped as high energy bonds of ATP. Also, the fermentation processes are proved to be hazardous in nature because either acid or alcohol is produced on oxidation. Apart from this, yeasts may also poison themselves to death if the concentration of alcohol reaches about 13%. Drawback of this process is that organisms cannot carry out complete oxidation of



glucose and are also unable to extract out the energy stored to synthesize a larger number of ATP molecules required for cellular metabolism.

Aerobic Respiration

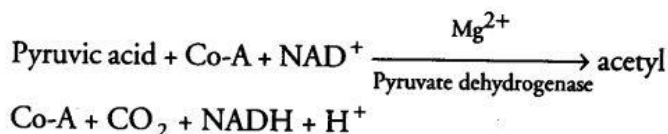
Aerobic respiration is the next step (after glycolysis) that leads to complete oxidation of organic substances. It occurs in the presence of oxygen. The oxygen acts as a final acceptor of electron and protons are removed from the substrate. For aerobic respiration to take place within the mitochondria, the final product of glycolysis, i.e., pyruvic acid is transported into from the cytoplasm mitochondria and thus, the second phase of respiration is initiated.

The process of aerobic respiration involves two crucial events:

- The complete oxidation of pyruvate occurs by the step-wise removal of all the hydrogen atoms, thereby, leaving three molecules of CO₂. This occurs in the matrix of mitochondria.
- The electrons removed as part of the hydrogen atoms are then passed on to molecular O₂ with the simultaneous synthesis of ATP. This on the contrary takes place on the inner membrane of the mitochondria.

Oxidative Decarboxylation of Pyruvic Acid

In mitochondria, pyruvic acid (formed by the glycolytic catabolism of carbohydrates in cytosol) undergoes oxidative decarboxylation (i.e., removal of CO₂ in aerobic conditions) forming a key compound, i.e., acetyl Co-A by the action of pyruvic acid dehydrogenase (in mitochondrial matrix) through a series of reactions.



Thus, acetyl Co-A acts as a connecting link between glycolysis and citric acid cycle. During this process, two molecules of NADH are produced from the metabolism of two molecules of pyruvic acid (produced from one glucose molecule during glycolysis). Tricarboxylic Acid (TCA) Cycle

The acetyl Co-A then enters a cyclic pathway, Krebs cycle (or tricarboxylic acid cycle, TCA) in mitochondrial matrix. Various coenzymes including NAD⁺ and Co-A also participates in the reaction catalyzed by pyruvic acid dehydrogenase. It was first elucidated by Sir Hans Krebs, a British Biochemist in 1940. The whole cycle explains how pyruvate is broken down to CO₂ and water.

Following are the steps of Krebs cycle

- Condensation: The Krebs cycle starts with the condensation of acetyl group with oxaloacetic acid and water to yield citric acid, a 6C compound. This is the first stable product of the cycle. This step is catalyzed by an enzyme citrate synthetase. Co-A is liberated during this reaction.



- ii. Isomerization: Citric acid then undergoes reorganization in two steps in order to form isocitrate in the presence of an enzyme aconitase.
- iii. Dehydrogenation: Isocitrate is converted into oxalosuccinate by the enzyme isocitrate dehydrogenase in presence of Mn^{2+} . This dehydrogenation results in the formation of NADH from NAD^+ .
- iv. Decarboxylation: Oxalosuccinate, a 6C compound undergoes decarboxylation to form a 5C compound known as α -ketoglutaric acid by the enzyme decarboxylase in presence of Mn^{2+} .
- v. Dehydrogenation: α -ketoglutaric acid gets converted to succinyl Co-A by decarboxylation and dehydrogenation. α -ketoglutarate dehydrogenase enzyme complex is required for this reaction. Mg^{2+} , TPP and lipoic acid are required for the functioning of α -ketoglutarate dehydrogenase enzyme complex.
- vi. Substrate level phosphorylation: Succinyl Co-A then splits into a 4C compound succinic acid and Co-A with the addition of water. During this conversion, a molecule of ATP or GTP (guanosine triphosphate). This reaction is catalyzed by an enzyme succinyl Co-A synthetase. ATP is produced in plants while as GTP in animals. GTP is also an energy carrier like ATP. Thus, this is the only high energy phosphate produced in the Krebs cycle.
- vii. Dehydrogenation: Succinyl Co-A is oxidized to fumaric acid by enzymes succinate dehydrogenase. At this step $FADH_2$ is synthesized from FAD^+ .
- viii. Hydration: Fumaric acid undergoes hydration and gets converted to Malate (4C) in presence of the fumarase
- ix. Dehydrogenation: Malate undergoes dehydrogenation and gets converted to oxaloacetic acid (4C). this reaction is catalyzed by the enzyme malate dehydrogenase. At this step, NAD^+ gets converted unto NADH

For continuous oxidation of acetyl Co-A, continued replenishment of oxaloacetic acid is necessary which is continuously synthesized during the Krebs cycle.

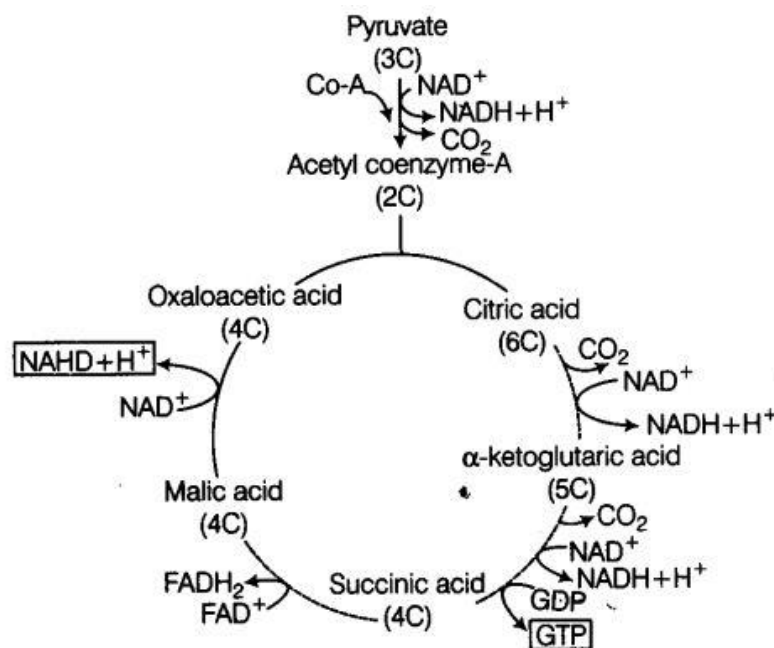


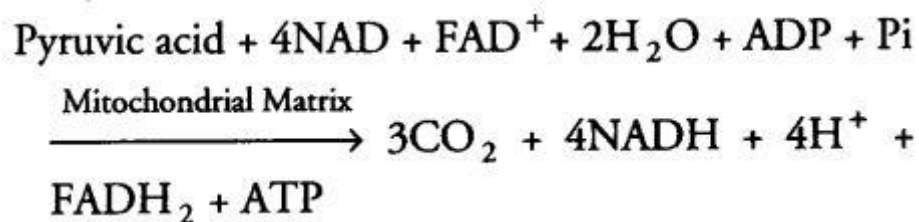
Fig 14.3 The citric acid cycle

Output of Krebs' Cycle or Citric Acid Cycle

From one complete Krebs cycle (for the oxidation of 1 molecule of pyruvate), 3 molecules of NAD⁺ are reduced to NADH + H⁺, one molecule of FAD⁺ is reduced to FADH₂ and one molecule of ADP is reduced directly from ATP (by substrate level phosphorylation).

Thus, for the breakdown of 2 molecules of pyruvate (produced from 1 molecule of glucose) through Krebs cycle, a total of 4 NADH, 2 FADH₂ and 2ATP molecules are generated.

The summary equation for this phase of respiration is as follows:



Till now, glucose has been broken down to release CO₂ and 8 molecules of NADH+H⁺, 2 molecules of FADH₂ and 2 molecules of ATP.

Importance of Citric Acid Cycle

The citric acid cycle is important in the following ways

This is the major pathway for the formation for ATP molecules.

Many intermediate compounds of this cycle are used in the synthesis of other biomolecules.

Differences between glycolysis and Krebs cycle

Glycolysis	Krebs' Cycle
It takes place in the cytoplasm.	It takes place in the matrix of mitochondria.
It is a linear pathway.	It is a cyclic pathway.
It occurs in aerobic as well as anaerobic respiration.	It occurs in aerobic respiration only.
It consumes 2 ATP molecules.	It does not consume ATP.
It yields 2 NADH per glucose molecule.	It yields 6 NADH molecules and 2 FADH ₂ molecules from 2 acetyl coenzyme-A molecules.
It generates 2 ATP molecules net from 1 glucose molecule.	It generates 2 GTP/ATP molecules from 2 acetyl coenzyme-A molecules.
It oxidises glucose partly, producing pyruvate.	It oxidises acetyl coenzyme-A fully.
It does not produce CO ₂ .	It produces CO ₂ .
All enzymes catalysing glycolytic reactions are dissolved in cytosol.	Two enzymes of Krebs' cycle reactions are located in the inner mitochondrial membrane, all others are dissolved in matrix.

Electron transport system and oxidative phosphorylation:

The metabolic pathway, through which the electron passes from one carrier to another, is called Electron transport system. It is present in the inner mitochondrial membrane. ETS comprises of the following main parts:

- ✚ Complex I – NADH Dehydrogenase.
- ✚ Complex II – succinate dehydrogenase.
- ✚ Complex III – cytochromes bc₁
- ✚ Complex IV – Cytochromes a-a₃ (cytochromes c oxidase).
- ✚ Complex V – ATP synthase.

NADH₂ produced in the citric acid cycle oxidized by NADH Dehydrogenase, and electrons are then transferred to ubiquinone located in the inner membrane.

FADH₂ is oxidized by succinate dehydrogenase and transferred electrons to ubiquinone.

The reduced ubiquinone is then oxidized with transfer of electrons to cytochrome c via cytochromes *bc₁* complex.

Cytochrome c is small protein attached to the outer surface of the inner membrane and acts as a mobile carrier for transfer electrons from complex III and complex IV.

When electrons transferred from one carrier to another via complex I to IV in the electron transport chain, they are coupled to ATP synthase for the synthesis of ATP from ADP and Pi.



One molecule of NADH_2 gives rise to 3 ATP.

One molecule of FADH_2 gives rise to 2ATP.

Oxygen plays a vital role in removing electrons and hydrogen ion finally production of H_2O .

Phosphorylation in presence of oxygen is called oxidative phosphorylation.

Total ATP Production -

Process Total ATP produced:

Glycolysis $2\text{ATP} + 2\text{NADH}_2$ (6ATP) = 8ATP

Oxidative decarboxylation 2NADH_2 (6ATP) = 6ATP

Krebs's Cycle 2GTP (2ATP) + 6NADH_2 (18ATP) + 2FADH_2 (4ATP) = 24 ATP

Energy production in prokaryotes during aerobic respiration = 38 ATP

Energy production in eukaryotes during aerobic respiration = $38 - 2 = 36$ ATP (2ATP are used up in transporting 2 molecules of pyruvic acid in mitochondria).

Respiratory Quotient

"Respiratory quotient is the ratio of CO_2 produced to O_2 consumed while food is being metabolized."

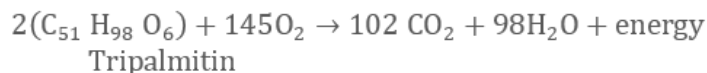
$$\text{RQ} = \frac{\text{Volume of CO}_2 \text{ evolved}}{\text{Volume of O}_2 \text{ consumed}}$$

where RQ stands for Respiratory Quotient. RQ depends on the type of respiratory substrate in respiration. When carbohydrate is the substrate, RQ becomes 1 because it is completely oxidized. It implies that the amounts of O_2 and CO_2 are equal. This reaction is displayed in the figure below –



$$\text{RQ} = \frac{6\text{CO}_2}{6\text{O}_2} = 1.0$$

When respiration uses fats, the RQ becomes less than 1. Following equation shows the calculation of RQ when fatty acid and tripalmitin are used as substrate:



$$\text{RQ} = \frac{102\text{CO}_2}{145\text{O}_2} = 0.7$$

The respiratory quotient is at 0.9 when protein is the respiratory substrates.

Plant Growth and Development

All plant organs are made up of various kinds of tissues which occupy specific locations within an organ and perform specific designated functions. Thus, the development of a plant follows a very precise pattern, during this period complex body organization is formed.

The life of a plant initiates from a single cell called zygote. All the structures of plants such as roots, stems, leaves, flowers, fruits and seeds arise from a single cell in a very orderly sequence.

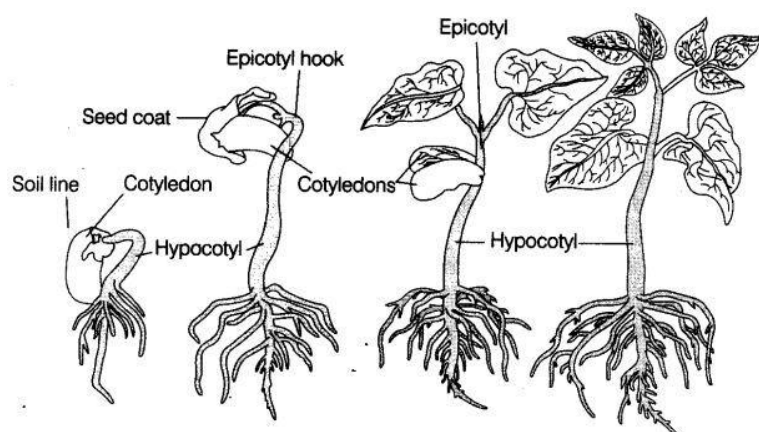


Fig. 15.1 Germination and seedling development in bean

Growth

It is regarded as an essential, fundamental and one of the most conspicuous characteristics of a living being. Growth can be defined as a dynamic, irreversible permanent increase in size of an organ, its parts or even an individual cell. The growth is generally accompanied by the metabolic processes, i.e., anabolic and catabolic reactions occurring in an organism (mainly protein synthesis). Thus, growth in living organism is an intrinsic phenomenon (unlike, non-living organisms in which growth is extrinsic).

Plant Growth Generally is Indeterminate

Growth of plant is unique as they retain the capacity for unlimited growth throughout their life. In plants the growth is generally confined only to the meristematic tissues present at certain locations in the body. Meristems in the plant have certain cells that have the capacity of dividing and self-perpetuation. The new cells produced by the action of division of meristematic cells, soon lose the ability of dividing and make up the plant body. The form of growth in which newly producing cells are always being added to the body of the plant by the activity of meristems is called open form of growth. If the meristem ever ceases to divide, the growth of the plant will not occur and they may undergo a period of dormancy depending upon the seasonal changes in the climate.

Regions of Growth

Apical, lateral and intercalary are the special regions where growth is localized in plants. At the apex of every root and shoot apical meristems are present which are responsible for the elongation of plant along their axis. This is known as primary growth of the plant.

A meristematic tissue consists of a group of cells, which remain in active and continuous state of division, and they retain their power of division. It consists of immature, living, thin-walled cells, which are rich in cytoplasm.

In the mature plant, meristem is also found in intercalary and lateral regions. The lateral meristems, vascular cambium and cork cambium appear later in life in dicotyledonous plants and gymnosperms and are responsible for the increase in the girth of the stem. This increase in girth is known as secondary growth of the plant.

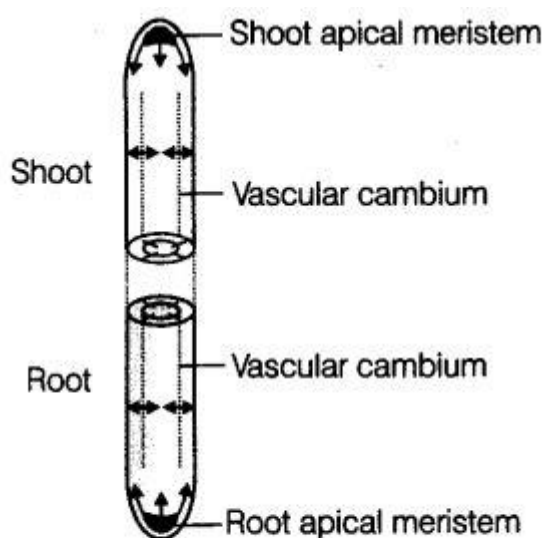


Fig. 15.2 Diagrammatic representation of locations of root apical meristem, shoot apical meristem and vascular cambium. Arrows exhibit the direction of growth of cells and organ

Growth is Measurable

As states that at cellular level, growth is the consequence of increase in the amount of protoplasm. It is difficult to measure the increase in the protoplasm directly, so it can generally be measured by measuring some quantity of it that is more or less proportional to it. Hence, growth can be easily measured by a variety of parameters such as fresh weight, dry weight, leaf Area, volume etc.

Growth can be expressed in terms of increase in the cell number, e.g., Single root apical meristem in maize which give rise to more than 17,500 new cells per hour. It can also be expressed as an increase in the size of the cell, e.g., Cells in watermelon

increases about 3,50,000 times per hour. Growth can be measured in terms of its length, e.g., Pollen tube and can also be measured in terms of surface area, e.g., In a dorsiventral leaf.

Phases of Growth

Under favorable conditions, growth of plant shows a characteristic course. The period of growth is generally divided into three phases. All three phases can be easily understood by taking the example of root tip.

Meristematic Phase

This phase is also known as division phase. The cells that are constantly dividing, i.e., both at the apex of the root and shoot represents the meristematic phase of growth. The cells forming the meristematic phase have various characteristic features like:

- ✚ Rich in protoplasm.
- ✚ Has large conspicuous nuclei.
- ✚ cell walls are primary in nature.
- ✚ Cell wall is thin and cellulosic
- ✚ Cells have numerous plasmodesmatal connections.

Elongation Phase

This phase lies just behind the growing parts, i.e., behind the meristematic zones away from the tip. The cells forming the meristematic phase have various characteristic features like:

- ✚ Increased vacuolation.
- ✚ Enlargement of cell.
- ✚ Deposition of new cell wall.
- ✚ Enlargement of cell during this phase occurs in all direction.
- ✚ Maximum elongation is seen in conducting tissues and fibers.

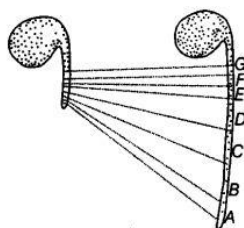


Fig. 15.3 Detection of zones of elongation by the parallel line technique. Zones A, B, C, D immediately behind the apex have elongated most.

Maturation Phase

Just behind the phase of elongation, occurs a phase of maturation. It occurs further away from the apex, i.e., more proximal to the elongation phase. The cells forming the meristematic phase have various characteristic features like:

- ✚ Cells attain maximum thickening of their wall.
- ✚ Protoplasmic modifications are maximum.

Growth Rate

The growth rate is defined as the increased growth per unit time. Rate of growth can be expressed mathematically. It shows increase that may be arithmetic or geometrical in nature.

Arithmetic Growth

Somatic cells increase in number due to mitosis. In this type of growth, following mitotic cell division, only one daughter cell continues to divide, while others follow differentiation and attains maturity.

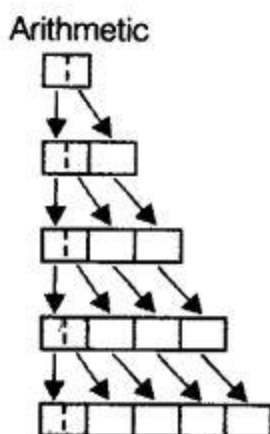


Fig. 15.4 Diagrammatic representation of arithmetic growth

Expression of arithmetic growth can be exemplified by a root elongating at a constant rate. A linear curve is obtained on plotting the length of root against time.

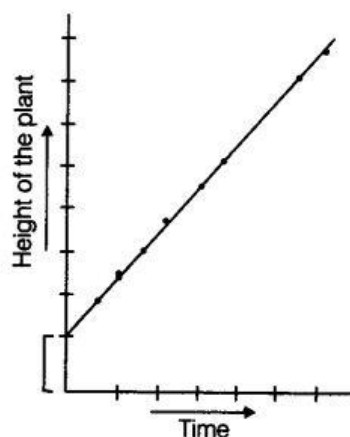


Fig. 15.5 Constant linear growth, a plot of length L against time t

$$L_t = L_0 + rt$$

where L_t = Length at time ' t '

L_0 = Length at time 'zero'

and r = Growth rate/elongation per unit time.

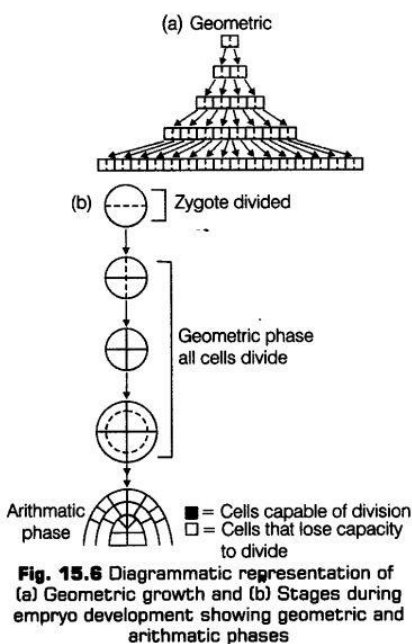
Geometrical Growth

In living organisms, during geometric type of growth rate, pattern follows three important phases

Lag Phase: It is the initial or the beginning phase. It is mainly characterized by very slow growth.

Log Phase: It is also called as exponential phase or grand growth phase. It is the middle phase of the system and is characterized by very fast and rapid growth of the plant body. After initiation of growth, it increases rapidly at an exponential rate. During this phase, both progeny cells undergoing mitotic cell division retain the ability to divide and continue dividing till the next phase appears till the time nutrient supply is appropriate.

Stationary Phase: it is the steady growth phase. This phase occurs when either the plant reaches maturity or the supply of nutrients become limited. Due to these mentioned factors, the growth of the plant slows down to come to a halt.



Under favorable conditions, the characteristic course of growth is observed. Thus, if we plot the parameter of growth rate against time, the typical shaped, a sigmoid curve is seen. It shows a characteristic feature of all living organism growing in a natural environment. This curve is typical for all cells, tissues and organs of a plant.

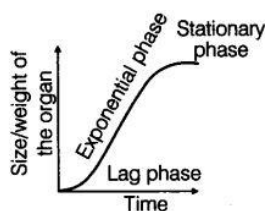


Fig. 15.7 An Ideal sigmoid growth curve typical of cells in culture and many higher plants and plant organs

The exponential growth can be expressed as

$$W_1 = W_0 e^{rt}$$

Where W_1 is the final size (weight/ height, number etc.) W_0 is the size at the beginning of the period, t is the time of growth, e is the base of natural logarithms and r is the relative growth rate that measures the ability of the plant to produce new plant material, known as efficiency index.

The final size (W_1) depends on the initial size (W_0).

Quantitative Comparisons of Growth Rate

The quantitative comparisons between the growth of living systems is done in following two way:

Absolute Growth Rate

It is known to be the measurement and comparison of total growth per unit time.

Relative Growth Rate

It is the growth of the given system per unit time expressed on a common basis, e.g., Per unit initial parameter.

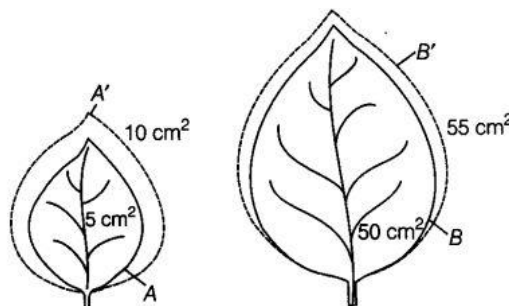


Fig. 15.8 Diagrammatic comparison of absolute and relative growth rate. Both leaves *A* and *B* have increased their area by 5 cm² in a given time to produce *A'* *B'* leaves.

Leaves *A* and *B* shown in the figure have grown 5 cm² in one day. Although their sizes are different, i.e., 5 cm² and 50 cm² respectively but both of them shows absolute increase in area in the given time to give leaves *A* and *B*, i.e., 5 cm² in both cases. Out of these two the relative growth rate is higher or faster in leaf *A*.

Factors affecting plant growth

The growth of a plant is influenced by a variety of external and internal factors. Growth of plant involves synthesis of protoplasm, cell division, cell enlargement and cell differentiation. Some of the factors due to which growth of plants is influenced are mentioned below:

Water:

It is the first and the foremost requirement of the plants for the enlargement of cell, maintaining turgidity of growing cells, for extension of growth. It also acts as a medium for many enzymatic activities. In water stress conditions growth of the plants seems to get retarded.

Oxygen:

It helps in releasing metabolic energy essential for growth activities.

Nutrients

These acts as (macro and micro essential nutrients) major raw materials for protoplasmic synthesis and also acts as a source of energy. However, under nutrient deficient conditions the growth of the plant is affected.

Light

The requirement of the light to the plants for its growth is called photoperiodism. It helps in



synthesis of food. It also determines the root and shoot growth. Along with light, gravity also serves as an environmental signal that affects certain phases/stages of growth.

Temperature

For normal and appropriate growth of plant optimum temperature range is necessary, i.e., 25-30°C (this happens because enzymatic reactions are very fast at optimum temperature range).

Plant Development:

Differentiation:

During growth, meristematic cell divides by mitotic division to form daughter cells. The cells from root and shoot apical meristem, cambium or other meristems tend to differentiate and mature to perform specific functions. This act leading to maturation is known as differentiation. e.g., Cell tends to lose their protoplasm, in order to form tracheary element. These cells also develop a very strong, elastic, lignocellulosic secondary cell wall in order to carry out water to long distance even under extreme conditions.

Dedifferentiation:

The living differentiated cells also show another interesting phenomenon during which they regain the capacity to divide mitotically under certain conditions. The dedifferentiated cell can act as a meristem, e.g., Formation of meristems interfascicular cambium and cork cambium from fully differentiated parenchyma cells.

Redifferentiation:

The products of dedifferentiated cells or tissue when lose the capacity to divide but mature to perform specific functions is known as redifferentiation, e.g., Secondary cortex and cork. Parenchyma cells that are made to divide to form callus under controlled laboratory conditions are examples of dedifferentiated tissue. From the above discussion, it is clear that growth in plants is open in spite of differentiation shown by them. It is so because cells/tissue that arise out of the single or same meristem shows different structures after attaining maturity. Thus, the final structure at maturity of a cell/tissue arising from the same tissue is also determined by the location of the cells, e.g., Cells positioned away from the root apical meristems differentiate as root cap cells, while those which are pushed to the periphery develop and mature as epidermis.

Development

It is the process that includes a series of changes that an organism goes through during its life cycle, i.e., from germination till senescence.

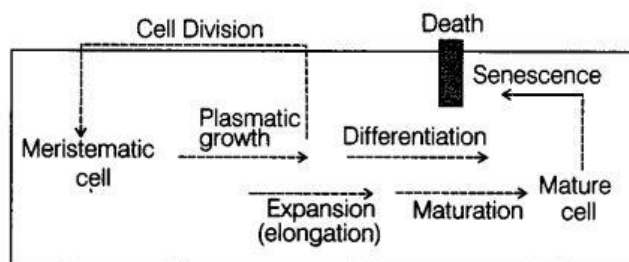


Fig. 15.9 Sequence of the developmental process in a plant cell

In broad terms development is the sum total of both growth and differentiation in plants. The developmental process, of growth and differentiation is controlled by several intrinsic and extrinsic factors. The intrinsic factors includes, both intracellular (genetic) or intercellular factors (such as plant growth regulators). While as the extrinsic factors includes, light, temperature, water, oxygen, nutrition, etc.

Plasticity

Plasticity refers to a phenomenon in which plants follows different pathways in response to environment or phases of life forming different kinds of structures, e.g., Heterophylly, the phenomenon in plants by which more than two types of leaves occurs on the same plant.

Plant Growth Regulators

It has been suggested from sufficient evidences that the plants have certain chemical substances, which help to the control the mechanism of growth in the plant. Plant growth regulators are variously described as plant growth substances, plant hormones or phytohormones. These are the small, simple organic molecules of diverse chemical composition produced naturally in higher plants that controls the growth and other physiological functions. These are required in a very small amount by the plant.

Classification of Plant Growth Regulators (PGR)

On the basis of functions, they perform in a living plant body in broad terms, PGRs are divided into two groups:

Plant Growth Promoters:

PGRs that shows growth promoting activities such as cell division, cell enlargement, tropic growth, pattern formation, flowering, fruiting, seed formation, etc., are called plant growth promoters, e.g., auxins, gibberellins and cytokinins.

Plant Growth Inhibitors:

These perform function in response to wounds and stresses i.e., of biotic and abiotic origin. These are also involved in various growth inhibiting activities like dormancy and abscission, e.g., Absciscic acid. The gaseous form of PGR, i.e., ethylene, can fit in either category and may

function both as promoter and inhibitor. But largely it functions as an inhibitor of growth activities.

Details of Plant Growth Regulators

1. Auxins

This was the first growth hormone to be discovered. It came into existence through the observation of Charles Darwin and his son Francis Darwin. They observed the coleoptiles of canary grass that responded to unilateral illumination by growing towards the source of light (phenomenon known as photoperiodism).

After performing series of experiments, they came to the conclusion that coleoptile tip was the site that has the property of transmittable influence due to which bending of complete coleoptile was caused. The first PGR i.e., auxin was isolated by FW Went in 1928, from coleoptile tip of oat seedlings.

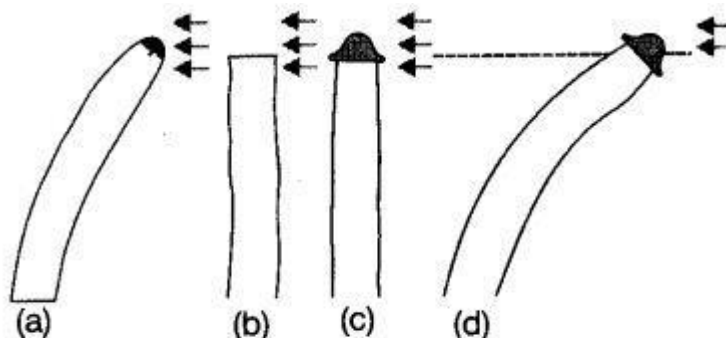


Fig. 15.10 Experiment used to demonstrate that tip of the coleoptile is the source of auxin. Arrows indicate direction of light

Auxin (Gk. Auxein: to grow) was initially isolated from the urine of human, but later on, their presence was also found in plants and was proved to be the first PGR ever known. The real plant auxin is chemically known as Indole-3-acetic Acid (IAA).

The term is also applied to other natural and synthetic compounds having various growth regulating properties. Production of auxin generally takes place in the region of growing apices of the stems and roots from where they migrate to the site of their action.

Auxins can move only through cell to cell by diffusion, i.e., they cannot move through vascular tissues.

Types of Auxins: There are generally two basic categories in which auxins are divided:

Natural Auxins: They occur naturally in plants and fungi e.g., Indole Acetic Acid (IAA) and Indole Butyric Acid (IBA).

Synthetic Auxins: These are prepared from synthetic compounds that causes several responses similar to natural auxins. They can easily move in all directions inside the plants, e.g.,



Naphthalene Acetic Acid (NAA), 2, 4- dichlorophenoxyacetic acid (2, 4-D), 2, 4, 5-trichlorophenoxyacetic acid (2, 4, 5-D). All these types of auxins are extensively been used in agricultural and horticultural practices.

The compounds, which can be converted into auxins, are called auxin precursors, e.g., IAA is synthesized from an aminoacid tryptophan.

Functions of Auxins

Auxins performs several physiological functions in the plants such as:

- i. Cell Elongation: Auxin stimulate the elongation of cells of shoots.
- ii. Initiation of Roots: In contrast to stem, higher concentration of auxin inhibits the elongation of shoots, but it initiates more lateral branches of roots.
- iii. Inhibition of Abscission: Natural auxins delay abscission of young fruits and leaves and also used to control pre-harvest fruit drop.
- iv. Apical Dominance: Presence of auxin in higher concentration (in higher plants) in shoot apex, promotes apical dominance. It is been seen commonly in many vascular plants, that presence of apical buds does not allow the lateral buds to grow. They only start developing into branches when the apical bud is removed.
- v. Promotes Flowering: Presence of auxin helps in promoting flowering in pineapple litchi, etc.
- vi. Parthenocarpy: Auxins are applied to unpollinated pistil and make them develop into seedless fruits, which carry a better market value.
- vii. Metabolism: Application of auxin can enhance metabolism due to mobilization of plant resources.
- viii. Eradication of Weeds: Auxins are used as weedicides and herbicides. Application of 2, 4-dichlorophenoxyacetic acid (2, 4-D) is widely done in order to kill dicotyledonous weeds. It does not affect mature, monocotyledonous plants.
- ix. Helps in Cell Division: Besides cell elongation auxin may also be active in cell division.
- x. Controls Xylem and Phloem Differentiation: Auxin controls differentiation of xylem and phloem in stems and roots. There are evidences that low concentration of auxin induces phloem differentiation while higher concentration of auxin is responsible for differentiation of both xylem and phloem tissues.

2. Gibberellins

In early part of 20 century. The bakanae (foolish seedlings), was reported to be caused by a fungal pathogen *Gibberella fujikuroi*, symptoms shown by the plant were elongated stems, little or no production of grains and plant became weak thus, it was later identified that the



active substance was gibberellic acid. The Japanese plant pathologist E. Kurosawa, reported the appearance of symptoms of the disease in uninfected rice seedlings when they were treated with sterile filtrate of fungus.

There are more than 100 different gibberellins reported from widely different organisms like fungi and higher plants. All of them are known to be slightly acidic in nature. thus, they are termed as Gibberellic Adds (i.e., GA, GA₁, GA₂ and so on). However, GA₃ is the most important gibberellic acid which was first to be discovered. It was most extensively studied.

Functions of Gibberellins

Gibberellins show various important physiological effects:

- i. Elongation of Internodes: It elongate the internodes so, as to increase the height of the plant. They cause an increase in length of axis and is also used in increasing length of grapes stalks.
- ii. Elongation of Genetically Dwarf Plants: It has been seen that if gibberellins are administered to a dwarf plant (pea, maize, etc), it may help in overcoming dwarfism. It also causes fruits to elongate and improve their shape, e.g., in apples etc.
- iii. Bolting and Flowering: The gibberellins also helps in promoting bolting (internode elongation) just prior to their reproductive phase or flowering. This is seen in rosette plants like beet, cabbage as these plants shows retarded internodal growth and profuse leaf development. Rosette plants require either long days or cold night for bolting process and for the initiation of flowering.
- iv. Breaking Dormancy: It also helps in overcoming natural dormancy of buds, tubers, seeds, etc. and allows them to grow.
- v. Flowering: This can also be induced in long day plants by the action of gibberellins.
- vi. Delays Senescence: Gibberellins can delay the ripening of fruits such as Citrus fruits, apples, etc. This can be also used for safe and prolonged storage of the fruits.
- vii. Malting Process: The process of malting in brewing industry can be speedup by the use of GA₃.
- viii. Sugar Yield: As carbohydrate is stored in the form of sugar in the stems of sugarcane. Thus, if crop of sugarcane is sprayed with gibberellins. It results in increased length of the stem. This, enhance, increases the yield of sugarcane as much as 20 tons per acre.
- ix. Early Seed Production like and when sprayed on juvenile conifers, hastens the maturity period of them leading to early seed production.

3. Cytokinins

F Skoog and his coworkers, while studying the nutritional requirements of tissue culture derived from the internodal segments of tobacco stems, observed that from that internodal segments, a callus (i.e., a mass of undifferentiated cells) proliferated, only when the nutrient medium containing auxin was supplemented with the extract of vascular tissues or yeast or



coconut milk (water of endosperm of coconut) or DNA. It was later found that the active substances were a modified form of adenine which was crystallized and identified as Kinetin. Further the compounds that exhibited kinetin like properties were termed as cytokinins.

These are growth promoters that are basic in nature. They have specific effects on cytokinesis (division of cytoplasm) and were discovered as kinetin (a modified form of adenine, a purine). Lethom et. al., (1964) while searching for a substance with cytokinin like activity isolated Zeatin from corn kernels and coconut milk. Now presently, several naturally occurring cytokinins and some synthetic compounds having cell division promoting activities have been identified after the discovery of Zeatin.

Natural cytokinins are known to be synthesized in the regions where rapid cell division takes place, e.g., root apex, developing shoot buds, young fruits, etc., out of these roots are the major source of synthesis of cytokinins, from where, they move upwards through xylem. The liquid endosperm of coconut is known as coconut milk. This contains some factors, that shows kinetin like activity and enhance, stimulate the growth in many plant tissues (in vitro). Zeatin is also a naturally occurring cytokinin isolated from maize grains. It is remarkably known to be more active than any other cytokinin.

Functions of Cytokinins

Cytokinins have following remarkable physiological effects:

- i. Promotes cell division: This is one of the most common and important biological effect of kinetin on plants, i.e., to induce cell division in the presence of sufficient amount of auxin (IAA).
- ii. Reduces apical dominance: They promote the growth of lateral buds by breaking apical dominance.
- iii. Morphogenesis: Differentiation or morphogenesis of plants tissues/organs is seen to be in control, if ratio of cytokinins and auxins is proportionate.
- iv. Resistance: They also increase resistance of plants to high or low temperature and diseases.
- v. Delays senescence These also helps in delaying senescence (ageing) of leaves and other organs by controlling synthesis of protein and mobilization of resources or nutrients.
- vi. Tissue culture: Cytokinins are essential for tissue culture; apart from cell division they are also involved in morphogenesis.
- vii. Shelf life: Administration of cytokinins to harvest fruits and vegetables keeps them fresh for several days and increase their shelf life. Shelf life of flowers and cut shoots can also be increased by using cytokines.

4. Ethylene



Cousins (1910), confirmed the release of a volatile substance from ripened oranges that enhance the ripening of stored unripen bananas. This volatile substance was later identified to be a gaseous plant growth regulator, i.e., ethylene.

It is a simple gaseous plant growth regulator, which is synthesized from the amino acid methionine. In plants synthesis of ethylene takes place in almost every part of the plant, i.e., roots, leaves, flowers, seeds, fruits, etc. Most important effect of ethylene is promotion of senescent changes in the plant. Thus, it is synthesized by tissue in large amounts that undergo senescence and also by ripening fruits due to this property it is also known as fruit ripening hormone. As ethylene is a volatile substance, its production in one plant may influence the growth of other plants near to it.



Functions of Ethylene:

Ethylene shows various important physiological effects:

- i. In dicot seedlings, ethylene influences the horizontal growth of seedling, swelling of the axis and formation of apical hook.
- ii. It is highly effective in fruit ripening. It also increases the rate of respiration. This rise in the respiration rate is called respiratory climacteric.
- iii. Helps in breaking seed and bud dormancy.
- iv. Initiation of germination in peanut seeds and sprouting of potato tubers is also due to the production of ethylene in plants.
- v. In deep water rice plants, ethylene promotes rapid internode petiole elongation.
- vi. It proves to be helpful in increasing absorption surface of plants by promoting growth of root and formation of root hairs.
- vii. It also stimulates flowering in fruits like pineapple, mango and other related plants.
- viii. Ethylene apart from so many positive responses also has negative feedback.
- ix. Release of ethylene commonly inhibits the synthesis of auxins.
- x. Ethylene is known to control fruit ripening in various fruits like tomatoes and apples.
- xi. It also helps in accelerating abscission in flowers and fruits (causes thinning of fruits like cotton, cherry, walnut, etc.).
- xii. Helps in promoting female flowers enhance, the yield of the fruits, e.g., Cucumber.

As ethylene helps in regulating these many physiological processes in plants. It is known to be the most widely used PGR in agricultural field.

Ethephon: It is the most widely used compound as a source of ethylene. This tends to absorb readily in an aqueous solution and transported within the plant. This slowly releases ethylene.

5. Absciscic Acid

With the progression in the research on plant growth regulators three independent researchers reported the purification and chemical characterization of three different kinds of inhibitors (during mid 1960), i.e., inhibitor B, abscission II and dormin. Later, three were proved to be chemically identical in nature and were named Absciscic Acid (ABA).

It is slightly acidic growth hormone that functions as a growth inhibitor by interacting with other mentioned growth hormones, i.e., auxins, gibberellins and cytokinins. Thus, like other PGR, absciscic acid also has a wide range of effects on growth and development of plants.

As its production is stimulated under stress (unfavorable conditions such as drought, water lodging, excessive temperature, etc.). Thus, it is known as stress hormone. It acts antagonistically to gibberellic acid. This hormone is transported to all parts of the plants through the process of diffusion by conductive channels.



Functions of Absciscic Acid

Absciscic acid shows various important physiological effects:

- i. It has a primary role in regulating abscission and dormancy of buds and seeds. By inducing dormancy, it helps the seeds to withstand the desiccation and other factors related to unfavorable growth.
- ii. It acts as a general plant growth inhibitor and also inhibits metabolism of plants.
- iii. It has its role in inhibition of seed germination.
- iv. Also plays an important role in seed development and maturation.
- v. Absciscic acid stimulates the closure of stomata.
- vi. Absciscic acid is also known as dormin as promotes several kinds of dormancy in plants.

The Mechanism of Stomatal closing by ABA:

ABA binds to receptors of the plasma membrane at the surface of the guard cells. The receptors in turn activate several interconnecting pathways, which causes a rise in pH in the cytosol promoting the transfer of Ca^{+2} from the vacuole to the cytosol. All this causes stomata to close, and opening of stomata occurs when conditions are just reverse to it. Interaction between Growth Regulators

For the regulation of every phase of growth, i.e., for differentiation and developmental processes in plants two or more phytohormones are intimately related to each other. These can either act synergistically or antagonistically.

Thus, every PGR has one or the other role to play. Likewise, there are also number of events in the life of a plant where more than one PGR is also involved to affect that particular event to takes place, e.g.,

- i. Dormancy of seeds and buds is mostly due to absciscic acid, while it is broken down by gibberellins.
- ii. Auxins and cytokinins acts antagonistically in controlling apical dominance, i.e., auxins cause apical dominance, while cytokinins helps to overcome them.
- iii. Senescence is prevented by both auxins and cytokinins, while its stimulation is done by absciscic acid.
- iv. Auxins and cytokinins acts synergistic in promoting cell division

Photoperiodism

Have you ever wondered why certain flowers bloom only in certain seasons? Why do we get certain fruits in one particular season and not the others? This is because seasonal changes involve changes in the length of day and night and some plants need a certain amount of light to flower. This is photoperiodism. Photoperiodism applies not only to plants but animals too.



‘Photo’ means ‘light’ and ‘period’ means ‘length of time’. Therefore, by definition, photoperiodism is the reaction of plants and animals to the length of day and night.

Photoperiodism in Plants:

Most flowering plants have the ability to sense changes in season (i.e. the length of day and night) and flower at the right time. To do this, they make use of photoreceptor (light-sensitive) proteins called ‘phytochrome’.

Plants need exposure to light for a ‘critical duration’. This duration is different for different plants. Based on this critical duration, plants can fall into the following three categories:

1. Long Day Plants (LDP)

- i. These plants flower when the days are longer.
- ii. They require more than the critical duration of light to flower (usually 14-16 hours).
- iii. The light period is very critical in LDP plants. Prolongation of the light period or a brief exposure to light during the dark period boosts flowering in these plants.
- iv. One usually does not find LDP plants in places where the length of a day is too short.
- v. They are also called ‘Short Night Plants’.
- vi. Examples – spinach, radish, hibiscus etc.

2. Short Day Plants (SDP)

- i. These plants flower when the days are shorter.
- ii. They need less than the critical duration of light (about 8-10 hours) and a continuous dark period (about 14-16 hours) to flower.
- iii. The dark period is very critical for SDP plants and has to be continuous. These plants will not flower if the dark period is briefly interrupted by light.
- iv. SDP plants are usually not found in places where the length of a day is too long.
- v. They are also called ‘Long Night Plants’.
- vi. Examples – soybean, tobacco, chrysanthemum etc.

3. Day Neutral Plants (DNP)

- i. These plants do not follow this restriction of critical duration.
- ii. In other words, they are ‘neutral’ to the length of day or night.
- iii. Examples – tomatoes, pea plants, rose etc.

Vernalization:

Are plants only dependent on light to flower and germinate? Is there any other factor that influences flowering? Yes! In addition to light, another factor that influences flowering in plants is temperature. This dependency on temperature is Vernalization.



Vernalization is defined as the qualitative or quantitative dependence of plants on exposure to a low temperature to flower. Temperature affects flowering, metabolic activities, and germination of seeds in plants.

Plants that grow in mild weather germinate at low temperatures whereas those that grow in hot regions germinate at high temperatures. Some plants need exposure to a low temperature to germinate. Furthermore, a plant can be induced to flower in a growing season by exposing it to low temperature. Therefore, it shortens the vegetative phase and hastens flowering in plants.

Examples of Vernalization

Food plants such as wheat and barley have a 'spring variety' and a 'winter variety'. The 'spring variety' is usually planted in the spring season. As a result, it flowers and produces grains by the end of the growing season. The 'winter variety', however, is planted in autumn. It germinates over winter, grows in the spring and is harvested in summer. In contrast to the spring variety, the winter variety will not flower or produce grains within the flowering season if planted in spring.

Biennial plants are plants that take two years to flower. They grow leaves, stem, and roots in the first year and then enter a period of dormancy in the cold months. They need this period of cold or vernalization to flower in the subsequent months. Eventually, biennial plants flower, produce fruit and die in the next spring/summer. Examples are carrots, sugarbeet, and cabbages.

Factors Needed for Vernalization

- i. Low Temperature: 50 day treatment between 2°C and 12°C.
- ii. Water: Plants need proper hydration to receive the stimulus from cold temperatures.
- iii. Actively dividing cells: For vernalization to work the cells need to be actively dividing. It does not work on dry seeds and therefore, the seeds need to be moist before exposure to low temperature.
- iv. Nutrients
- v. Aerobic respiration

Site of Vernalization

The site that perceives the cold stimulus can be different in different plants. It could be the apical meristem in the shoots, the germinating seed or the vegetative parts such as leaves.

Advantages

- i. Prevents plants from maturing too early in the growing season. Therefore, they get enough time to mature.
- ii. Induces early flowering and reduces the vegetative phase of plants.
- iii. It increases yield in plants.
- iv. Provides resistance to cold and diseases.
- v. It enables biennial plants to behave like annual plants.
- vi. Vernalization allows plants to grow in regions they normally do not grow.
- vii. Also, it helps to remove the wrinkles on kernels of *Triticale* (wheat and rye hybrid).



Further Readings:

6. Biology, Textbook for Class XI, NCERT
7. www.easybiologyclass.com
8. www.biologydiscussion.com
9. www.botanystudies.com
10. www.britannica.com