BUREAU'S

HIGHER SECONDARY (+2)

BIOLOGY

|Vol.-1|

Approved by Council of Higher Secondary Education, Odisha, Bhubaneswar

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FOREWORD

Modern life is changing very fast. Keeping pace with it the life science or Biology, its syllabus and even the examination pattern in the national level has also been restructured. Aim is to create the best manpower who can understand Biology, the problems of modern man and other organisms perfectly well and tackle it adequately.

The Council of Higher Secondary Education, Odisha in its maiden attempt integrated the Botany and Zoology syllabi together, to create the new syllabus of Biology. This has been done to inculcate the nuances of the subject in systematic and cohenent manner as per the standard prescribed be National Council of Education, Research & Training, New Delhi.

It gives me immense pleasure to note the publication of Bureau's Higher Secondary (+2) Biology Vol.-I. The board of writers have done a tremendous work in the preparation of the book with upto date concepts in very simplified version. I am specifically thankful to Dr. B. K. Choudhury and Dr. P. K. Mohanty who have devoted a lot of time in final proof reading, revision of chapters and setting up labelled diagrams at the appropriate places in the book. The board of reviewers comprising Dr. Manoranjan Kar, Dr. Baman Chandra Acharya, Dr. Basanta Kumar Choudhury, Dr. Subash Chandra Das and Dr. Pradeep Kumar Mohanty have devoted their valuable time in reading all the chapters, correcting the concepts and enriching the book in all the aspects, so that it can cater to the needs of our higher secondary students.

Firstly I thank all the employees of our Bureau and the DTP operator, Shri Ashok Kumar Ojha and the press, Print-tech Offset Pvt. Ltd., Bhubaneswar for the publication of the book. I am very much thankful to our Deputy Director, Shri Biraj Bhusan Mohanty for his sincere efforts in co-ordinating in this maiden venture of publishing a Biology book in +2 level.

My sincere thanks to the Principal Secretary in the Department of Higher Secondary Education, Govt of Odisha for his interest in the publication of the book. I am also grateful to the Chairman, CHSE, Odisha for awarding the Bureau the task of preparation and publication of this Biology book. The Bureau is also indebted to the syllabus committee for selecting the writers and recommending this book as the one and only prescribed text book for our higher secondary students. The bureau will humbly appreciate the constructive comments and suggestions to improve the standard of the book.

Director
Odisha State Bureau of Textbook
Preparation and Production
Bhubaneswar

PREFACE

In the preceding centuries we have talked about space, the atmosphere and the Earth. Our focus has been on the space explorations, we have undertaken a through study on space technology, mining exploration, oceanic resource exploitation and future technologies that can benefit us. As the result, all round progress and development were evident everywhere. In this scenario of unprecedented development, the human population doubles in matter of decades. Earlier this doubling was occurring in the course of several millennia. Consequently, our per capita consumption of resources increased, we domesticated wild plants for food and animals for our multifarious requirements. The cascading effect of overexploitation of the natural resources led to heating up of our mother Earth beyond tolerable limits and resultant irreversible climate change. Under the above conditions, time has come to understand the living biotic resources of this planet so that it can be exploited under sustainable limits and enough may be left back for our future generations.

Everyone should understand the value of all living beings, the microbes, plants and animals and how they coexit in nature in mutual harmony for ages. Any damage to these intricately associated living organisms and unethical interference in their normal life cylce patterns will jeopardise our very existence.

Keeping all these facts in view, the Council of Higher Secondary Education (CHSE), Odisha has made significant changes in the syllabi of Biology. The syllabus has been framed exactly in the pattern of National Council of Education Research and Training (NCERT), New Delhi. The task of writing the book was entrusted to Odisha State Bureau of Textbook Preparation and Prdoduction, Bhubaneswar. The board of writers and reviewers appointed by the Bureau have strived hard to write this Biology book merging Botany and Zoology portions together so that the beginners can have a synchronised understanding of the subject.

The book is now open for the teachers, students and other stakeholders in Biology to assimilate the content and study materials to take on the variety of challenges in their immediate and future life. The board of writers and reviewers will be happy to receive valued feedback for further improvement of the book. The concepts, ideas and contents presented in the text book are not all original. These might have been assimilated from standard texts and other supporting materials.

The board of writers and reviewers acknowledge their gratitude to Odisha State Bureau of Textbook Preparation and Production, Bhubaneswar, CHSE, Odisha and Department of Higher Education, Government of Odisha for assigning the task of writing the book.

Board of
Writers & Reviewers

BIOLOGY SYLLABUS

(To be implemented from the session 2016-17)

CLASS - XI

(Theory)

Unit-I : DIVERSITY IN LIVING WORLD (Periods 10)

1. What is living?; Biodiversity; Need for classification; Three domains of life; Taxonomy and Systematics; Concept of species and taxonomical hierarchy; Binomial nomenclature; Tools for study of Taxonomy- Museums, Zoos, Herbaria, Botanical gardens.
2. Five kingdom classification; Salient features and classification of Monera, Protista and Fungi into major groups; Lichens; Viruses and Viroids.
3. Salient features and classification of plants into major groups-Algae, Bryophytes, Pteridophytes, Gymnosperms and Angiosperms (three to five salient and distinguishing features and at least two examples of each category); Angiosperms- classification up to class, characteristic features and examples.
4. Salient features and classification of animals- non-chordates up to phyla level and chordates up to classes level (three to five salient features and at least two examples).

Unit-II : STRUCTURAL ORGANIZATION IN ANIMALS AND PLANTS (Periods 12)

5. Morphology and modifications in plants; Tissues; Anatomy and functions of different parts of flowering plants- Root, stem, leaf; inflorescence- cymose and racemose; flower, fruit and seed (To be dealt along with the relevant practical of the Practical Syllabus).
6. Animal tissues (epithelial, connective, muscular, nervous); Morphology, anatomy and functions of different systems (digestive, circulatory, respiratory, nervous and reproductive) of an insect (cockroach). (Brief account only).

Unit - III : CELL STRUCTURE AND FUNCTION (Periods 12)

7. Cell theory and cell as the basic unit of life; Structure of prokaryotic and eukaryotic cell; Plant cell and animal cell; Cell envelope, cell membrane, cell wall; Cell organelles-structure and function; Endomembrane system- endoplasmic reticulum, Golgi bodies, lysosomes, vacuoles; mitochondria, ribosomes, plastids, microbodies; Cytoskeleton, cilia, flagella, centrioles (ultra structure and function); Nucleus- nuclear membrane, chromatin, nucleolus.
8. Chemical constituents of living cells: Biomolecules- structure and function of proteins, carbohydrates, lipid, nucleic acids; Enzymes-types, properties, enzyme action.
9. Cell division: Cell cycle, mitosis, meiosis and their significance.

Unit - IV : PLANT PHYSIOLOGY **(Periods 20)**

10. **Transport in Plants:** Movement of water, gases and nutrients; Cell to cell transport-Diffusion, facilitated diffusion, active transport; Plant-water relations-Imbibition, water potential, osmosis, plasmolysis; Long distance transport of water- Absorption, apoplast, symplast, transpiration pull, root pressure and guttation; Transpiration-Opening and closing of stomata; Uptake and translocation of mineral nutrients-Transport of food, phloem transport, Mass flow hypothesis; Diffusion of gases (brief mention).

11. **Mineral Nutrition:** Essential minerals, macro and micronutrients and their role; Deficiency symptoms; Mineral toxicity; Elementary idea of Hydroponics as a method to study mineral nutrition; Nitrogen metabolism- Nitrogen cycle, biological nitrogen fixation.

12. **Photosynthesis:** Photosynthesis as a means of Autotrophic nutrition; Where does photosynthesis take place; How many pigments are involved in Photosynthesis (Elementary idea); Photochemical and biosynthetic phases of photosynthesis; Cyclic and non-cyclic photophosphorylation; Chemiosmotic hypothesis; Photorespiration; & and C4 pathways; Factors affecting photosynthesis.

13. **Respiration:** Exchange of gases; Cellular respiration- glycolysis, fermentation (anaerobic), TCAcycle and electron transport system (aerobic); Energy relations -Number of ATP molecules generated; Amphibolic pathways; Respiratory quotient.

14. **Plant growth and Development:** Seed germination; Phases of plant growth and plant growth rate; Conditions of growth; Differentiation, dedifferentiation and ^{A}differentiation; Sequence of developmental process in a plant cell; Growth regulators-auxin, gibberellin, cytokinin, ethylene, ABA; Seed dormancy; Vernalisation; Photoperiodism.

Unit-V : HUMAN PHYSIOLOGY **(Periods 30)**

15. **Digestion and Absorption:** Alimentary canal and digestive glands; Role of digestive enzymes and gastrointestinal hormones; Peristalsis, digestion, absorption and assimilation of proteins, carbohydrates and fats; Calorific value of proteins, carbohydrates and fats (brief account); Egestion; Nutritional and digestive disorders-PEM, indigestion, constipation, vomiting jaundice, diarrhea.

16. **Breathing and Respiration:** Respiratory organs in animals (tracheal, brancheal, cutaneous, pulmonary); Respiratory system in humans; Mechanism of respiration (breathing) and its regulation in humans- Exchange of gases, transport of gases, Respiratory volumes; Disorders related to respiration- Asthma, Emphysema, Occupational respiratory disorders.

17. **Body fluids and Circulation:** Composition of blood, blood groups, coagulation of blood; Composition of lymph and its function; Human circulatory system-Structure and working of human heart, blood vessels; Cardiac cycle, cardiac output, ECG; Double circulation; Regulation of cardiac activity; Disorders of circulatory system-Hypertension, Coronary artery disease, Angina pectoris, Heart failure.

18. **Excretory products and their elimination:** Modes of excretion-Ammonotelism, ureotelism, uricotelism; Human excretory system- structure and fuction; Mechanism of Urine formation, Osmoregulation; Regulation of kidney function- Renin-angiotensin, Atrial Natriuretic Factor, ADH and Diabetes insipidus; Role of other organs in excretion; Disorders- Uraemia, Renal failure, Renal calculi. Nephritis; Dialysis and artificial kidney.

19. **Locomotion and Movement:** Types of movement- ciliary, flagellar, muscular, Skeletal muscle- contractile proteins and muscle contraction; Skeletal system and its functions (To be dealt with the relevant practical of Practical Syllabus); Joints; Disorders of muscular and skeletal system- Myasthenia gravis, Tetany, Muscular dystrophy, Arthritis, Osteoporosis, Gout.

20. **Neural control and Coordination:** Neuron and nerves; Nervous system in humans-central nervous system (brain, spinal cord), peripheral nervous system and visceral nervous system; Generation and conduction of nerve impulse; Reflex action; Sensory perception; Sense organs; Elementary structure and function of eye and ear.

21. **Chemical coordination and Regulation:** Endocrine glands and hormones; Human endocrine system- Hypothalamus, Pituitary, Pineal, Thyroid, Parathyroid, Adrenal, Pancreas, Gonads; Mechanism of hormone action (Elementary Idea); Role of hormones as messengers and regulators, Hypo- and hyperactivity and related disorders (Common disorders e.g. Dwarfism, acromegaly, cretinism, goiter, exopthalmic goiter, diabetes, Addison's disease).

Imp: Diseases related to ail the human physiology systems to be taught in brief.

(NB: I b, c; II a; III and IV units are to be taught by Botany Faculty. I a, d; II b; V units are to be taught by Zoology Faculty.)

CONTENT

UNIT-I: DIVERSITY IN THE LIVING WORLD

BIODIVERSITY

CHAPTER 1

So far as the scientific knowledge, till date, is concerned, earth is the only planet sheltering living organisms of diverse forms in different habitats. The evolution theory states that the earth is created from the sun about 4.5 billion years ago and subsequently, life originated on it nearly 3.6 billion years back in sea water. As time progressed, more and more complex forms of organisms evolved from simple forms and eukaryotes originated from prokaryotes, creating various species of organisms such as microbes, plants and animals, in the course of organic evolution.

1.1. WHAT IS LIVING?

Everybody easily understands the differences between the living and non-living. But it remains a difficult task to define 'life'. We explain the distinctive characters the living organisms possess such as growth, movement or locomotion, digestion, respiration, excretion, reproduction and response to stimuli and adaptation to the changing environment. Some of the internal processes which are not perceived from outside include metabolic reactions, actions of enzymes and hormones, functioning of the immune system and many more. Many of these phenomena are similar in many organisms and in others are different. Combining all these, we can define life as the condition that distinguishes animals, plants and microorganisms from inorganic and organic physical matter and dead organisms and it is expressed by the functions stated above. Organisms undergo continual change, till death. Some important properties of organisms are discussed below.

(a) Metabolism : The cells of organisms contain within them diverse types of inorganic and organic molecules of variable sizes, which make up the internal cellular environment. They participate in thousands of different biochemical reactions to carry out diverse functions essential for the survival of organisms. These reactions sumtotally constitute metabolism, which is further divided into anabolism (constructive process) such as synthesis of protein molecules and catabolism (destructive process) such as breakdown of glucose molecules in cellular respiration. Many metabolic processes are similar in microbes, plants and animals, while some other processes are specialized in certain groups or organisms. A metabolic reaction may be demonstrated in the laboratory ***(in vitro*** condition). Non-living matter don't perform such metabolic processes.

(b) Physiological Processes : Based on the number of cells in the body, we divide organisms into unicellular (single-celled) and multi-cellular (many-celled) types. While all the life processes are performed within the same cell in a unicellular organism, groups cells or tissues or organs carry out different functions in multi-cellular organisms. On the other hand, animals and plants also differ from each other by some functions such as intake of water and nutrients from the soil and photosynthesis occurring in plants, but not in animals. However, the basic design of the physiological processes remains similar to a greater extent in different groups of organisms.

(c) Growth : Organisms have a characteristic feature of growth upto a certain age. But in plants, the body (mass) continues to grow throughout the life. Thus, increase in body mass is considered as growth of organisms. In unicellular organisms, the single-celled body grows only by mass, while in multicellutar organisms there is an increase in the mass and number of cells of the body. Through growth the organisms reach the adult stage, when they reproduce offsprings of their kind. The organisms also repair their damaged parts or some regenerate their lost parts through the formation of new cells by cell division. Although dead organisms do not grow, some objects such as mountains and sand mounds grow in size by depositing materials on their surfaces through some geophysical processes. In contrast, the organisms grow from inside. Considering this, we can say that growth is a characteristic feature of organisms.

(d) Reproduction and Continuation of Race : For continuation of their races the organisms reproduce and the characters of the parents pass on to their progeny in the process. Basically, there are two types of reproductions: asexual and sexual. In asexual reproduction only one parent is involved; while in sexual reproduction: both male and female parents are involved. Most of the single-celled and some lower multicellular organisms reproduce by several asexual methods. Bacteria, unicellular algae, ***Amoeba,*** etc divide by fission whereas fungi produce large number of spores by sporulation. Yeast and ***Hydra*** create young ones by budding. Filamentous algae, many fungi, protonema of mosses, ***Planaria*** multiply their number by fragmentation. In higher plants and animals, the common practice of creating progeny is the sexual method of reproduction, in which sex cells or gametes (sperm and egg) fuse to produce a zygote, which in due course gives rise to an offspring of its own kind. However, some organisms may not reproduce sexually due to sterility.

(e) Response to Stimuli : Another important feature of the living organisms, from prokaryotes to the most developed eukaryote, is the ability to sense the changes happening in their environment or surrounding. They respond to various physical, chemical and biological stimuli, originating in their environment for safeguarding their existence. All organisms are influenced by external stimuli such as light, temperature, water, pollutants, etc. However, in addition to all these factors animals are affected by the presence of other organisms in their vicinity. The organisms possess the ability to regulate the chemical substances entering into their bodies. Plants and animals with seasonal breeding habits are affected by the photoperiod (day length).

A living system is more complex than the most sophisticated super computer. Whereas the molecules individually can't create life, their combined interactions make life possible. A group of cells or a tissue can perform a function that a single cell can't; a tissue can't do a work that an organ can and so on. All the tissues, organs and organ systems with interactions among themselves in higher groups, constitute a functional organism. The level of organization among the ascending order of groups of organisms is cellular grade through tissue grade to organ and organ-system grade.

All organisms are self-replicating, self-regulating and evolving systems which have the ability to respond to the environmental stimuli. Biology as a discipline is the study of organisms, which encompasses Microbiology (study of microbes), Botany (study of plants) and Zoology (study of animals).

Thus, some defining features of organisms are:

1. Metabolic reactions occur in their cells, which are essential for the survival of the organisms.
2. Various physiological processes take place which carry out diverse functions.
3. Growth in number of cells and body mass in multicellular organisms and growth in body mass only in unicellular organisms.
4. Both asexual and sexual methods of reproduction take place for continuation of the race.
5. They respond to various environmental stimuli and thus possess consciousness.

1.2. BIODIVERSITY:

We observe a large number of different kinds of organisms around us, such as grass, herbs, shrubs trees, insects, frogs, lizards, birds and human. The microorganisms present everywhere around us can't be seen with naked eyes, but can only be observed under microscopes. The variety of life forms existing in nature is termed as 'biological diversity' or 'biodiversity'. Broadly speaking, it is the "richness of the living species or the variation of life at all levels of biological organization. In a finer meaning, it refers to genetic diversity, i.e. a diversity of genes among individuals of a species and also among different species of organisms.. It also includes the complex assemblages of communities and ecosystems. Thus, biodiversity comprises of the totality of genes, species and ecosystems of a region. The term 'Biological Diversity' was first used by Jenkins and Lovejoy (before 1975), but W G Rosen (1985) cut short the usage, Biological Diversity and coined the term 'Biodiversity'. E O Wilson (1988) first used the term in one of his publications.

1.3. NEED FOR CLASSIFICATION :

There is a large number of organisms in both terrestrial and aquatic ecosystems. Each organism constitutes a species. A study conducted by the United Nations Environment Programme (UNEP) in 1995 estimated that there were around 13.6 millions of living species existing on earth, out of which the biologists were able to identify only 1.75 million species. The organisms possess unique characters, by which they are distinguished from each other. Based on similarities of characters, the organisms are divided into groups for convinience of their study. For example, if we say animals with hairs on the body, we understand them as mammals. The plants bearing flowers and producing seeds enclosed within a carpel are called as angiosperms. Some superficial characters sometimes are misleding. For example ***Hydra*** is radially symmetrical and starfish, too is radially symmetrical. However, they are placed in different groups based on anatomical and embryological characters. It is, therefore, important that organisms be classified on the basis of anatomical and embryological characters, in addition to morphological characters.

The plants and animals are identified in different names in different languages in various parts of the world. Such names are vernacular names. It creates communication problems among different regions of the world. For scientific study of organisms, a standardized name is given to a particular organism that is identified throughout the world. This process of naming organisms is called **nomenclature** or more appropriately as biological nomenclature. An organism is first studied correctly before naming it and assigning a group to which it belongs. This process is known as **identification.**

For the purpose of nomenclature, the biologists have prepared guidelines which are followed by all throughout the world. The International Code for Botanical Nomenclature (ICBN) has framed principles for assigning botanical names to plants. Similarly, recommendations framed by the International Code of Zoological Nomenclature (ICZN) are used for naming animals. The scientists make sure that a name assigned to an organism has not been used for any other organism earlier.

1.4. BINOMIAL NOMENCLATURE :

As per the framed guideline, a scientific name given to an organism consists of two distinct parts: the first part is the genus or generic name, while the second part is the species or specific name. This system of assigning names with two parts is called **Binomial Nomenclature,** which was proposed by the Swedish Naturalist Carolus Linnaeus (1707-1778). For his contribution to the field of nomenclature and classification, Linnaeus is referred to as the **Father of Taxonomy.** Some of the important rules of binomial nomenclature are mentioned below.

1. Each biological name consists of two parts : the first part is the genus or generic name and the second, species or specific name. For example, the zoological name of tiger is ***Panthera tigris*** and the botanical name of banyan tree is ***Ficus benghalensis.***

2. The first alphabet of the genus is in block capital, while that of the species is small and both names are written in italics.

3. There is a space between the generic and specific names.

4. When written with hand, the two names are underlined separately, but in printed materials the words are written in italics.

5. The scientific names are derived from Latin or are Latinized, irrespective of their origin from other languages.

6. The name of the author, who first described the species, followed by the year of its description, is mentioned after the specific epithet. The author name may be mentioned in abbreviated form, e.g. Linnaeus as Linn. Thus the scientific name of human is ***Homo sapiens*** Linn., 1758.

1.5. THREE DOMAINS OF LIFE :

According to the traditional system of classification introduced by Linnaeus, kingdom is the highest category in the classification of organisms. However, Carl Woese proposed the three domain system of biological classification in 1977, which adds a level or category in the classification higher than the kingdom. He suggested three domains of life, such as **archaea, bacteria** and **eukaryota.** Under each domain there are one or more kingdoms. All these domains have distinct characteristic features that are used to identify them. For example, the system divides prokaryotes into archaea and bacteria domains based on the fundamental differences in the 16S rRNA genes.

The three domain system is designed with an emphasis on evolutionary lines of descent. In this system, archaea are more closely related to eukaryotes than they are to bacteria. For classification, an organism is first placed under a domain, then under a kingdom, and then under different descending order of categories and finally assigned a species name.

1.5.1. Domain Archaea :

The **Kingdom Archaebacteria** comes under the archaea domain. The organisms are prokaryotic, which have no nuclear membrane, have a unique biochemistry and RNA features that separate them from bacteria. They also have a unique evolutionary history that makes them the oldest organisms in comparison to the bacteria or eukaryote domains. The organisms often have characteristics that allow them to survive in tough or extreme environments. Common examples of archaea are methanogens (methane producing) acidophiles (surviving in highly acidic environments), thermophiles (surviving in extreme heat conditions), and halophiles (surviving in conditions of high salt concentration).

1.5.2. Domain Bacteria :

This domain is also prokaryotic and it consists of the **Kingdom Eubacteria.** The organisms under this domain have diacyl glycerol diester lipid in their cell membranes, have no nuclear membrane and contain a genome composed of bacterial rRNA. The domain contains most pathogenic prokaryotic organisms, which have been studied extensively. Examples include cyanobacteria (which carry out photosynthesis), bacterial pathogens (which cause tuberculosis and several skin infections), spirochaetes (gram negative bacteria, such as that causing syphilis) and firmicutes (gram positive bacteria, many of which are found within the human gut).

1.5.3. Domain Eukaryota :

The domain includes all eukaryotes. These are multicellular organisms which possess nuclear membranes and contain DNA as the genetic material. Their cells contain membrane bound organelles, such as mitochondria, endoplasmic reticulum and chloroplasts, which perform specialized functions. Four kingdoms are included in this domain: **Protista, Fungi, Plantae** and **Animalia.** One of the primary characteristics, which distinguishes them from prokaryotes is that eukaryotes undergo both mitosis and meiosis. All multicellular organisms are eukaryotes, though many but not all single celled organisms are eukaryotes.

1.6. TAXONOMY AND SYSTEMATICS :

Taxonomy is the branch of biology that deals with the collection, identification, classification, nomenclature and preservation of organisms. This makes a detailed scientific study of the characters, both external and internal, of an organism to find out its similarities and dissimilarities with others, which is essential for its classification. The modern taxonomic study also considers structure of the cell, chromosomes and genes, molecular features, embryonic development, ecology, etc for distinguishing between closely related organisms. Taxonomists make sure that organisms which do not share a common ancestry are not classified under the same group. Charles Darwin proposed that all organisms existing on earth shared a common ancestry. Taxonomy is an older branch of study than Systematics.

On the other hand, **Systematics** deals with the evolutionary relationships that exist between different groups of organisms. It tries to determine the organisms and/or groups of organisms, which share common ancestry. It is concerned with the quantum of evolutionary changes that may have occurred among different ancestors. The word systematics has been derived from the Latin word 'systema', which means systematic arrangement of the organisms. Linnaeus titled one of his books as ***'Systema Naturae'*** that enlisted about 10,000 species of animals and plants. The scope of systematics, at present, not only includes the work of taxonomy, but also consists of establishing relationships between organisms from evolution point of view. This helps us to form the phylogenetic tree of life and understand the evolutionary history of life on earth.

1.7. CONCEPT OF SPECIES AND TAXONOMICAL HIERARCHY :

Kingdom is the largest taxonomic group. It is divided and sub-divided into groups and sub-groups based on true relationships. For example, the kingdom Animalia is divided into eleven animal phyla. Each phylum is divided into two or more **classes** and each class into two or more **orders** and so on. The ultimate and indivisible unit in this system is the **species.** However, on rare occasions, the species is divided into **sub-species** or **varieties.** Each of these ranks in a taxonomic classification is known as a **taxonomic category.** When all the taxonomic categories are arranged in a descending order, it forms a **taxonomic hierarchy.** Thus, **Kingdom is the largest category,** while **the species smallest.** The following is a taxonomic hierarchy exhibiting only important categories.

Kingdom

Phylum

Class

Order

Family

Genus

Species

An animal is placed in an appropriate taxonomic category, which is assigned a name. The name of the taxonomic category forms a **taxon.** For example, Phylum is a taxonomic category. It is assigned the name Coelenterata for ***Hydra*** and Chordata for human. Thus, Phylum is a taxonomic category, while Coelenterata and Chordata are two taxa of the same category.

As time passed on, more animals were discovered. It became difficult to put the newly discovered animals in the existing categories. To overcome this situation, taxonomists introduced new categories by adding prefixes, super- and sub- to the existing categories. Consequently, sub-kingdom, super-phylum, sub-phylum, super-class, sub-class, super-order, sub-order, super-family, sub-family etc. were introduced. These categories, which were subsequently introduced into the hierarchy were called **intermediate categories.**

1.7.1. Scheme of Classification :

The scheme of classification begins with concept of a species and is a category used in hierarchial classification.

1. **Species** (Plural; species): Species is defined as a group of individuals, which have the capacity to interbreed amongst themselves to produce fertile offsprings. This is the basic unit of classification and it helps us to understand taxonomy and evolution. Normally, species is the lowest and indivisible taxonomic category, but on occasions, the species is divided into sub-species, ranked as the lowest unit. ***Panthera leo*** (Lion), ***Panthera tigris*** (Tiger), ***Panthera pardus*** (Leopard) are species of the same Genus, ***Panthera.*** Asiatic lion is scientifically named as ***Panthera leo persica*** Here, ***persica*** is the sub-species.

2. **Genus** (Plural; Genera): Two or more species having common ancestry and similar features are grouped into a genus. Otherwise speaking, a genus is a group of related species with common ancestry. The genus occupies a significant position in classification. In binomial nomenclature, a species cannot be named unless it is assigned to a genus. The genus may be **monotypic** or **polytypic.** In **monotypic,** it has only a single species [e.g.; ***Homo*** sapiens (Man)]. Conversely, in polytypic, it has many species [e.g.; ***Panthera leo*** (lion), ***Panthera tigris*** (tiger), ***Panthera pardus*** (leopard), and ***Panthera onca*** (jaguar)].

3. **Family :** This category includes one or more related genera and is separated from other related families by important and characteristic differences. The genera ***Panthera*** (tiger, lion, leopard etc.) and ***Felis*** (cat) are included in the same family Felidae. The family, Felidae is quite different from the family Carnivorae (dog, fox, wolf etc.). Both families belong to the same order, Carnivora.

4. **Order:** It is the next higher taxonomic category and includes related families. Families, Felidae (cat), Viverridae (civet), Hyaenidae (hyena), Canidae (dog), Ursidae (bear) are all included in the same order Carnivora.

5. **Class :** This category includes two or more related orders. Orders like Insectivora (hedgehog, mole), Chiroptera (bat), Primates (monkey and man), Rodentia (hare and squirrel), Edentata (ant eater), Carnivora (cat and dog), Cetacea (whale and dolphin) and Proboscidea (elephant) are included in the class Mammalia.

6. **Phylum or Division** (Plural; phyla): Classes of different organisms having some common features are included under a phylum or division. The phylum Chordata includes a number of classes like Cyclostomata, Osteichthyses, Chondricthyses, Amphibia, Reptilia, Aves and Mammalia.

7. **Kingdom :** This is the highest taxonomic category. Two or more related phyla come under one kingdom. According to the Linnaean system of classification, all plants come under the **Kingdom, Plantae,** while all animals come under the **Kingdom, Animalia.**

1.8. TOOLS FOR STUDY OF TAXONOMY :

Correct identification and classification of animals, plants and microbes is of vital importance. It requires methodical and detailed study of organisms in the field as well as in the laboratory. For such taxonomic study, collection of actual specimens of animals and plants is very much essential. The actual specimens are throughly studied and their characters enlisted, which then leads to their correct classification and nomenclature. It requires a thorough training in systematics for carrying out such studies. Procedures and techniques have been formulated for identification, preservation of the biological specimens. The information gathered on such accounts is stored in databases and made available to others.

Taxonomic studies on various species of organisms bear great significance considering their usefulness in the fields of agriculture, forestry and industry. Our knowledge on various bio-resources, their diversity and measures required for their conservation are also enhanced by these studies. The biologists need the help of some taxonomical tools or aids for carrying out such studies. Some of these tools include museums, zoos, herbaria and botanical gardens.

1.8.1. Museums :

Biological museums contain many preserved specimens of animals and plants. Even complete skeletons, skulls, disarticulated bones, skins and other hard parts of some animals are also preserved here (Fig. 1.1). Educational institutions such as schools and colleges set up their own museums for the purpose of study, reference and research. Natural history museums also have collections and exhibits of animals, plants and ecosystems. Most of the animal specimens are preserved in jars or containers containing preservative solutions such as formalin and alcohol. Many plants or their parts and some animals such as insects are preserved as dry specimens. Insects are kept in insect boxes by fixing them with pins after due processing. Higher animals like reptiles, birds and mammals are usually preserved as surffed specimens. The preserved specimens in the museum provide information about characters of species, natural variations and evolutionary relationships among organisms.

Fig. 1.1 : Different preserved animal specimens and exhibits placed in a museum.

1.8.2. Zoos (Zoological Parks) :

These are protected places where wild animals live in enclosures under human care. Attempts are often made to provide them with the conditions similar to natural habitats. The key objectives of zoos are to display the animals to the public, study their behaviour and breed the endangered species for increasing their number. Special enclosures are developed for reptiles, birds, mammals, insects and other animals. Fishes and other aquatic life forms are kept in aquaria and water bodies. Visitors are asked to visit the zoo by adhearing strictly to the regulations outlined by the zoo authorities. Attempts are made to generate awareness among the visitors for conservation of wild animals and other forms of biodiversity.

Fig. 1.2 : Nandankanan Zoological Park, Bhubaneswar

1.8.3. Herbaria :

A herbarium is a collection of plant specimens and data relating to them, which are preserved for future taxonomic studies of plant and research. Herbaria may be placed in specifically designed and protected houses or rooms. The specimens may be whole plants or plant parts such as flowers, stems, leaves, seeds, and fruits that are dried, pressed and mounted on sheets of paper. Some may also be stored in boxes or preserved in alcohol or other preservatives. The herbarium sheets are tagged with labels carrying information such as date and place of collection; local, English and botanical names; family of the plant; collector's name; etc. The sheets are catalogued according to a universal system of classification. Although a plant looks different when it is dried, most of the key features needed for taxonomic studies can be found in a well-prepared specimen. The oldest herbaria in the world are found in Europe, which are more than three hundred years old.

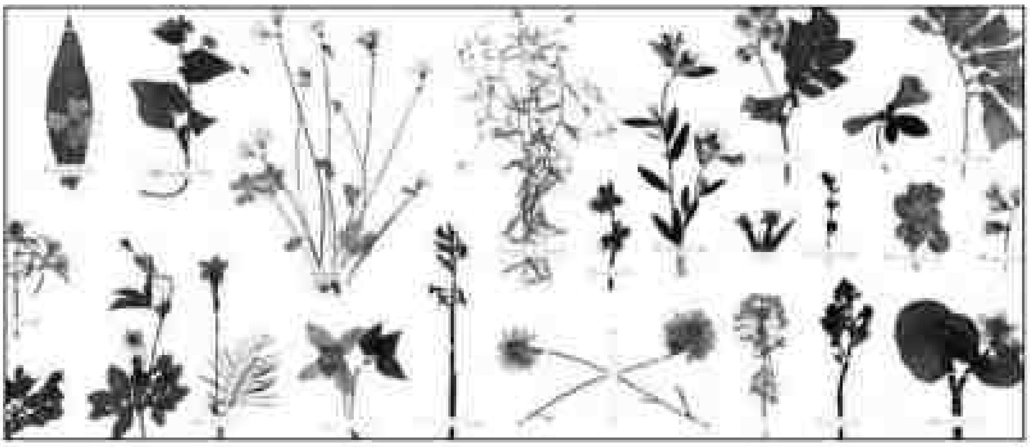


Fig. 1.3 : A herbarium sheet containing various plant specimens.

1.8.4. Botanical Gardens (Botanic Gardens) (Fig. 1.4):

These are specialized gardens dedicated to the collection, cultivation and display of a variety of living plants, labelled with their botanical names and families. There may be special collections of rare and exotic plants as well as greenhouses and shade houses. The collections may include big trees, shrubs, herbs, cacti and aquatic species. A botanical garden may provide the visitors services such as tours, educational displays, art exhibitions, book rooms, and in addition, open-air theatrical and musical performances, and other forms of entertainment. The plant species grown here are referred to for the identification of collected specimens, and also used for education, research and conservation purposes. The botanical gardens, often with associated herbaria, are mostly run by scientific research institutions and universities. Some of the famous botanical gardens of India include Indian Botanical Garden, Howrah, Kolkata; Lal Bagh (Mysore State Botanical Garden), Bengaluru; National Botanical Research Institute, Lucknow; Brindavan Garden, Mysore; Government Botanical Garden, Ooty (Tamil Nadu); and Garden of Agri-Horticultural Society of India, Kolkata. The Indian Botanical Garden, Howrah is the largest botanical garden in India.

Fig. 1. 4 : Acharya Jagadish Chandra Bose Indian Botanic Garden, Kolkata

SAMPLE QUESTIONS

GROUP-A

(Objective-type Questions)

1. Choose the correct answer:

(i) How many years ago did life originate on Earth?

a. 3 billion b. 3.5 billion
c. 4 billion d. 4.5 billion

(ii) Which one of the following is a characteristic feature of living?

a. Reproduction b. Response to stimuli
c. Metabolism d. All of these

(iii) Which of these statements is wrong?

a. Breakdown of glucose molecules in respiration is catabolism.
b. Many metabolic processes are similar in microbes, plants and animals.
c. In some non-living objects metabolic processes also occur.
d. Immune system is a characteristic of living beings.

(iv) Find out the wrong one.

a. A single-celled organism grows only in mass.
b. A multicellular organism grows not only in mass, but also in number of cells.
c. Fungi produce large number of spores during reproduction.
d. Gametes fuse to produce offsprings in asexual reproduction.

(v) Identify the incorrect statement.

a. Plants are influenced by external stimuli such as light, temperature and water.
b. All organisms don't possess consciousness.
c. Combined interactions of molecules make life to continue.
d. Organisms have the ability to regulate the chemical substances entering into their bodies.

(vi) Richness of the living species on earth is termed as:

a. Ecosystem b. Community
c. Biodiversity d. Population

(vii) Who is referred to as the Father of Taxonomy?

a. W G Rosen b. E O Wilson
c. John Ray d. Carolus Linnaeus

(viii) Full form of ICBN is:

a. International Code for Botanical Nomenclature

b. International Code for Biological Nomenclature

c. International Code for Bacterial Nomenclature

d. International Code for Bryophyte Nomenclature

(ix) Who proposed the three domain system of biological classification?

a. Carl Woese b. R H Whittaker

c. Charles Darwin d. Robert Hooke

(x) In the scientific name of man, *sapiens* represents name of the:

a. Genus b. Species

c. Scientist d. Place

(xi) The scientific names are derived from which language?

a. English b. French

c. Latin d. Greek

(xii) Under which domain does the Kingdom Protista come?

a. Archaea b. Bacteria

c. Eukaryota d. Plantae

(xiii) Which is not true about the organisms of the domain Bacteria?

a. Have diacyl glycerol diester lipids in their cell membranes

b. Have no nuclear membrane

c. Contain a genome composed of bacterial rRNA

d. Thermophiles and halophiles come under the domain.

(xiv) Which of the following about organisms is not dealt with by Taxonomy?

a. Nomenclature b. Identification

c. Classification d. Evolutionary history

(xv) Which chemical solution is used for the preservation of organisms?

a. Nitric acid b. Formalin

c. Chloroform d. Sodium hydroxide

(xvi) Name the botanical garden present in Bengaluru.

a. Lal Bagh b. Empress Garden

c. Indian Botanic Garden d. Malampuzha Garden

(xvii) Binomial system of Nomenclature was proposed by

a. Carious Linnaeus b. R.H. Whittaker

c. Carl Woese d. J.B. Lamarck

2. Answer the following :

(i) Name the author of the book *'Systema Naturae'.*

(ii) Under which domain comes the Kingdom Animalia?

(iii) Arrange the following taxa from highest to lowest: Genus, Class, Phylum, Order.

(iv) Which botanical garden is named after Sir Jagadish Chandra Bose?

(v) Which district Nanadankanan Biological Park is situated?

GROUP-B
(Short Answer-type Questions)

1. Answer the following in three sentences each :

(i) What is taxonomical hierarchy?

(ii) Explain the concept of species.

(iii) State the usefulness of taxonomic tools.

(iv) Write down the names of the phylum, class, order and family, and the scientific name in respect of man, housefly, mango and wheat.

(v) What are the objectives of zoological parks?

2. Differentiate between two words in the following pairs of words :

(i) Anabolism and Catabolism

(ii) Archaea and Bacteria

(iii) Taxonomy and Systematics

(iv) Genus and Species

(v) Museum and Herbarium

CLASSIFICATION OF LIVING WORLD

CHAPTER 2

Classification of Living Organisms

For systematic study of any living organism, it is primarily necessary to know where it is placed in the living world. Is it a simple primitive organism, autotrophic or a complex and highly developed heterotrophic organism ? What are the characters that identify its position at a particular level in the living world ? This is called classification. Classification denotes arrangement of living beings in specific groups on the basis of their origin, evolution, morphology, anatomy and cytology etc. Through this method, the exact position of an organism in this living world can be known accurately. Over the years, various systems of classification of living organisms have been developed.

2.1. TWO KINGDOM SYSTEM

All the diverse groups of organisms are placed in two major groups called the plants and animals from the very ancient times. Greek philosophers, Aristotle (384-322 BC) and his disciple, Theophrastus underlined the importance of classification of the living organisms. They classified plants and animals into subgroups on the basis of certain similarities and dissimilarities among them. Carolus Linnaeus (1707-1778), who is known as the father of modern botany and also the father of taxonomy, divided all the organisms into two kingdoms such as plantae and animalia on the basis of certain structural and functional characters. For example, the plant cells have a cell wall that exists outer to the plasma membrane. Generally, the plants have ability to synthesize their own organic food. All the higher plants are, by and large, static and have no ability to move from one place to another. Further the plants are less responsive to external changes in their environment.

Animal kingdom lack the nonliving component of the cell called the cell wall. They do not synthesize their own food and hence are dependent on the plants for food, directly or indirectly. The animals, therefore, are heterotrophic. Animals move about freely for various purposes like food, shelter etc. Animals react instantly to stimuli or any changes in the environment. The Characters that separate plants from animals are given in the table 2.1.

TABLE - 2.1

Two Kingdom system of classification

Sl. No.	Character	Plantae	Animalia
1.	Cell Wall	Present	Absent
2.	Mode of nutrition	Autotrophic	Heterotrophic
3.	Locomotion	Absent *	Present
4.	Response to Stimuli	Absent *	Present

* In most cases.

Merits

1) Plants and animals were divided into two kingdoms not abruptly but based upon specific characters.

2) It initiated a systematic methods to classify the living organisms. More and more characters were, later, taken into consideration in order to develop better methods.

Demerits

1) This system of classification has not dealt upon the status of microorganisms in the living world Example - Viruses, Bacteria. The reason may be the organisms were not properly known by that time.

2) Certain organisms like slime molds and *Euglena* have certain characters similar to plants and animals. Slime molds are tiny plants without cell walls whereas *Euglena* are minute animals with green pigment system. Hence, their position in the living world was uncertain.

3) The position of the prokaryotes was completely ignored.

2.2. THREE KINGDOM SYSTEM

It was proposed by a German Zoologist Ernst Haeckel (1886). This system of classification was based upon the morphology, tissue system, nutrition pattern and functioning of the different parts of the body of the living organisms.

He divided the living world into three kingdoms such as Protista, Animalia and Plantae (Table 2.2). All unicellular organisms were kept in the kingdom protista, which included fungi, protozoans, algae and bacteria. So, a separate kingdom protista was created to accommodate all mircrobes and certain other organisms which do not fit to the plant and animal kingdoms.

TABLE - 2.2

Three kingdom system of classification.

LIVING WORLD

1. **Unicellular organisms**
2. **No morphological complexities.**
3. **No tissue system.**
4. **Autotrophic or heterotrophic**
5. **Motile or nonmotile**
6. **Prokaryotic or eukaryotic**

Kingdom - Protista.
(All types of Algae, Fungi, Protozoa, Bacteria)

1. **Multicellular Organisms**
2. **Morphological Complexties**
3. **Tissue systems present**
4. **Eukaryotic**

Autotrophic

Kingdom- Plantae (Plants)

Heterotrophic

Kingdom- Animalia (Animals)

Merits

1) Recognition of the importance of the micro-organisms in the living world.

2) More characters were taken into consideration to classify the living beings.

Demerits

1) Nucleated and anucleated organisms kept together in Protista.

2) Heteotrophic bacteria and fungi placed along with autotrophic algae.

2.3. FOUR KINGDOM SYSTEM

In this system of classification of the world of living beings , a new kingdom was added to the Haeckel's "three kingdom system". Acellular prokaryotes were given the status of a kingdom. The organisms like Bacteria, and blue-green algae (now called Cyanobacteria) were included in it. The four kingdoms were monera, protoctista, plantae and animalia. This type of classification was purely based on cell organization and mode of nutrition.

Monera comprised of acellular organisms with no true nucleus. Their modes of nutrition were variable being autotrophic or heterotrophic. However, single celled or multicellular eukaryotic organisms like algae, fungi, protozoans were included under protoctista. Again the mode of nutrition of these organisms are variable i.e. autotrophic, heterotrophic, absorptive or endozoic. The plantae comprised of eukaryotic, multicellular, autotrophic organisms. The organisms with similar cellular organization but heterotrophic nutrition were placed under animalia (Table 2.3).

This system of classification was proposed by Stanier and van Niel and fully developed by Copeland in 1956.

TABLE - 2.3

Four kingdom system of classification.

Living World

Sl.No.	Character	Monera	Protoctista	Plantae	Animalia
1.	Cell Organization	Prokaryotic Acellular Primitive	Eukaryotic Unicellular, Primitive	Unicellular or Multicellular complex	Multicellular complex
2.	Nutrtion	Autotrophic or Heterotrophic	Autotrophic or Heterotrophic	Autotrophic	Heterotrophic

Although this system of classification rectified certain drawbacks of the Three-kingdom system, yet assemblage of fungi, algae and protozoan in one group was not acceptable.

2.4 FIVE KINGDOM SYSTEM OF CLASSIFICATION

American taxonomist Robert H. Whittaker proposed the Five-kingdom system of classification of the living organisms in the year 1969. This system was based on three criteria (a) Cellular organization : the cells may be prokaryotic or eukaryotic (b) Body organization : the organisms with unicellular and simple structure to multicellular complex body, (c) Mode of nutrition: from autotrophic to heterotrophic and absorptive. Ecological role of the organisms was also taken into account in classifying the world of living beings. This system classifies the organisms into five kingdoms namely Monera, Protista, Mycota (Fungi),Plantae and Animalia.

TABLE - 2.4

Five Kingdom System of Classification.

Sl.No.	Creation	Organization	Kingdom with Example
1.	**Complexity of cell structure**	**1 { Prokaryotic - acellular Eukaryotic - Unicellular**	**Monera- Bacteria, Cyanobacteria Protists- Diatoms, Slime molds**
2.	**Mode of nutrition & Complexity of Body organization**	**2 { Autotrophic - multicellular Heterotrophic- multicellular Heterotrophic - multicellular**	**Plantae - Green Plants Mycota or Fungi - Absorptive Animalia - Ingestive**
3.	**Ecological Role.**	**3 { Producer Decomposer Consumer**	**Green Plants, Monera, Protista Fungi, Monera, Protista Animals**

Micro-organisms were spread in the Kingdoms - Monera, Protista and Mycota. Fungi were given the status of a separate kingdom above the protists. According to this system the primitive prokaryotic organisms under Monera gave rise to unicellular, Protists. The kingdoms of Mycota, Plantae and Animalia developed in three independent lines. The characteristic features of the kingdoms are given in Table 2.4.

2.4.1. Kingdom Monera : *Example - Bacteria, Cyanobacteria (Blue green algae)*

(1) Unicellular organisms with no nucleus and nuclear membrane comprise this kingdom. Besides, all the membrane bound organelles such as mitochondria, chloroplasts, lysosomes etc. are absent from the monera cell. Photosynthetic organisms have pigments enclosed by ingrowths of the plasma membrane.

(2) The only cytoplasmic organelle that occur in these organisms is ribosome.

(3) The major component of the cell wall is peptidoglycan.

(4) Flagellated ones have single thread like structures . The major component of it, is flagellin with no 2+9 organization.

(5) The organisms under this group show variation in nutrition. These may be autotrophic or heterotrophic. Many heterotrophic ones are important in causing decay and decomposition.

(6) Sexual reproduction very rarely occurs in these organisms . Mostly the organisms reproduce vegetatively or asexually. Sometimes genetic recombination may occur.

(7) Only a single naked chromosome is present in the cell. DNA component in it, is circular with no chromosomal basic proteins.

Many types of bacteria are included under it.

Archaebacteria

These are most primitive bacteria, and are seen under extreme conditions of environment such as marshy saline soil, hot springs etc.

The cell membrane lipids are glycerol isopronyl ethers. The cell wall lacks murein. Certain methanogenic bacteria, extremely halophilic bacteria, thermophilic sulphur bacteria etc. are catergorised under this group (Fig. 2.1)

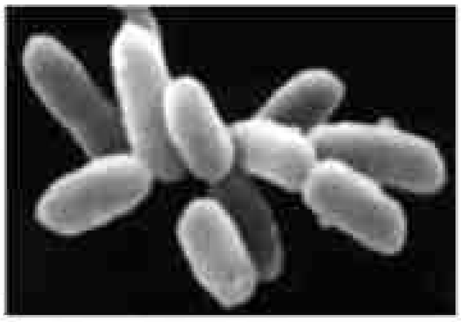


Fig. 2.1 : Methanogenic bacteria (an Archaebacteria)

Eubacteria

These are true bacteria having a rigid cell wall. If motile, flagella are borne by these organism. On the basis of nutrition, eubacteria may be autotrophic or heterotrophic. Autotrophs may be photosynthetic or chemosynthetic.

Phototrophic autotrophs include Cyanobacteria or Blue green algae. They have chlorophyll-a similar to higher green plants. These may have unicellular, colonial or filamentous thallus. Cyanobacteria may occur in fresh water or marine habitats, colonial forms are surrounded by gelatinous envelop. Some of these play important role in fixing atmospheric nitrogen. These nitrogen fixers have specialized cells called heterocysts. Example of it are *Anabaena, Nostoc* (Fig. 2.2).

Chemo synthetic autohophs use energy obtained by oxidation of inorganic substances such as nitrate, ammonia, sulphur, iron etc. These organisms do not liberate oxygen in the synthesis of complex building materials. However, these play important role to regulate nitrogen, phosphorus etc.

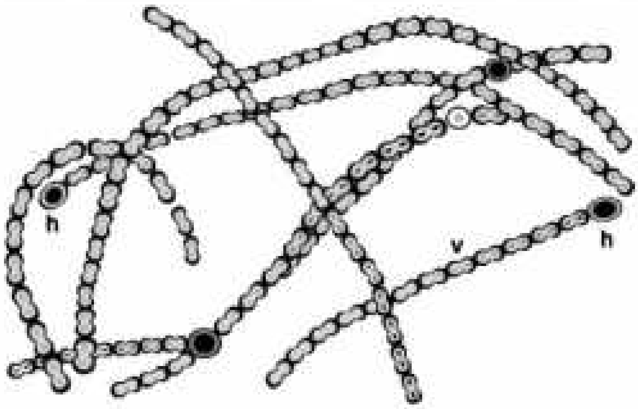


Fig. 2.2 : Cyanobacteria : *Anabaena*, v- Vegetative filament, h- Heterocyst

Heterotrophic eubacteria occur in huge number. They may be parasitic or saprophytic many of them play pivotal role in ecosystem as decomposers. Souring and curdling of milk, production organic acids, antibiotics and many other industrial products are obtained by manipulating the activities of these organisms. They are also causative agents of many diseases to man, animals and plant. Cholera, typhoid, tetanus, leprosy etc are the disease caused by bacterial pathogens. They occur in variety of forms. The major forms of such bacteria are: Cocci (circular), Bacilli (rod shaped), Vibrio (coma like) and Spirilli (spiral) (Fig. 2.3A).

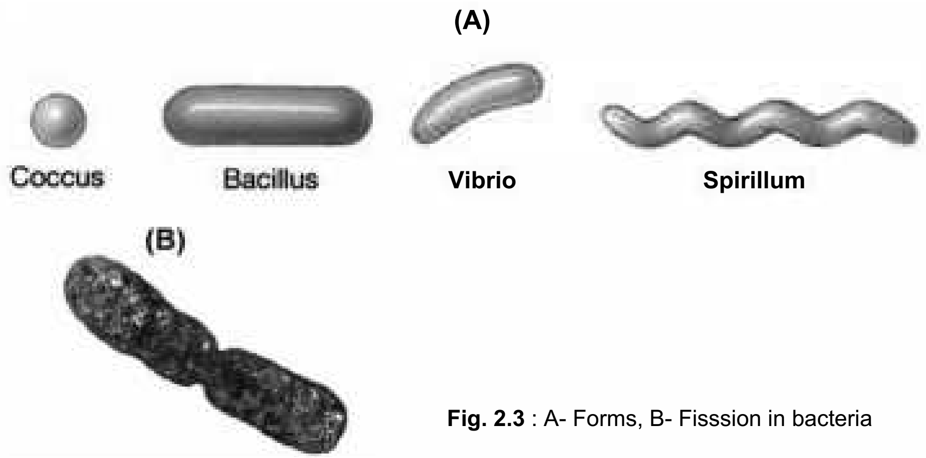


Fig. 2.3 : A- Forms, B- Fisssion in bacteria

Normally bacteria under suitable conditions, reproduce by fission (Fig. 2.3B). Within a very short time, a large number of progenies may be formed by this method. When conditions become unsuitable, bacteria may reproduce sexually by exchanging the genetic material partially or completely.

Mycoplasma are the smallest organisms which completely lack cell wall (Fig. 2.4) These can live without oxygen many mycoplasma are pathogenic to humans and animals.

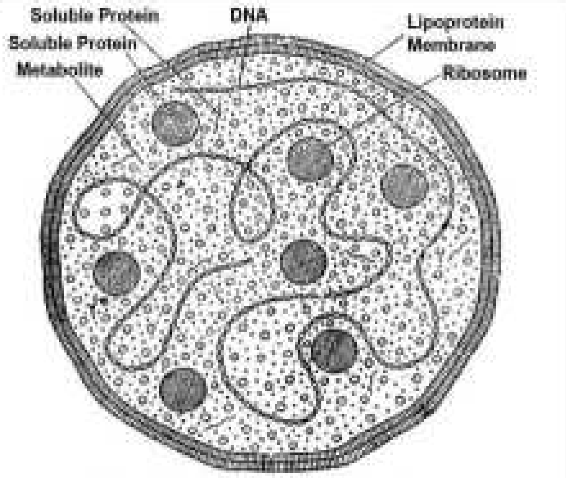


Fig. 2.4 : Structure of Mycoplasma

2.4.2. Kingdom Protista *: Example - Dinoflagellates, Euglenoids, Slime molds, Protozoans*

1. The organisms are unicellular eukaryotes.
2. These are predominantly aquatic.
3. Cell wall when present is constituted mainly of cellulose.
4. All membrane bound organelles are present.
5. Flagella when present show 2+9 flagellin arrangement.
6. Nutrition in these organisms is very often photosynthetic (autotrophic).
7. Asexual and sexual reproductions occur.
8. The DNA component is associated with basic protein called histones.

The characteristics of its main representatives are :

Dinoflagellates

These are marine life forms and are photosynthetic in nature. Depending on the dominating pigment systems of the cells these may be yellow, green, blue or red in appearance. Photosynthetic reserves accumulate as starch or starch-like compounds. Also, it may accumulate in the form of oils.

The cell walls are made of cellulose. The nucleus is distinctive (Fig. 2.5). Majority of genera have distinctive asymmetrical motile cells, biflagellate which are morphologically unlike.

Asexual reproduction takes place by cell division or by means of zoospores or aplanospores. Sexual reproduction is seen in few members of Dinoflagellates. It occurs by conjugation of gametes. Toxins released by these organisms kill marine animals.

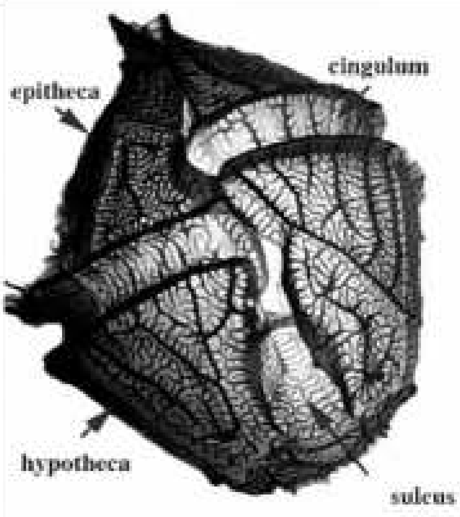


Fig. 2.5 : Structure of Dinoflagellates

Euglenoids

These unicellular life forms are motile *(Euglena).* Motile forms may be uniflagellate is biflagellate. These occur in stagnant fresh water bodies.

The cells lack cell walls but surrounded by flexible proteinaceous pellicle (Fig. 2.6). The reserve food material is paramylum, an insoluble form of carbohydrate. These organisms are photosynthetic in the presence of sunlight. However, when deprived of sunlight, organisms become heterotrophic. Pigmented euglenirds have similar pigment systems of higher plants. These organisms can reproduce asexually or sexually.

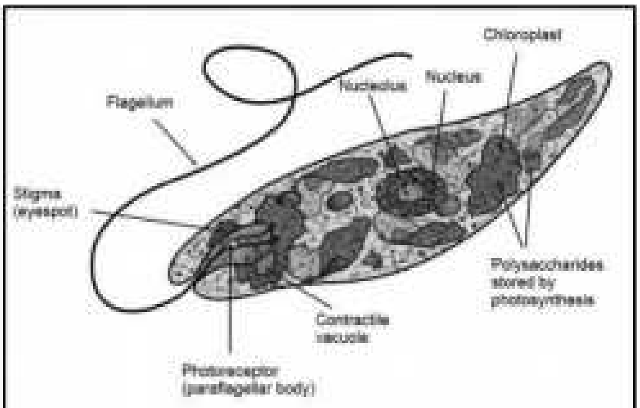


Fig. 2.6 : Structure of *Euglena*

Slime molds

The slime molds are saprophytic in nature. They lack cell wall, hence, the organisms have naked protoplast called plasmodium. In certain cases, many small naked plasmodia aggregate to form pseudoplasmodia (Fig. 2.7)

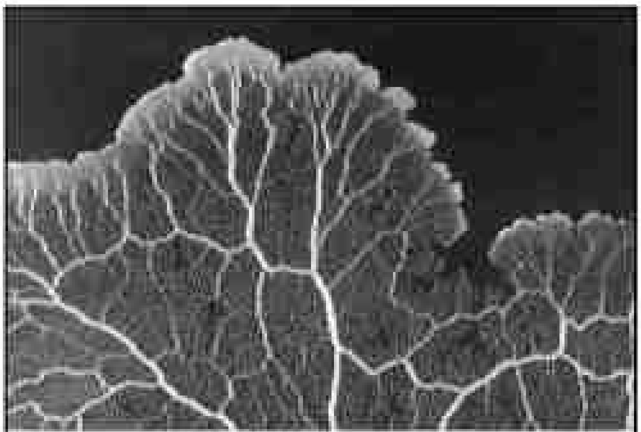


Fig. 2.7 : Slime mold

Reproduction takes place asexually by means of unineucleate spores, each with a distinct cell wall. In most cases, spores are borne within or upon fruiting bodies of definite shape. When the germinating nonmotle spores or motile swarmers fuse in pairs, they develop into diploid plasmodia. Sometimes, the spores directly develop into haploid plasmodia.

Protozoans

These are the protists which show more animal-like features. Previously these were kept in the animal kingdom. There are 4 types of Protozoans.

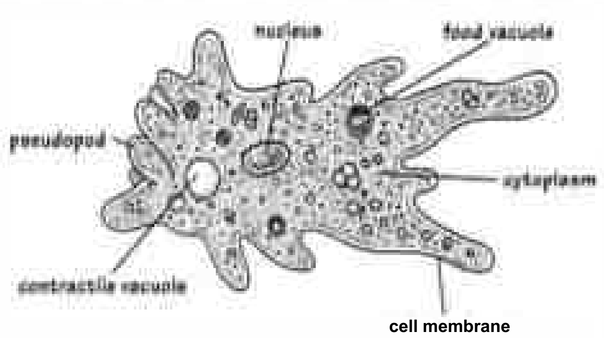


Fig. 2.8 : Structure of an *Amoeba*

(a) Amoeboid : These may occur in fresh water of marine or amphibious habitats. These forms possess pseudopodia as locomotory organelle. Example : *Amoeba, Entamoeba* (Fig. 2.8)

(b) Flagellated: Flagellated forms may be free living or parasitic. Example: Trypanosoma.

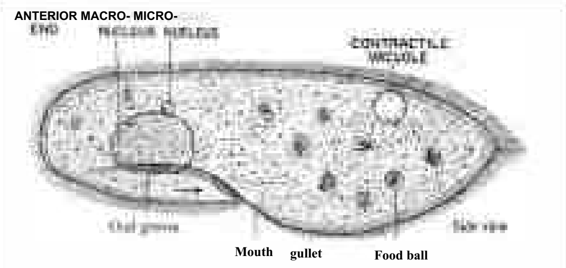


Fig. 2.9 : Structure of *Paramaecium*

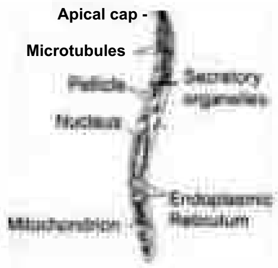


Fig. 2.10 : Structure of *Sporozoite* of *Plasmodium*

(c) Ciliated : These are aquatic and motile due to the presence of cilia. They have a gullet that opens to the outside of cell surface (Fig. 2.9) The coordinated movement of cilia cause water move into the gullet. Example: Paramecium

(d) Sporozoans : These are the infectious agents which have spore-like stages in their life cycle. Example: *Plasmodium* (Fig. 2.10).

2.4.3. Kingdom - Mycota or Fungi

Example - Aspergillus, Penicillium, Saccharomyces (Yeast)

1. These are uni or multicellular - achlorophyllous, spore bearing thallophytes.
2. Major component of cell wall may be cellulose or chitin or both.
3. In most cases, multicellular, thread like structures, branched in various patterns are called mycelia (singular - mycelium). These constitute the thallus. Individual branches of it are called hypha (plural-hyphae).
4. These are heterotrophic, may be saprophytic or parasitic.
5. Mode of nutrition is absorptive which means the enzymes secreted by the hyphae digest complex nutrients of the host. The simplified nutrients are then absorbed by the organisms.
6. The reproduction may be vegetative, asexual and sexual. Asexual reproduction takes place under favourable conditions.
7. The reserve food materials are glycogen.

The fungi are heterotrophs. When they grow on dead, decaying organic matter, the nutrition in called saprophytic. Those live on living hosts and obtain nourishment from them, are called parasites. They can also live on other organism with mutual benefit, i.e. as symbionts- the classic example is algae and fungi live with one supporting other. Here, the composite organism is called lichen. Sometimes, certain fungi live in the root systems of higher plants and the association is called mycorrhiza.

Reproduction in fungi takes place by vegetative, asexual and sexual methods. When the hyphae of the fungal mycelia break accidentally and new progeny can grow, then, the vegetative method is called fragmentation.

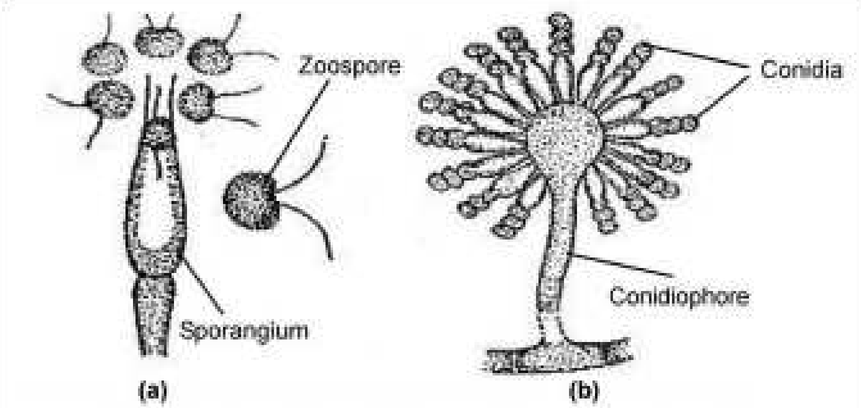


Fig. 2.11 : Asexual reproduction by (a) Zoospores (b) Conidia

Asexual reproduction in fungi occur by motile or nonmotile spores. The motile spores are usually endogenously borne in sporangia and are called zoospores or sporangiospores (Fig. 2.11a). Nonmotile spores are exogenously borne and are called conidia (Fig. 2.11b).

Since fungal thallus is predominantly haploid in nature, sexual reproduction is completed with plasmagamy, karyogamy and meiosis.

On the basis of the morphology of the mycelium, mode of spore formation and fruiting body formation, the kingdom fungi can be conveniently divided into 4 divisions such as Phycomycetes, Ascomycetes, Basidiomycetes and Deuteromycetes. Besides this, there are various other modes of classification of fungi.

Phycomycetes

Phycomycetean fungi are the primitive ones in the kingdom. They occur in aquatic, damp moist habitats as saprophytes or may be parasites on aquatic to terrestrial organisms. Mycelia are haploid in nature.

The mycelium is aseptate, coenocytic. The fungal wall, here, may be composed of cellulose or chitin or both. Asexual reproduction generally occur under favourable conditions. Asexual reproductive units such as motile zoospores or nonmotile aplanospores are borne in specialized structures called sporangia. Sexual reproduction may be isogamous oranisogamous. As a result of sexual reproduction, diploid zygospores are formed. When anisogamous, male reproductive units are called antheridia or spermatia. Female reproductive organs differ from male ones in structure and called oogonium. This difference is very much discernible in oogamous type of reproduction. *Mucor, Rhizopus* (Fig. 2.12) are predominantly saprophytic. *Albugo, Peronospora* (Fig. 2.13) etc are parasitic phycomycetean fungi.

Ascomycetes

These fungi typically possess asci (Singular: Asus) and ascopores, as a result of sexual reproduction. Among large number of these fungi, Yeast (Saccharomyces) and certain yeast-like organisms are unicellular but most of the fungi in the group are multicellular mycelia. However, fungal mycelia are haploid in most cases. Ascomycetean fungi are saprophytic or parasitic- Mycelia are branched and incompletely septate.

The asexual reproductive units called conidia are exogenously borne on conidiophores, the modified structures of hphae. Sexual reproductive structures are ascopores borne inside the ascus. The asci are organized into fruiting bodies called ascocap. Examples: *Aspergillus, Penicillium* (Fig. 2.14).

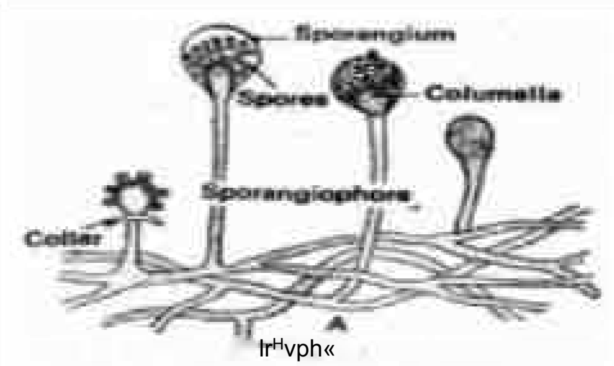


Fig. 2.12 : Structure of *Mucor* mycelium with Sporangium and Sporangiophore

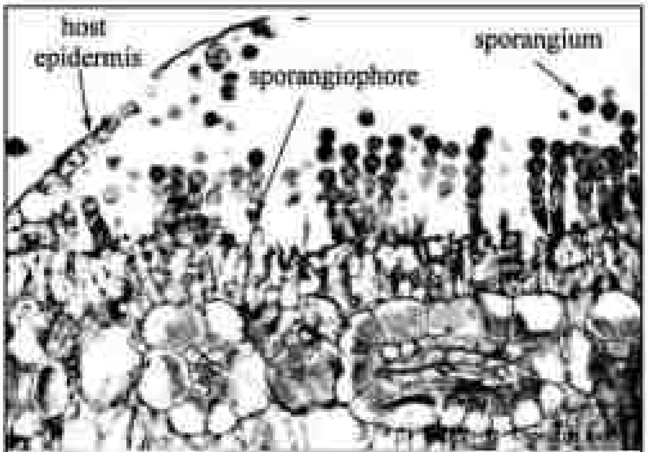


Fig. 2.13 : Albugo in the host plant with reproductive units

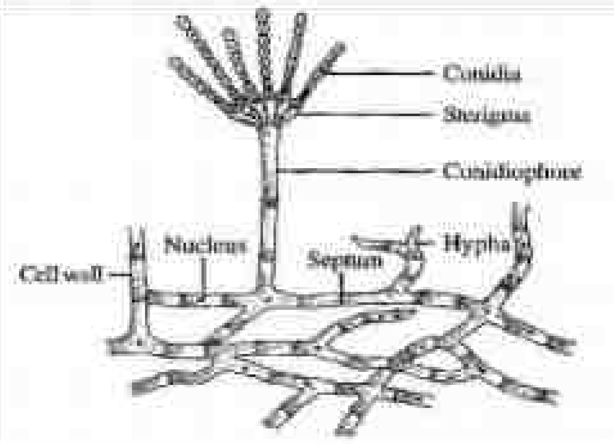


Fig. 2.14 : Penicillium Mycelium with reproductive units

Basidiomycetes

A unique type of spore, the basidiospore borne upon a unique type of sporangium, the basidium is produced by all Basidiomycetean fungi. The number of basidiospores is usually four. Basidiomycetes include fungi like mushrooms, puffballs, the smuts, the rust etc. These fungi grow on soil, moist wood as saprophytes and invade plants as parasitic smuts or rusts. The mycelium is branched. Germination of basidiospore leads to formation of uninucleate cells called primary mycelia. Cells of mycelia become binucleate very soon leading to formation of secondary mycelia or dikaryotic mycelia. In this condition, the paired nuclei divide simultaneously.

Common method of vegetative reproduction is fragmentation, the sex organs are not formed in basidiomycetes. Plasmogamy is effeceted by fusion of vegetative cells or somatic cells of primary mycelia. Karyogamy and meiosis result in the formation of basidiospore which are borne on basidia. The basidia are organized into fruiting bodies called basidocarps. Common members under the group areAgaricus (mushrooms) (Fig. 2.15a) *Ustilago* (smut) and *Puccinia* (Rust) (Fig. 2.15b).

Fig. 2.15a : Mushrooms

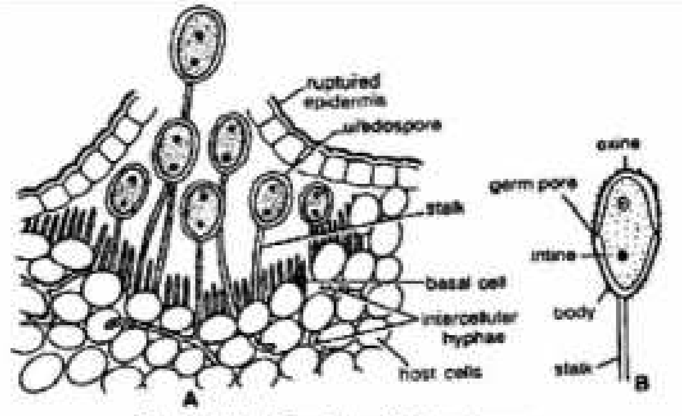


Fig. 2.15b : *Puccinia* with teleutosorus

Deuteromycetes

Deuteromycetes are called imperfect fungi. It includes those fungi in which there is no formation zygotes, ascospores or basidiospores. This means their sexual reproduction or perfect stage formation is not known. Once the sexual reproduction is detected, then, these are segregated and placed at their rightful place on the one of the above described divisions. Examples : *Altemaria, Colletotrichum* etc.

Lichens

Lichen, consist of two separate entities a fungus and an alga, so intimately associated together that they form a composite unit, called lichen. The fungus almost surrounds the algal component and the combined growth results in such a structure and definite form that the lichens are divided into genera and species. The algal and fungal components are respectively called phycobionts and mycobionts. Algae synthesize the food and fungi provide shelter and absorb mineral nuhents. Linchens can grow under very tough and adverse environmental conditions. They are used as indicators of pollution.

2.4.4. Kingdom - Plantae

1. It includes mainly multicellular, eukaryotic and autotrophic organisms.
2. The major component of the cell wall is cellulose.
3. The cells contain few large vacuoles and no structure like centrosome.
4. These organisms are also called producers.
5. The reserve food material is generally starch.
6. Growth in higher plants is always terminal.
7. The trees generally grow being fixed to the soil.

8. Reproduction may be vegetative , asexual or sexual.

   (Example : Multicellular algae, bryophytes, pteridophytes, phanerogams.)

   Detailed description of the kingdom is given seprately below.

2.4.5. Kingdom-Animalia

1. All the heterotrophic multicellular organisms are under this kingdom.
2. Higher animals show organ organization.
3. Cell wall is lacking
4. Large number of small vacuoles with centrosome present in their cells. Higher animal cells do not have vacuoles.
5. Animals mostly show locomotion .
6. Reproduction occurs in higher animals by sexual method.
7. Reserve food material is glycogen.
8. Growth occurs equally in all parts of the body.

   Detailed description of the division is given separately.

Merits

1. This system of classification is based on origin and evolution of the organisms, hence, phylogenetic one.
2. Since prokaryotes are distinctly different from all other organisms, they were given the status of a kingdom.
3. Likewise, Fungi are organisms with cell wall but the composition of cell walls and their physiological and nutritional properties are distinctly different. Hence, the organisms were kept in a separate kingdom.

Demerits

1. There were various complexities in this classification. For example, one type of organism such as, algae were spread among the Protista, Monera, and Plantae.
2. All groups are polyphyletic and not monophyletic in origin as underlined by this classification.
3. Protista is an artificial and heterogeneous group as per this clasification. It comprises of walled and organisms, lacking cell wall, Again, the organisms may be photosynthetic or nonphotosynthetic.
4. No place was assigned to for the viruses.

TABLE-1.6
Character Kingdoms under 5-kingdom system.

Sl. No.	Character	Monera	Protista	Mycota	Plantae	Animalia
1.	Cell types	Prokaryote	Eukaryote	Eukaryote	Eukaryote	Eukaryote
2.	Complexity	Uni Multicellular	Unicellular	Multicellular	Multicellular	Multicellular
3.	Nucleus	Primitive	Well organized	Well organized	Well organized	Well organized
4.	Cell Wall	Noncellulosic	Cellulose or absent	Cellulose or Chitin or both	Cellulose	Absent
5.	Chloroplast	Present or absent	Present or absent	Absent	Present	Absent
6.	Movement	Motile or Non-motile	Motile	Motile or nonmotile	Nonmotile	Motile
7.	Tissue System	Absent	Absent	Absent	Present	Present
8.	Nutrition	Auto or heterotrophic	Auto or heterotrophic	Heterotrophic & absorptive	Autotrophic	Heterotrophic
9.	Ecological role	Producer/ decomposers	Producer/ Decomposer /Consumer	Heterotrophic /decomposer	Autotrophic	Heterotrophic
10.	Sexual reproduction	Absent	Present	Present	Present	Present

In all these systems of classification, viruses have posed problem in assigning them to a specific position, hence, their status in living world is dealt separately.

2.5. VIRUSES

Russian botanist Dmitri Iwanowski (1892) discovered the viruses causing tobacco mosaic disease. Later, W.M. Stanley (1935) isolated these agents and identified them. He concluded that viruses are complex aggregation of only nucleic acids and proteins. These are noncellular, ultramicroscopic structures. They grow and multiply only inside the living cells. Hence, their status in the living world is a long vexed question. They were not even taken into consideration in any system of classification. However, some give the viruses the status of the living beings whereas others strongly object to it.

Living characters

1. Growth and reproduction are chief identifying characters of living beings. Viruses possess both, they grow, reproduce and even undergo mutation.

2. Like living pathogenic organisms, they are transmissible. (Even the bacterial filter papers, that can hold back the smallest bacteria, cannot do so for viruses. They pass through these filters.)
3. In extremely dilute dosages, the viruses are effective in causing disease.
4. These are obligate parasites.

The viruses are hence, given the status of primitive microorganisms from which higher forms of life have evolved.

The adherents of nonliving hypothesis have observed that (1) The viruses can be extracted in the form of crystals from the diseased tissues. (2) They are quite inert, apparently lifeless outside the living cell. Hence, they can be treated like any chemical agents . They can neither metabolise nor multiply in this form. (3) They are not infective themselves. However, once they come in contact of suitable host, they are capable of causing infection.

All these prompted the proponents of regressive theory to assume that the viruses are degenerate microorganisms being degraded from primitive, living organisms. Therefore, viruses are referred to as cell components.

Adherents of the theory believe that the viruses are part of the cell. The nucleic acid, is the genetic component which have the ability to leave the cell and be transferred to other cells. It is independent enough to pass from cell to cell and impose its patterns on the infected host cells. Similar structures are shown by the cellular organelles like mitochondria and chloroplasts, but they have so strongly integrated in the living cells that they have lost their ability of transmission from one cell to another (Fig. 2.16).

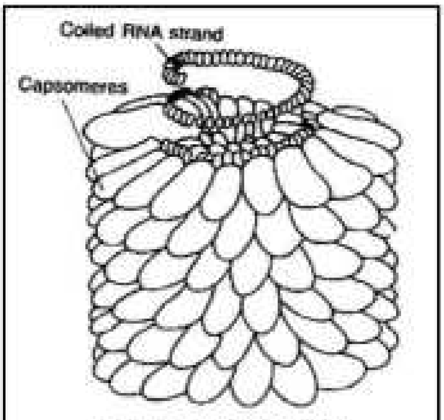


Fig. 2.16 : Structure of Tobacco mosaic virus

2.5.1. Viroids

Viroids are infectious agents which are smaller than viruses. The potato spindle tuber disease is caused due to such entities. A free RNA with very low molecular weight only compose it. This was first discovered T.O. Diener in 1971.

SAMPLE QUESTIONS

1. **Fill in the blanks choosing appropriate answers given in the brackets.**
   (a) In two-kingdom system of classification----------- were ignored.
   (eukaryotes, plants, prokaryotes, animals)
   (b) The major component of the cell wall of bacteria is —.
   (Peptidoglycan, Cellulose, Chitin, Lipoprotein)
   (c) The core of the viruses are composed of —.
   (Protein, Carbohydrate, Vitamins, Nucleic acid)
   (d) Fungi have------- mode of nutrition.
   (Absorptive, ingestive, autotrophic, epiphytic)
   (e) Viruses are living because they grow and —.
   (respire, reproduce, recognise hosts, transmissible)

2. **Choose the correct answer from the words given in the brackets.**
   (a) In two kingdom system, the status of one of the following type of organisms was ignored. (Fungi, Bacteria, Bryophytes, Pteridophytes)
   (b) Three-kingdom system of classification was proposed by (Haeckel, Linnaeus, Whittaker, Copeland).
   (c) One of the following components of viruses penetrate into the host cell (protein, capsid, nucleic acid, carbohydrates)
   (d) The character which separates plants from animals is the occurrence of (ribosome, nucleus, mitochondria, cell wall)
   (e) Fungi show one of the following types of nutrition.
   (Autotrophic, absorptive, ingestive, swallowing)

3. **Write notes in 2 to 3 relevant and meaningful points.**
   (a) Two kingdom system of classification
   (b) Three kingdom system of classification.
   (c) Characteristic features of algae.
   (d) Characteristic features of fungi.
   (e) Viruses, as living beings
   (f) Mycoplasma
   (g) Phycomycetes

4. **Differentiate in 2 to 3 relevant and meaningful points.**
   (a) Prokaryotes & Eukaryotes.
   (b) Protista & Monera
   (c) Mycota & Plantae
   (d) Amoeboid protozoans and ciliated protozoans
   (e) Archaebacteria and Eubacteria

5. Give an account of 5- Kingdom system of classification. Add a note on its merits and demerits.

6. Classify the living world as per the 5 kingdom system of classification. Give important features of each with examples. Mention the merits and demerits of the system.

CLASSIFICATION OF PLANT KINGDOM

CHAPTER 3

3.1. PLANT KINGDOM :

In the previous Chapter (1.2) the broad classification of living organisms under the "Five Kingdom Classification" system proposed by Whittaker (1969) has been described. The five kingdoms are Monera, Protista, Fungi, Animalia and Plantae. In this chapter, further details of classification within the kingdom plantae have been described below. Kingodm plantae is popularly known as plant kingdom.

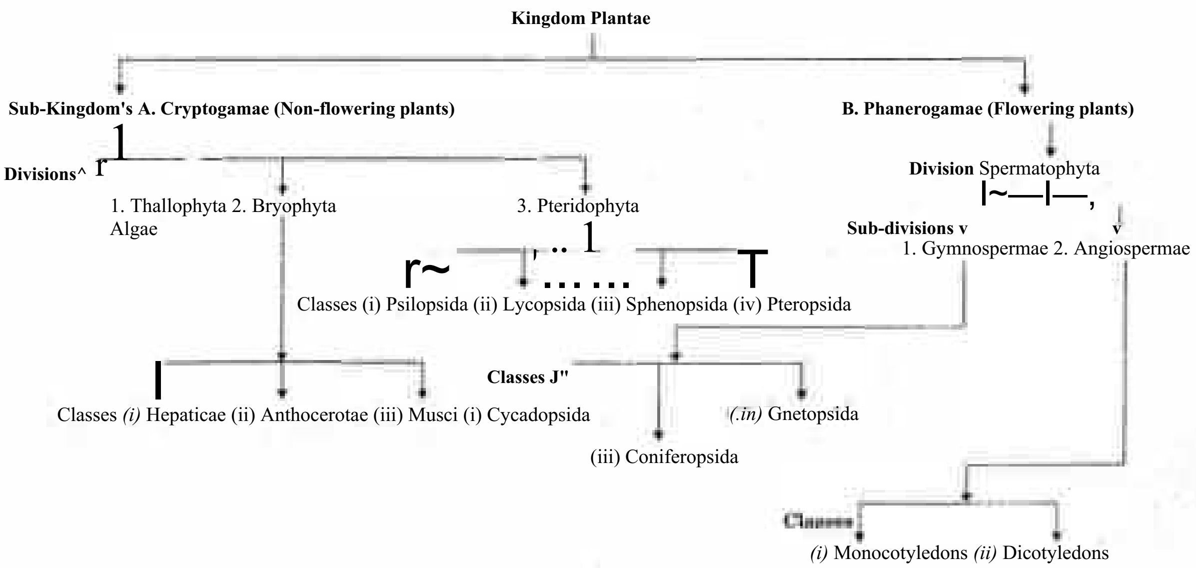
We must emphasize here that our understanding of the plant kingdom has changed overtime. The members of Fungi, Monera and Protista having distinct cell walls once included under plant kingdom, have now been excluded from plantae under five kingdom classification. So the cyanobacteria, referred to as blue-green algae are not Algae any more. Therefore in this chapter the kingdom-plantae will be described under Algae, Bryophytes, Pteridophytes, Gymnosperons and Angiosperms.

3.2. CLASSIFICATION OF PLANTS : PLANT KINGDOM

Much earlier to Whittaker's five kingdom classifciation (1969), the time tasted and most widely accepted traditional classification system was proposed by Eichler in 1883. According to Eichler, the plant kingdom has been divided into two sub-kingdoms (i) Cryptogamae (non flowering and seedless plants) and (ii) Phanerogamae (flowering and seed plants). The sub-kingdoms were further divided into divisions and classes as stated below (Table 3.1). Cryptogams are divided into division Thallophyta, Bryophyta and Pteridophyta. The phanerogams are divided into one division spermatophyta which futher divided into sub-divisions. Gymnosperms and Angiosperms. The Angiosperms are divided into Monocots and Dicots.

Table-3.1

A Traditional System of Classification of plants



It is quite interesting to note here that, later on, certain modifications and more appropriate terminologies appeared in literature.

(i) All archegonium (female sex organ) bearing plants were included under "Archegoniatae" (Bryophytes, Pteridophytes and Gymnosperms).

(ii) All the plants above the level of Thallophyta were considred under the sub-kingdom- 'Embryophyta' (the embryo bearing plants, such as; Bryophata, Pteridophyte, Gymnosperms and Angiosperms.

(iii) All plants having distinct vascular strands (Xylem and Phloem) were considered under 'Tracheophyta' (Pteridophytes Gymnosperms and Angiosperms)

(iv) All the seed bearing plants are groups under Spermatophyta.

3.3. ALGAE:

The algae are simple, thalloid, chlorphyll-bearing (green), autotrophic and largely aquatic (both fresh water and marine) plants. They grow in a variety of habitats; moist stones, soil and moist wood. Some of them also are seen to grow in association with fungi (Lichen) and animals (e.g. on sloth bear)

The form and size of Algae is highly variable (Fig. 3.1 - 3.3). The size ranges from the unicelluar microscopic forms like *Chlamydomonas* to colony-forming forms *Volvox* and to filamentous forms like *Ulothrix* and *Spirogyra.* The brown algae *(Lamniaria, Fucus, Dictyota)* and red algae *(Polysiphonia)* form massive thalloid plant bodies (Figs. 3.1-3.3).

The cells constituting the plant body are haploid and eukaryotic. Hence, the plant body is a gametophyte. Generally starch is the predominant reserve food material. The vascular and mechanical tissue are abset in Algae.

Algae reproduces by vegetative, asexual and sexual methods. Vegetative reproduction takes place by fragmentation in which each fragment develops into a new thallus. The asexual reproduction is by the formation of different types of spores, also commonly called zoospores. They are flagellated, motile and on germination, give rise to new thalli. Sometimes under unfavourable environment, non-motile spore-like alpanosporse or hypnospores may develop and ultimately they form a new thallus when environmental conditions are congenial.

Sexual reproduction takes place by fusion of two (male and female) gametes. The gametes may be similar in size and flagellated as in *Chlamydomonas,* or non-flagellated as in *Spirogyara.* This type reproduction by fusion of similar gametes is called isogamous. In some species of *Chlamydomonas* the two flagellated gametes are dissimilar in size and such reproduction is called anisogamous. Fusion between one large, nonmotile (static) female gamete and a smaller motile male gamete is called oogamous, as in *Volvox* and *Fucus.* Embryo stage is absent in the life cyle of Algae.

The Algae are divided into three main classes : Chorophyceae (Green Algae), Phaeophyceae (Brown Algae) and Rhodophyceae (Red Algae) (Table 3.2).

Economic importance of Algae :

(1) The algae are useful to man in many ways. At least half of the total carbon dioxide fixation on earth is carried out by algae through the process of photosynthesis. Algae being photosynthetic, increase the level of oxygen in their immediate environment. Algae growing in the seas (occupying nearly $^{3}/_{4}$ of earth's surface) provide oxygen to all living organisms. The carbon dioxide which forms polluted air are absorbed mostly by the marine algae. Thus maximum air purification is done by marine algae.

(2) Algae are very important as primary producers of energy-rich compounds which form the basis of food cycles of all aquatic animals living in fresh as well as marine water. *Spirogyra* are predominantly seen in fresh water system and play important role in this respect.

(3) As many as 70 species of marine algae like *Laminaria* and *Sargassum* are used as food. *Microcystis,* commonly called kelp, is a food delicacy in Japan.

(4) Certain marine red and brown algae produce large amounts of hydrocolloids which are water-holding colloidal substances. Algin from brown algae and carrageen from red algae are very important for their commercial uses. Agar or sometimes called Agar-agar is one of the commercial products synthesised form *Gelidium* and *Gracilaria.* Agar is used in nutrient media to grow bacteria, fungi and other microbes in the laboratory. It is also used in prepration of ice-creams and various jellies. Iodine is commercially obtained from *Fucus* and *Laminaria.*

(5) *Chlorella* and *Spirulina* are unicellular algae, very rich in useful proteins for human body which are used as food supplements even by space travellers.

3.3.1. Green Algae (Chlorophyceae):

The name chlorophyceae is divided from two Greek words : *Chloros* meaning green and *Phytos* meaning plant. They include all green algae (nearly 7000 living species). Most of them are found in fresh water and few found in marine habitat.

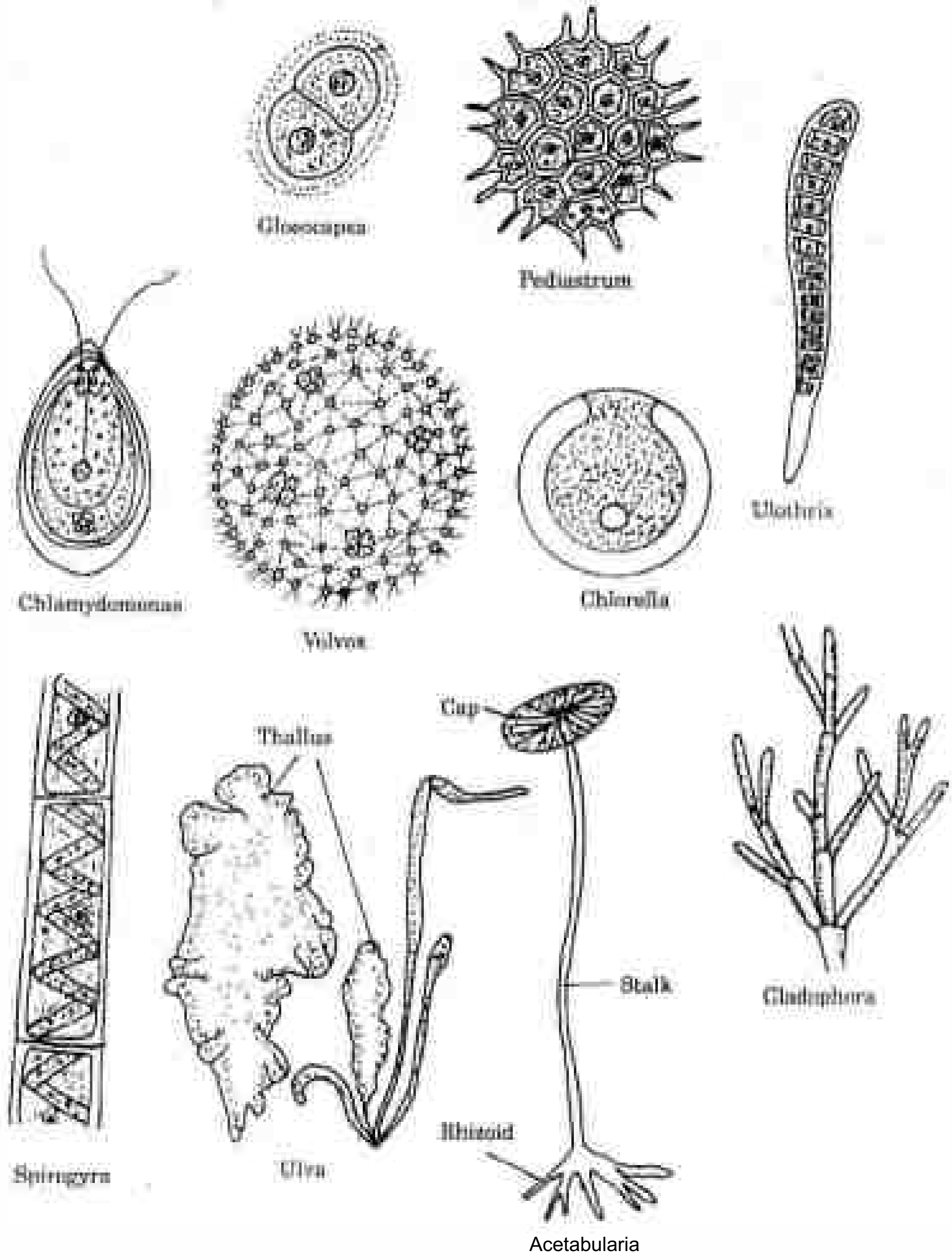


Fig. 3.1 : Some Green Algae (Chlorophyceae)

The plant body may be unicelluar (eg. *Chlamydomonas* - flagellated, *Chlorella* - non flagellated), colonial (eg. *Volvox)* or filamentous (eg. *Ulothrix, Spirogyra)* (Fig.3.1). They look grass-green due to presence of the dominant pigments chlorophyll a and b. The pigments are localized in definite chloroplasts (in the grana) which may be discoid plate-like, reticulate, cup-shaped, spiral or ribbon shaped in different species. Most of them have one or more storage bodies known as pyrenoids. They store starch as reserve food and also contain protein. Some algae store food in the form of oil droplets. The algal body is composed of cells with rigid cell wall. Like plants the algal cell wall contains cellulose in the inner layer and pectose in the outer layer.

The reproduction takes place by three methods. The vegetative reproduction takes place by fragmentation. Asexual reproduction takes place by flagellated zoospores produced in the zoosporangia, alpanospores, akinetes and autospores. The sexual reproduction shows considerable variation in the type and formation of gametes (sex cells) and may be isogamous, anisogamous or oogamous. The green algae exhibit three types of life cycles; haplontic, diplontic and diplo-haplontic.

The commonly found green algae are *Chlomydomonas, Volvox, Ulothrix, Chloralla, Spirogyra, Cladophora* (Fig. 3.1).

3.3.2. Brown Algae (Phaeophyceae):

The word Phaeophyceae is derived from two Greek words; Phaios (brown) and Phyton (plant). The members of Phaeophyceae are called brown algae, consisting of nearly 2000 species which are found primarily in cooler marine habitats. They exhibit great variation in size and form and range from simple branched filamentous forms *(Ectocarpus)* to profusely branched forms as represented by kelps *(Macrocystis)* (Fig. 3.2). *Macrocystis* is a giant alga that reaches a height of 40-100 meters. Unicelluar form is not seen in brown algae. The plant body is a thallus which has not been differentiated into root, stem and leaves.

The cells composing the thallus possess chlorphyll a, chlorphyll c, carotenoids and xanthophylls. They vary in colour from olive green to various brownish shades depending upon the amount of pigments, xanthophyll and fuco-xanthin in them. The reserve food is stored as complex carbohydrates in the form of laminarin and mannitol. The basic vegetaive cells have a cell wall consisting of cellulose. Cell wall is covered on the outside by a gelatinous coating of algin containing phycocolloids. The protoplast contains, in addition to plastids, a centrally located vacuole and the nucleus.

The plant body is commonly attached to the substratum by a holdfast. Some free floating forms are *Sargassum* and *Fucus.* So the plant body is composed of holdfast, stipe (a stalk) and lamina, the leaf like photosynthetic organ (also called frond). They may have vesicles for providing buoyancy.

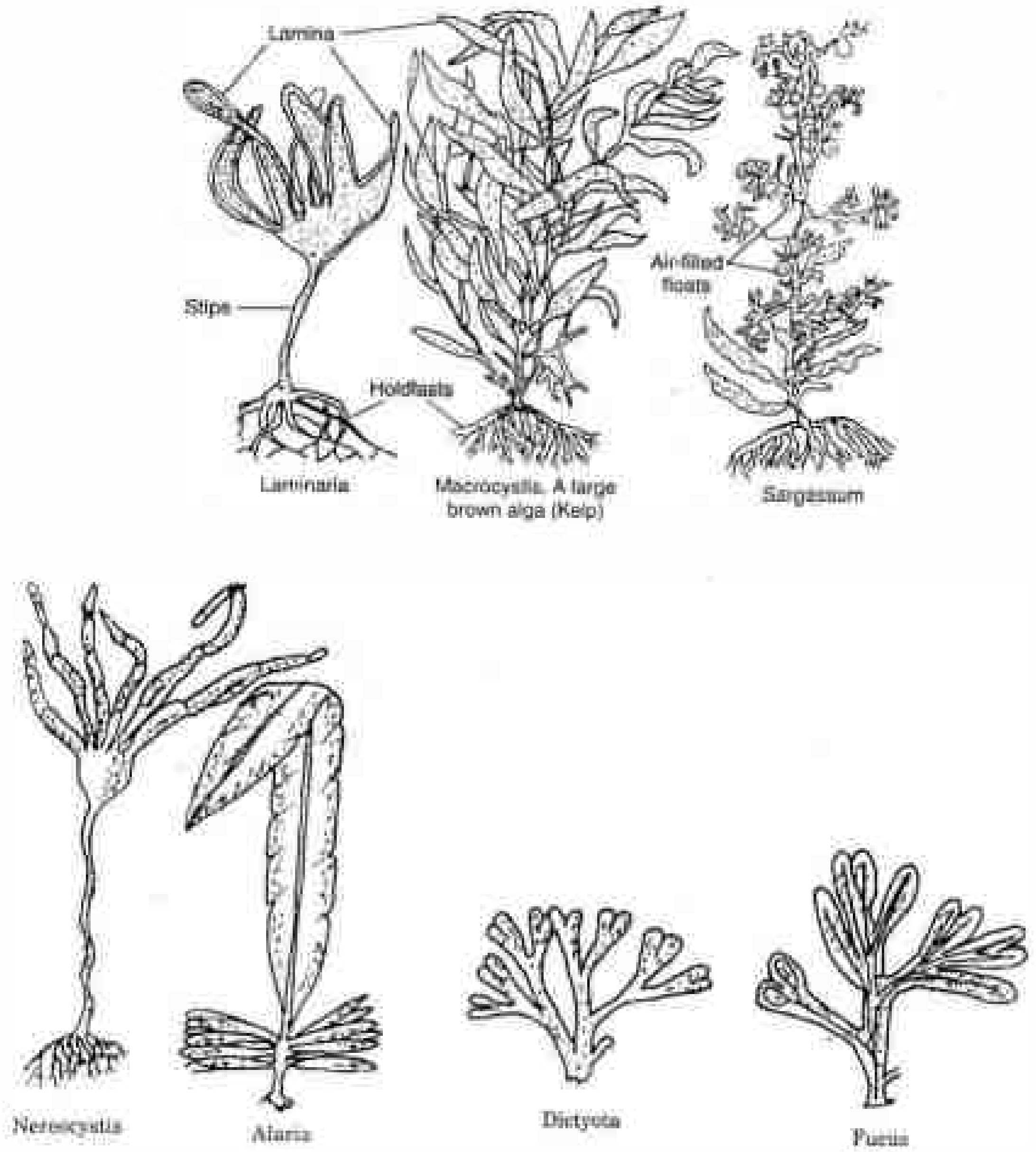


Fig. 3.2 Some Brown Algae (Phaeophyceae)

Vegetative reproduction takes place by fragmentation. Asexual reproduction takes place usually by pear-shaped biflagellate (unequal and laterally attached) zoospores in most of the brown algae. Sexual reproduction may be isogamous, anisogamous or oogamous. Union of gametes takes in water or within the oogonium in oogamous species. The garnets are pyriform (pear-shaped) and each has two laterally attached flagella.

The common examples of brown algae are *Ectocarpus, Dictyota, Laminaria, Sargassum, Fucus, Macrocystis* etc. (Fig. 3.2)

3.3.3. Red Algae (Rhodophyceae):

The name Rhodophyceae is derived from two Greek words; rhodo meaning red and phyton meaning plant. The members of Rhodophyceae are called red algae, consisting of around 5000 species. Majority of red algae are marine seaweeds found in warmer and well lighted regions, close to surface water or seas. A few are fresh water forms (eg. *Batrachospermum).* Some species are also seen at greater depths of seas (ocean) where relatively very little ilight penetrates.

The thallus is multicellular. Some of them are having complex body organization. They totally lack flagellated cells. They possess a pre-dominance of red pigments, r-phycoerythrin (a phycobilin) in addition to chlorophyll-a and phycobilins (phycocyanin) in their body. They store food as floridean starch which is very similar to amylopectin and glycogen in structure. The cell wall is composed of sulphonated mucopolysaccharides called phycocolloids besides cellulose and pectic substances. The most important phycobillins of red algae are agar, carageenin and porphyrin.

Red algae reproduce vegetatively by fragmentation. Asexual reproduction takes place by nonmotile spores called neutral spares, monospores, carpospores etc. Sexual reproduction

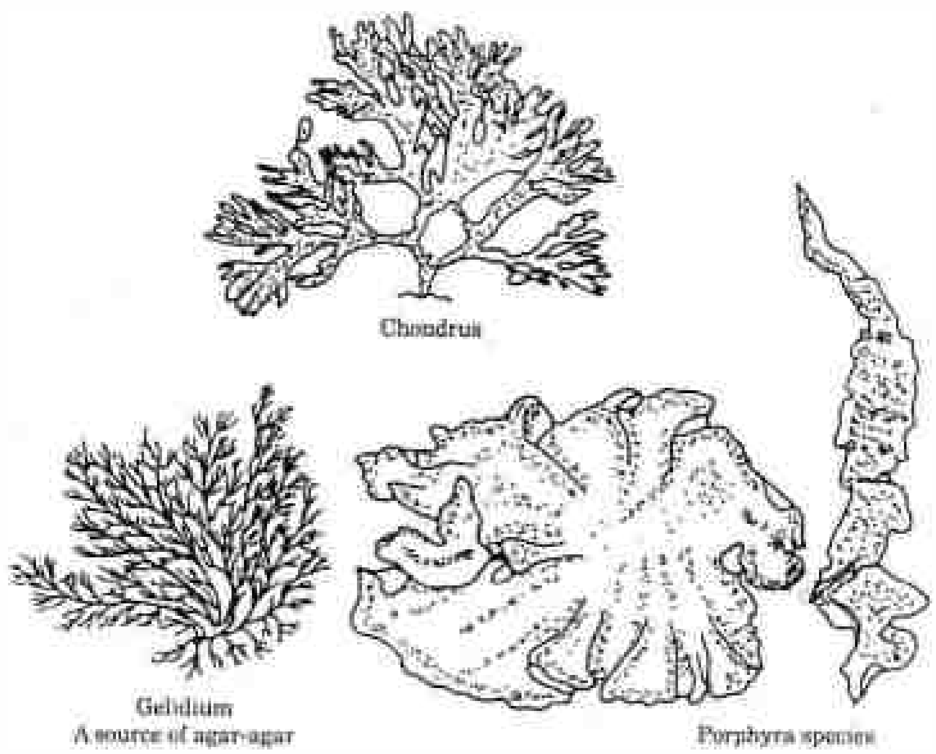


Fig. 3.3 : Some Red Algae (Rhodophyceae)

is of oogamoue type and takes place by non-motile gametes. The sex organs are male, antheridium or spermatangium (contains spermatium-male gametes) and female carpogonium a flask-shaped structure contaning female gamete. The fertilized carpogonium remains attached to the parent plant forming a diploid structure called carposporophyte. Some red algae involve alternation of haploid and diploid generations in their life cycle.

The common members of red algae are; *Polysiphonia, Porphyra, Gracilaria, Chondrius, Gelidium.* (Fig. 3.3).

Table 3.2

Divisions of Algae and their main characteristics

Kingdom	Group name	Photosynthetic pigments		Storage material	Complexity of structure	Habitat
		Chlorophyll	Others			
Plantae	Red algae (Rhodophyceae)	a	Phycobilins (phycoerythrin and phycocyanin	Special strach called floridean srarch	Unicelluar to multicellular	Fresh water (some) Brackish water, Salt water (most)
	Brown algae (Phaeophyceae)	a + c	Special carotenoid (fucoxanthin)	Mannitol Laminarin (carbohydrade) and lipid	Multicellular	Fresh water (River) Brackish and salt water
	Green algae (Chlorophyceae)	a + b	P-carotene and other carotenoids	Starch	Unicellular to multicellular	Fresh water Brackish water Salt water

3.4. BRYOPHYTA:

The name Bryophyta has been derived from two Greek words bryon meaning moss and phyton the plant. The Bryophytes having about 25000 species are non-vasular and first land plants, commonly growing in moist, damp and shaded areas (habitat). They grow densely together and often form green carpets or mats on damp soil, rocks, walls, building roofs, tree trunks, hills especially in rainy seasons. Bryophytes are also called amphibians of the plant kingdom because they can live in soil but are dependent on water for sexual reproduction. They play an important role in plant succession forming biomass on bare rocks and dry soils. They help in soil formation and are a part of xerosere.

They are small plants of both prostrate and erect habit and usually grow upto 15 cms. (Fig.3.4). But one moss Dawsonia from Newzeland grows upto 60 cm in height.

The plant body is a green-coloured (haploid) gamephyte and not differentiated into true stem, root and leaf. It is thallus like, avascular and attached to the substratum by unicelluar or multicelluar rhizoids.

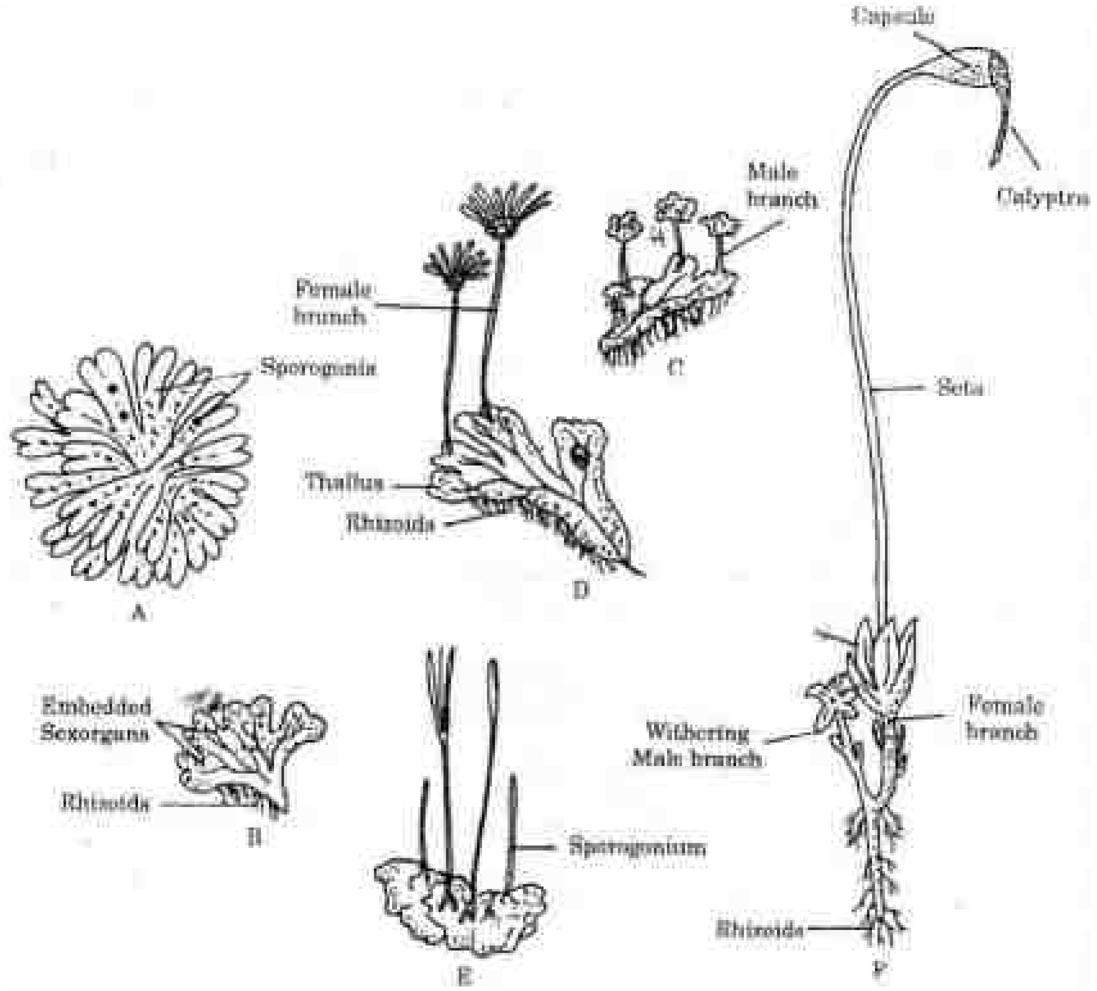


Fig. 3.4 : Some Bryophytes. A-B. Riccia, C-D. Marchantia (Liverworts)
E. Anthoceros (Hornworts), F. Funaria (Moss)

The gametophytic main plant body produces gametes. The male sex organs are called antheridia (Fig. 3.6) which produce biflagellate antherozoids. The female sex organ called archegonium, a flask shaped structure consisting of a basal venter (containing an egg, the female gamete) and upper slightly elongated neck (Fig. 3.5). Archegonium is a structure which is seen for the first time among the bryophytes. Therefore the bryophytes are the first archegoniate plants found during evolution of plants.

The antherozoids are released into water where they come in contact with archegonium of the plant. Antherozoid enters through the neck, moves upto the venter and fuses with the egg or oognium to produce a zygote (2n). Now the zygote a diploid structure and the first cell of the sporophyte. It does not undergo reduction division immediately, but forms the multicellular sporophyte (2n). The sporophyte is not free living but depedent fully on the photosynthetic gametophyte for its shelter and nourishment (food). The zygote undergoes divisions to form a multicelluualar embroyo which grows into the sporophyte. The sporophyte may be a globular structure consisting of only sporogenous cells or it may have a particular definitive structure having foot, seta and capsule (containing sporogenous cells). The sporogenous cells undergo reduction division (meiosis) to produce haploid spores. The haploid spore, the first cell of gametophytic generation germinates to produce the gametophyte.

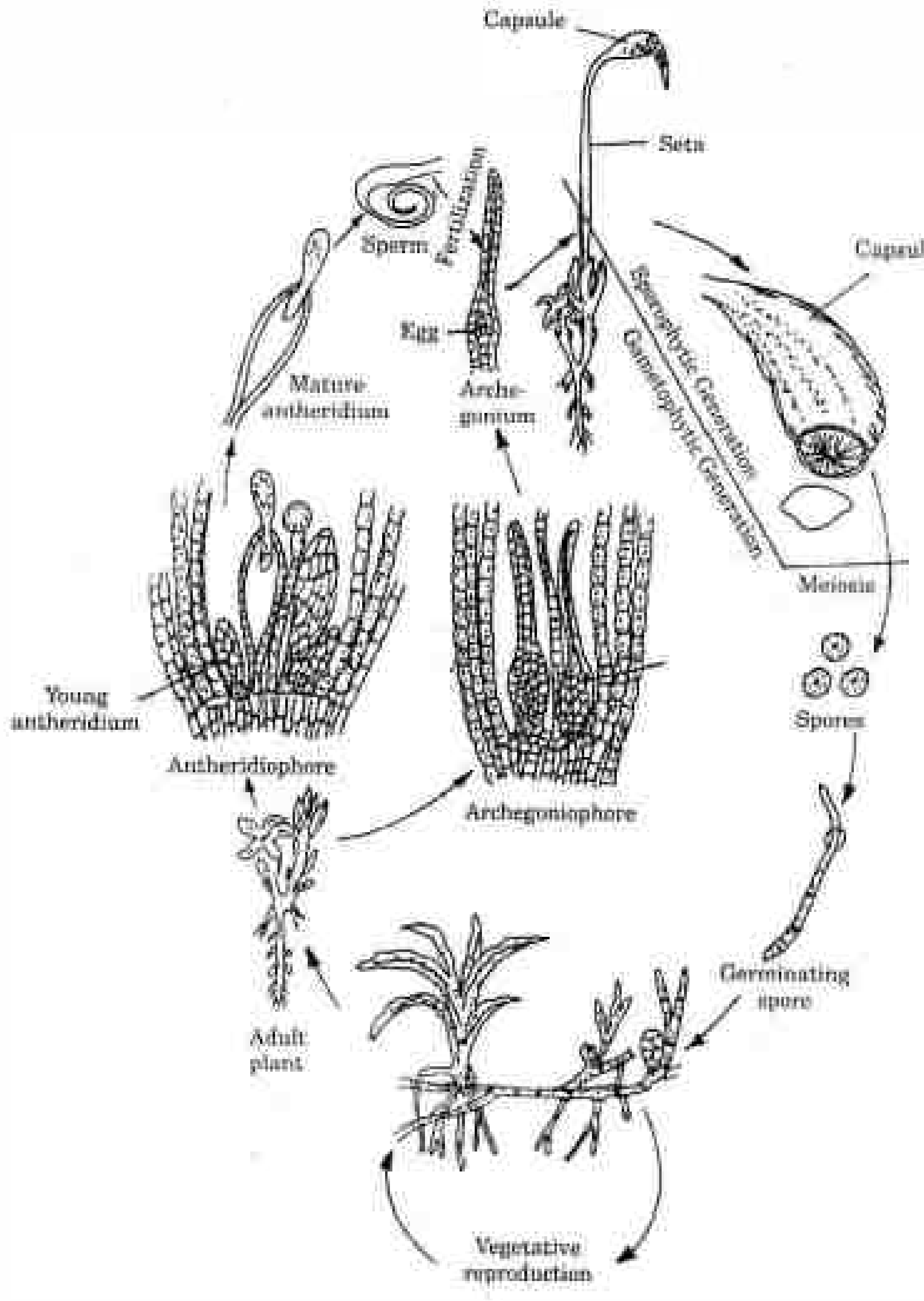


Fig. 3.5 : Antheridum, Archegonium and lifecycle of Funaria (Moss) showing alternation of generations

The Bryophytes are divided into 3 classes; Hepaticae (The Liverworts), Anthocerotae (Hornworts) and Musci (Mosses). Common representatives of Bryophytes are *Riccia, Marchantia, Anthoceros, Porella, Sphagnum, Funaria, Polytrichum* (Fig. 3.4)

Economic importance of Bryophytes :

1. Bryophytes as land colonizers - Primarily the mosses first spread over the dry barren areas and stablilize the soild surface and increase the water holding capacity of the soil. Due to continuous death and decay of mosses alongwith lichens, the organic matter content of land is increased. Thickness of soil increses in this way. The rocky and dry land becomes suitable for growth of higher plants (herbs, shrubs and trees in sequence). In this way, plant succession takes place in a gradual and step-wise manner and climax forest is formed.

2. Sphagnum and Peat - *Sphagnum,* also called peat moss or bog moss is a perennial aquatic moss, when established on the shores of lakes or ponds. The moss gradually encroaches the watery areas, creep over the water and completely covers the surface of the water-body. They secrete acids. The spreaded moss accumulates and form a thick dark coloured compressed mat over the years called peat which when dried can be used as fuel in place of coal. Peat is also used to cure skin diseases.

3. The mosses like *Sphagnum* are used as a favoured packaging material for transporting cut flowers, living seedlings, seeds and plants. They are also used as a water retaining constituent for preparing seedbeds and nursery stocks.

4. After proper disinfective treatments, *Sphagnum* has been used to replace the absorbent cotton for dressing wound, specially during war time.

5. Medicinal uses - *Marchantia polymorpha* is used to cure pulmonary tubercolosis and afflictions of liver. Extracts of *M.polymorpha, Polytrichum commune* are said to possess antitumour properties. A decoction of dried *Sphagnum* in hot water is used by tribals for treatment of ailments of eye and to control acute haemorrhage. *P. commune* is used in removing kidney and gall bladder stone. Extracts from mosses like *Polytrichum, Sphagnum* etc. have antibiotic properties against bacteria like Streptococcus, Shighella, Salmonella and Staphylococci.

6. Bryophytes in geochemical evalution - Some bryophytes have been discovered to grow in some areas rich in particular metals. For instance, some mosses grow in areas, very rich in copper. *Nardia scaleris* grow in areas that have deposits of gypsum. Such bryophytes are of great help to geologists for evaluation or identification of areas for metal.

7. Ornamental / Decorative materials - Mossess are used extensively for ornamental purposes, particularly in making floral arrangements and bouquets for gifts.

3.4.1. Hepaticae (Liverworts):

The liverworts grow usually in moist shady habitats, such as; banks of streams marshy ground, damp soil, deep in the woods, bark of the trees and overthe surface of ground soil. The plant body a green, prostrate, dorsiventral and thalloid gametophyte with unicelluar rhizoids for anchoring the soil or surface of the substratum. The branching is repeatedly dichotomous and the thallus becomes lobed to look like a liver, hence this group called liverworts (Fig. 3.4)

Asexual reproduction takes place by fragmentation of thalli or by formation of specialized structures called gemmae. The gemmae which develop within gemma cups, are green multicellular asexual buds. When get detached from the parent body, they germinate to form new individuals.

Sexual reproductive organs are antheradia (male) and archegonia (female), produced either on the same or on different thalli. The zygote formed by the union of male and female gametes is a diploid cell and the first cell of sporophyte. Sporophyte has no or very little green tissue and may be diffrentiated only into a special capsule or a structure having foot, seta and capsule. Sporophyte is small and completely dependent on the gametophyte. Spores are produced as a product of meiosis in sporogenous tissue in the capsule. Spores germinates and produce free living gametophytes. The examples of liverworts are *Riccia, Marchantia* and *Porella* (Fig. 3.4).

3.4.2. Anthocerotae (Hornworts):

They have dorsiventral prostrate thallus with unicellular rhizoids. Plant body is a gametophyte which may be a simple thallus or having a leafy axis.

The sporophyte consists of capsule, seta and foot. The seta becomes much elongated at maturity and looks like a cylindrical horn (hence the name hornwort) with some amount of green tissue. So the sporophyte, although attached to the gametophyte completely, is partially depended on gametophyte for nutrition.

The examples of hornworts are *Anthoceros, Pellia* and *Riccardia* (Fig.3.4)

3.4.3. Musci (Mosses):

They have erect and radially symmetrical leafy plant body (gamotophyte). The predominant stage of life cycle of a moss is the gametophyte which consists of two distinct stages, the protonema stage and leafy stage. The spore on germination, first develops into a juvenile protonema, a creeping, green filamentous and branched protonema. It bears multicellular branched rhizoids which ultimately anchors the body with soil. The leafy stage develops from the protonema as a lateral bud. The leafy stage consists of upright slender axis bearing spirally arranged leaves.

Vegetative reproduction is by fragmentation and budding in secondary protonema. The sex organs are antheridia and archegonia produced at the apex of the leafy axis. After fertilization the zygote develops into a sporophyte consisting of foot, seta and capsule. After meiotic cell divisions of sporogenous cells, the spores are dispersed from the capsule. The sporophyte is partially dependent on the gametophyte.

The common examples of mosses are *Funaria, Polytrichum, Sphagnum* etc. (Fig. 3.4, 3.5).

3.5 PETRIDOPHYTA:

The Pteridophyta (Gk: Pteris - feather, phyton - plant) commonly called the oldest, seedless, vascular cryptogams and are represented by about 400 genera (Fossil and Living) and more than 10000 species. They are the first vascular land (terrestrial) plants. They dominated the forests of the carboniferous period, about 300 million years ago. The main plant body is a sporophyte, the dominant phase of life cycle and differentiated into stem, root and leaf like organs. They are the highest evolved cryptogams. Some tree-ferns *(Cyathia, Celeotium)* may attain a height of 20 meters.

Pteridophytes are commonly found in cool, damp and shady places, though some species grow well in sandy soil. They are found in tropical and temperate regions of the world.

The leaves in these plants are of two types; small called microphylls (e.g. *Selaginella)* and larger ones called macrophylls (e.g. ferns) (Fig. 3.6). The Sporophytes bear sporangia that are subtended by leaf like appendages called sporophylls. The sporophylls in some cases form distinct structures called strobilus (e.g., *Selaginella)* or compact cone (e.g., *Equisetum)* (Fig.3.6). The Sporangia produce spores by meiosis in spore mother cells. The spores develop into inconspicuous, small but multicellular gametophytic body called prothallus which is monoecious (bearing sex organs in the same prothallus). The prothallus is free living, mostly photosynthetic and thalloid in nature. The gametophytic bodies require cool, damp and shady places fortheir growth. Because of such restricted habitat requirement and need of water for fertilization, the living pteridophytes have spread to limited or restricted and narrow geographical regions.

The gametophytes bear male and female sex organs called antheridia and archegonia respectively. The antherozoids (male gametes) released from antheridia with the help of water reach to the archegonium. A zygote (2n) is formed as a result of fusion of male (antherozoid) and female gametes (egg) and forms the first cell of the sporophytic generation. Zygote develops into multicellular well differentiated sporophyte which is the dominant phase of life cycle of pteridophytes.

In majority of pteridophytes, the spores are of similar sizes. Such plants are called homosporous. In *Selaginella* and *Salvia,* two kinds of spores mega or macro (large) and micro (small) spores are formed and plants bearing such spores are called heterosporous. The mega spores and microspores germinate to form female and male gametophytes respectively. The female gametophytes are retained on the parent sporophytes for variable periods till the development of roots within the female gametophyte. The zygote develops into a young sporophyte. This is a tendency to form the seed and called seed habit. Seed habit leads to formation of seed plants.

The plants show clear alternation of generations in their life cycle. The sporophyte and gametophyte are autotrophic and independent of each other.

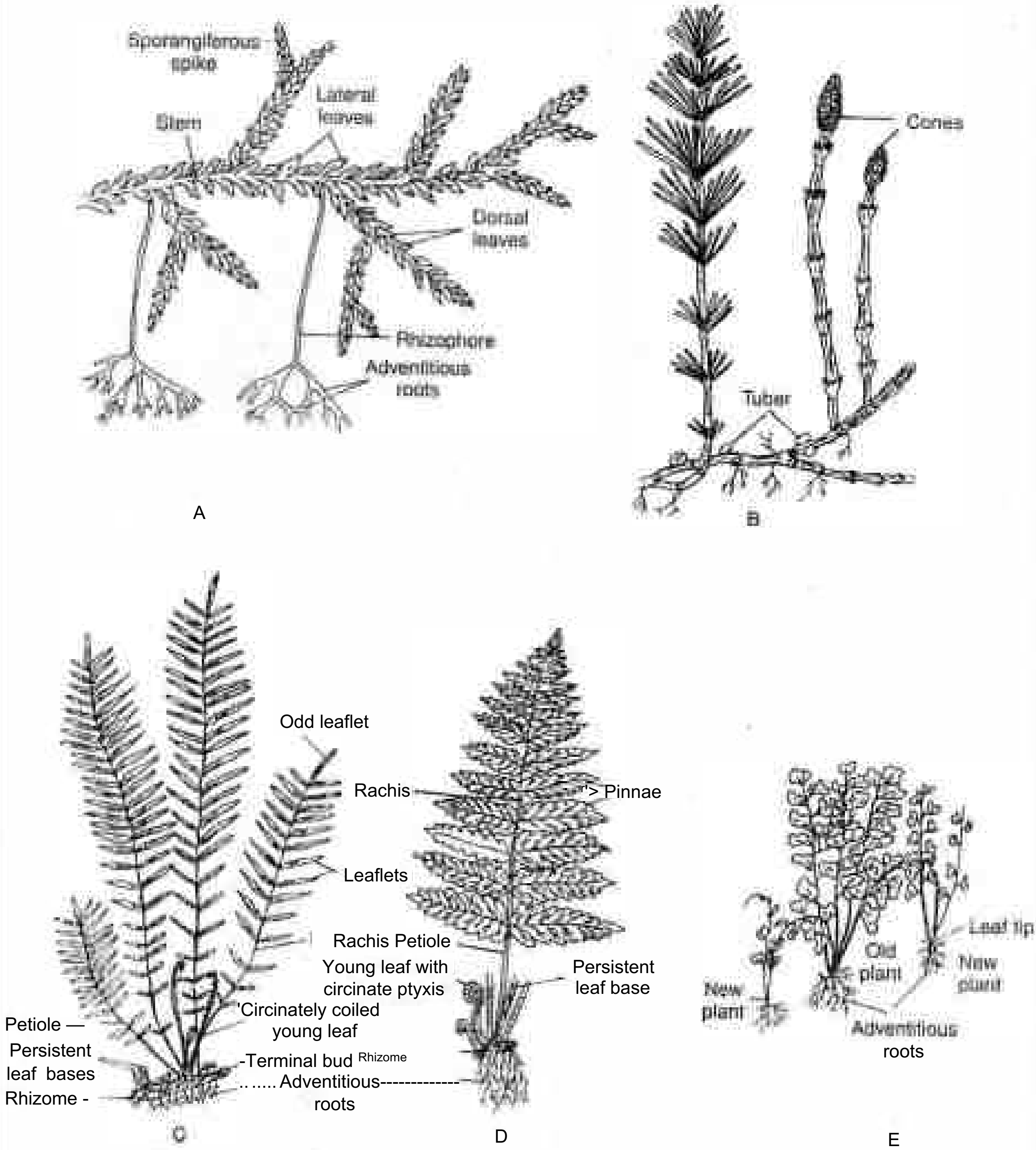


Fig. 3.6 : Some Pteridophytes. A. Selaginella (Club Moss), B. Equisetum (Horsetail), C. Pteris (Fern), D. Dryopteris (Fern), E. Adiantum (Fern).

Classification of Pteridophytes :

The pteridophytes comprise of four classes.

1.	Psilopsida (Psilophytes)	-	Most of them are fossils except few living members, e.g. *Psi lot um.*
2.	Lycopsida (Clubmosses)	-	They grow as prostrate aggregates like mosses, e.g. *Lycopodium, Selaginella* (Fig. 3.6)
3.	Sphenopsida (Horsetails)	-	They have articulated stem with whorls of branches and scale- like leaves. The spore producing bodies borne at the ends of branches resemble the tail of the horse, hence the name 'horsetails' e.g. *Equisetum.* (Fig. 3.6)
4.	Pteropsida (Ferns)	-	Ferns are most conspicuous amphibian pteridophytes which have underground stem (rhizome), adventitious roots and aerial pinnately compound leaves called fronds, e.g. *Dryopteris, Cyathia, Pteris, Adiantum, Marsilea* (Fig. 3.6)

Economic importance : Afew economic uses pteridophytes are given below :

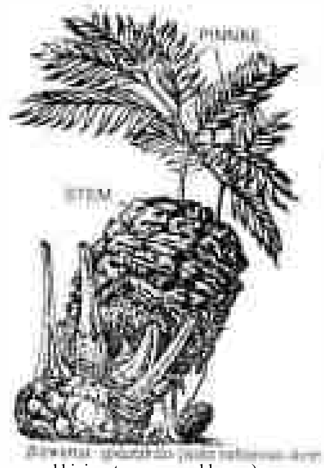
1.	*Lycopodium clavatum*	-	Spores used in rheumatism and cramps. Leaves are chewed for arresting food poisoning.
2.	*Psilotum nudum*	-	Oily spores given to infants to cure diarrhoea.
3.	*Selaginella repande*	-	Root paste applied over white patches in Leprosy.
4.	*Equisetum*	-	The entire plant is used for cooiling gonorrhoea. The plant paste applied in bone fractures.
5.	*Dryopteris cochlea*	-	Whole plant extract taken orally for snake bite. The powdered rhizome in water is taken for rheumatism and Leprosy.
6.	*Dicranopteris*	-	Fronds are used in asthma. The young fronds grinded in milk given to remove sterility in women.
7.	*Adiantum*	-	Rhizome and fronds are used in wound healing, boils, glandular swellings dysentery, ulcers and scorpion bites. Fronds are diuretic and the decoction is given to reduce fever.
8.	*Marsilea*	-	It is very rich in minerals and commonly eaten as leafy vegetable.

3.6. GYMNOSPERMS :

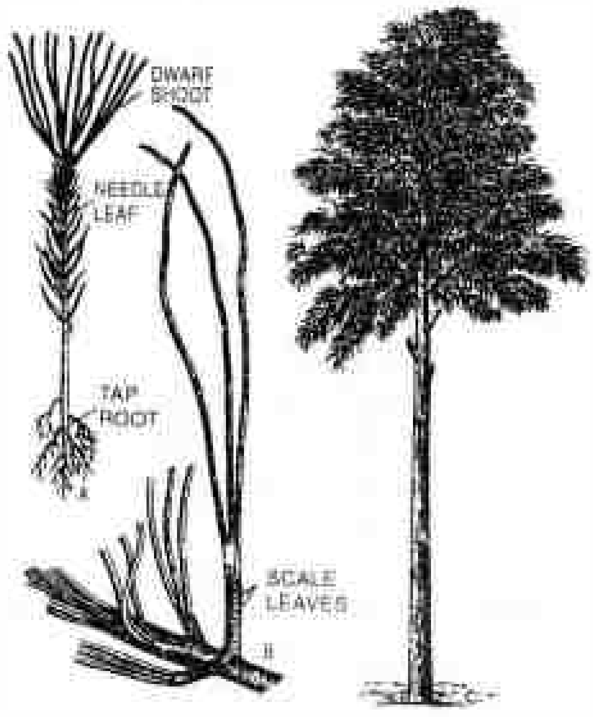
The word Gymnosperm was used in 300 B.C. by Theophrastus, a pupil of Aristotle in his book 'Enquiry into plants'. He used this term to embrace all those plants whose seeds were unprotected. The Gymnosperms (gymnos-naked, sperma-seeds) are plants in which the ovules are not enclosed by any ovary wall. No ovary is present in Gymnosperms. So the seeds developed from ovules are naked (not covered) and remain exposed before and after fertilization.

Gymnosperms and Angiosperms are grouped under Spermatophytes.

. *Cycas circinnalis* (After Blume)



and bipinnate compound leaves)
(After Engler and Prantl).



Young seedling of *Pinus.* B. Dwarf shoots *of Pinus insularis* (one shown entire, others are dissected! C. A *Pinus tree.*

, A twig of *Gnetum* gnemon bearing male strobili.

Fig. 3.7 : Some Gymnosperms

Gymnosperms are found throught the surface of the globe, mostly in high altitudes. They are evergreen, some are deciduous, woody, xerophytic and include medium size to very tall trees and shrubs. One of the tallest, a giant redwood tree is *Sequoia gigantea* which lives for 4000 years. Gymnosperms formed dominant vegetation on the earth about 200 million years ago and later replaced by the angiosperms. Some of them live for thousands of years. Gymnosperms, today are represented by nearly 70 living genera 725 species.

The main plant body is a well differentiated sporophyte (dominant phase of life cycle) consisting of root, stem, leaves and flowers. The gametophyte is very much reduced and remains within the sporophyte. The gametophyte is fully dependent on the sporophyte.

These perennial woody trees have stems, may be unbranched *(Cycas)* or profusely branched *(Pinus, Cedrus)* (Fig. 3.7). Leaves (foliage leaves and scale leaves) are well adapted to tolerate extreme temperature, water scarcity and wind. The pinnate leaves of *Cycas* persist for few years. The needle-like leaves of pines (reduced surface area), sunken stomata and thick cuticle help to reduce water loss. Roots are tap roots and in some genera (in *Pinus)* have fungal association in the form of mycorrhiza. In *Cycas,* small specialized roots called coralloid roots associated with nitrogen-fixing Cyanobacteria are present.

The vascular tissues are arranged into bundles just like angiosperms. However xylem does not have vessels and phloem with no companion cells except in *Gnetum.*

Gymnosperms are heterosporous. They produce two kinds of haploid spores (meiospores-as a product of meiosis), microspores and megaspores within two different types of sporangia called microsporangia and megasporangia respectively, Again all sporangia are borne on sprophylls (micro / or megasporophylls) which are arranged spirally along the axis to form lax strobili or compact cones. The male (microsporangiate) cone or strobilus bears microsporophylls and microsporangia (pollen sacs). The microspore develops into a male gametophyte during gametophytic generation which is highly reduced and confined to a limited number of cells, called a pollengrain. The pollen grains are released from microsporangia and move by air currents.

The female cone (strobilus) consists of megasporophylls which bear the exposed megasporangia called ovules. The ovules are integumented (seed coat) with an opening called micropyle. The ovule initially is filled with nucellus (nuceller tissue). Near the micropyler end, one of the nuceller cells gets differentiated into megaspore mother cell (2n) which divides meiotically to form four megaspores (n). Usually one haploid megaspore develops into a multicellular female gametophyte that forms two or more archegonia, the female sex organs bearing female gametes (egg). The female gametophyte is completely retained within the megasporangium or ovule, which is also dependent on the sporophytic tissue.

The pollen gains enter through the microphyle of ovule, produce pollen tubes which grow towards archegonia and discharge the two male gametes near mouth of neck of archegonia.

One male gamete reaches the egg inside the venter, fertilization is effected and a diploid zygote (2n) is formed. The formation of pollen tube by pollen grain during fertilization process is called siphonogamy. Fertilization of one male gamete with the egg inside venter of achegonium results in formation of a diploid zygote (2n).

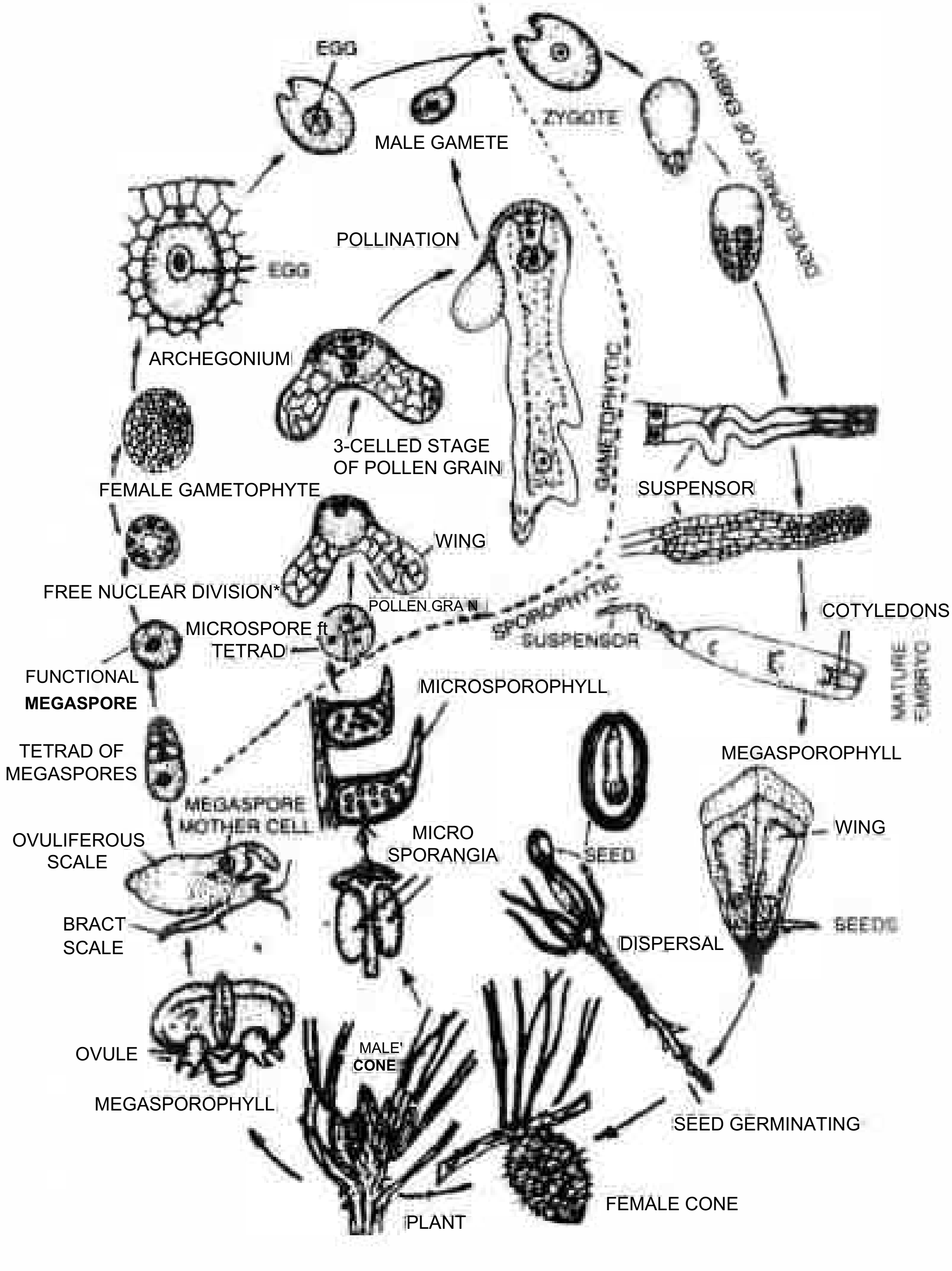


Fig. 3.8 : Diagrammatic Life Cyle of a Gymnosperm, Pinus

The zygote develops into an embryo, the future sporophyte. The whole ovule develops into the seed. Formation of many embryos within one ovule, called polyembryony is common in pines. Seeds are not enclosed by any other outer covering like ovary wall as in case of angiosperms. In Gymnosperms, there is no ovary. So seeds are uncovered or naked, hence the name 'gymnosperms', the naked-seeded plants. They have epigeal mode of germination. Plants show distinct alternation of generations.

Classification of Gymnosperms : Gymnosperms includes three classes

1. Cycadopsida (Cycads) - They are represented by both fossil and living members and constitute a small group of gymnoperms. The living members are xerophytic and look like palms having fern like leaves. Plants are dioecious, means the microporophylls and megasporophylls are borne in separate plants. Examples: *Cycas, Zamia, Macrozamia, Bowenia.*
2. Coniferopsida (Conifers) - Conifers having more than 500 living species are the most dominant gymnosperms, mostly occurring in colder regions. The plants with their conical canopy bear cones as their male and females reproductive structures. The plant body has resin canals containing an aromatic, antiseptic semifluid called resin. Examples : *Pinus, Ginkkgo, Cedrus, Abies, Cupressus.*
3. Gnetopsida (Gnetum and allied plants) - This group includes climbing shurbs, shurbs and small trees. The external and internal features of *Gnetum* resemble angiosperms. Reproductive organs are borne in whorls or inflorescence. They have vessels in the xylem. Examples : *Genetum, Ephedra* and *Welwitschia.*

Economic imprtance of Gymnosperms : They are greatly valued in world because of their importance to human beings.

1. Wood - Most of the species provide wood or timber for construction works, furniture and house building.
2. Resins - Resins produced by mostly conifer are unaffected by water and protect against insects. Pine gum, oil of terpentine, varnishes forwood paining, laundry soap, greases, printing ink, printing driers, shoe polish and insecticides are manufactured from resins.
3. Essential oils and falty oil production-
   (i) A fatty oil from conifer wood pulp used in manufacture of paints, soap, linoleum and emulsifiers.
   (ii) Spruce oil obtained from *Abies, Picea;* oil from *Cryptoneria, Araucaria, Cedar;* wood oil from *Thuja* and various essential oils from gymnosperms (mostly pines) are used by us in various ways.
4. Paper and Board (Cellulose and Pulp) - In USA, 85% of pulp used for paper making come from conifers. Himalayan conifers produce excellent pulp for paper industry.

5. Food - Pine kernels preserved in honey are eaten, seeds all pines theoritically have high food value.

6. Tannins - Tannins utilized for tranforming hides to leather. In petroleum industry, tannins are used as dispersant to control mud during oil well drilling. Barks of many confers like *Tsuga, Sequoia, Larix, Picea* contain high concentration of tannins.

7. Decoration and ornamental use - Mostly the leaves of *Thuja, Araucaria, Cycas, Cupressus* are used for decoration purpose. *Ginkgo* is called 'maiden hair tree' planted in most of Budhist temples in India, Japan, and China as ornamental tree.

8. Medicinal use - Ephedrine used as pulmonary decongestant is extracted from *Ephedra.*

3.7. ANGIOSPERMS :

The angiosperms are flowering plants in which seeds are enclosed with the ovary. The ovule develops into seed and the ovary into fruit. Angisperms are exceptionally a large group of plants consisting of 2,50,000 known species.

They are most recent and highly developed plants appeared on earth surface about 130 million years ago. Today they are the most dominant plant group and found to grow in almost every kind of habitat. They range in size from tiny, almost microscopic *Wolfia* to large tall trees of *Eucalyptus* over 100 meters. They may be annual, biennial or perennial herbs, shrubs or trees.

The plant body is differentiated into stem, root and leaves. At maturity plants bear flowers which produce fruits and seeds. The vascular tissue are arranged in the form of vascular bundles. The xylem contains vessels and phloem has companion cells in addition to other vascular elements.

The flowers are reproductive organs having two or one accessory whorls, perianth or calyx and corolla and two essential whorls, androecium and gynoecium. The whorls, calyx, corolla, androecium and gynoecium are composed of sepals, petals, stamens and carpels respectively. (Fig. 3.9)

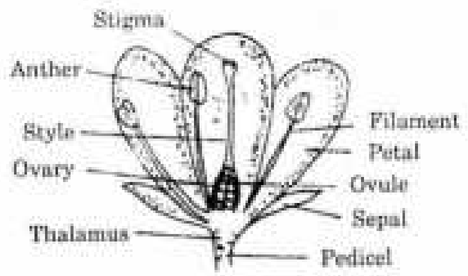


Fig. 3.9 : Vertical section - an Angiospermic Flower

A stamen, the male sex organ of the flower, consists of a slender filament and an anther at the tip. Anther contains single or more microporangia (inside the lobes). The sporogenous cells of microsporangium undergo meiotic cell division to form microspores or pollen grains (Fig.3.10). The carpel or pistil, the female sex organ of the flower,

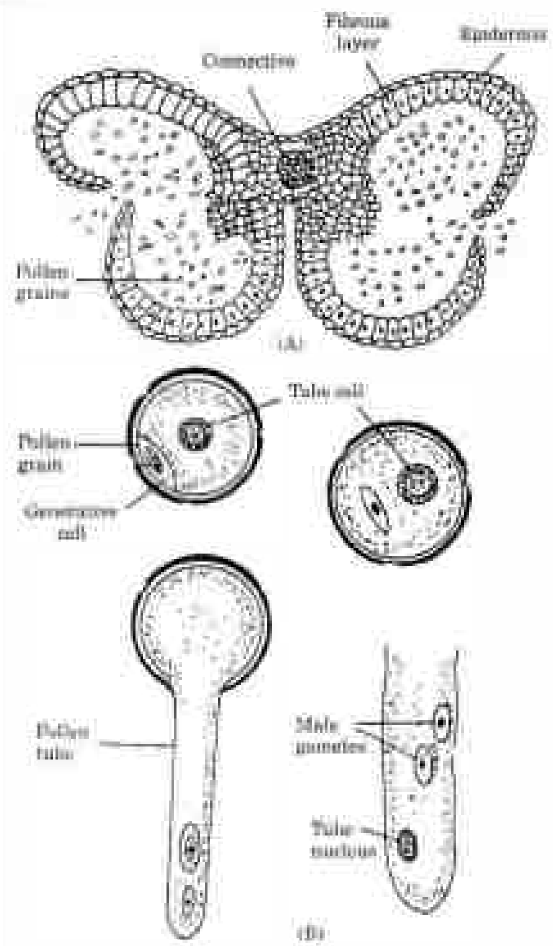


Fig. 3.10 : A. T.S of Mature Anther of Angiosperm, B. Pollen grain (Microspore) and its germination forming male gametophyte.

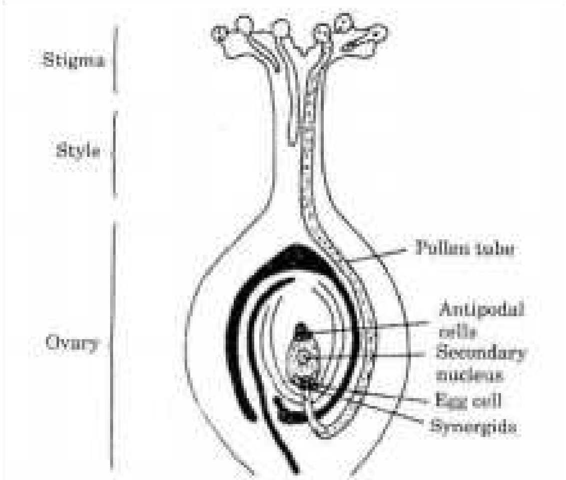


Fig. 3.11 : V.S of carpel of an Angiosperm showing mature ovule and fertilisation process.

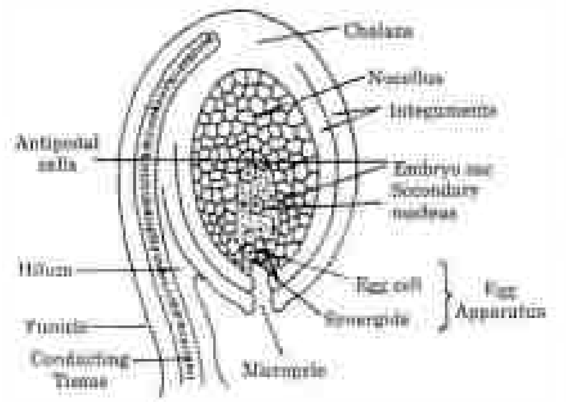


Fig. 3.12 : V.S of Angiospermic Ovule (Megasporangium) showing Integuments, Nucellus, Embryo sac and Funiculus

consists of ovary, style and stigma (3.11). The ovary encloses one to many ovules. An ovule consists of nucellus surrounded by two integuments with a fine opening microphyle. Pollen grains enter into the ovule through the micropyle. Four megaspores are formed as a result of meiotic cell division of megaspore mother cell produced by necellus. One or all the four haploid megaspores are utilized to form a female gametophyte or embryo sac with the nucellus of ovule. So the embryo sac contains all haploid cells and consists of (i) a three-celled egg apparatus (one egg cell + two synergids), (ii) three antipodal cells and (iii) two polar nuclei. The two haplaid polar nuclei fuse to form a diploid secondary nucleus.

Pollen grains after pollination from the anthers are carried by wind or other agencies to the stigma of the pistil. This is called pollination. Pollen grains germinate on the sticky surface of the stigma and produce pollen tubes (siphonogamy) which grow through the tissues of stigma and style to reach the ovlue. The pollen nucleus divides to form two male gametes. Ultimately pollen tubes enter egg apparatus of the female gametophyte or embryo sac where two male gametes are discharged. One male gamete fuses with the egg cell called syngamy to form a diploid zygote and the other fuses with diploid secondary nucleus to form a triploid primary endosperm nucleus (PEN). Because there are two fusions, this event is termed as double fertitization, an event unique to angiosperms. The zygote develops into the embroys or future sporophyte. The embryo may develop a single or two cotyledons. The primary endosperm nucleus develops into endosperm which provides nutrition to the growing embryo inside the ovule. The synergids and antipodals degenerate after fertilization. During these events the ovules develop into seeds and the ovary develops into a fuit. Atypical lifecyle is given in Fig. 3.13.

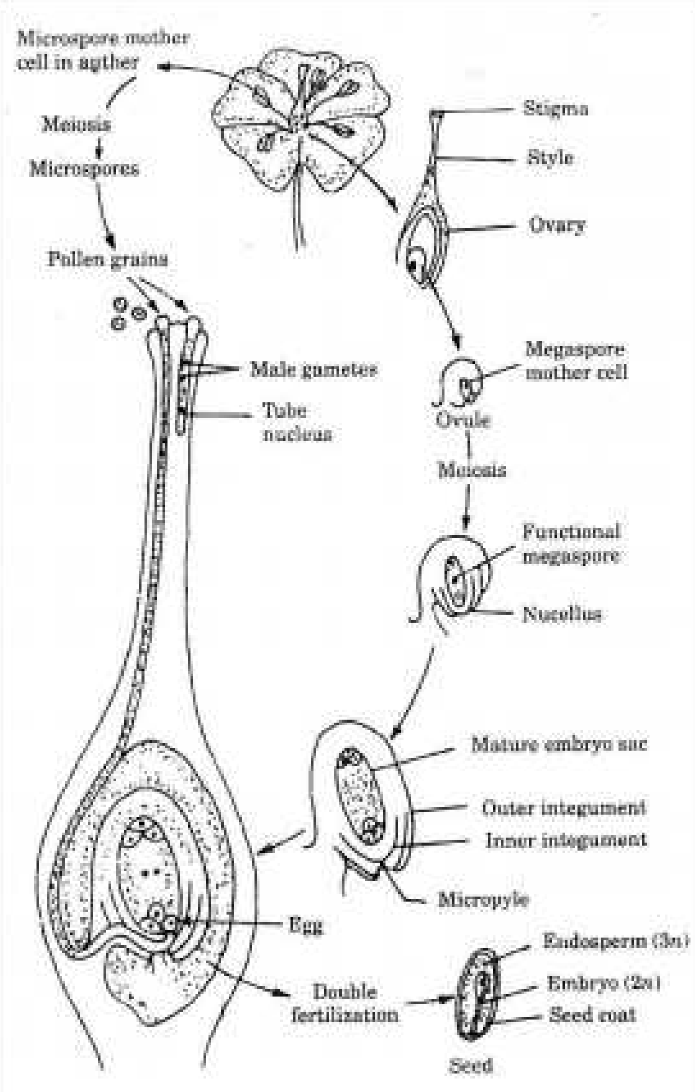


Fig. 3.13 : Life cycle of typical Angiosperm

Classification :

The angiosperms are divided into two classes, (i) dicotyledons and (ii) monocotyledons. The dicotyledons are characterized by having two cotyledons in their seeds while monocotyledons have only one cotyledon.

Class I Dicotyledons : The members of this class have leaves with reticulate (net like) venation, which show alternate, spiral or whorled phyllotaxy (arrangement of leaves). The flowers are tetramerous or pentamerous having four or five members in the various

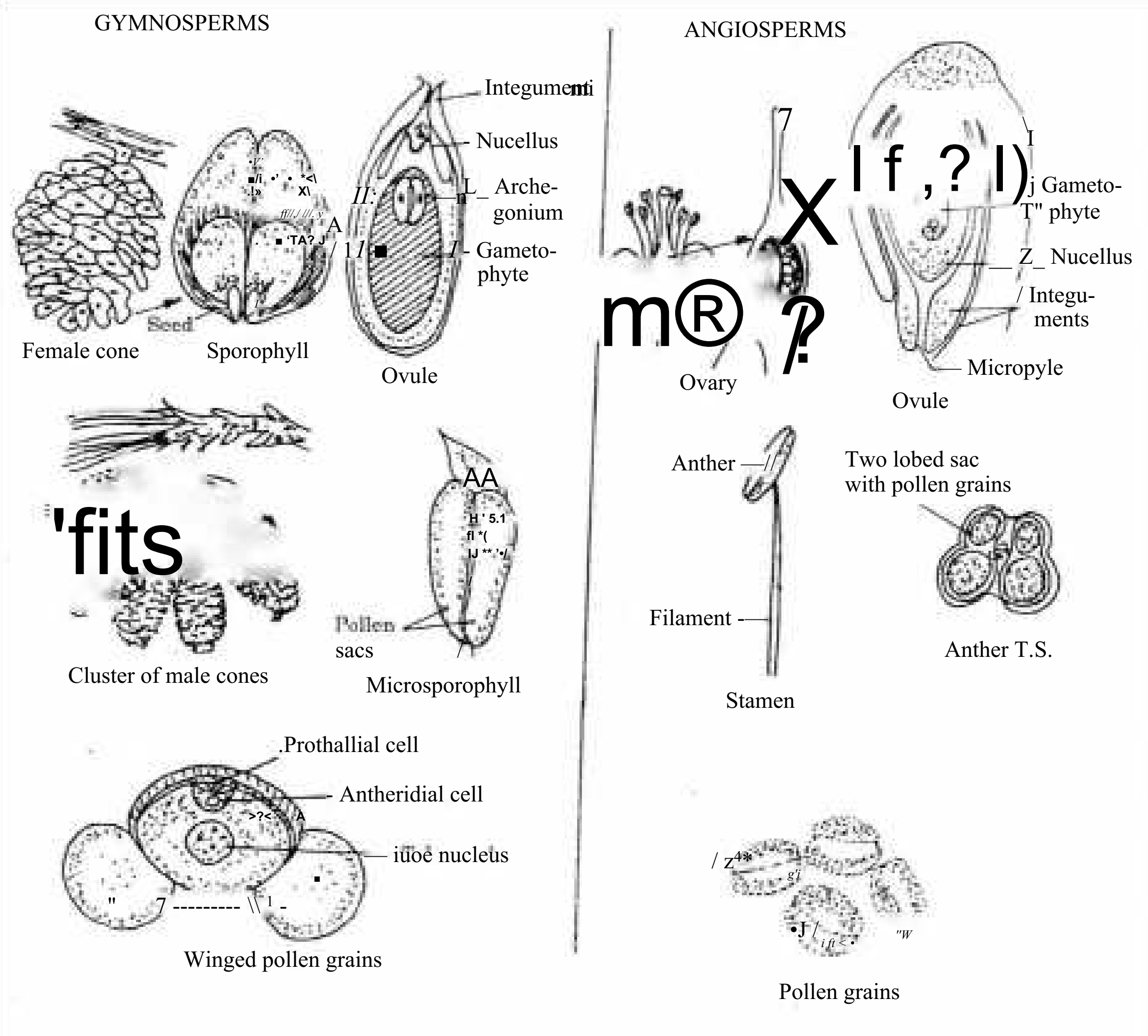


Fig. 3.14 : Reproductive organs of Gymnosperms and Angiosperms

floral whorls, respectively. The vas cular bundles are open. *i.e.* cambium is present between the xylem and phloem. The seeds have two cotyledons.

Class II : Monocotyledons *(Mono* = one, *cotyledons* = cotyledons) : The leaves are simple with a parallel venation pattern. The vascular bundles are closed (cambium absent) and scattered in the parenchyma. The flowers are trimerous (having 3 mem-bers in each floral whorl). The seeds possess only one cotyledon. The monocotyledons have, seven series, on the basis of the nature of perianth and condition of the ovary.

Economic importance of Angiosperms : The angiosperms provide with food, fodder, fuel, shelter, clothings, medicines and several other commercially important products.

3.8. LIFE CYCLES AND ALTERNATION OF GENERATIONS

As we have studied in the above, it is learnt that during life cycle of any sexually reproducing plant, there is an alternation of generations between the gamete producing haploid gametophyte and spore producing diploid sporophyte. Three basic patterns of life cycles are (i) Haplontic, (ii) Diplontic and (iii) Haplo-diplontic.

1. **Haplontic -** The dominant photosynthetic (green) phase is a free-living gametophyte. The sporophytic generation is represented by the one celled diploid zygote. There is no free living sporophyte which is completely dependent on gametophyte. The diploid zygote undergoes meiosis and forms haploid spores which in turn divide mitotically to form the gametophyte. This is called haplontic type of life cycle. This pattern is seen in algae, such as *Volvox, Spirogyra* and many other algae.

2. **Diplontic -** Here the diploid sporophyte is the green or photosynthetic, dominant and independent phase of the life cycle. The gametophytic phase which is fully dependant on the sporophyte and is represented by the single to few celled haploid gametophyte. This pattern is called diplontic type of life cycle and seen in all seed bearing plants (gymnosperms and angiosperms. Fucus (an algae) has diplontic patter of life cycle.

3. **Haplo-diplontic -** This is an intermediate pattern of life cycle in which both the phases are multicelluar and visible structures.

   A dominant prostrate or erect photosynthetic thalloid haploid gametophyte alternates with the short-lived multicelluar sporophyte. Here the sporophyte is totally or partially dependent on the gametophyte for its anchorage and nutrition. All Bryophytes show this pattern of haplo-diplontic life cycle.

   In pteridophytes, the diploid green and vascular sporophyte is the dominant phse of life cycle. Here alternation of generation is between multicelluar sporophytic or autotrophic and short-lived independent haploid gametophyte. This is also haplo-diplontic pattern of life cyle. In addition to all pteridophytes, some algal genera such as Ectocarpus, Polysiphoria and kelps exhibit haplo-diplontic pattern.

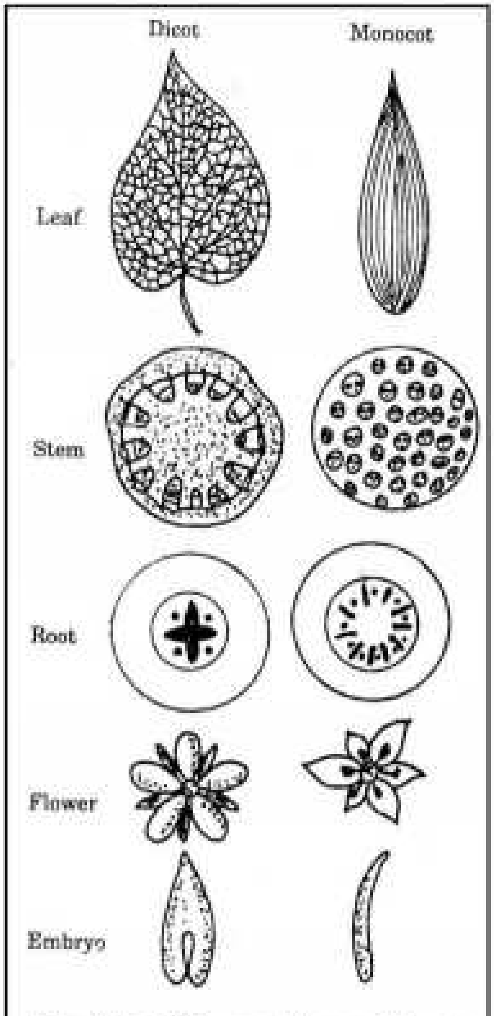


Fig. 3.15 : Difference between different organs of Diocots and Monocots.

3.9. SUMMARY OF SALIENT FEATURES OF ALL PLANT GROUPS OF KINGDOM PLANTAE

ALGAE

1. Algae are chlorophyll bearing green simple, thalloid, autotrophic, eukaryotic organisms have dominant gametophytic haploid bodies and largely aquatic.
2. Algae usually reproduce vegetatively by fragmentation, asexually by formation of different spores (zoopores, aplanospares, hypnospores) and sexually by formation of gametes which may show isogemy, anisogamy or oogamy.
3. The zygote never develops into embryo and true visible alternation of generations is absent but the life cycle pattern usually falls under haplontic type.
4. Depending on the type of pigment possessed, type of storage food materials, the algae are divided into three major classes such as, chlorophyceae (green algae), phaeophycea (brown algae) and Rhodophyceae (red algae). These are many other minor classes of algae.
5. Algae are used as food *(Sargassum, Macrocystis, Chlorella, Spirulina),* production hydro colloids (algin from brown algae, carrageen form red algae) and for production of agar-agar, a gellifying substance (from red *aWgae-Gelidium* and Gracilaria)

BRYOPHYTA

1. Bryophytes having nonvascular, prostrate or erect, small, thallose or foliose gametophytic bodies are the amphibians of the plant kingdom and considered as first land plants and first archegoniates in the plant kingdom.
2. The main thallus body is a multicelluar, many cells thick, fixed to soil where they usually grow by rhizoids or and scales and dependent on water for sexual reproduction.
3. During sexual reproduction, the male and female gametes formed in the sex organs, antheridia and archegonia respectively, fuse to form a zygote which develops into multicellular body, the sporophyte. It is usually consisting of foot, seta and capsule containing haploid spores.
4. There is an alternation of generations between a gametophyte, the dominant phase of life style and a fully dependent (on gametophyte) sporophyte which thus, exhibits a haplo-diplontic pattern of life cycle.
5. Bryophytes are classified into (i) Hepaticae (Liverworts having prostrate dorsiventral thallus) (ii) Anthocerotae (Hornworts, also having prostrate gametophytes with erect horn like sporophytes) and Musci (mosses having effect upright slender axes bearing spirally arranged leaves and sporophytes at tips)

6. Bryophytes are great land colonisers and used as peat (Sphagnum moss); medicinally to cure kidney or gall bladder stone *(Polytrichum commune),* pulmonary disorders *(Marchantia polymorpha),* skin diseases; packaging materials (mosses) and for geochemical evaluation of metals.

PTERIDOPHYTES

1. The petridophytes are the first vascular land plants with independent sporophyte, the main plant body, differentiated into stem, root and leaves with well defined vascular tissue.
2. They have haplo-diplontic life cyle pattern where sporophyte phase is the dominant phase of life cycle in contrast to the haploid gametophytic phase which is short lived and reduced.
3. The haploid spores produced by sporangia borne on the sporophyte, germinate in cool-damp environment to form gametophyte and bear sex organs, the antheridia (male) and the archegonia (female).
4. Water is required for transfer a male gametes to the archegonium where zygote is formed after fertilization.
5. The zygote is retained in the archegonium and develops into multi-cellular embryo that grows into a sporophyte.
6. Many pteridophytes have economic importance and in addition to decorative use (Ferns), these have many medicinal uses, such as cure for diarrhoea *(Psilotum nudum),* asthma *(Dryopteris);* wound healing *(Adiantum),* rheumatism (Dryopteris) etc.

GYMNOSPERMS

1. Gymnosperms are naked-seeded plants with well developed vascular system in which ovules are not enclosed by any ovary wall and after fertilization seeds remain exposed.
2. The main plant body is a long-lived sporophyte differentiated into stem, leaves and roots and alternates with the very reduced gametophytic phase, showing a diplontic type of life cycle pattern.
3. The individual male and female cones or strobili are formed by aggregation of spirally arranged micro and megasporophylls which develop micro sporogia and megasporangia that, in turn, produce haploid microspores and megaspores respectively.
4. The microspore or pollen grain germinates to form pollen tube through which male gametes are released into the ovule where it fuses egg cell present in archegonium.
5. Pollination is anemophilous and after the process of fertilization, the zygote develop into an embryo and the ovules into seeds.

6. They have great economic importance and provide us food (pine kernels), timber (pines), resins from pines (as varnishes, oil of terpentine, gums, greases, printing ink), tannins for converting hides into leather *(Tsuga, sequoia, Larix)* medicines (Ephedrine from Ephedra) and other very useful products.

ANGIOSPERMS

1. The angiosperms are closed seeded, most advanced (sprophytes) with highly developed reproductive structures (stamens and carpele / pistils) and after fertilization the ovlues develop into the seed and the ovary which encloses ovules develops into fruits.
2. The anther of stamens produces haploids pollen grains (male gametophyte) after meiosis and ovules inside ovaries form the haploid female gametophyte or emboryo sac which contains egg cell.
3. The male gametes formed in the male gametophyte pass through the pollen tube formed by pollen grains entering the female gametophyte, one fuses with the egg cell (syngamy) and the other with secondary nucleus, hence effect double fertilization, and form diploid embryo and triploid endosperm (triple fusion) respectively.
4. Double fertilization and triple fusion are unique to angiosperms which are further classified into dicotyledons and monocotyledons; depending upon the number of cotyledons present in the embryo.
5. The gametophytic phase is highly reduced and fully dependent on the dominant sporophytic plant and the life cycle pattern is diplontic.
6. Angiospermic plant provide us food, fodder, fuel, shelter, clothing, medicines and several other commercially important products.

The angiosperms are classified into monocotyledons and dicotyledons.

SAMPLE QUESTIONS

1. Choose the correct answer from the words given bracket:

(i) One the following is a vascular cryptogam
(Bryophytes, Pteridophytes, Gymnosperms, Angiosperms)

(ii) One of the following features of Gymnosperms is seen among lower group of plants
(Seed, Ovule, Archegonium, Nucellus)

(iii) Haplontic life cycle pattern is seen in one the following plant groups.
(Algae, Angiosperms, Gymnosperms, Bryophytes)

(iv) In which of the following zygote does not give rise to embryo.
(Pteridophyte, Gymnosperms, Algae, Angiosperms)

(v) One of the following is a naked seeded plant
(Angiosperms, Gymnosperm, Bryophyta, Algae)

2. Select the correct answer of the following :

(i) Green algae possess
(a) Chlorophyll a, b (c) Chlorophyll a, Carotenes
(b) Chlorophyll a, c (d) Chlorophyll b, carotenes

(ii) Agar is obtained from
(a) Gelidium (c) Spirogyra
(b) Riccia (d) Laminaria

(iii) Colour of brown algae is due to-
(a) Carotenodis (c) Phycocyanin
(b) Phycoerythrin (d) Fucoxanthin

(iv) The largest alga out of four of the following
(a) *Spirogyra* (c) *Macrocystis*
(b) *Fucus* (d) *Sargassum*

(v) The land plants that lack vascular tissue
(a) Bryophyta (c) Pteridophyta
(b) Angiosperms (d) Cycads

(vi) Sprophyte is fully dependent and parasitic on gametophytic body is
(a) Bryophyta (c) Monocots
(b) Gymnosperm (d) Di cots

(vii) Seedless vascular plants are the
(a) Liverworts (c) Ferns
(b) Mosses (d) Monocots

(viii) Multicellular branched rhizoids and leafy gametophytes are found in

(a) All pteridophytes (c) Some pteriidophytes

(b) Bryophytes (d) Gymnosperms

(ix) Smallest angiosperms is

(a) *Striga* (c) *Eucalyptus*

(c) *Wolfia* (d) *Nicotiana*

(x) Which of the following algae is very rich in proteins.

(a) *Uolthrix* (c) *Gelidium*

(b) *Chlorella* (d) *Oscillatoria*

(xi) A seed plant having a palm like habit is

(a) *Pinus* (c) *Cycas*

(b) *Gnetum* (d) *Ginkgo*

(xii) Gymnosperms are characterized by

(a) Small leaves (c) Fruits

(b) Naked Ovules (d) Ciliated sperms

(xiii) The thallus of Riccia is

(a) Triploid (c) Diploid

(b) Haploid (d) Polyploid

(xiv) Peat is formed by

(a) *Riccia* (c) *Sphagnum*

(b) *Anthoceros* (d) *Funaria*

(xv) The sporophyte consisting of foot, seta and capsule is seen in

(a) *Riccia* (c) *Selaginella*

(b) *Cycas* (d) *Funaria*

3. Fill in the blanks.

(i) Bog moses is a common name of.

(ii) is the tallest anigosperms.

(iii) Ferns contain underground stem called.

(iv) In red algae the reserved food is.

(v) The gymnosperms areseeded plants

(vi) The angiosperms areseeded plants.

(vii) Spirally arrangedconstitute a cone.

(viii) Production of spores of different sizes is called.

(ix) There is a single cotyledon in the embryo ofclass of angiosperms.

(x) Gametophytes and sporophyte are independent of each other in.

4. Write notes on (explain briefly the following terms) :

Heterospory, Archegonium, Antheridium, Haplontic, Diplontic, Sporophyll, Embryosac, Isogamy, Double fertilisation, Triple fusion, Protonema.

5. Differentiate between :

(i) Red algae and Brown algae

(ii) Liverworts and Moss

(iii) Bryophytes and Pteridophytes

(iv) Syngamy and Triple fusion

(v) Monocots and Dicots

(vi) Algae and Fungi

Long answer-type questions :

1. Describe the basis of classification and general characters of algae.
2. Name plant group which bear archegonia and describe the characteristic feature of first achegoniate land plant.
3. If both Gymnosperms and Angiosperms bear seeds, then why they are classfied separately.
4. What are Gymnosperms? Describe their economic importance.

❑ ❑ ❑

CLASSIFICATION OF ANIMAL KINGDOM

CHAPTER 4

Every day we come across with different kinds of animals surrounding us. We know few of them in our local language. They differ in their structures and forms. So far over a million species of animals have been described and they have been classified scientifically and many of them still remain to be explored. So the need for classification becomes all the more important to provide scientific names and to put them in right position in the animal kingdom.

4.1. METHOD OF CLASSIFICATION :

Although the animals differ in structure and form, there are some basic features common to many in relation to the level of organization of cells; body symmetry, types of coelom and patterns of digestive, circulatory, reproductive and nervous systems. These features are used as the basis of animal classification and some of them are discussed hereunder.

4.1.1. Levels of Body Organisation :

All the animals in the animal kingdom are multicellular except protozoa. Since their body consist of many cells, they show three levels of body organization such as (i) **cellular level,** (ii) **tissue level** and (iii) **organ and organ system level.** For example, in sponges, the cells are arranged as loose cell aggregates, i.e., they exhibit cellular level of organisation because most of the life activities are performed by individual cells. On the contrary, in higher forms some division of labour occur among the cells.Similar or nearly similar types of cells, performing the same function are grouped into tissues. Animals possessing this feature are said to be in tissue level of organisation (e.g., coelenterates). A still higher level of organisation, i.e., organ and organ system level is exhibited by members of Platyhelminthes and other higher-phyla, where tissues are grouped together into organ, and organs into organ systems. In animals like annelids, arthropods, molluscs, echinoderms and chordates, organs have been associated to form functional systems and each system is concerned with a specific physiological function. This pattern is called organ system level of organisation.

Organ systems in different groups of animals exhibit various patterns of complexities. For example, the digestive system in platyhelminths has only a single opening to the exterior that serves both as mouth and anus, and hence, is called incomplete. A complete digestive system has two openings, mouth and anus. Similarly, the circulatory system may be of two types: (i) **open type** in which the blood is pumped out of the heart into a cavity and the cells and tissues are directly bathed in it or (ii) **closed type,** in which the blood is circulated through a series of vessels of varying diameters (arteries, veins and capillaries).

Animals can be categorised on the basis of their symmetry. Sponges are mostly asymmetrical, i.e., any plane that passes through the centre does not divide them into equal halves. When the plane of division passing through the central axis of the body divides the organism into two identical halves, they are called symmetrical. The body symmetry is of two types i.e. **radial** and **bilateral.** In radial symmetry, any plane of division passing through the central axis of the body divides the organism into two identical halves. Coelenterates, ctenophores and echinoderms have this kind of body symmetry [Fig. 4.1 (a)]. In bilateral symmetry like those an annelids„arthropods, chordates, etc., only one plane of division passing through the central axis divides the animal into two identical halves the right and left [Fig. 4.1 (b)].

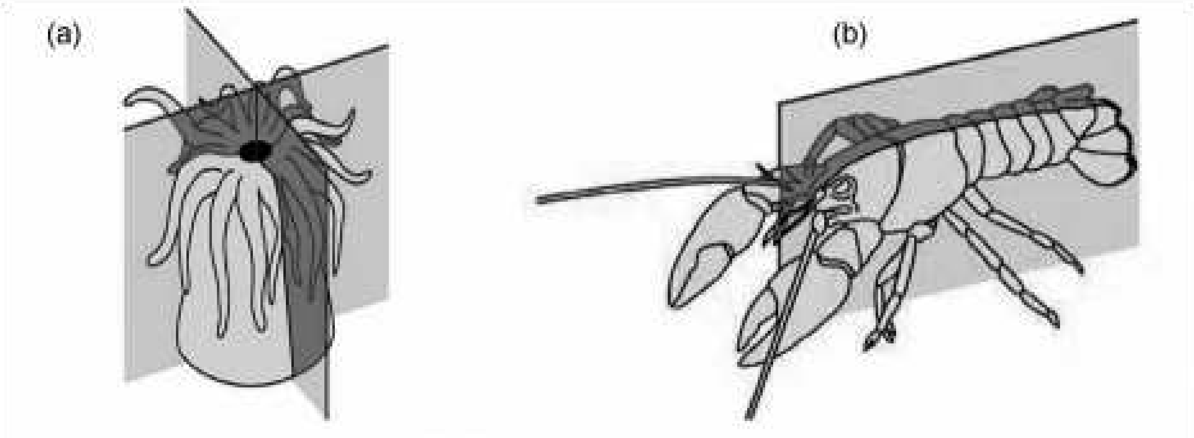


Fig. 4.1 : Body symmetry of animals. (a) Radial, (b) Bilateral

4.1.2. Diploblastic and Triploblastic Organisation :

In tissue grade of animals, the cells are arranged in two or three embryonic layers i.e. an **external ectoderm,** a **middle mesoderm** and an **internal endoderm.** Animals having two germ layers like ectoderm and endoderm are called **diploblastic animals,** e.g., coelenterates. Anon-cellular gelatinous layer, **mesoglea,** is present between the ectoderm and the endoderm [Fig. 4.2 (a)]. Further above the scale, there is a transition between diplobastic and triploblastic plans. Here, there is a third layer between ectoderm and endoderm, the **mesnchyme.** It contains free and wandering cells in a gelationous matrix (e.g., platyhelminths). In aschelminths, there is a third layer of muscle-like cells in between. However, this layer does not give rise to coelom. This group, too, is in the transition between diploblasic and triploblastic body plans. Triploblastic animals have all the three germinal layers namely ectoderm mesoderm

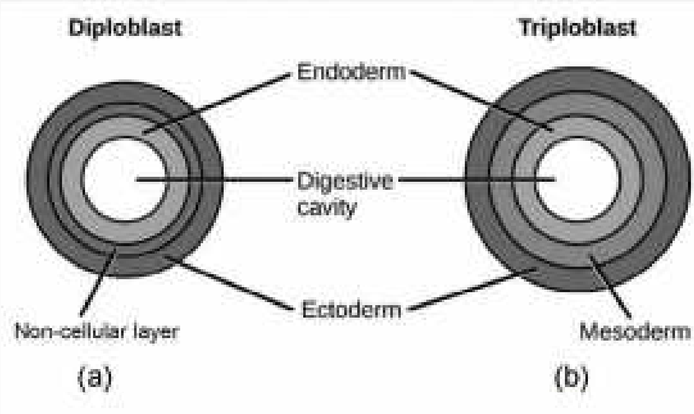


Fig. 4.2 : Germinal layers and body plans in animals, (a) Diploblastic, (b) Triploblastic

and endoderm, arranged concentrically from outer to inner and further more, the mesoderm gives rise to coelom, the true body cavity, (e.g., annelids to mammals)

4.1.3. Coelom :

Presence or absence of a cavity between the body wall and the gut wall is a very important criterion in classification. The body cavity, which is lined by mesoderm is called coelom [Fig. 4.3 (c)].The animals, in which the body cavity is absent are called **acoelomates,** e.g., platyhelminths [Fig. 4.3 (a)]. In some animals, the body cavity is not lined by mesoderm. Instead, a layer of muscle-like cells is present between the ectoderm and endoderm. Such a body cavity is called **pseudocoelom** and the animals possessing them are called **pseudocoelomates,** e.g., aschelminths [Fig. 4.3 (b)].

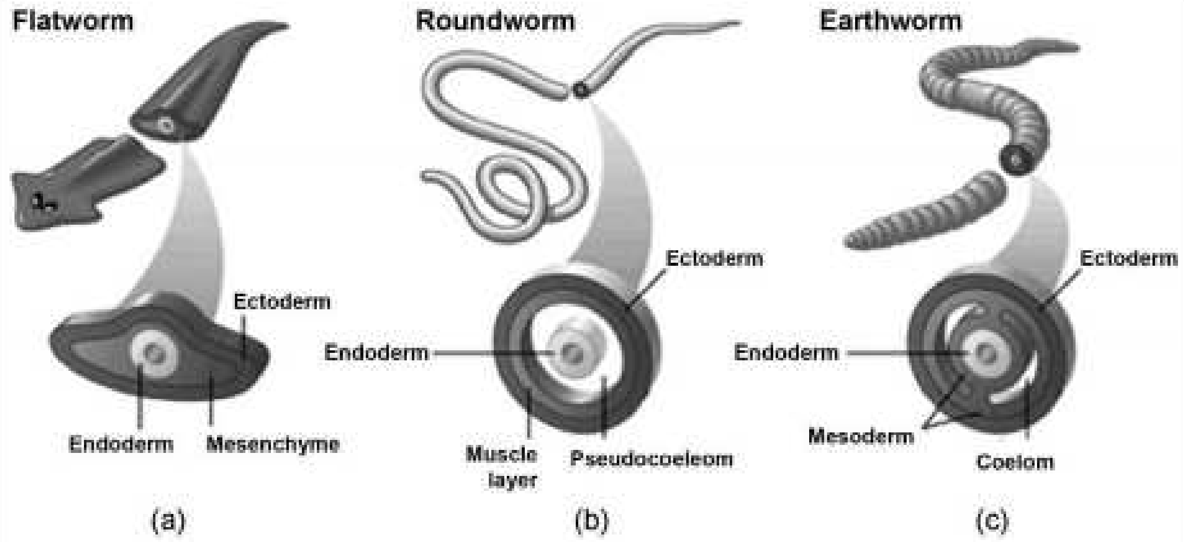


Fig. 4.3 : Body cavities in animals. (a) No body cavity (acoelomate), (b) pseudoceolomate and (c) coelomate

Animals possessing coelom are called **coelomates,** e.g., annelids, molluscs, arthropods, echinoderms, hemichordates and chordates.

4.1.4. Segmentation :

In some animals, the body is externally and internally divided into segments with a serial repetition of most of the organs. For example in annelids (earthworm and leech), the body is metamerically segmented and the phenomenon is called as **metamerism.** However, in higher forms, metamerism is evident only in embryonic stages, which is secondarily lost in the adults.

4.1.5. Notochord :

Notochord is a mesodermally derived solid and cylindrical rod-like structure formed on the dorsal side during embryonic development in some animals. Animals with notochord are called chordates and those animals which do not posses this structure are non-chordates, e.g., Porifera to Hemichordala.

4.2. CLASSIFICATION OF ANIMAL KINGDOM :

The **Kingdom Animalia** is divided into two sub-kingdoms, **parazoa** and **metazoa** on the basis of cell aggregation in the body.

4.2.1. SUB-KINGDOM I, PARAZOA

Phylum Porifera (Fig.4.4)

1. Animals of **cellular grade of organization** with incipient tissue formation. It includes the only phylum, **Porifera (L., *porus,* pore; *ferre,* to bear).**
2. Sedentary and solitary or colonial.
3. No organ system, digestive tract and mouth.
4. Body is porous with many internal cavities or canals lined by flagellated cells, known as **choanocytes.** The canals constitute a canal system, through which a continuous current of water flows through the body.
5. The body wall consists of two layers: outer **pinacoderm,** made up of a layer of flat cells, known as **pinacocytes** and inner **choanoderm** made up of flask-shaped flagellated cells, known as **choanocytes.**
6. The two are cemented together by a **mesenchyme** containing a matrix and several types of free and wandering mesenchyme cells.
7. The embryonic undifferentiating cells of the mesenchyme are known as **archaeocytes.** These can differentiate into any of the adult cell types during exigency, particularly during regeneration.
8. Endoskeleton is made up of calcareous or silicious spicules and/or sponging fibers.
9. Respiratory, excretory and nervous systems and sense organs are absent.
10. Generally hermaphrodite. Reproduction occurs by both asexual and sexual methods. Asexual reproduction occurs by budding and **gemmule** formation.
11. Fertilization is internal and cross fertilization is the rule.
12. Development is direct or indirect through free swimming larvae, known as **amphiblastula** and **parenchymula.**
13. Most have remarkable power of **regeneration.**

[e.g.; *Leucosolenia, Sycon, Spongilla* (fresh water sponge), *Euplectella* (Venus' flower basket), *Hyalonema* (Glass-rope sponge) and *Euspongia* and *Hippospongia* (Bath sponges)]

Porifera is divided into three classes : Calcarea, Hexactinellida and Demospongiae.

PORIFERA

CLASS I	CLASS II	CLASS III
CALCAREA	**HEXACTI NELLI DA**	**DEMOSPONGIAE**
e.g.; Leucosolenia, Syon and *Grantia*	*e.g.; Spongilla, Euplectella* and *Hyalonema*	*e.g.; Euspongia* and *Hippospongia* (Bath sponges)

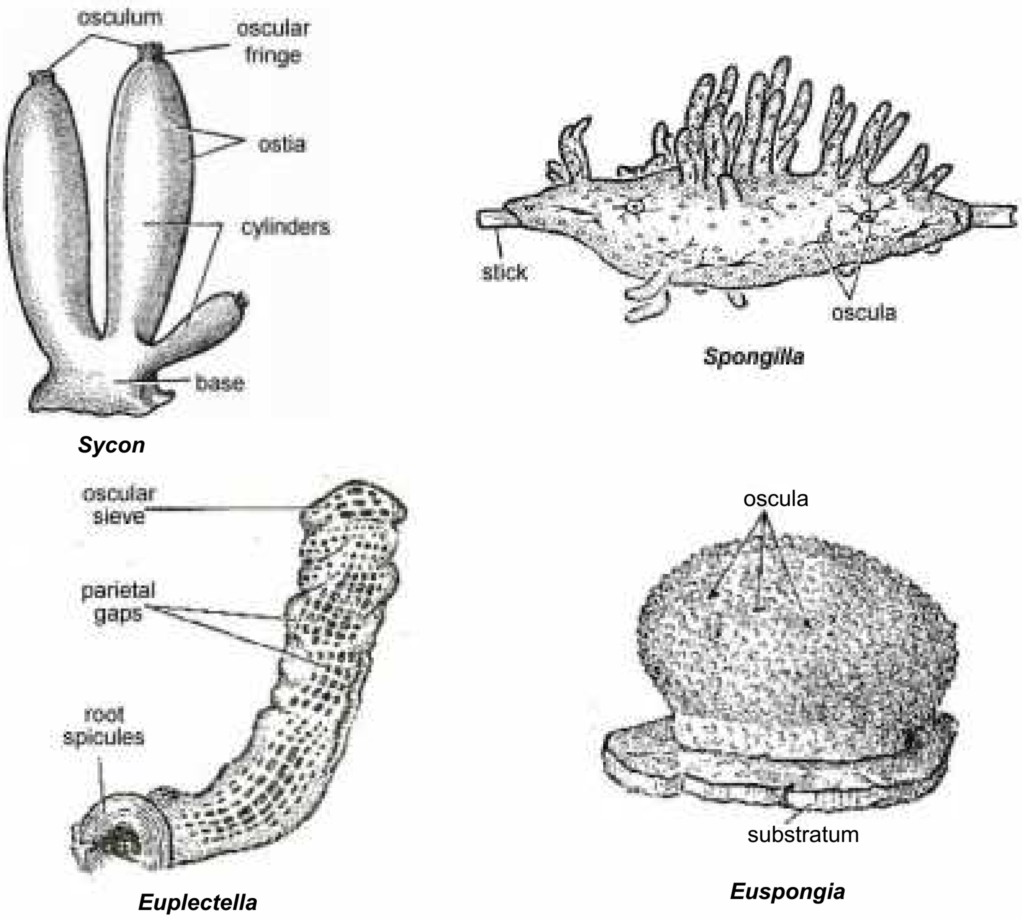


Fig.4.4 : Representative types from Porifera

4.2.2. SUB-KINGDOM II, METAZOA

1. Animals of **tissue or organ and organ system grade of organization.**
2. Mouth and digestive tract are present.

It is divided into two grades, such as **Radiata** and **Bilateria** based on the primary body symmetry

4.2.2.1. GRADE I, RADIATA :

Phylum, Coelenterata (Fig.4.5)

1. Animals with **tissue grade of organization.** It includes only one phylum, **Cnidaria** or **Coelenterata (Gr., *koilos,* hollow; *enteron,* intestine).**
2. Two types of forms, such as **polyp** and **medusa** exist. Some are exclusively polypoid, while others are medusoid. Still some others have both forms in their life cycle.
3. The primary body symmetry is **radial** or **biradial.**
4. Digestive cavity or coelenteron or gastro-vascular cavity is the only cavity in the body. Anus is absent.
5. **Diploblastic** animals i.e. body wall has two primary germ layers, **outer ectoderm** and **inner endoderm** cemented together by a non-cellular gelatinous **mesogloea.**
6. **Interstitial cells** are embryonic undifferentiated cells, present both in ectoderm and endoderm, among other cells. These cells can differentiate into any other kind of cell during exigency, especially during regeneration.
7. A coelenterate has a mouth encircled by tentacles, armed with stinging cells, **nematoblasts** or **cnidoblasts.**
8. Digestion is both **intra-** and **extra-cellular.**
9. Nervous system is primitive and **diffuse.**
10. Reproduction is both asexual and sexual.
11. Asexual reproduction takes place by budding.
12. Development is indirect through a **planula larva.**
13. Some exhibit the phenomenon of **polymorphism.**
14. Have a remarkable power of **regeneration.**

[e.g.; *Hydra, Obelia, Physalia* (Portuguese man of war), *Aurelia* (Jelly fish) *Adamsia* (Sea anemone), and a great variety of corals]

Coelenterata is divided into three classes : Hydrozoa, Scyphozoa and Anthozoa or Actinozoa.

COELENTERATA

CLASS I
HYDROZOA
e.g.; Hydra Obelia* and *Physalia
(Portuguese Man of war)

CLASS II
SCYPHOZOA
***e.g.; Aurelia* (Jelly fish)**

CLASS III
ANTHOZOA OR ACTINOZOA
***e.g.; Adamsia* (Sea anemone) and**
Corals

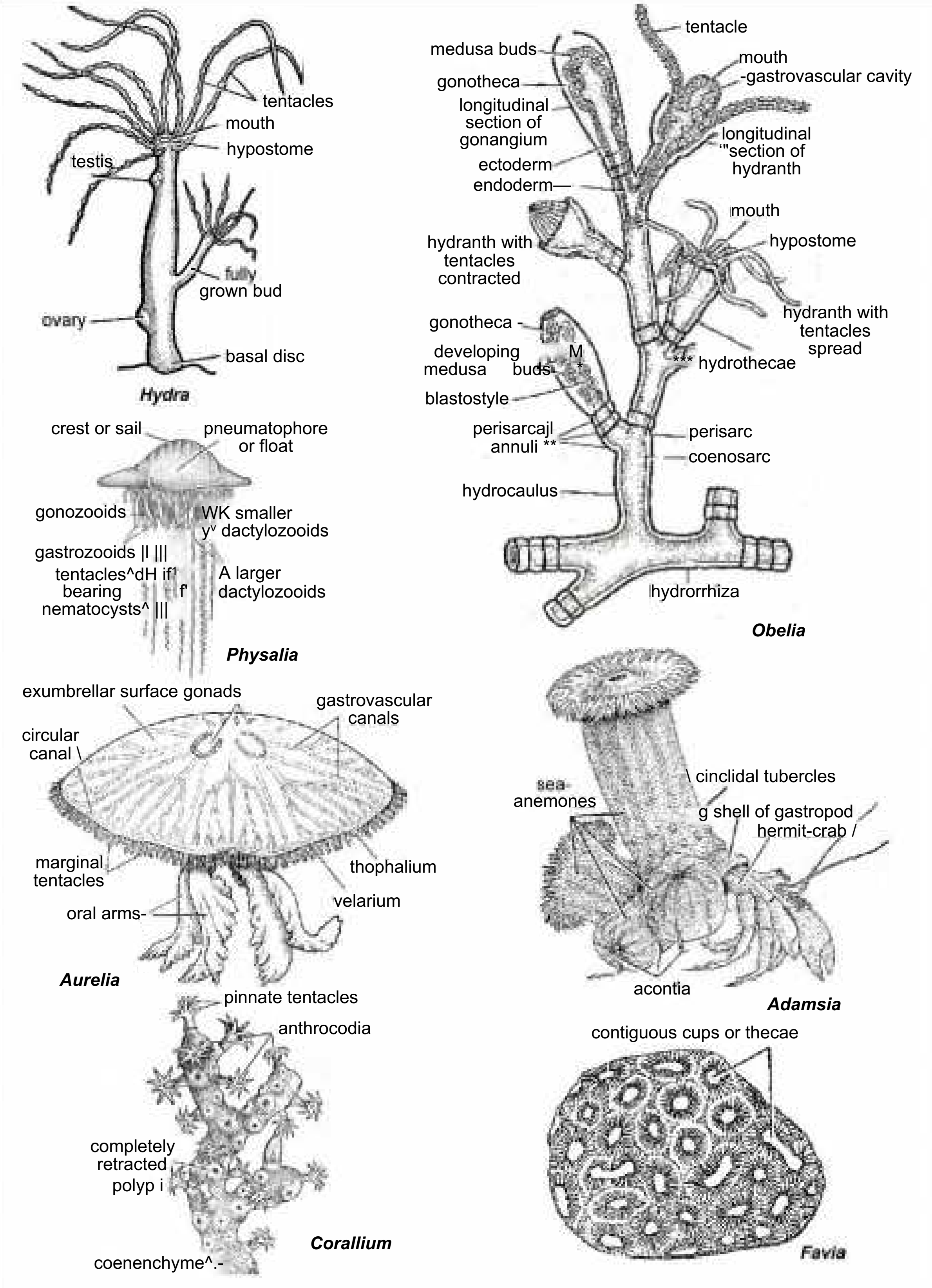


Fig.4.5 : Representative types from Coelenterata

Difference between Parazoa and Metazoa :

Parazoa	**Metazoa**
1. Includes multicellular animals, but the cells do not exhibit cell-cell cooperation.	1. Cells are specialized and exhibit cell-cell cooperation among themselves.
2. Cellular grade of organization.	2. Tissue and organ system grade of organization.
3. Diploblastic.	3. Triploblastic.
4. Digestive cavity is absent.	4. Digestive cavity present.
5. Canal system is present, (e.g.; Animals belonging to the Phylum Porifera)	5. Canal system is never present, (e.g.; Animals belonging to the phyla, Coelenterata and above in the evolution scale)

4.2.2.2. GRADE II, BILATERIA :

1. Animals with **organ system grade of organization.**
2. The primary body symmetry is **bilateral.**
3. Anus is generally present.

Bilateria is divided into **Acoelomata, Pseudocoelomata** and **Coelomata** on the basis of the absence or presence of a true body cavity, the **coelom.** We mention again that the coelom is a cavity present between the ectoderm and endoderm and derived from and lined by mesoderm.

1. Group I, Acoelomata :

1. Coelom is absent. The region between the digestive tract (endoderm) and body wall (ectoderm) is filled with **mesenchyme.** Mesenchyme contains free and wandering cells in a matrix. The mesenchyme cells are not organized into a germ layer.
2. Incipiently triploblastic, since mesenchyme is not organized into mesoderm.
3. Body is unsegmented and if segmented, the youngest segment is close to the head (e.g.; *Taenia).*
4. Excretory system consists of **protonephridia** with **flame cells.**
5. Acoelomata includes one phylum, Platyleminthes.

Phylum, Platyhelminthes (Gr., *platys,* flat or broad; *helminthes,* worm) (Fig.4.6):

1. Includes mostly endo-parasitic animals, commonly known as **flat worms.**
2. Bilaterally symmetrical acoelomate animals.
3. Two layers, ectoderm and endoderm are cemented by a mesenchyme. The mesenchyme has embryonic undifferentiated cells, known as **neoblasts,** among other cells. The neoblasts can differentiate into any other kind of cell during exigency, especially during regeneration.
4. Endo-parasitic animals have **suckers** and **hooks** for clinging and attachment.
5. Alimentary canal may be present in some free living forms or absent in parasitic forms. If alimentary canal is present, an anus is absent.
6. Respiratory and circulatory systems are absent. Respiration occurs by the general surface of the body by diffusion.
7. Excretory system consists of single or paired **protonephridia** with **flame cells** or **solenocytes.**
8. Nervous system is primitive with a nerve centre at the anterior end with one or three pairs of nerve cords.
9. Generally hermaphodites. Cross fertilization in *Turbellaria* and *Trematoda* and self fertization in *Cestoda* occur.
10. Development generally is indirect through one or a few larval forms.
11. Some exhibit remarkable power of **regeneration.**
12. Parasitic forms exhibit **parasitic adaptations.**

[e.g.; *Planaria, Fasciola hepatica* (Liver fluke), *Schistosoma* (Blood fluke) and *Taenia solium* (Tape worm)]

Platyhelminthes is divided into **three classes: Turbellaria, Trematoda and Cestoda.**

PLATYHELMINTHES

CLASS I	CLASS II	CLASS III
TURBELLARIA	**TREMATODA**	**CESTODA**
e.g.; Pl an aria	***e.g-fasciola and Schistosoma***	***e.g.; Taenia solium***

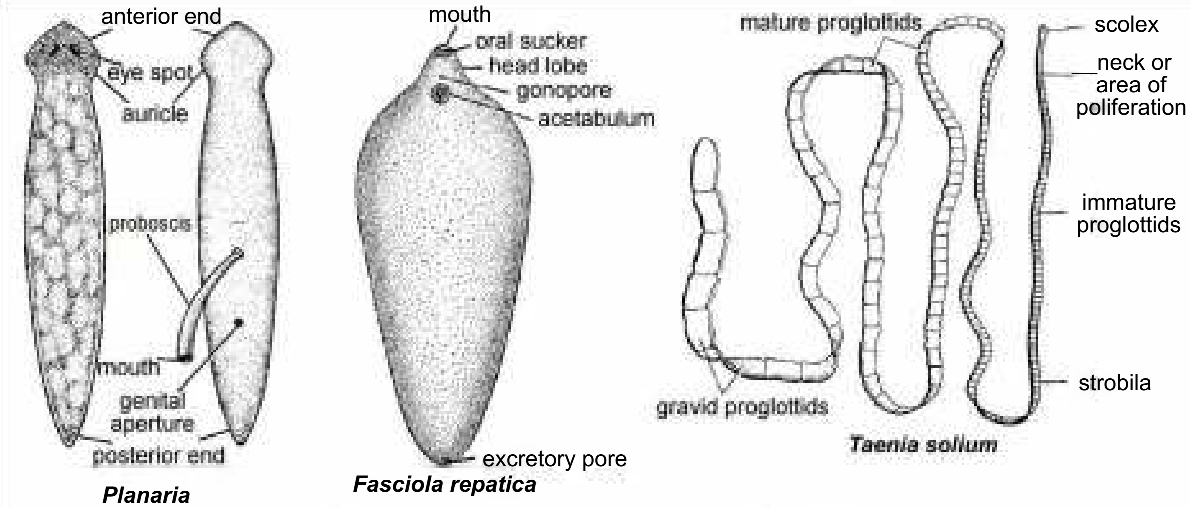


Fig.4.6 : Representative types from Platyhelminthes

2. **Group II, Pseudocoelomata :**

   1. There is a cavity between the digestive tract and body wall, but it is not lined by mesoderm. Therefore, it is known as a **pseudocoelom** or **pseudocoel.**
   2. Anus present.
   3. It includes one phylum, **Nemathelminthes** or **Aschelminthes.**

Phylum, Nemathelminthes (Gr. *Nematos,* thread; *eidos,* form; *helminthes,* worm) (Fig. 4.7):

1. Includes animals, possessing cylindrical body and hence, known as **round worms.**
2. The body is covered by a cuticle
3. The ectoderm is **syncytial.**
4. Longitudinal muscle fibers are present in four bands
5. Alimentary canal is more or less straight with mouth and anus present at two extreme ends.
6. Respiratory and circulatory systems are absent. Respiration occurs by diffusion through the general surface of the body.
7. Flame cells and nephridia are absent. Excretory system is in the form of English alphabet H' with longitudinal excretory canals.
8. Nervous system consists of a distinct circumenteric nerve ring, from which arise anterior and posterior longitudinal nerves.
9. Sexes are separate, exhibiting sexual dimorphism.
10. Fertilization is internal and development is direct. The fertilized egg hatches into an embryo, which moults four times before becoming an adult.
11. Most are endoparasites, exhibiting remarkable parasitic adaptations.

[e.g.; *Ascaris lumbricoides, Ancylostoma duodenale* (Hook worm), *Enterobius vermicularis* (Human pin worm or thread worm) and *Wuchereria bancrofti* (Filarial worm)].

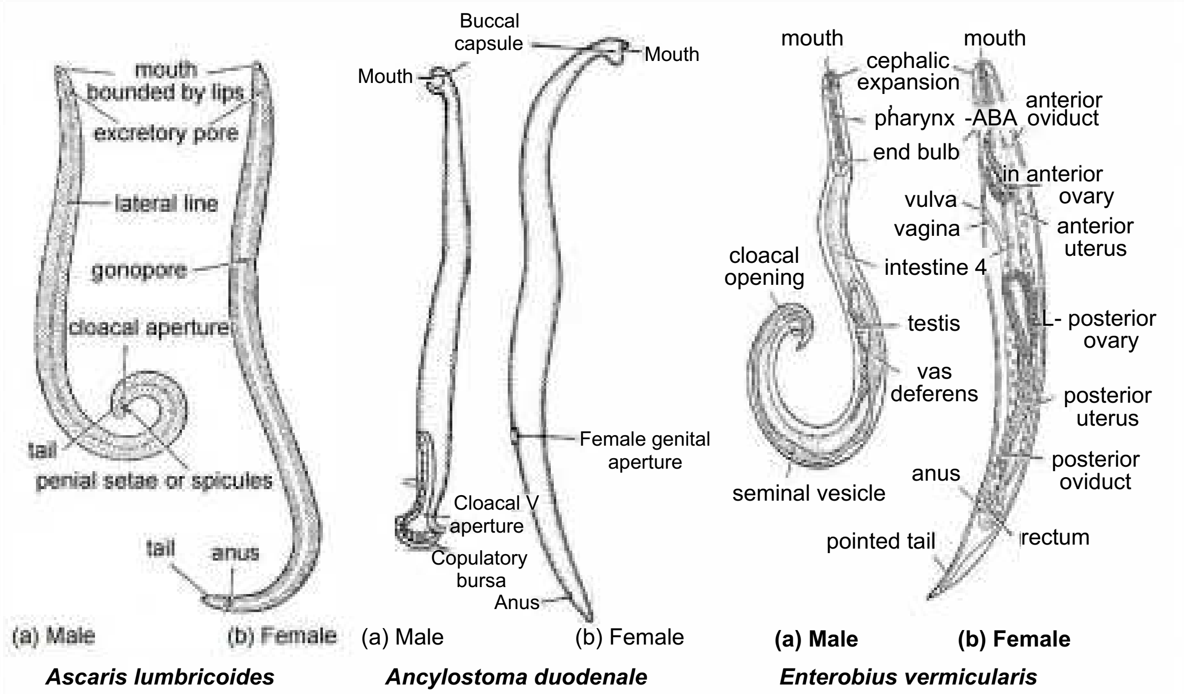


Fig.4.7: Representative types from Nemathelminthes

There is no certain agreement about the classification of Nemathelminthes. However, some texts describe **Nematoda** as one single class of the phylum.

3. Group III, Coelomata:

1. Coelom is present.
2. Truly **triploblastic** animals.
3. Excretory organs are **protonephridia** with **flame cells** or **metanephridia** with or without **nephrostomes.**

Coelomata is divided into **Schizocoela (Protostomia)** and **Enterocoela (Deuterostomia),** based on the nature and origin of the coelom.

(a) Schizocoela (Protostomia):

In some texts, this group has been described as **Annelid superphylum,** which includes three major phyla, **Annelida, Arthropoda and Mollusca.** It is characterized by:

1. The coelom is **schizocoelic** i.e. it originates as a cavity in the mesoderm.
2. Cleavage is **spiral** and **determinate.**
3. Blastopore becomes the mouth.

4. Skeleton, if any, is ectodermal.
5. **Trochophore** type of larva.

Phylum, Annelida (L., *annelus,* ring; Gr., *eidos,* ring) (Fig. 4.8):

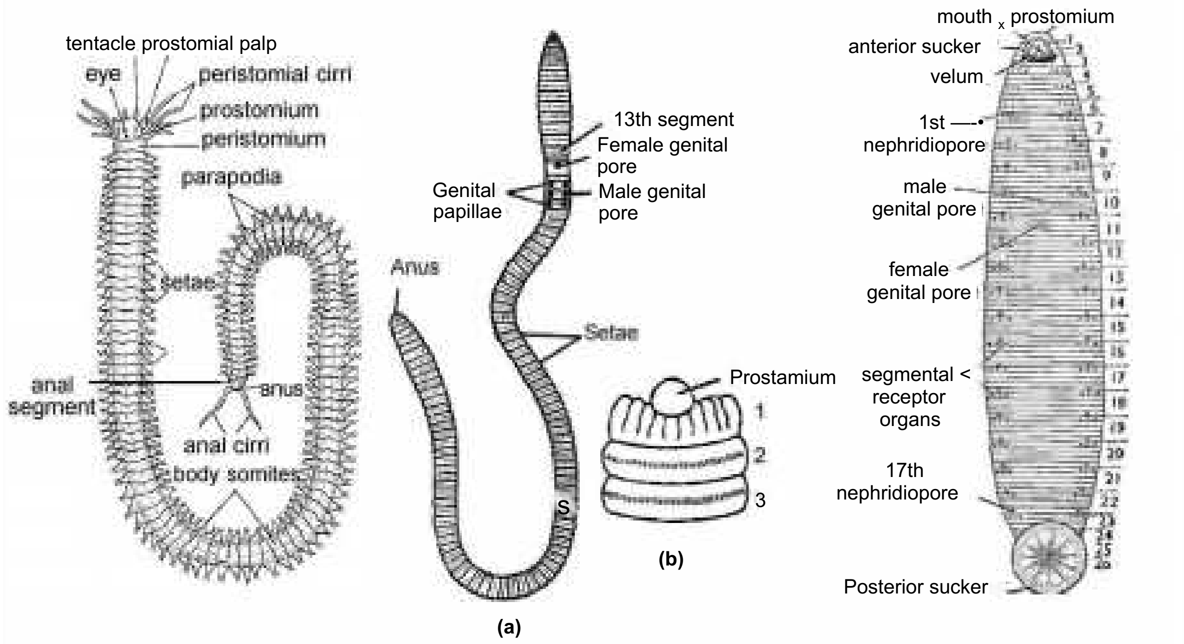
1. Body generally elongated, cylindrical or flattened dorso-ventrally and worm-like.
2. Body is metamerically segmented.
3. There is a pre-oral muscular projection, known as the prostomium. It is not a true body segment.
4. The first true body segment is known as **peristomium,** which follows the prostomium.
5. In a majority, the locomotor structures, known as **setae,** are present.
6. The coelom is **schizocoelic** and spacious. It is filled with a coelomic fluid.
7. In aquatic forms, such as in *Nereis,* lateral paddle-like **parapodia** are present.
8. The alimentary canal is straight and simple with mouth and anus present at opposite extremities.
9. Circulatory system is of closed type. Blood is red due to the presence of red blood pigment dissolved in the plasma.
10. Excretion occurs by segmentally arranged **nephriidia** and **chloragogen** or **yellow cells.**
11. Nervous system consists of a pair of cerebral ganglia, a sub-pharyngeal ganglion and a ganglionated solid ventral nerve cord.
12. Usually hermaphrodites, but some are monoecious.
13. Development is direct or indirect through a **trochophore larva.**

[e.g.; *Pheretima posthuma* (Earthworm), *Nereis* (Clamworm or Sandworm) and *Hirudinaria granulosa* (Indian cattle leech)]

Annelida is divided into three classes, Polychaeta, Oligochaeta and Hirudinea on two counts. The first is based on the presence or absence of locomotor structures (setae or chetae). Secondly, if setae are present, these are numerous or few.

ANNELI DA

CLASS I	CLASS II	CLASS III
POLYCHAETA	OLIGOCHAETA	HIRUDINEA
e.g.; Nereis	*e.g.; Pheretima posthuma*	*e.g.; Hirudinaria granulosa*



Nereis ***Pheretima posthuma*** (Earthworm) ***Hirudinaria granulosa*** (Cattle leech)

Fig.4.8 : Representative types from Annelida

Differences between pseudocoelomata and coelomata :

Pseudocoelomata	Coelomata
1. Body cavity is a pseudocoelom or false coelom	1. Body cavity is a true coelom.
2. Pseudocoelom is not lined by mesoderm.	2. Coelom is lined by mesoderm on both sides.
3. It is derived from blastocoel of the embryo.	3. It arises as a cavity in the embryonic mesoderm.
4. Internal organs are not suspended within this cavity. (e.g.; Animals belonging to the Phylum, Nemathelminthes or Aschelminthes)	4. Internal organs are suspended within this cavity. (e.g.; Animals belonging to the phyla, Annelida and above in the evolution scale)

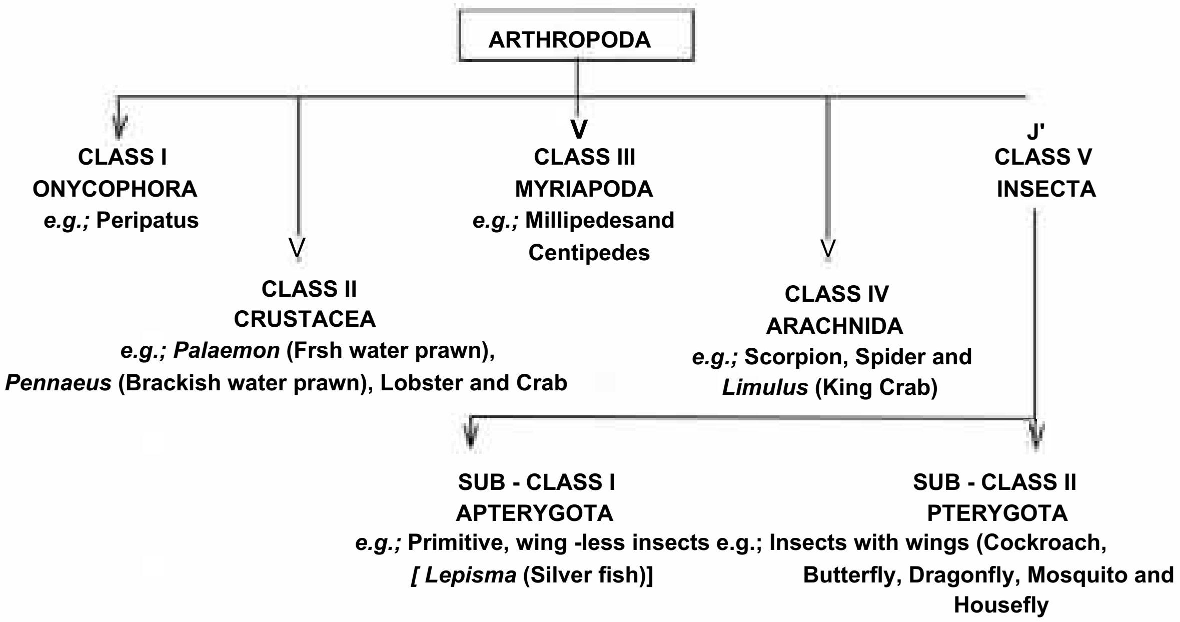
Phylum, Arthropoda (Gr., *arthros,* jointed; *podos,* foot) (Fig. 4.9):

1. The body is segmented and each segment bears paired **jointed appendages.**
2. The body is generally divided into **head, thorax** and **abdomen.** However, in some forms the head and thorax fuse forming a **cephalothorax.**
3. **Jointed appendages** are present.

4. The body is covered by a **cuticle,** made of **chitin.**
5. Coelom is reduced and a spacious blood-filled cavity, known as **haemocoel** is present.
6. Alimentary canal is divided into **fore gut, mid gut** and **hind gut.** The mouth is surrounded by many jointed appendages. These together constitute the **mouth parts**.
7. Respiration occurs by **gills** in aquatic forms, **trachea** and **book lungs** in air breathing (terrestrial) forms.,
8. Circulatory system is of **open type** with the heart being dorsal in position.
9. Excretion occurs by **malpighian tubules** or **green glands** or **coxal glands.**
10. Nervous system consists of a brain lying in the head that is followed by a **ganglionated double ventral nerve cord.**
11. Sexes are separate. The phenomenon of **sexual dimorphism** is often exhibited.
12. Reproduction is sexual and fertilization is internal.
13. Development is direct or indirect through one or a few larval stages.

[e.g.; *Peripatus, Palaemon* (Fresh water prawn), *Pennaeus* (Brackish water prawn), Lobster, Crab, Millipedes, Centipedes, Scorpion, Spider, *Limulus* (King crab) *Lepisma* (Silver fish), *Periplaneta americana* (Cockroach), Butterfly and Moth, Mosquito, House fly].

Phylum, Arthropoda is primarily divided into five classes: **Onychophora, Crustacea, Myriapoda, Arachnida** and **Insecta.** Class, Insecta is further divided into two sub-classes: **Apterygota** [includes wing-less insects, e.g.; *Lepisma* (Silverfish)] and **Pterygota** (includes insects with wings).



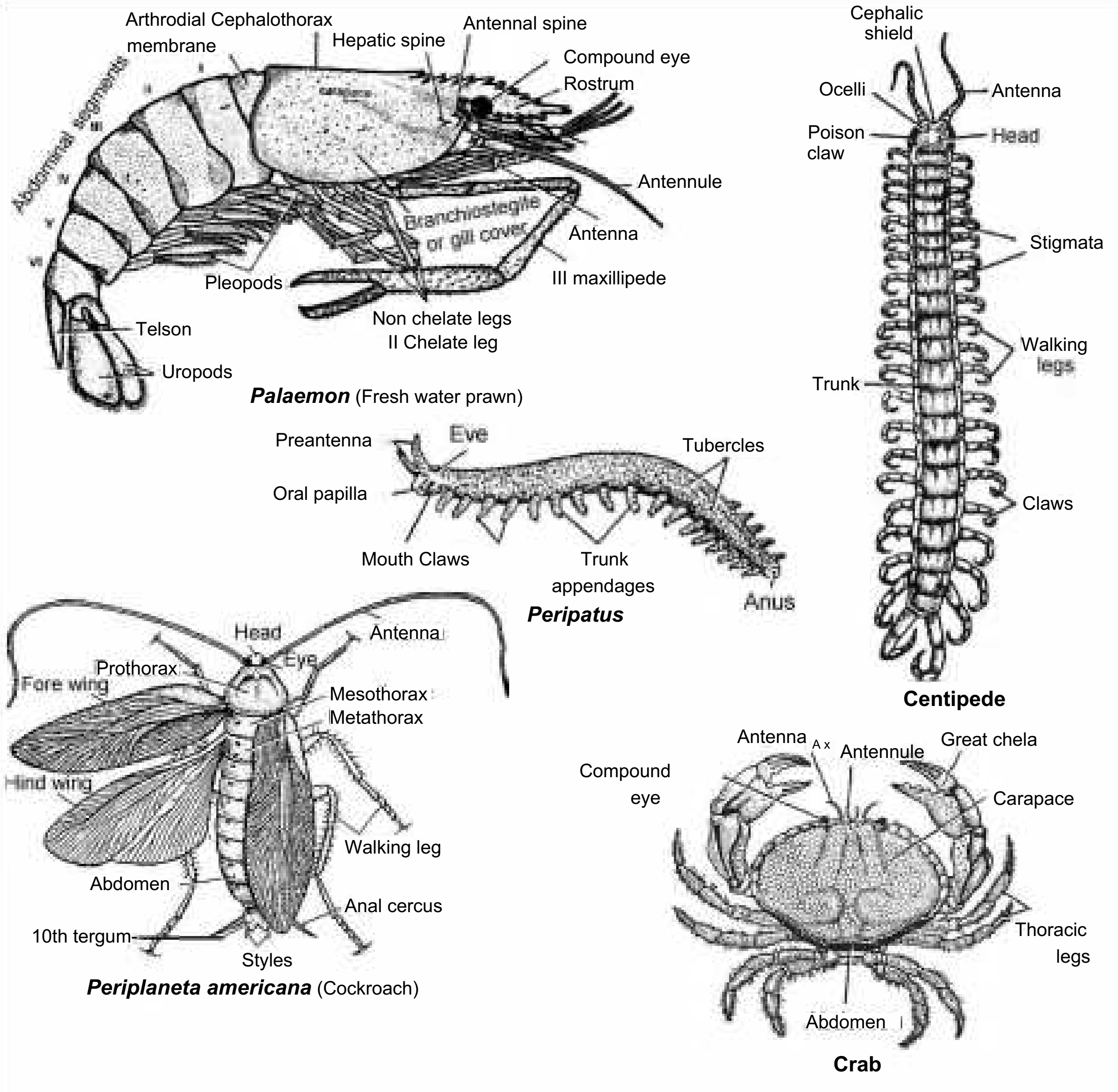


Fig.4.9 : Representative types from Arthropoda

Differences between pseudocoel and haemocoel

Pseudocoel	Haemocoel
1. False body cavity, not lined by mesoderm	1. Mesoderm-lined true body cavity, filled with haemolymph or blood.
2. It is derived from blastocoel of the embryo.	2. It arises as a cavity in the embryonic mesoderm.
3. It is not filled with blood. (e.g.; Animals belonging to the Phylum, Nemathelminthes or Aschelminthes)	3. It is filled with blood or haemolymph, (e.g.; Animals belonging to the phylum, Arthropoda)

Phylum, Mollusca (L., *mollis* or *molluscs,* soft) (Fig. 4.10):

1. Aquatic, mostly marine but a few fresh water forms.
2. Body is secondarily unsegmented and bilaterally symmetrical. A few, like *Pila,* are secondarily asymmetrical due to a phenomenon called **torsion** that occurs during the development.
3. The body is divided into **head, foot** and **visceral mass.** All visceral organs constitute the **visceral mass** that is covered by a fold of the body wall, known as **mantle.**
4. The mantle secretes a **calcareous** (calcium carbonate) **shell.**
5. The coelom is reduced to the cavities of the pericardium and the cavities, where gonads are present.
6. The digestive tract is simple and tubular with mouth and anus present at opposite ends. However, in gastropods, the tract twists due to torsion and consequently, the mouth and anus come close to each other at the anterior end.
7. Respiration, in aquatic forms, takes place by **gills** or **ctenidia.** In terrestrial forms it occurs by **pulmonary sacs.**
8. Excretion is performed by a pair of kidneys.
9. Nervous system is centralized with a brain in the head, which is followed by nerves to different parts of the visceral mass.
10. Sense organs are in the form of eyes, **tentacles, osphradium** and **statocyst.**
11. Sexes are generally separate, but some are hermaphrodites.
12. Development is direct or indirect through larval stages known as **trochophore, velliger** and **glochidium.**

[e.g.; *Pila globosa* (Fresh water snail / Apple snail), *Unio* (Fresh water mussel), *Pinctada sps* (Pearl oyester), *Sepia* (Cuttie fish), *Loligo* (Squid) and *Octopus* (Sea devil)]

The phylum, Mollusca is divided into six classes: **Monoplacophora, Amphineura, Scaphopoda, Gastropoda, Bivalvia or Pelecypoda and Cephalopoda.**

MOLLUSCA

- **CLASS I MONOPLACOPHORA** *e.g.; Neopilina*
- **CLASS II AMPHINEURA** *e.g.; Chiton*
- **CLASS III SCAPHOPODA** *e.g.; Dentalium*
- **CLASS IV GASTROPODA** *e.g.; Pila globosa* **(Apple snail)**
- **CLASS V PELECYPODA** *e.g.; Unio* **(Fresh water mussel),** *Pinctada sps,* **(Pearl oyster)**
- **CLASS VI CEPHALOPODA** *e.g.; Sepia* **(Cuttie fish),** *Loligo* **(Squid) and** *Octopus* **(Sea devil / Devil fish).**

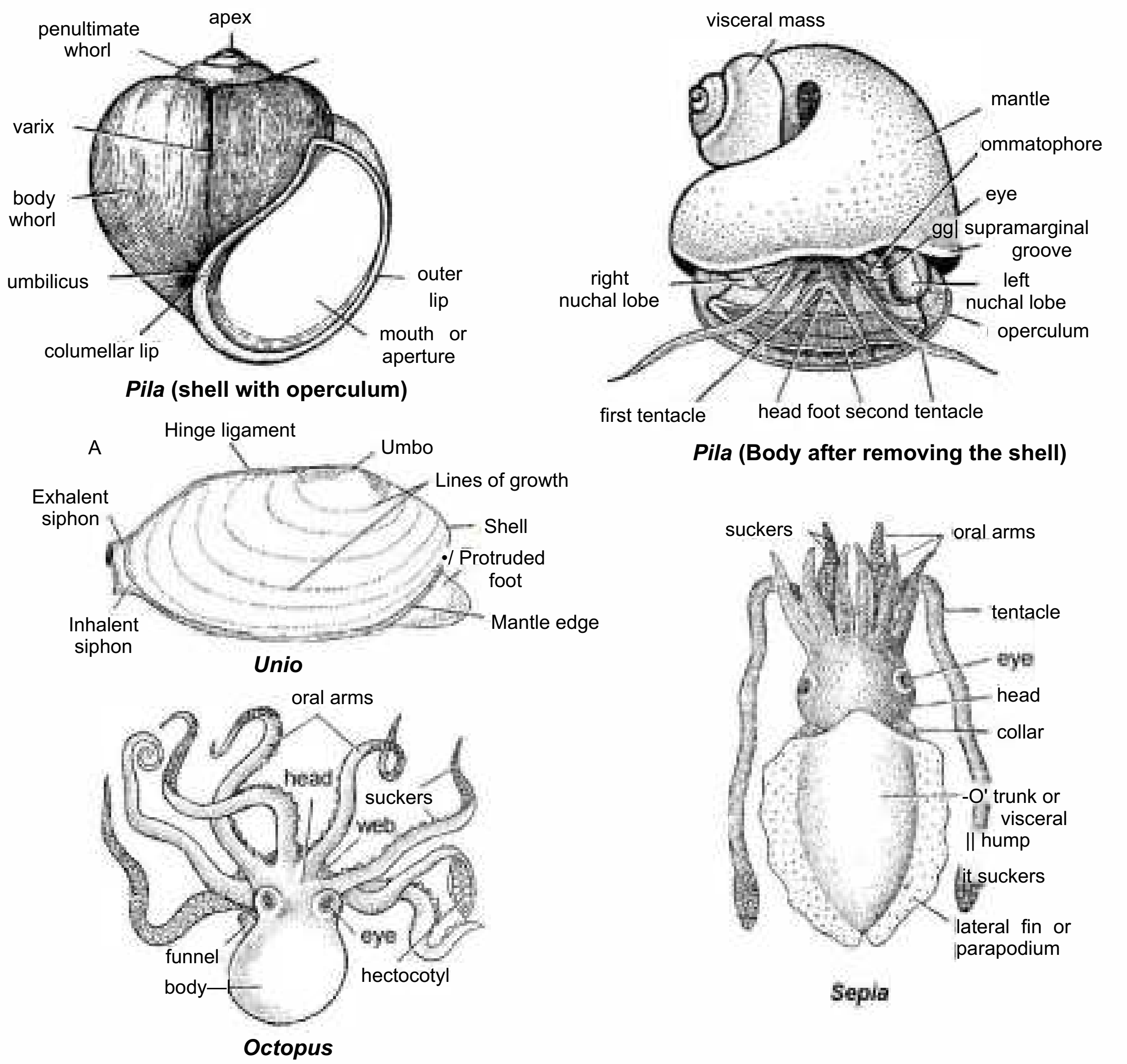


Fig.4.10: Representative types from Mollusca

(b) Enterocoela (Deuterostomia):

In some texts this group has been described as the **Echinoderm superphylum** that includes three major phyla, **Echinodermata, Hemichordata** and **Chordata.**

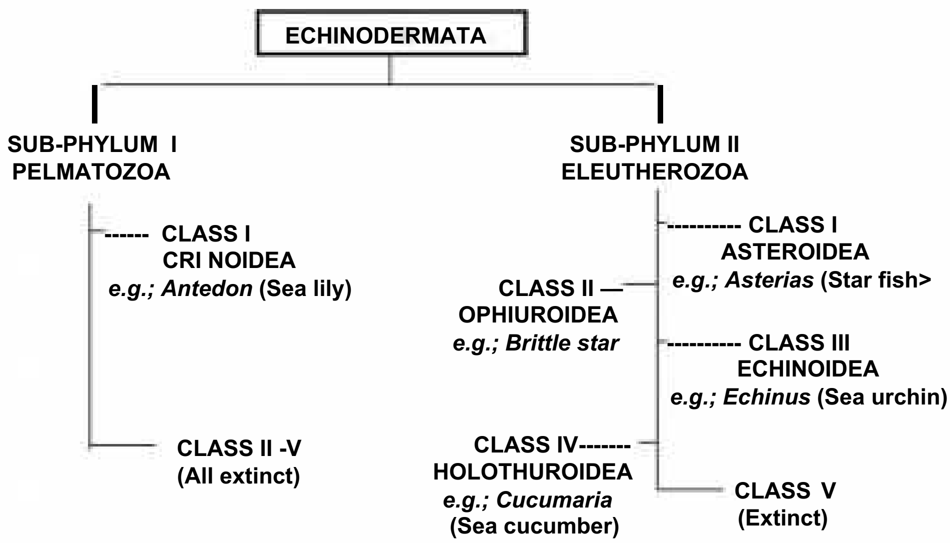
1. The coelom is enterocoelic i.e. it originates as pouches from the endoderm.
2. Cleavage is **radial** and **indeterminate.**
3. Blastopore becomes the anus.
4. Skeleton is **mesodermal.**
5. **Pluteus** type of larva.

Phylum, Echinodermata (Gr., *echinos,* spiny; *derma,* skin) (Fig.4.11):

1. Exclusively marine animals having **pentamerous radial symmetry.** This symmetry is considered as secondary. The primary symmetry refers to the symmetry of their larvae, which is **bilateral.** This fact justifies their inclusion in the grade, Bilateria.
2. Body shape is variable like star-shaped, globular, spherical, etc.
3. Body is with distinct oral and aboral sides. No definite head, however, is present.
4. The skin is tough and leathery bearing **spines** and **calcareous dermal ossicles.**
5. A characteristic **water vascular system** or **ambulacral system** is present with numerous tube feet, which help in locomotion.
6. Alimentary canal is a straight or coiled tube.
7. Respiration occurs by diffusion through the body wall.
8. Blood vascular system, also known as **haemal system,** is of open type.
9. Excretion occurs through the body surface.
10. Nervous system is primitive
11. Sense organs are poorly developed.
12. Sexes are separate and reproduction is sexual.
13. Fertilization is external and development is indirect through characteristic larval forms, such as **bipinnaria; auricularia; pluteus,** etc.

[e.g.; *Antedon* (Sea lily), *Asterias* (Star fish), *Cucumaria* (Sea cucumber), *Echinus* (Sea urchin), *Ophioderma* (Brittle star)]

The phylum, Echinodermata is primarily divided into two sub-phyla, **Pelmatozoa** and **Eleutherozoa,** based on whether the form is sedentary or free-living. Pelmatozoa is divided into five classes, of which one, **Crinoidae** is living, while others are extinct. Eleutherozoa is divided into five classes, of which four are living and one is extinct. The living classes are : **Asteroidae; Ophiuroidae; Echinoidae** and **Holothuroidae.**



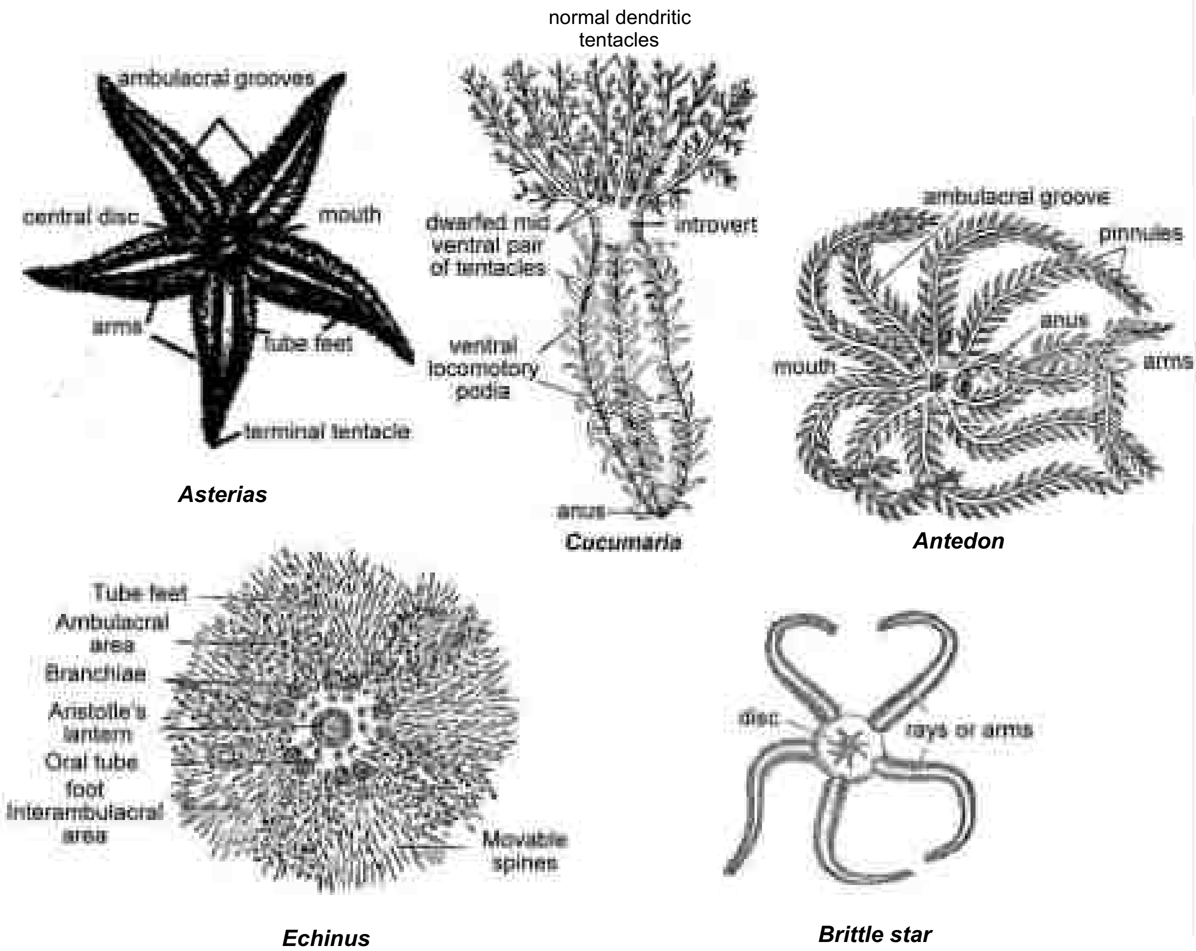


Fig.4.11 : Representative types from Echinodermata

Differences between schizocoelic coelom and enterocoelic coelom

Schizocoelic coelom	Enterocoelic coelom
1. The coelom is formed by the splitting of mesoderm bands.	1. The coelom is derived from the dorso-lateral mesodermal pouches from the wall of the archenteron.
2. The mesoderm is derived from a source other than the archenteron.	2. The mesoderm is derived from the archenteric roof.
3. The mesodermal cells separate off from the endoderm early during development.	3. The mesodermal cells remain associated with the endoderm and separate off late during the embryonic development.
(e.g.; Animals belonging to the phyla, Annelida, Arthropoda and Mollusca)	(e.g.; Animals belonging to the phyla, Echinodermata Hemichordata and Chordata)

Phylum, Hemichordata (Gr., *hemi,* half; *chorda,* string or cord) (Fig. 4.12):

1. Exclusively **marine, solitary** or **colonial.**
2. **Triploblastic** and **bilaterally symmetrical.**
3. Body is **vermiform** (worm-like), divided into **proboscis, collar** and **trunk.**
4. **Coelom is enterocoelic,** divided into single **protocoel** and paired **mesocoel** and **metacoel.**
5. A pre-oral muscular extension, the **buccal diverticulum** is present. It was considered as homologous to the notochord of chordates. However, due to its structural dissimilarity, it is no longer considered as a notochord homologue. It is simply termed as a **stomochord.** Based on this, Hemichordata is separated off from Chordata and assigned with a phylum status and placed among non-chordates.
6. **Pharyngeal gill clefts** are present in pairs in the trunk.
7. Digestive tract is well defined and the anus is terminal at the posterior end.
8. Respiration is branchial i.e. takes place by gill pouches.
9. Circulatory system is of closed type. A **heart vesicle** or **pericardium** is present in the proboscis.
10. Excretion by a **proboscis gland** or **glomerulus.**
11. Nervous system is primitive comprising of an **intra-epidermal nerve plexus.**
12. Sexes are separate and fertilization is external.
13. Development is either direct or indirect through a larval form, known as **tornaria larva.**

[e.g.; *Balanoglossus* (Tongue or Acorn worm), *Saccoglossus, Cephalodiscus, Rhabdopleura]*

The phylum, Hemichordata is divided into two main classes : (1) **Enteropneusta** and (2) **Pterobranchia.**

Phylum, Chordata :

1. The name of the phylum is so because of the presence of a **notochord.**
2. The notochord is a solid chord consisting of **vacuolated cells** surrounded by two **connective tissue sheaths.**
3. In a few chordate groups, the notochord persists as such, while in a majority, it is transformed into a vertebral column by ossification and segmentation.

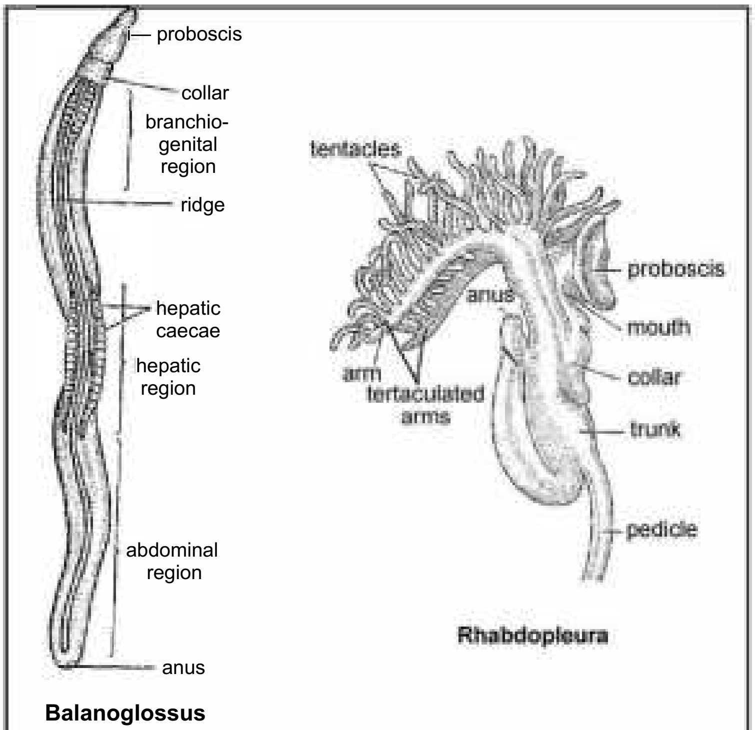


Fig.4.12: Representative types from Hemichordata

HEMI CHORDATA

CLASS I
> ENTEROPNEUSTA
e.g.; Balanoglossus* and *Saccoglossus

CLASS II
> PTEROBRANCHIA
e.g.; Cephalodiscus* and *Rhabdopleura

4. The pharynx is perforated by **pharyngeal gill slits** or **clefts,** which help in respiration. In a majority of chordates, the pharyngeal gill slits are lost secondarily.
5. There is a dorsal tubular nerve cord just dorsal to the notochord. It is simple in primitive chordates, while in higher chordates, it specializes as a brain at its anterior end. The nervous system consists of three elements, **central nervous system** or **CNS** (brain and the spinal cord), **peripheral nervous system** or **PNS** (cranial and spinal nerves) and **autonomic nervous system** or **ANS (sympathetic** and **para-sympathetic nerves** innervating the visceral organs).
6. Blood vascular system is of closed type. The heart is ventral in position. Barring a few primitive chordates, the blood contains nucleated corpuscles and the red blood corpuscles contain the red coloured respiratory pigment, **haemoglobin.**
7. Barring a few primitive chordates,the excretory organs are **pro-, meso-** or **metanephric kidneys.**
8. Generally, the sexes are separate with defined sexual dimorphism.
9. Fertilization is external or internal.
10. A majority are **oviparous,** while some are **viviparous.**
11. There is a **tail.** A tail is a post-anal extension of the body and thus, the anus comes to lie on the ventral side.

See Fig.4.13 for a generalized chordate plan.

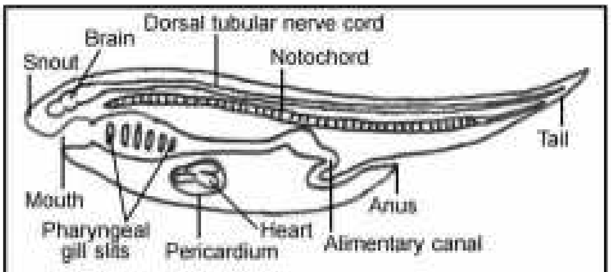


Fig. 4.13 : A generalized chordate plan

Chordata is divided into three sub-phyla: **Urochordata, Cephalochordata** and **Craniata** or **Vertebrata** The representatives of Urochordata and Cephalochordata are considered as primitive chordates and hence are grouped together as **Protochordata** or **Acraniata.** This classification is based on the absence or presence of a cranium and a vertebral column. Cranium and vertebral column are two elements of the endoskeleton of vertebrates and both always go together i.e. wherever there is a cranium, there is a vertebral column. Protochordates have notochord, but, the notochord does not transform into vertebral column and therefore, are not supposed to have a cranium. This logic is enough to assign the synonym, acraniata, to Protochordata.

Sub-phylum, Urochordata (Gr., *uras,* tail; *chorda,* string or cord) (Fig.4.14):

1. Body is sac-like, covered with a **test of tunicin.** Hence, the name of the group is also mentioned as **Tunicata** in some texts.
2. There are two apertures : **banchial** and **atrial.** Branchial aperture opens into a pharynx, while the atrial aperture leads from an **atrial cavity** or **atrium.**
3. The body has a peculiar symmetry i.e. the branchial aperture is considered as the anterior end, while the opposite end is posterior. The atrial aperture is the dorsal side, while its opposite side is ventral.
4. Notochord is absent in the adult. However, it is present in the larva and confined to the tail region. Hence, the name of the group is Urochordata, which literally means, **tail notochord.**
5. The nerve cord is also absent in the adult. The nervous system is represented by only a dorsal ganglion and a few nerves originating from it. A full-fledged nerve cord is present in the larva, which degenerates during metamorphosis.
6. The degeneration of both the notochord and nerve cord occurs during metamorphosis, which has been termed as **retrogressive metamorphosis.**
7. The pharynx is perforated by many **gill slits** or **clefts.**
8. The interior of the pharynx is furnished with two special structures, **endostyle** and **dorsal lamina** to facilitate ciliary or filter feeding.
9. Hermaphrodites. The male and female gonads are united into one structure.
10. Development is always indirect with a tadpole larva, known as **ascidian tadpole larva.**

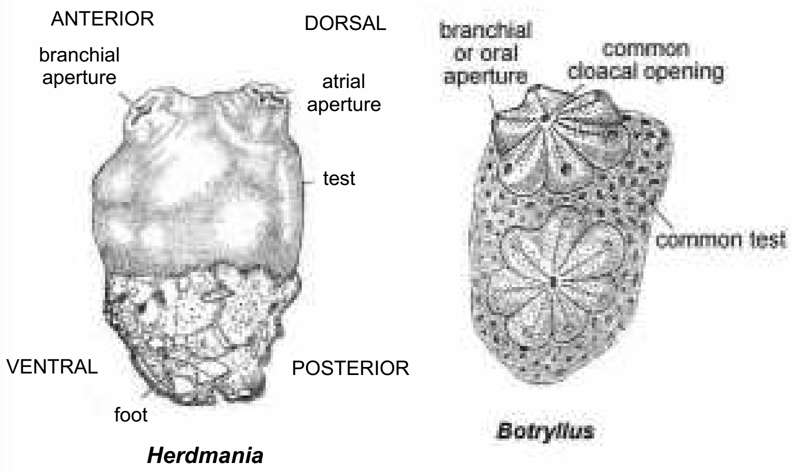


Fig. 4.14: Representative types from Urochordata

UROCHORDATA

CLASS I
----> LARVACEA
e.g.; Oikopleuraand

CLASS II
—> ASCI DI ACEA
e.g.; Herd mania* and *Ascidia

CLASS III
----> THALIACEA
e.g.; Salpa* and *Doliolum

11. The larva possesses all the diagnostic chordate characters, out of which the notochord and the nerve cord degenerate during retrogressive metamorphosis,

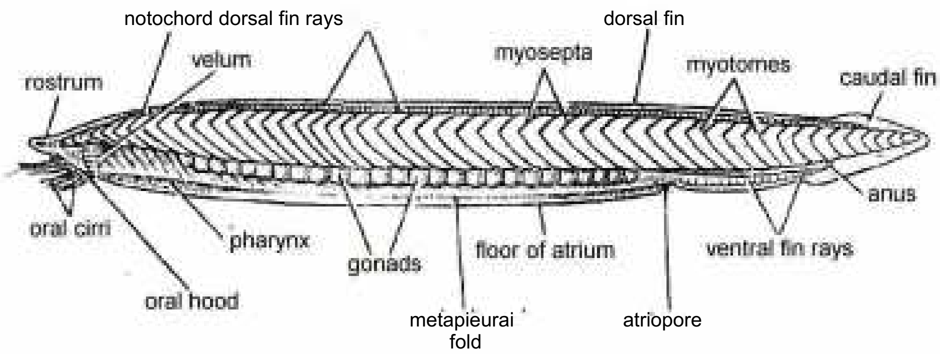
[e.g.; *Herdmania* (Sea squirt), *Ascidia, Botryllus, Salpa, Doliuolum,* and *Oikopleura]*

The sub-phylum is divided into three classes: **Larvacea, Ascidiacea** and **Thaliacea.**

Sub-phylum, Cephalochordata (Gr., *kephale,* head; *chorda,* string or cord) (Fig. 4.15):

1. Solitary, marine, burrowing in the sand or mud.
2. Body is fish-like with tapering ends.
3. Unpaired dorsal, ventral and caudal fins are present.
4. The notochord extends all along the length of the body i.e. up to the extreme anterior end of the head, **rostrum.** Normally, the notochord does not extend into the head in chordates. This is an exceptional character and this character gives the name of the group as Cephalochordata.
5. The pharynx is perforated by **gill slits** or **clefts.**
6. The interior of the pharynx is furnished with two special structures, **endostyle** and **dorsal lamina** to facilitate ciliary or filter feeding.
7. An ectoderm-lined **atrial cavity** is present, which opens to the exterior through an atrial opening or **atriopore.**
8. The body is with **segmented muscle** or **myotomes.**
9. Respiration is **branchial.**
10. Blood-vascular system is of closed type with no heart, blood corpuscles and blood pigment.

11. Excretion takes place by **protonepridia.**
12. Nervous system consists of an ill-developed brain at the anterior end which is followed by a tubular nerve cord.
13. Sexes are separate and development is direct.
14. The group is represented by two genera, ***Branchiostoma (= Amphioxus)*** and ***Asymmetron.***



Amphioxus

Fig.4.15: Amphioxus, a representative type from Cepholochordata

Sub-phylum, Vertebrata or Craniata (Gr., *kranion,* head)

All chordates barring protochordates are grouped together as Vertebrata or Craniata. Vertebrates are characterized by the presence of the following :

1. An endoskeleton of cartilages and bones.
2. Endoskeleton is classed under: (i) **axial** and (ii) **appendicular.**
3. The axial endoskeleton is constituted by the **skull** (skeletal frame of the head), **vertebral column, sternum and ribs.**
4. Both form the basis of the formation of the taxon, Vertebrata.
5. The vertebral column is a modification of the notochord.
6. The appendicular skeleton consists of **limb bones** and **girdles** (except fishes)

Vertebrata is divided into two **super-classes : Agnatha** and **Gnathostomata.**

Super-class, Agnatha (Gr., a, no; *gnathos,* jaw):

1. Fish-like marine animals.
2. Jaws are absent, hence, are known as **jaw-less vertebrates.**
3. Paired appendages (fins) are absent.

4. It is divided into two classes: **Ostracodermi** and **Cyclostomata.**
5. Ostracodermi includes extinct jaw-less vertebrates, while Cyclostomata represents the living jaw-less vertebrates.

Class, Cyclostomata (Gr., *cyclos,* circular; *stoma,* mouth) (Fig.4.16):

1. Marine jaw-less vertebrates, which generally migrate to fresh water of rivers for spawning.
2. The body is eel-like, devoid of scales.
3. Mouth is circular and remains open throughout life.
4. Paired fins are absent. However, median fins, such as dorsal, ventral and caudal fins are present.
5. Paired naked gill openings (1-16 pairs) are present on the lateral side of the body.
6. There is a single median nostril, hence, the name of the group is also **Monorrhina.**
7. Endoskeleton is cartilaginous.
8. The notochord is persistent.
9. The skull is cartilaginous and poorly developed. It is followed by a **branchial basket.**
10. Sexes are separate. Gonads are singular and without gonoduct.
11. Development is direct or indirect through a characteristic larval stage, **ammocoetes.**

[e.g.; *Petromyzon marinus* (Lamprey), *Myxine glutinosa* and *Bdellostoma* (Hag fishes)]

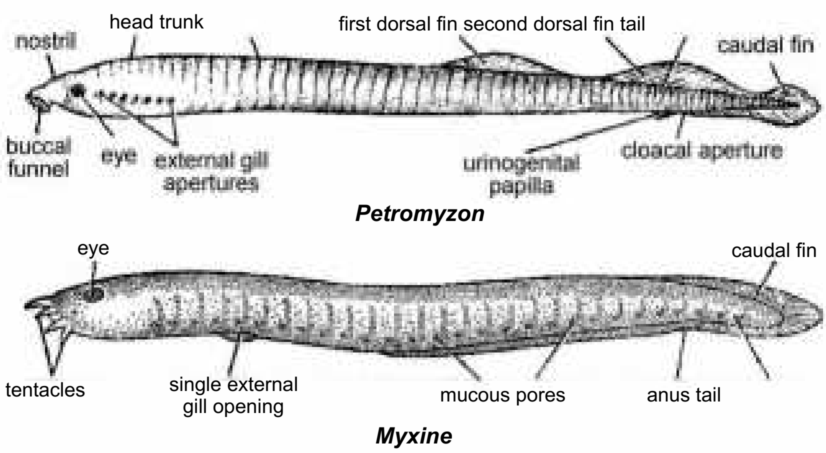


Fig.4.16 : Representative types from Cyclostomata

Super-class, Gnathostomata (Gr., *gnathos,* jaw; *stoma,* mouth):

1. Mouth is guarded by upper and lower jaws.
2. Endoskeleton is made up of both cartilages and bones.
3. The notochord is transformed into a vertebral column that is constituted by several vertebrae.
4. **Paired appendages** (fins or limbs) are present.

Differences between Agnatha and Gnathostomata

Agnatha	Gnathostomata
1. Jaws are absent.	1. Defined jaws are present.
2. Mouth is circular in outline and can not be closed.	2. Mouth can be closed by the jaws.
3. Paired appendages (paired fins) are absent.	3. Paired appendages (paired fins or limbs) are present.
4. Cranium and vertebral column are not well developed.	4. Cranium and vertebral column are well developed.
5. Single external nostril.	5. A pair of external nostrils.
6. Internal ear with two semicircular canals.	6. Internal ear with three semicircular canals.
[e.g.; Animals belonging to the Class, Cyclostomata *(Petromyzon* and *Myxine)]*	(e.g.; Animals belonging to Classes, Pisces to Mammalia)

Gnathostomata is divided into two series: **Pisces** and **Tetrapoda.**

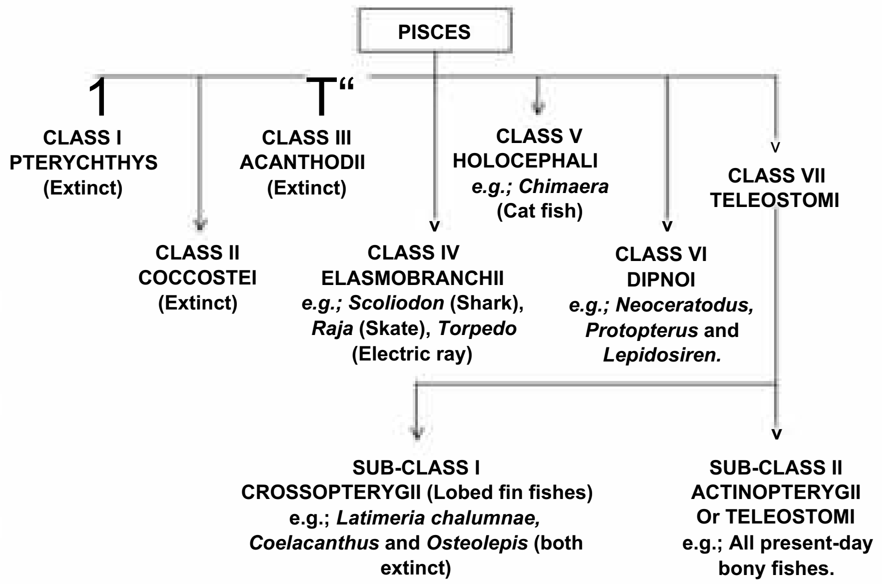
Series, Pisces *piśces,* fishes) (Fig. 4.17):

1. Aquatic animals having streamlined body.
2. Body is covered by **dermal scales.** Scales are of several types : **placoid, cycloid, ctenoid** and **cosmoid.**
3. Internal gills, open to outside through paired gill openings. The gill openings are naked or covered by **opercula** (singular, operculum).
4. Respiration is **branchial.** However, in some forms **(lung fishes)** respiration is pulmonary i.e. occurs by lungs in addition to being branchial.
5. Some air-brerathing fishes possess **accessory respiratory organs** for aerial respiration.
6. Both median (unpaired) and **paired fins** are present.
7. Two pairs of paired fins, the **pectoral** and **pelvic,** characterize fishes.
8. The median fins include the dorsal, ventral and caudal fins.
9. The endoskeleton is cartilaginous or bony.

10. Lateral line system is well developed. This system functions as a **rheoreceptor** i.e. it detects the direction of the water current by perceiving vibrations.
11. The heart is two chambered consisting of an atrium and a ventricle. It is **venous** i.e. only deoxygenated blood circulates through it.
12. Single circulation.
13. Only the **internal ear** is present.
14. Kidney is **mesonephros.**
15. Sexes are separate. Development is indirect.

[e.g.; *Scoliodon* (Shark); *Raja* (Skate); *Torpedo* (Electric ray); *Chimaera* (Cat fish); *Neoceratodus, Protopterus* and *Lepidosiren* (Lunf fishes); *Latimeria chalumnae', Labeorohita* (Rohu); *Catla catla* (Bhakura); and *Anabas testudineus* (Climbing perch)]

The series, Pisces is divided into seven classes : **Pterychthys, Coccostei, Acanthodii, Elasmobranchii, Holocephali, Dipnoi** and **Teleostomi.** The first three classes are extinct and often classed together as **Placodermi.** The latter four classes are living. Elasmobranchii includes all cartilaginous fishes. Holocephali is a small class and includes **rat fish.** It combines the characters of both cartilaginous and bony fishes. Therefore, it is considered as a connecting link between the two. The class Dipnoi includes **lung or air-breathing fishes.** There are only three discontinuously distributed representatives of this class. Teleostomi is divided into two sub-classes : Crossopterygii and Actinopterygii. The sub-class, Crossopterygii is very significant from the fact that it includes fishes possessing **lobed fins** or **archipterygeal fins.** These fishes are considered as the ancestors of the present-day land dwellers. All, except ***Latimeria chalumnae,*** are extinct. This representative has survived millions of years without any significant evolutionary change. Therefore, it is considered as a **living fossil.** In another classification, the cartilaginous fishes and bony fishes are grouped together as Chondrichthyes and Osteichthyes, respectively.



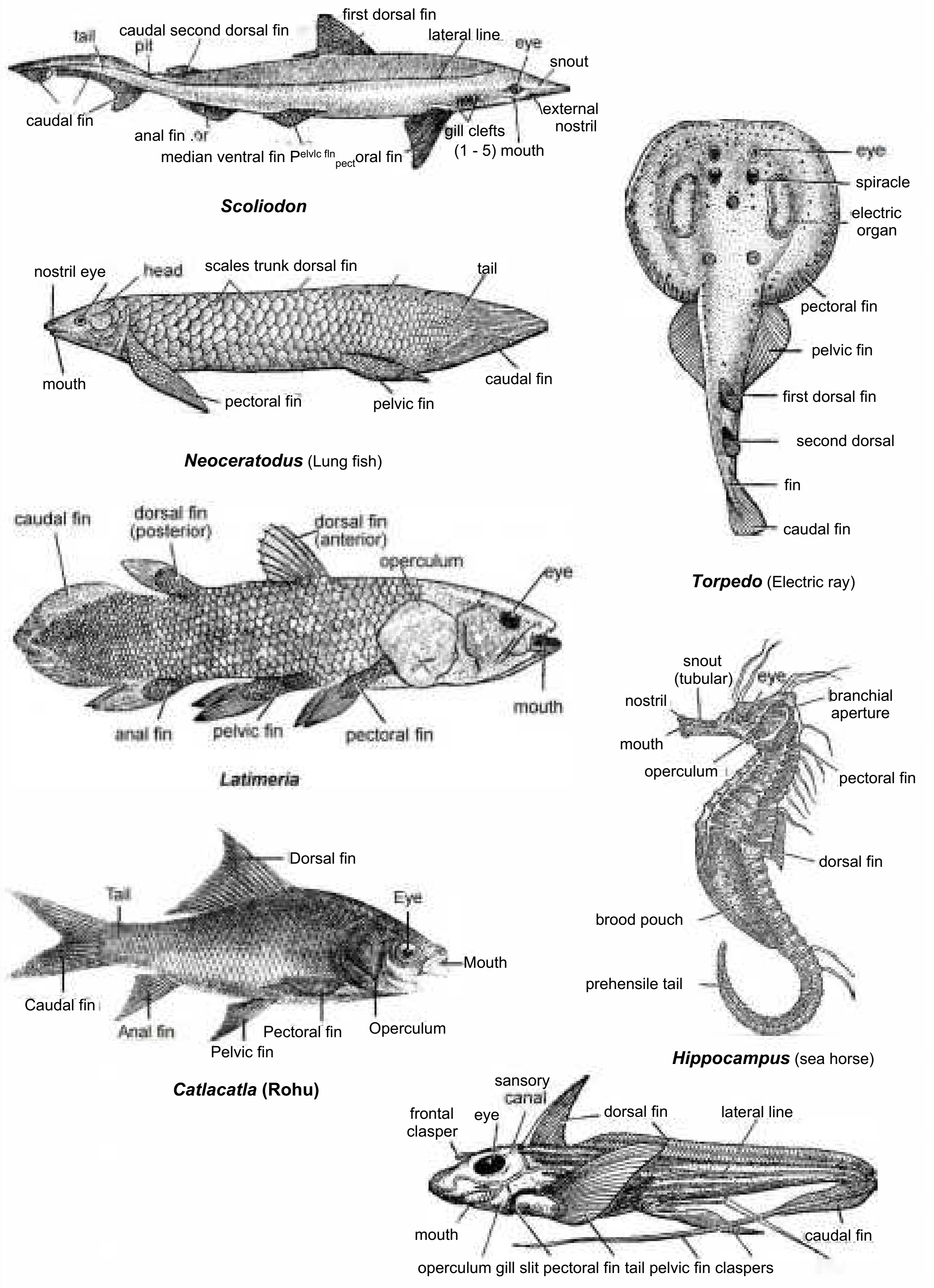


Fig. 4.17: Representative types from Pisces

Series, Tetrapoda (Gr., *tetra,* four; *podos,* foot):

1. Possess two pairs of appendages or limbs: a pair of **fore limbs** and a pair of **hind limbs.**
2. The limbs are **pentadactyl** i.e. each possesses five digits or fingers. However, in some tetrapods, limbs may bear less than five fingers. This is a secondary reduction in the normal number.

Difference between Pisces and Tetrapoda :

Pisces	Tetrapoda
1. Aquatic vertebrates.	1. Aquatic, terrestrial, arboreal or aerial vertebrates.
2. Presence of paired fins (pectoral and pelvic fins).	2. Presence of paired pentadactyl limbs (fore and hind limbs).
3. Respiration, generally, takes place by gills.	3. Respiration, generally, takes place by lungs.
4. Generally oviparous.	4. Oviparous or ovoviviparous or viviparous.
(e.g.; All fishes)	(e.g.; Animals belonging to Classes, Amphibia to Mammalia)

Tetrapoda is primarily divided into Anamniota and Amniota based on the absence or presence of extra-embryonic membranes (amnion, chorion, yolk sac and allantois). Anamniota includes the only class, Amphibia. Amniota includes three classes: Reptilia, Aves and Mammalia.

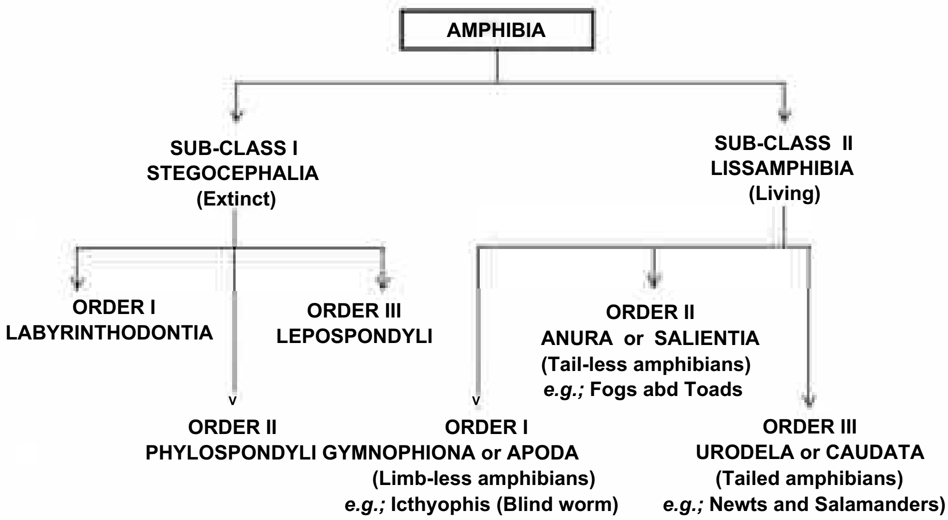
Class, Amphibia (Gr., *amphi,* double or both; *bios,* life) (Fig. 4.18):

1. The skin is smooth and moist with mucous glands. It is naked without scales.
2. Body is divided into head, trunk and tail. There is no neck between the head and the trunk.
3. Two pairs of pentadactyl limbs are present.
4. A pair of tympanum is present.
5. Respiration is of three types: **cutaneous, bucco-pharyngeal** and **pulmonary.**
6. Heart is three chambered with two auricles and a single ventricle.
7. The excretory organ is a pair of **opisthonephric kidneys.**
8. There is a **cloaca,** the converging chamber of the rectum and the urino-genital ducts. The cloaca discharges out through a **cloacal aperture.**
9. There are ten pairs of cranial nerves.

10. Poikilothermal or cold blooded vertebrates.
11. All undergo **aestivation during summer** and **hibernation during winter.**
12. Skull is **dicondylic** i.e., with **two occipital condyles.**
13. Sexes are separate. **Oviparous.**
14. Eggs are without shell and laid in water.
15. Fertilization is external.
16. **Development is indirect** with aquatic **tadpole larvae of anurans** or **axolotl** or the like larvae of urodeles. An aquatic larva undergoes a remarkable **metamorphosis** into a terrestrial adult. Thus, amphibians spend a part of their life cycle on land and the other in water.
17. Most amphibians exhibit the phenomenon of **parental care.**
18. Most urodeles exhibit the phenomenon of **neoteny** and **paedogenesis.** Neoteny is a prolongation of the larval life and paedogenesis is the attainment of sexual maturity during the larval life.
19. A few urodeles are permanently neotenic i.e. they fail to metamorphose and live with larval features.

[e.g.; *Ichthyophis* (Blind worm), *Bufo melanostictus* (Common toad), *Hoplobatrachus tigerinus (=Rana tigerina)* (Indian bull frog), *Polypedates maculatus* (Jumping frog), *Ambystoma tigrinum* (Tiger salamander), *Salamandra* (Terrestrial salamander), *Amphiuma* (Congo eel), *Triton* (European salamander), *Necturus* (Mud puppy)]

Amphibia is primarily divided into two sub-classes **: Stegocephalia** and **Lissamphibia.** Stegocephalia includes all extinct amphibians belonging to three orders : **Labyrinthodontia, Phylospondyli** and **Lepospondyli.** Lissamphibia includes living amphibians belonging to three living orders : **Gymnophiona** or **Apoda** (limb-less amphibians), **Anura** or **Salientia** (tail-less amphibians) and **Urodela** or **Caudata** (tailed amphibians).



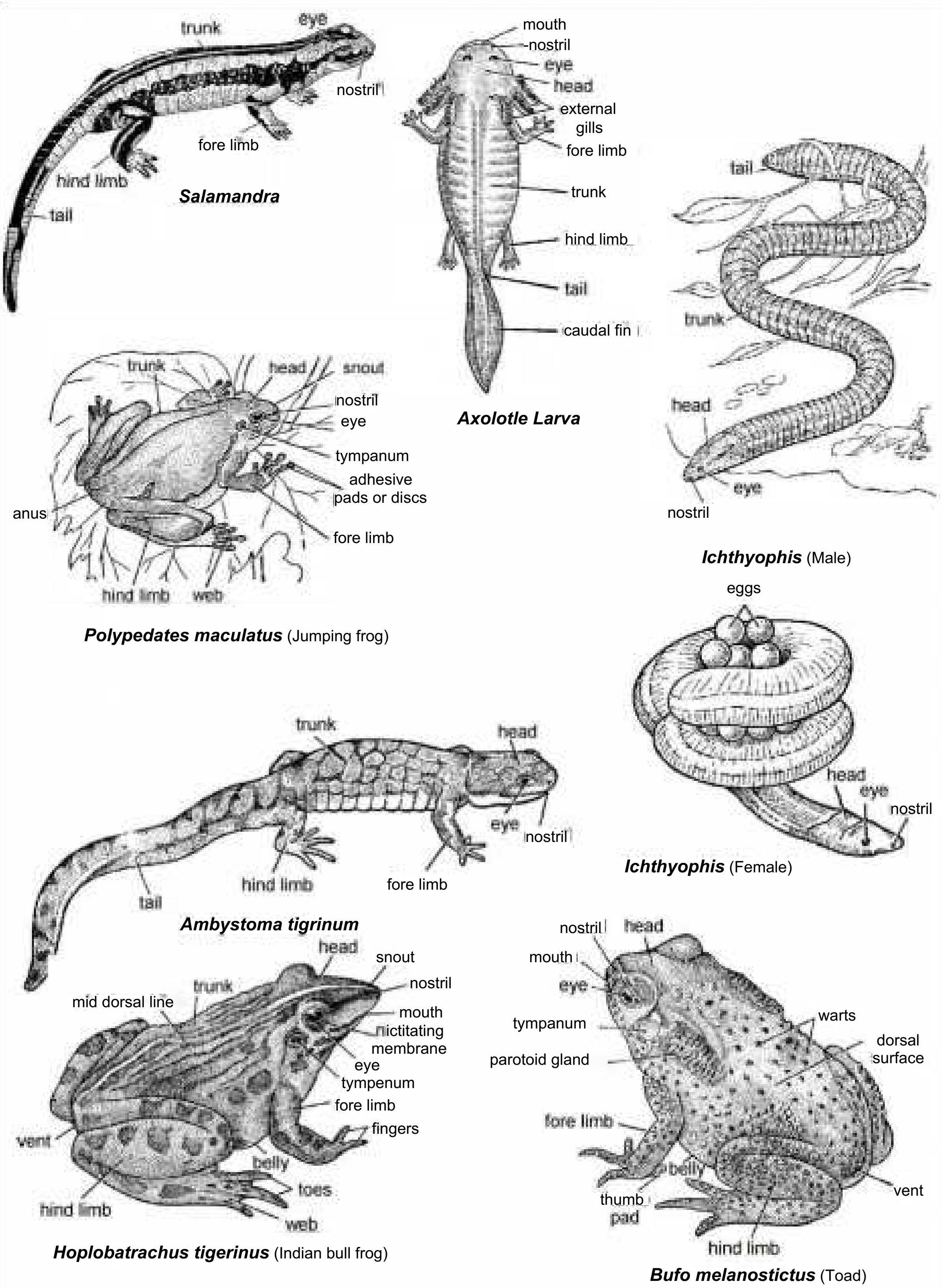


Fig.4.18 : Representative types from Amphibia

Class, Reptilia (L., *repere; reptum; reptiles,* to creep or to crawl) [Fig. 4.19 (a) and (b)J :

1. The skin is covered by **epidermal scales, scutes** or **shields.** Body is rough and dry due to the absence of epidermal glands.
2. Body is divided into head, neck, trunk and tail.
3. All, except snakes and a few lizards, have **pentadactyl limbs.**
4. The tympanum is depressed and hence, not visible.
5. Skull is **monocondylic** with a single occipital condyle.
6. Besides the **orbits** (cavities for the eye balls), the skull bears one or two pairs of **fossae** or **vacuities** in the temporal region known as **temporal fossae.** This character forms the basis of classification of Reptilia into four sub-classes.
7. Ribs form a true **sternum.**
8. Respiration is **pulmonary.**
9. **Heart is three chambered** with two auricles and a single ventricle. However, **in crocodiles, the heart is four chambered** with two auricles and two ventricles. **Double circulation.**
10. **Cold blooded animals.**
11. Kidneys are **metanephric.**
12. **Twelve pairs of cranial nerves.**
13. **Extra-embryonic membranes** are present.
14. Typical cloaca and cloacal aperture are present.
15. Sexes are separate with distinct **sexual dimorphism.** The males have copulatory organs called **hemipenis.**
16. Fertilization is internal and **shelled cledoic eggs** are laid on land.

[e.g.; *Lepidochelys olivacea* (Olive Ridley turtle), *Chelonia mydas* (Green sea turtle), *Hemidactylus flaviviridis* (Wall lizard), *Calotes versicolor* (Garden lizard), *Chamaeleon vulgaris* (Camouflaging lizard), *Varanus* (Monitor lizard), *Heloderma* (Only poisonous lizard), *Hydrophis* (Sea snake), *Naja naja* (Bicoelate cobra), *Naja kaouthia* (Monocoelate cobra), *Ophiophagus hannah* (King cobra), *Vipera russelli* (Russell's viper), *Echis carinatus* (Saw-scaled viper), *Bungarus coeruleus* (Common krait), *Bungarus fasciatus* (Banded krait), *Ancistrodon himalayanus* (Himalayan pit viper), *Gavialis gangeticus* (Gharial), *Crocodilus palustris* (Mugger), *Crocodilus porosus* (Marsh crocodile), *Sphenodon* (Tuatara)]. *Sphenodon* from Newzealand is considered as a living fossil.

Reptilia is divided into four sub-classes : **Anapsida, Synapsida, Euryapsida** and **Diapsida** based on the absence or presence of temporal fossae and if present, the number of temporal fossae. An outline classification with examples is presented in the next page.

REPTILIA

- **SUB-CLASS I ANAPSIDA**
  - **ORDER CHELONIA** (*e.g.;* Turtles and Tortoises)
- **SUB-CLASS II SYNAPSIDA** (All are extinct)
- **SUB-CLASS III EURYAPSIDA** (All are extinct)
- **SUB-CLASS IV DIAPSIDA**
  - **ORDER SQUAMATA**
    - **SUB-ORDER LACERTILIA** (*e.g.;* Lizards)
    - **SUB-ORDER OPHIDIA** (*e.g.;* Snakes)
  - **ORDER CROCODILIA** (*e.g.;* Crocodiles)
  - **ORDER RHYNCOCEPHALIA** (e.g.;Sphenodon)

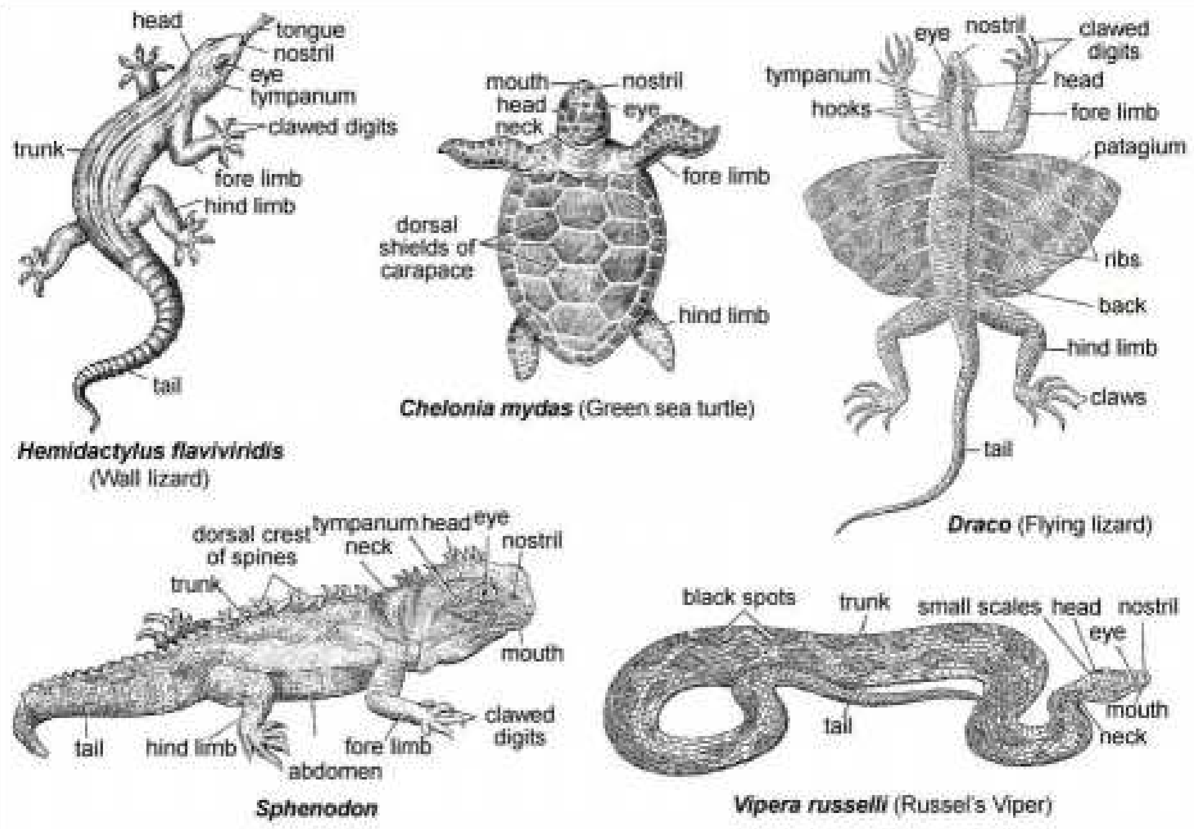
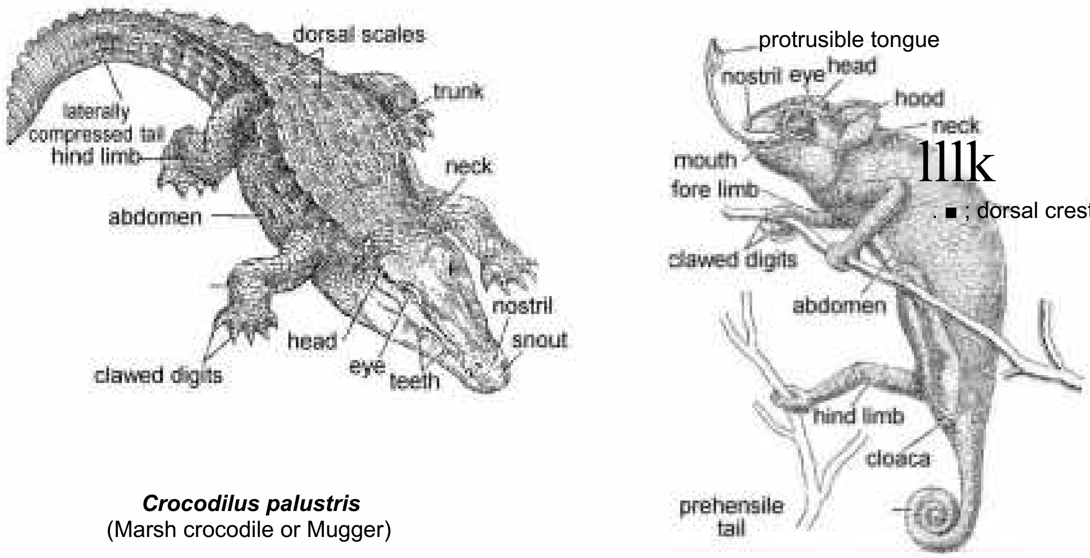


Fig.4.19 (a) : Representative types from Reptilia



Crocodilus palustris
(Marsh crocodile or Mugger)

Chamaeleon
(Chamouflaging lizard)

Fig.4.19 (b): Representative types from Reptilia

Class, Aves (L., *avis,* bird) (Fig.4.20):

1. Body is divided into head, neck, trunk and tail.
2. Entire body is covered by **feathers.** Legs are covered by **horny scales.**
3. Jaws are modified as a **horny beak.** No teeth are present.
4. Fore limbs are modified as **wings,** covered by feathers. Digits are absent in the fore limbs.
5. Each hind limb bears four digits, which help in walking, swimming and **perching.**
6. Bones are **pneumatic** i.e. they bear air cavities.
7. **One occipital condyle** in the skull.
8. Vertebrae are **heterocoelous.**
9. Sternum is broad having a boat shaped **keel** for attachment of muscle.
10. Heart is four chambered with two auricles and two ventricles.
11. The right **systemic arch** persists.
12. Respiration is pulmonary. The efficiency of respiration increases by the presence of **air sacs.**
13. Air-filled air sacs increase buoyancy.
14. A **voice box, syrinx** is present.
15. Kidneys are **metanephric.**
16. A **pecten** is present in each eye. It helps in distinct vision.
17. Sexes are separate with distinct sexual dimorphism.
18. Fertilization is internal and development is external.
19. Oviparous i.e., lay shelled eggs.
20. **Extra embryonic membranes** appear during development.

[e.g.; *Struthio camelus* (Ostrich), *Rhea americana* (South American ostrich), *Apteryx* (Kiwi), *Pavo cristatus* (Peacock), *Psittacula* (Parrot), *Passer domesticus* (House sparrow), *Corvus splendens* (Common crow)]

Aves is divided into two sub-classes: **Archaeornithes** (extinct birds) and **Neornithes** (both extinct and living birds). Neornithes is sub-divided into three super-orders: **Odontognathae** (extinct), **Palaeognathae** (flightless birds) and **Neognathae** (Flying birds). In old terminology, flightless and flying birds are grouped as **Ratitae** and **Carinatae,** respectively.

AVES

SUB-CLASS I
ARCHAEORNITHES
(All extinct)
(e.g.; *Archaeopteryx*)

SUB-CLASS II
NEORNITHES

SUPER-ORDER I
ODONTOGNATHAE
(All extinct)

SUPER-ORDER II
PALAEOGNATHAE
(Flightless birds)

SUPER-ORDER III
NEOGNATHAE
(Flying birds)

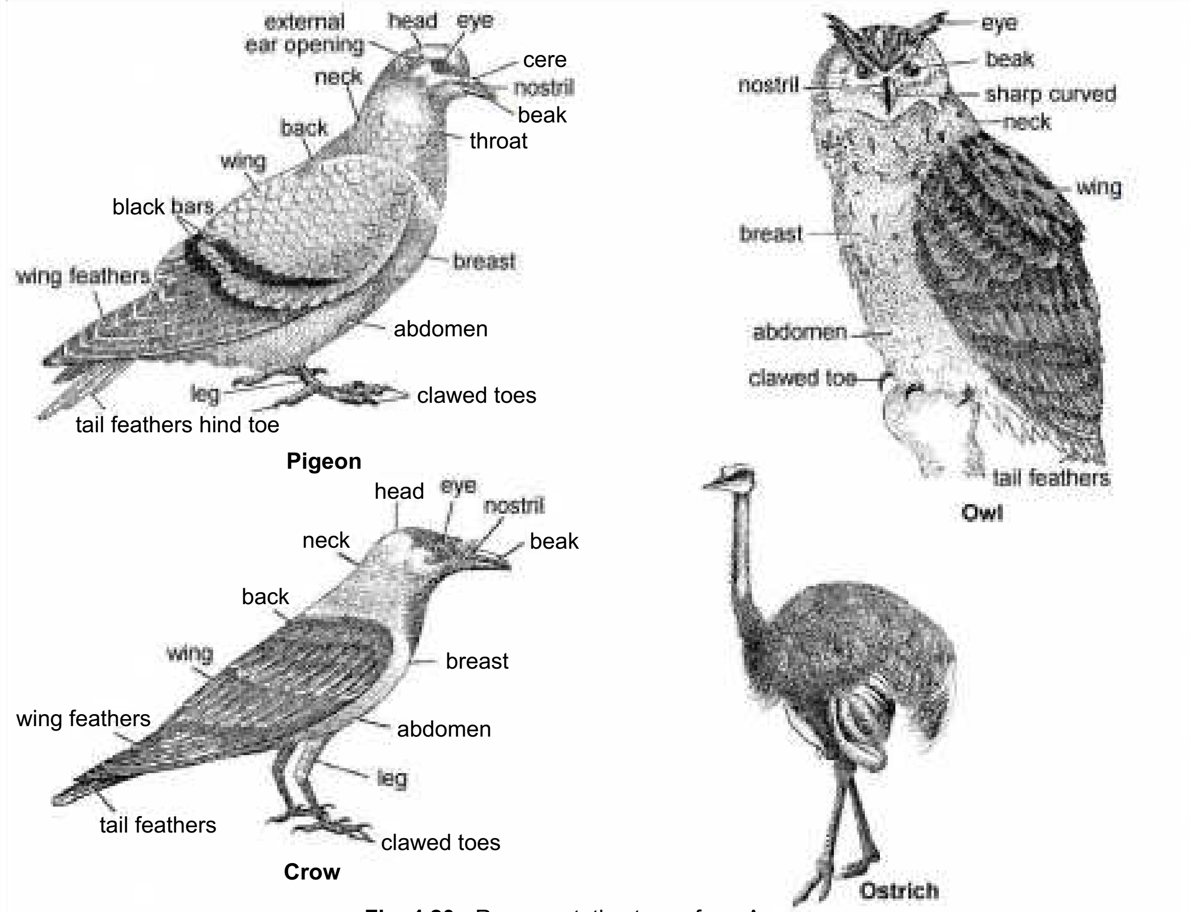


Fig. 4.20 : Representative types from Aves

Archaeopteryx:

Archaeopteryx is a fossil bird, dug out from the upper Jurassic sediments of Bavaria, Germany. The fossil is complete in the sense that the impressions of feathers are preserved in it. The fossil is characterized to have possessed both **reptilian** and **avian characters.** Some distinguishing reptilian characters are **the presence of teeth in the beak** and **presence of clawed digits in the wings.** A few distinguishing avian characters are **bipedal locomotion, the presence of feathers, modification of the fore limbs into wings and presence of a beak.** It, thus, represents a transition between reptiles and birds. The discovery of Archaeopteryx throws some light on the origin of birds from **bipedal arboreal ancestors.**

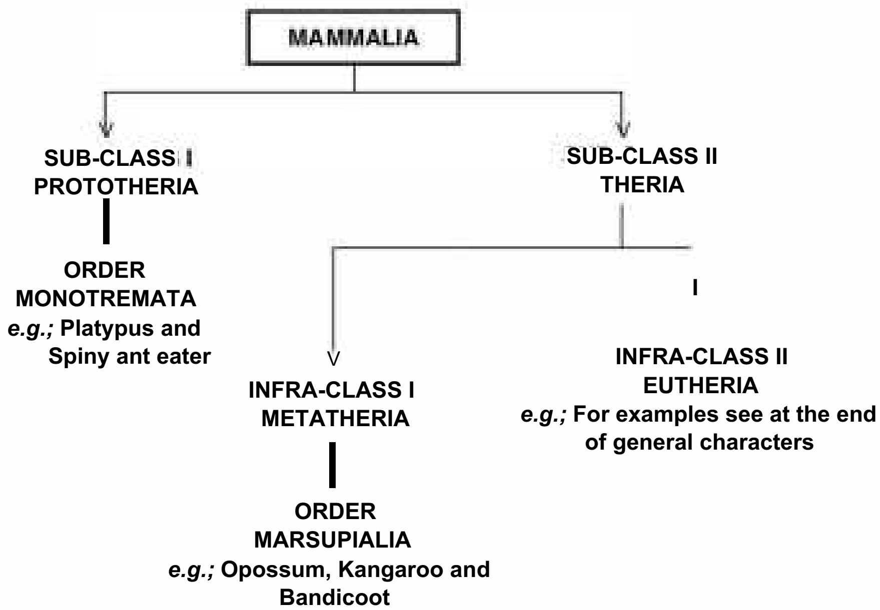
Class, Mammalia (L., *mamma,* breast) (Fig. 4.21):

1. The body is divided into **head, neck, trunk** and **tail.**
2. The trunk is divided into **thorax** and **abdomen.**
3. Two pairs of **pentadactyl limbs** are present. The digits end in **nails, claws** or **hooves.**
4. The **skin is hairy** bearing **sebaceous** (sebum, an oily secretion) and **sweat (sudorific) glands.** Hairs are secondarily lost in the order Cetacea (whales).
5. The **mammary glands** are present in both males and females. These are **modified sebaceous glands.** In females, these are more developed than in males and secrete milk following the birth of young ones.
6. **External ear** or **pinna** is present.
7. A **diaphragm,** a dome-shaped smooth muscular sheet or partition is present between the thoracic and abdominal cavities.
8. The teeth are **heterodont, thecodont** and **diphyodont.**
9. Urinary and anal apertures are separated.
10. Heart is four chambered with **double circulation.**
11. The **left systemic arch** only persists.
12. RBCs are non-nucleated except camel and llama.
13. Kidneys are **metanephric. Urinary bladder** is present.
14. Brain is well developed with a convoluted cerebrum.
15. Four optic lobes, known as **corpora quadrigemina** are present.
16. Two cerebral hemispheres are connected by **corpus callosum.**
17. There are **12 pairs of cranial nerves.**
18. Sexes are separate with a distinct sexual dimorphism.
19. The testes are lodged in a **scrotal sac** i.e. extra-abdominal. However, in a few (whale, dolphin and elephant), it is abdominal.

20. Seminiferous tubules possess somatic cells called Sertoli cells, which nourish the differentiating male germ cells.
21. The ovary possesses ovarian follicles in different stages of development. The mature ovarian follicle is known as **Graafian follicle.**
22. Following ovulation, the graafian follicle turns into a **corpuls luteum,** an endocrine structure secreting **progesterone.**
23. Fertilization is internal. All are **viviparous** except monotremes (Duck-billed Platypus).
24. The developing young is nourished by a tissue connection between the mother and the developing embryo. This structure is known as **placenta.**

[e.g.; *Ornythorhynchus* (Duck-billed Platypus), *Tachyglossus (=Echidna)* (Spiny ant eater), *Macropus* (Kangroo), *Didelphis* (Opossum), *Pteropus* (Bat or Flying fox), *Lemur,* Chimpanzee, Gorilla, Orang-utan, Gibbon, *Homo sapiens* (Human), *Manis* (Pangolin), *Hystrix* (Porcupine), Dolphin, Sperm whale, Blue whale, *Panthera leo persica* (Asiatic lion), *Panthera tigris* (Royal Bengal tiger), *Panthera pardus* (Leopard), Seal, Walrus, *Elephas maximus* (Asiatic elephant), *Equus domesticus* (Horse), *Axis axis* (Spotted deer), *Bos domesticus* (Cow)]

Mammalia is primarily divided into two sub-classes : **Prototheria** and **Theria.** Prototheria includes primitive **egg laying mammals,** distributed in Australia, Tasmania and New Guinea. It has only one order, **Monotremata.** The sub-class, Theria is sub-divided into two infra-classes : **Metatheria** and **Eutheria.** Metatheria includes **ovoviviparous** mammals possessing **marsupium** for the nourishment of the young ones. This infra-class has also one order, **Marsupialia.** Infra-class, Theria includes all modern mammals with typical mammalian characters.



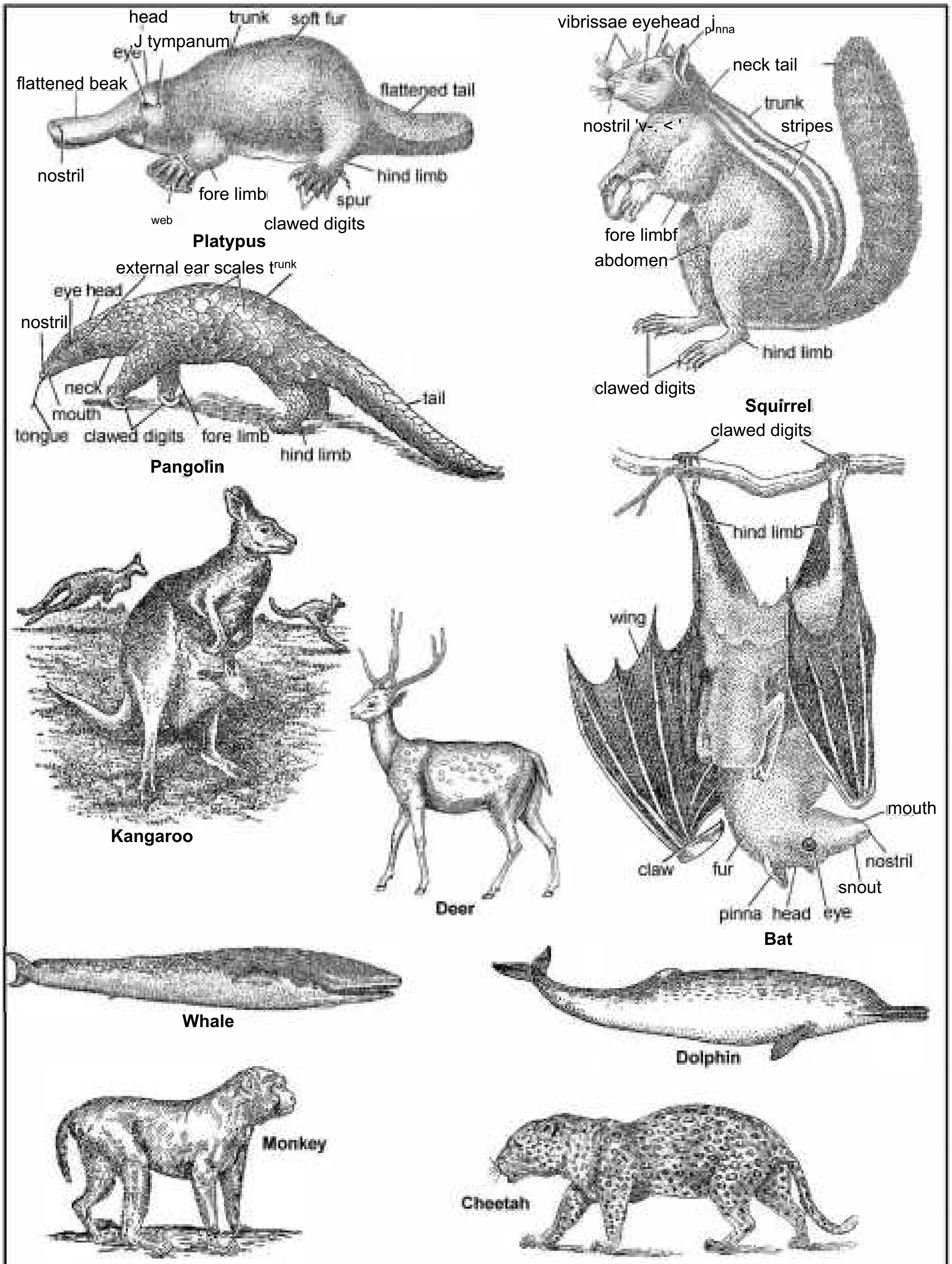


Fig. 4.21 : Representative types from Mammalia

SAMPLE QUESTIONS

GROUP - A
(Objective-type Questions)

1. Choose the correct answer :

(i) Spicules are present in the animals of the phylum.
(a) Porifera (b) Annelida
(c) Coelenterata (d) Platyhelminthes

(ii) What is common to fishes, amphibians and reptiles ?
(a) Scales (b) Shelled egg
(c) eggs (d) gills

(iii) Dolphin belongs to
(a) Amphibia (b) Mammalia
(c) Pisces (d) Reptilia

(iv) Sea horse belongs to
(a) Amphibia (b) Aves
(c) Pisces (d) Mammal

(v) Hair is absent in the mammalian order
(a) Cetacea (b) Chiroptera
(c) Primates (d) Rodentia

(vi) Asexual reproduction through gemmule formation takes place in
(a) Arthropoda (b) Coelenterata
(c) Porifera (d) Platyhelminthes

(vii) Which one of the following is a freshwater sponge ?
(a) Euplactella (b) Hyalonema
(c) Spongilla (d) Sycon

(viii) One of the following is not radially symmetrical.
(a) Hydra (b) Sea cucumber
(c) Snail (d) Starfish

(ix) Which one of the following is bilaterally symmetrical ?
(a) Jelly fish (b) Nematode
(c) Starfish (d) Sea Urchin

(x) Which of the following sets belong to class Cyclostomata ?
(a) Amphioxus & Herdmania (c) Petromyzon & Amphioxus
(b) Amphioxus & Balanoglossus (d) Petromyzon & Myxine

(xi) Annelides are :
(a) Triploblastic (c) Radially symmetrical
(b) Pseudocoelomate (d) Unsegmented

(xii) Warts are present in

(a) Amphibia (b) Mammalia

(c) Pisces (d) Reptilia

(xiii) What type of worms are the platyhelminths ?

(a) Blind worm (b) Flat worm

(c) Round worm (d) Thread worm

(xiv) In which of the following animals, a canal system is present ?

(a) Hydra (b) Starfish

(c) Sponge (d) Earthworm

(xv) The most highly advanced character in crocodile is :

(a) Four chambered heart (b) Powerful jaws

(c) Shelled eggs (d) Thecodont dentition.

(xvi) In which animal group, syrinx is present ?

(a) Aves (b) Pisces

(c) Amphibia (d) Reptilia

(xvii) *Planaria, Taenia* and *Fasciola* are

(a) Segmented (b) Coelomates

(c) Flat-worms (d) Radially symmetrical,

(xviii) Which of the following groups has largest number of species ?

(a) Aves (b) Protozoa

(c) Insecta (d) Mammalia

(xix) Find out the diploblastic animal

(a) Obelia (b) Earthworm

(c) Nereis (d) Liverfluke

(xx) In which phylum nematocysts are present ?

(a) Arthropoda (b) Annelida

(c) Mollusca (d) Coelenterata

(xxi) What type of larva is seen in Coelenterata ?

(a) Planula (b) Trochophore

(c) Tadpole (d) Redia.

(xxii) Which of the following animal group belongs to Acoelomata ?

(a) Annelida (b) Arthropoda

(c) Echinodermata (d) Platyhelminthes.

(xxiii) Which one is a pseudocoelomate ?

(a) Ascaris (b) Cockroach

(c) Starfish (d) Hydra

(xxiv) Which one is the intermediate host of *Fasciola hepatica ?*

(a) Cow (b) Man

(c) Pig (d) Snail

(xxv) Sexual dimorphism is seen in which phylum ?

(a) Coelenterata (b) Nemathelminthes

(c) Platyhelminthes (d) Porifera

(xxvi) In which animal the systemic aorta is seen only on the right side ?

(a) Frog (b) Crocodile

(c) Pigeon (d) Man

(xxvii) In which animal systemic aorta is present only on the left side ?

(a) Frog (b) Crocodile

(c) Pigeon (d) Man

(xxviii) Viviparity is not seen in which animal ?

(a) Bat (b) Platypus

(c) Monkey (d) Whale

(xxix) In which of the following phyla, compound eyes are present ?

(a) Annelida (b) Arthropoda

(c) Echinodermata (d) mollusca

(xxx) Pentamerous radial symmetry is seen in which phylum ?

(a) Arthopoda (b) Annelida

(c) Mollusca (d) Echinodermata

(xxxi) Which one is not an acraniata (acrania) ?

(a) Herdmania (b) Balanoglossus

(c) Amphioxus (d) Petromyzon

(xxxii) What type of scale is present in cartilaginous fishes ?

(a) Cycloid (b) Ctenoid

(c) Placoid (d) Ganoid

(xxxiii) Which class of animals is not marine ! ?

(a) Amphibia (b) Fishes

(c) Mammalia (d) Reptilia

(xxxiv) Class Aves includes animals with

(a) Scales (b) Feathers

(c) Hair (d) Smooth skin

(xxxv) Lizards are included in which class ?

(a) Pisces (b) Amphibia

(c) Reptilia (d) Mammalia

(xxxvi) Which one is a homoiothermic animal ?

(a) Shark (b) Lung fish

(c) Cat fish (d) Dolphin

(xxxvii) Which one is a poikilothermic animal ?

(a) Crocodile (b) Seal

(c) Pigeon (d) Whale

(xxxviii) Whales are included in the same class as that of

(a) Alligator (b) Dog fish

(c) Monkeys (d) Sea horse

(xxxix) Body temperature is regulated at a constant in

(a) Cow (b) Earthworm

(c) Frog (d) Snake

(xl) A distinguishing character of chordates is :

(a) Feather (b) Hairy skin

(c) Notochord (d) Stomochord

(xli) The chief distinguishing feature of a mammal is

(a) Pinna and teeth (b) Hairy skin andoviparity

(c) Hairy skin andmammary gland (d) Mammary gland and teeth

(xlii) Which of the following is not an insect ?

(a) Earwig (b) Head louse

(c) Spider (d) Silver fish

(xliii) Prawns, shrimps and lobsters belong to which class of the Arthropoda ?

(a) Arachnida (b) Crustacea

(c) Insecta (d) Myriapoda

(xliv) The animals of which phylum are aerial, aquatic and terrestrial.

(a) Annelida (b) Arthropoda

(c) Echinodermata (d) Mollusca

(xlv) The most important character of a mammal is

(a) A four chamber heart (b) Presence of corpus callosum

(c) Pressence of metanephric kidney (d) Presence of thecodont teeth.

(xlvi) Find out the odd member in the group.

(a) Crocodile (b) Dolphin

(c) Lizard (d) Turtle

(xlvii) Echinoderms are exclusively

(a) Esturiarine (b) Marine

(c) Pond living (d) Riverine

(xlviii) Which one is a true terrestrial animal ?

(a) Frog (b) Salamander

(c) Tortoise (d) Toad

(xlix) The genus of midwife toad is

(a) Alytes (b) Rhacophorus

(c) Hyla (d) Pipa

(l) A rabbit shows resemblance with a frog in :

(a) Nucleated RBC (b) Dorsal tubular nerve cord

(c) Oval RBC (d) Renal Portal system.

2. Answer each of the following in one word or more words, wherever necessary :

(i) Give an example of a diploblastic animal.

(ii) What is the term used for summer sleep ?

(iii) What is the term used for winter sleep ?

(iv) What is the alternative name for cold bloodedanimals ?

(v) What is the alternative name for warm blooded animals ?

(vi) In which invertebrate phylum carapace is present ?

(vii) In which phylum medusa is present ?

(viii) In which nonchordate phylum flame cells are present ?

(ix) In which phylum manntle is present ?

(x) What are the excretory organs of annelids known as ?

(xi) What is the free floating form of coelenterates known as ?

(xii) What is the name of stinging cell of coelenterates ?

(xiii) What is the symmetry of Pila ?

(xiv) Which animals communicate by pheromones ?

(xv) Name an egg-laying mammal.

(xvi) Which jawless chordates suck blood from the fishes ?

(xvii) Which phylum do sponges belong to ?

(xviii) Which phylum does the jelly fish belong to ?

(xix) Which one is the largest phylum (in terms of number of species) of the animal kingdom ?

(xx) The animals of which phylum are exclusively marine ?

(xxi) Which class does the blue whale belong to ?

(xxii) Which class the sea horse belongs to ?

(xxiii) Dinosaurs belong to which class ?

(xxiv) Newts and salamanders belong to which class of animals ?

(xxv) Which class does the Platypus belong to ?

(xxvi) Bats belong to which class ?

(xxvii) Which phylum do the corals belong to ?

(xxviii) Name the phylum and class of pigeon.

(xxiv) Crocodiles belong to which class ?

(xxv) To which phylum the scorpions belong ?

(xxvi) Name the phylum and class of *Octopus.*

(xxvii) *Ascaris* belongs to which phylum ?

3. Match the words of column I with those of column II.

(a)

I.	II.
A. Hydra	i. Round worm
B. Millipede	ii. Arthropoda
C. Ascaris	iii. Crustacea
D. Sea urchin	iv. Segmented worm
E. Leech	v. Cnidaria
	vi. Echinodermata

(b)

A. Limbless reptile	i. Lamprey
B. Jawless vertebrate	ii. Salamander
C. Amphibian	iii. Snake
D. Cartilaginous fish	iv. Shark
E. Flightless bird	v. Ostrich

(c)

A. Coral	i. Placoid scale
B. *Echidna*	ii. Monotremata
C. Crab	iii. Mollusca
D. *Octopus*	iv. Coelenterata
E. Sexual dimorphism	v. Amphibia
F. Cartilaginous fish	vi. Nematoda
	vii. Radial symmetry
	viii. Crustacea

GROUP - B

(Short Answer-type Questions)

1. Answer each within 50 words

(i) What do you mean by cellular grade of organization ?

(ii) What is metamerism ?

(iii) What is an archaeocyte ? What is its function ?

(iv) Why is the name of the phylum to which *Hydra* belongs, is Caelenterata ?

(v) Explain the meaning of Parazoa.

(vi) Which germ layer is the coelom derived from ? How many types of coelom are there ?

(vii) In which phylum, neoblasts are present ? What is their function ?

(viii) Explain about sexual dimorphism in *Ascaris.*

(ix) Ennumerate three important characters of the phylum, Arthropoda.

(x) Explain about enterocoelic coelom.

(xi) Despite being radially symmetrical, echinoderms are included in the division, Bilaria- Give reasons.

(xii) Describe about amphibious breathing habit in Pila ?
(xiii) Ennumerate three important chordate characters.
(xiv) What is retrogressive metamorphosis ?
(xv) Name two structures in the pharynx of *Amphioxus,* which fulfil the filter feeding mechanism.
(xvi) Distinguish Agnatha from Gnathostomata in two important features,
(xvii) Explain the meaning of Cyclostomata.
(xviii) What is a paired fin ? How many paired fins are present in a fish ? Name them.
(xix) What is a living fossil ? Name one living fossil among fishes.
(xx) Rat fish connects cartilaginous fishes and bony fishes. Explain.
(xxi) What is the function of lateral line system ?
(xxii) What is the basis of division of Tetrapoda into Anamniota and Amniota ?
(xxiii) Explain the meaning of Tetrapoda.
(xxiv) Frogs and toads belong to the class, Amphibia- Give one reason.
(xxv) Explain neoteny and paedogenesis.
(xxvi) What is a pentadactyl limb ?
(xxvii) What is the basis of division of the class, Reptilia into four sub-classes ?
(xxviii) Give the scientific names of three crocodiles found in Orissa,
(xxix) Ennumerate three identifying features of common cobra.
(xxx) Give the scientif names of two types of Kraits.
(xxxi) What is *Archaeopteryx ?* Enlist four of its important characters,
(xxxii) Give the common names of two flightless birds.
(xxxiii) Name two egg laying mammals.
(xxxiv) Kangroo is known as a marsupiale mammal- Why ?
(xxxv) Name two mammals possessing nucleated erythrocytes.
(xxxvi) What do you understand by oviparous and viviparous ?
(xxxvii) What is the type of body plan in Hydra ?
(xxxviii) What is the type of body plan in sponges ?
(xxxix) What is the type of body plan in flat-worms ?
(xl) What is the type of body plan in nematodes ?
(xli) What is the type of body plan in earthworm ?

2. Differentiate between two words in the following pairs of words :

(i) Diploblastic and Triploblastic
(ii) Homoiothermic and Poikilothermic
(iii) Urochordata & Cephalochordata
(iv) Amphibia & Reptilia
(v) Agnatha & Gnathostomata
(vi) Plathyelminthes & Nemathelminthes

(vii) Chondrichthyes & Osteichthyes.

(viii) Acraniata & Craniata

(ix) Chordata & Non-chordata

(x) Annelida & Arthropoda

(xi) Gemmule & Spicule

(xii) Radial & Bilateral symmetry

(xiii) Lizard & Snake

(xiv) Protostomia & Deuterostomia

(xv) Protostomia & Deuterostomia

(xvi) Eucoelomata & Pseudocoelomata

(xvii) Enterocoelic & Shcizocoelic coelom,

(xviii) Cartilagineous fish & Bony fish

(xix) Round worm & Flat worm.

(xx) Oviparity & Viviparity

(xxi) Marsupiale & Placentale.

UNIT-II: STRUCTURAL ORGANIZATION IN PLANTS AND ANIMALS

PLANT MORPHOLOGY AND ANATOMY

CHAPTER 5

I. MORPHOLOGY

Angiosperms (Gr. *Angeion :* case; *spermos:* seeds) are a group of plants characterized by production of flowers and formation of seed(s) within a fruit. The plant body shows a great range in size and diversity in form. This led to the morphological and physiological differentiation between various parts of plant body and the plant organ concept. The plant body is the sporophyte which is made up of several fundamental parts or organs (Fig.5.1). The morphologists divide

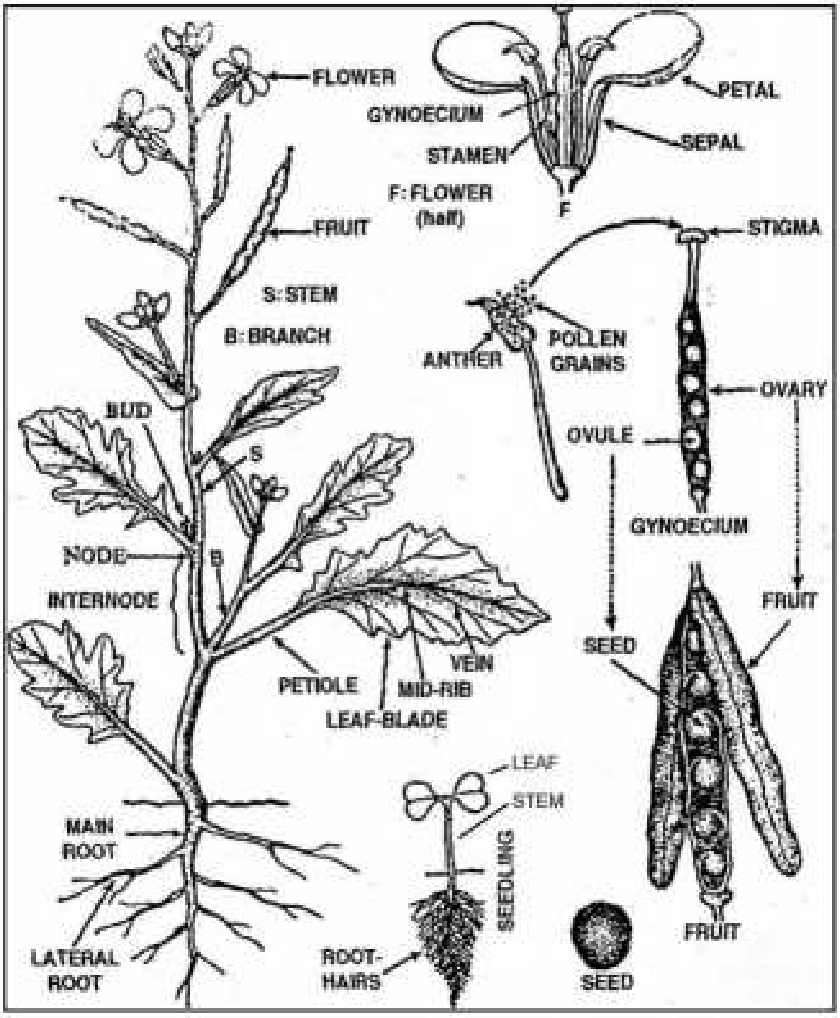


Fig.5.1 : Parts of an Angiospermic plant (Brassica caompestris)

the plant body into three basic organs - the root, stem and leaf. The main axis of the plant body consists of a root, normally developing under the ground, and a stem normally growing up. The root bears a number of lateral structures similar to it and forms the root system. The stem holds lateral appendages in the form of leaf and branch. The stem along with leaves and branches is called the shoot and forms the shoot system. The root system and the shoot system together constitute the vegetative body of the angiospermic pant. As the plant grows and reaches maturity, it forms flowers, fruits and seeds. These three constitute the reproductive system of the plant as the flower forms the fruit and seed after fertilization. The seed when germinates, gives rise to new plant and serves the function of multiplication of the plant.

5.1. THE ROOT:

The root is the underground or descending portion of the axis of the plant. The **radicle** of the embryo gives rise to the root. It is nongreen and devoid of nodes and internodes. Anatomically branch root arises from an inner layer, i.e., pericycle. So it is **endogenous** in origin. The root is positively geotropic, negatively phototropic and positively hydrotropic. The root developed from the radicle is called **primary root.** If primary root persists and gives rise to root system, it is called the **tap root system.** The lateral branches, those coming out from the primary root are known as **secondary roots.** The branch roots coming out from the secondary root are known as **tertiary roots.** The tap root branches in an acropetalous manner. Mainly tap roots are formed in dicotyledonous plants (Fig.5.2).

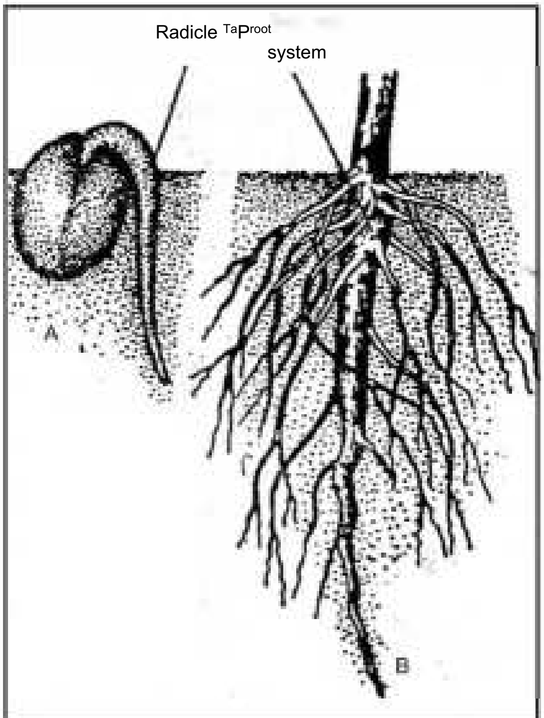


Fig.5.2 : Development of TAP-ROOT SYSTEM in dicots: (A) Germinating Dicot seeds with growing radicle; (B) Taproot system developed out of a radicle.

Most of the monocotyledonous plants show a differnt type of root system. In this case, although the radicle comes out first during germination as in dicotyledons and gives rise to primary root, this does not persist. A number of roots are developed from the base of such radicle (Fig.5.3), e.g., Rice. Such roots behave like primary roots and are known as **seminal roots.** Along with these, a tuft of fibre-like roots come out from the base of the plumule or lowermost node to form a distinct root system, known as **fibrous root system.**

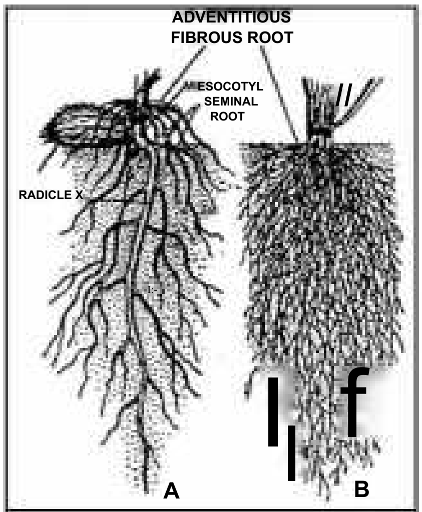


Fig.5.3 : Development of the ADVENTITIOUS FIBROUS ROOT SYSTEM in monocots. (A) Rice seedling showing radicle roots, seminal roots, adventitous fibrous roots on mesocotyl. (B) Ric plant with extensive fibrous root system.

A root can be differentiated into four organographic regions **root-cap region, region of elongation, root hair region and region of maturation** (Fig.5.4).

Characteristics of the root:

1. Root is the descending portion of the axis of the embryo and grows away from light, and positively geotrophic. It is nongreen in colour. Exceptional cases are seen in the aerial roots of *Tinospora, in which the root is green when exposed to light for a prolonged period. In some epiphytic orchids and submerged roots (e.g., Trapa).* the roots are green in colour.
2. It generally does not bear buds, however, the roots of *Aegie, Trichosanthes* bear buds for vegetative propagation.
3. At the terminal portion of the root there is a **root-cap** to provide a protective sheath to the tender root meristem. In *Pandanus,* the root-cap is distinct and multiple in nature. In aquatic plants **root pockets** are present.
4. The root bears unicellualr hairs, a little behind the apex (Fig.5.5a-d). These are having thin walls made of cellulose and are short-lived. When older root haris perish, newer ones are formed towards the apex.
5. Nodes and internodes are absent in the roots.
6. Lateral roots are developed from an inner layer, i.e. pericycle. So, these are endogenous in origin.

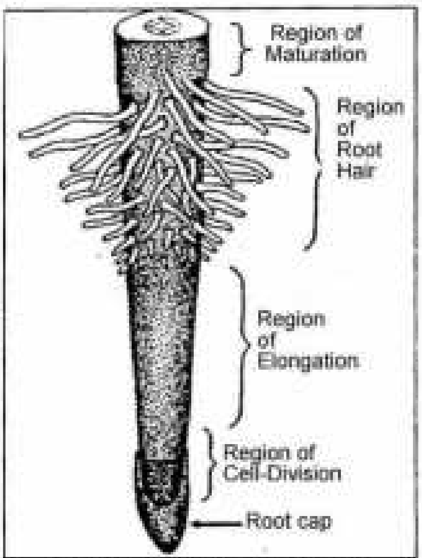


Fig.5.4 : Regions of the root

FUNCTIONS OF THE ROOT :

1. The tap root system bearing secondary, tertiary and other lateral roots ramify more and more in the soil and anchors the plant very firmly.
2. Root hairs absorb water and mineral salts from the soil and send it to the upper part of the plant.

5.1.2. KINDS OF ROOTS :

A. Tap root system :

A root system which develops from the radicle of the embryo is called **tap root system.** It serves the normal functions such as anchorage and absorption.

B. Adventitious root sysem :

The root developing from any portion of the plant other than the radicle of the embryo is known as adventitious root. It may develop from the base of the stem or from any node or internode of the branch, or even from the leaf. They serve the normal functions such as anchorage, absorption and conduction of solutes and water. Adventitious roots carrying on normal functions are of the following types.

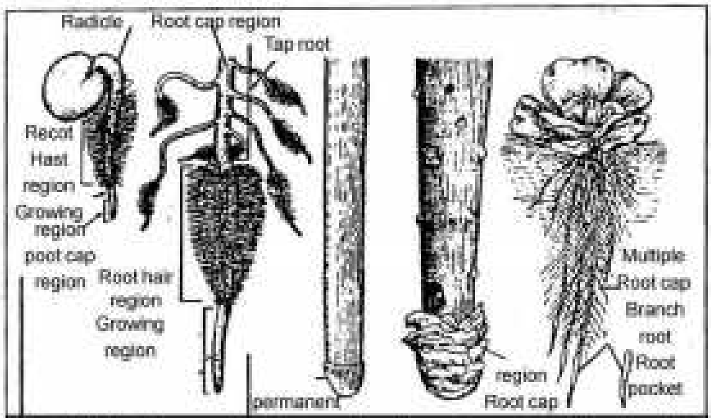


Fig.5.5.(A) : A germinating seed and a mature plant showing the four different regions of root : (B) Simple root cap of a hanging Ficus prop root; (C) Multiple root-cap of Pandanus; (D) Pistia stratiotes plant showing root-pockets

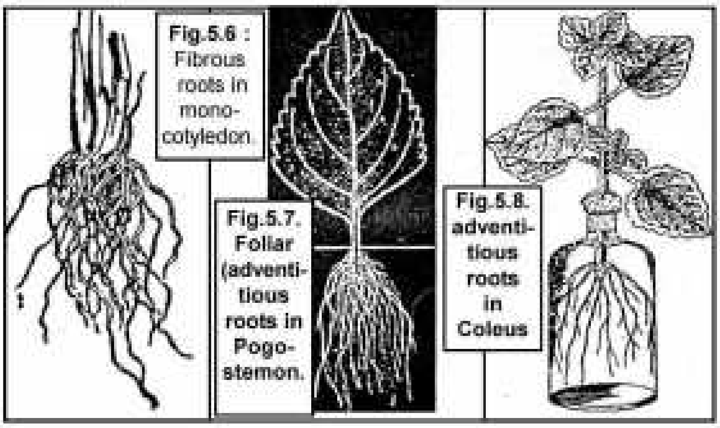


Fig.5.6 : Fibrous roots in mono-cotyledon

Fig.5.7. Foliar (adventi-tious roots in Pogo-stemon.

Fig.5.8. adventi-tious roots in Coleus

(i) Fibrous roots : (Fig.5.6)

Cluster of fibre like roots developed from the base of the plumule or from its lower nodes are known as **fibrous roots.** Such type of roots are seen in rice, maize, etc.

(ii) Foliar roots : (Fig.5.7) These roots develop directly from the leaf, from the petiole, or the vein. Ex. Petiole of rubber plant and leaf margin of *Bryophyllum* (Fig.5.10).

(iii) Adventitious roots : (Fig.5.8) These roots develop from the nodes and sometimes from the internodes of the stem, e.g,. *Oxalis* (Fig.5.9). Stem cuttings of rose, sugarcane, china rose, marigold, etc., give rise to such type of roots.

5.1.3. MODFICATION OF ROOTS :

Roots may be modified to different shapes in order to perform special functions besides there normal functions. Root modification is found both in tap root and adventitious root.

A. Tap root modification :

Tap root system is modified into different forms to carry out special functions such as storage of food. Such a root is known as modified tap root. It is differentiated into following types:

(i) Fusiform : (Fig.5.11) It is a modified tap root. The primary root is swollen in the middle while both the ends gradually taper forming a spindle shaped structure, e.g., Radish *(Raphanus sativus).*

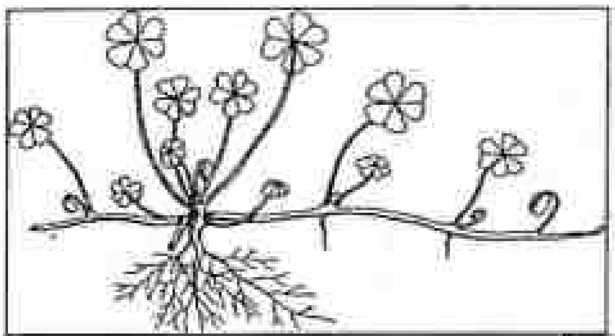


Fig.5.9 : Runner of wood-sorrel (Oxalis)

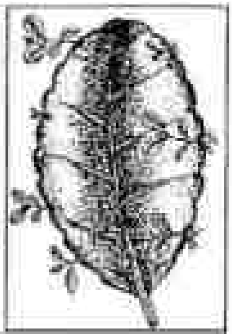


Fig.5.10 : Foliar buds and adventitious roots of sprout leaf plant (Bryophyllum)

(ii) Napiform : (Fig.5.12) The hypocotyl region is considerably swollen, becoming almost spherical and then abruptly tapering towards the lower end, e.g., Turnip *(Brassica campestris var. rapa)* and beet *(Beta vulgaris).*

(iii) Conical : (Fig.5.13) The roots swell, become broad at the base and gradually taper towards apex forming a cone like structure, e.g., Carrot *(Daucus carota).*

(iv) Tuberous or tubercular: (Fig. 5.15) In this case, the root is thick and fleshy but does not form any definite shape, e.g., *Mirabilis jalapa* (Fig.5.14).

(v) Pneumatophore: (Fig.5.15) These roots grow vertically up and come out of the water or marshy soil, like conical spikes. They occur in large numbers around the tree trunk. Such roots are provided with numerous pores (breathing pores) through which air is taken for respiration, e.g., *Rhizophora.*

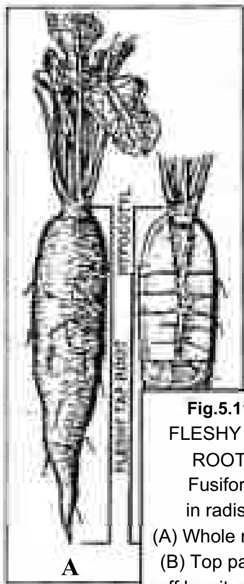


Fig.5.11 : FLESHY TAP ROOTS Fusiform in radish. (A) Whole radish; (B) Top part cut off longitudinally

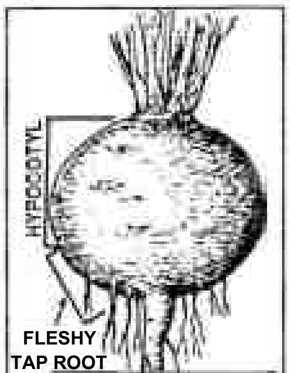


Fig.5.12 : FLESHY TAP ROOTS Napiform in turnip

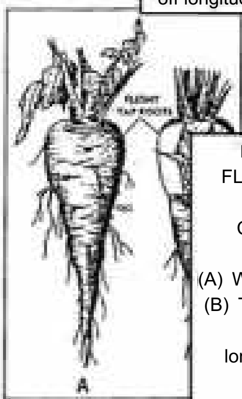


Fig.5.13 : FLESHY TAP ROOTS Conical in carrot (A) Whole carrot; (B) The top part cut off longitudinally showing parctically no

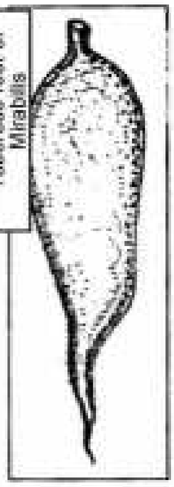


Fig.5.14 : Tuberous root of Mirabilis

B. Adventitious root modification :

Roots produced from any portion of the plant other than the radicle of embryo are called adventitious roots. It may be changed to different forms for special functions such as storage, mechanical support and vital functions.

(a) For storage of food :

(i) Tuberous root: In this case, adventitious roots grow from the nodes of the running stem. These roots swell and get modified to irrregular forms, known as tuber. These are produced singly, e.g., Sweet patato *(Ipomoea batatas)* (Fig. 5.16).

(ii) Fasciculated root:

In *Dahlia, Asparagus* the tuberous roots are developed from base of the stem in clusters (Fig.5.17).

(iii) Nodulose root:

The underground stem produces adventious roots. Some of the slender roots become suddenly swollen near the apex and formal nodule-like structures, e.g., Mango-ginger *(Curcuma amada)* (Fig.5.18).

(iv) Moniliform or Beaded root:

Swellings are found in the root at frequent intervals. It gives rise to a beaded or moniliform appearance, e.g., *Basella, Momordica, Vitis trifolia, Dioscorea alata* and many grasses (Fig.5.19).

(v) Annulated roots :

In this type, the root has a series of ring-like swellings appearing as if formed by number of discs placed one above another, e.g., *Cephalis ipecacuanha* (Fig.5.20).

(b) For mechanical support:

(i) Prop roots : The plant has a tap root system. The horizontal branches of the stem give rise to aerial roots that hang vertically downwards. On reaching the ground, these grow and act like pillars providing mechanical support to the plant, e.g., *Ficus benghalensis* (Fig.5.21).

(ii) Stilt roots : The plants like Screwpine have their own root system, but the anchorage is not very strong. Therefore, it develops adventitious roots from near the base of the stem which grow obliquely downwards, act like stilt and provide mechanical support *(e.g. Pandanus)* (Fig.5.22). The maize plant (Fig.5.23) also produces adventitious roots from the lower nodes which also act in a similar way.

(iii) Climbing roots :

These are found in some climbers. Aerial roots are developed from the nodes. These roots twine around and clasp the support and help in climbing, e.g., Betel *(Piper betel), Piper nigrum* and *Pothos,* etc. (Fig.5.24).

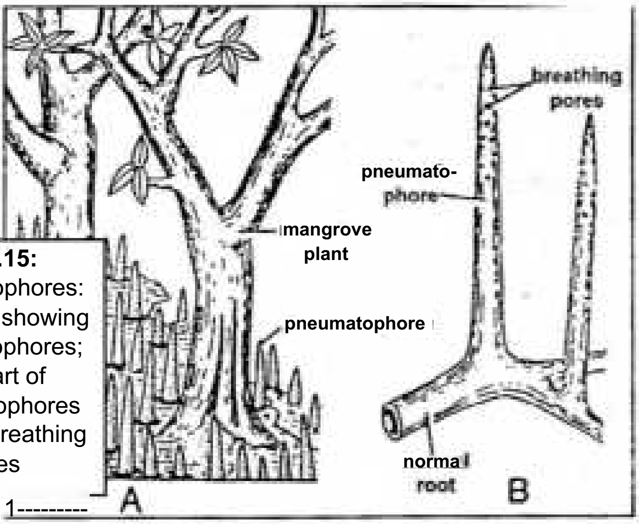


Fig.5.15: Pneumatophores: (A) Plants showing pneumatophores; (B) Part of pneumatophores showing breathing pores

Fig.5.16. Root tuber of sweet potato

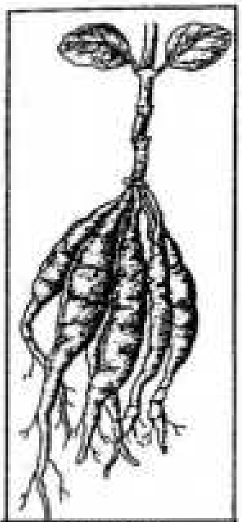


Fig.5.17. Fasciculated root of Dahlia

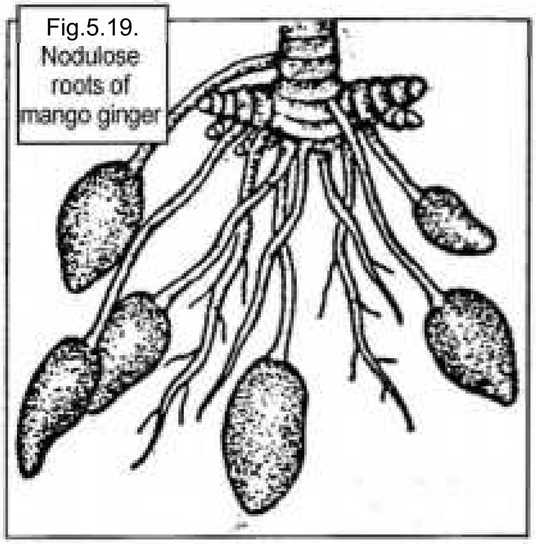


Fig.5.19. Nodulose roots of mango ginger

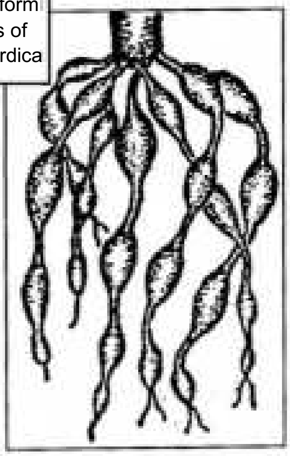


Fig.5.19. Moniliform roots of Momordica

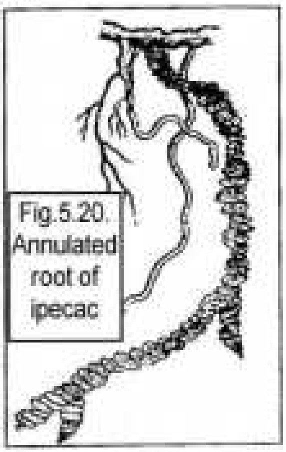


Fig.5.20. Annulated root of ipecac

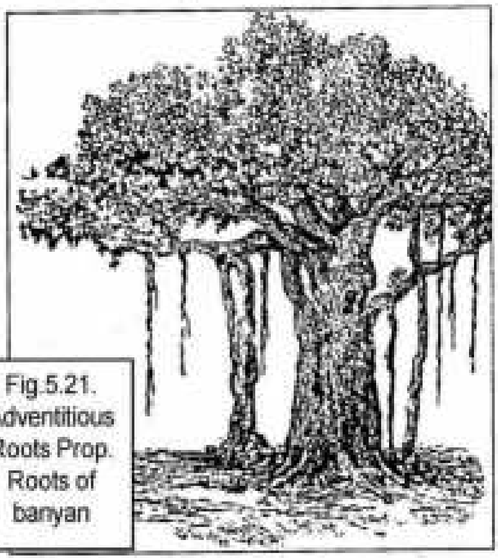


Fig.5.21. Adventitious Roots Prop. Roots of banyan

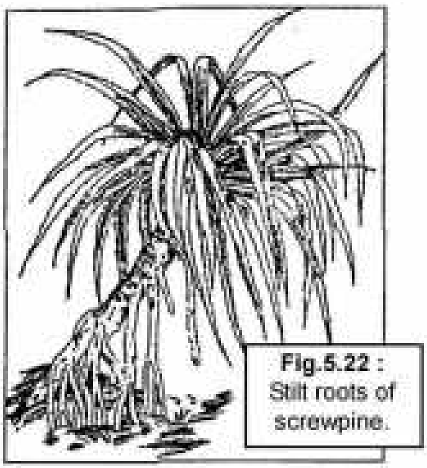


Fig.5.22 : Stilt roots of screwpine.

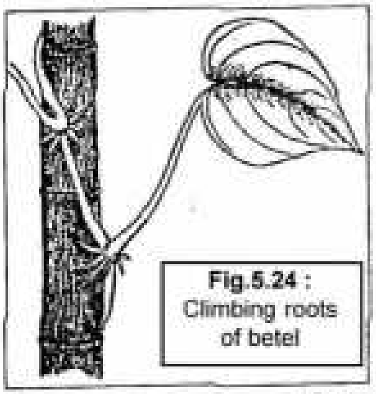


Fig.5.24 : Climbing roots of betel

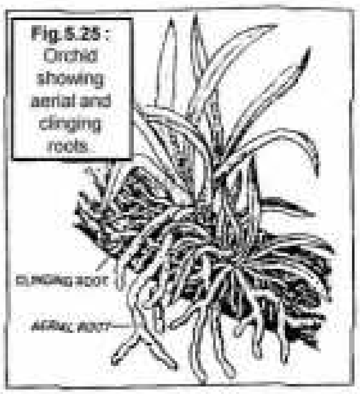


Fig.5.25 : Orchid showing aerial and clinging roots

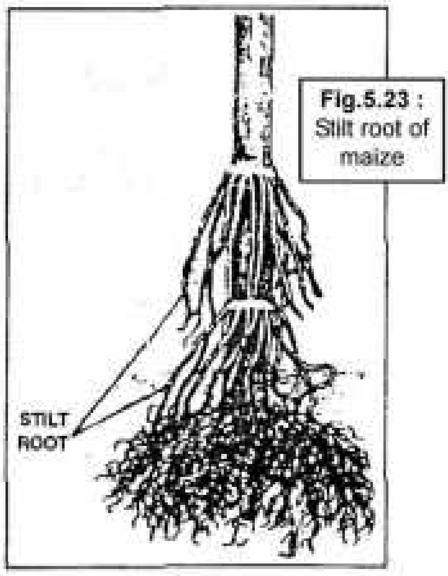


Fig.5.23 : Stilt root of maize

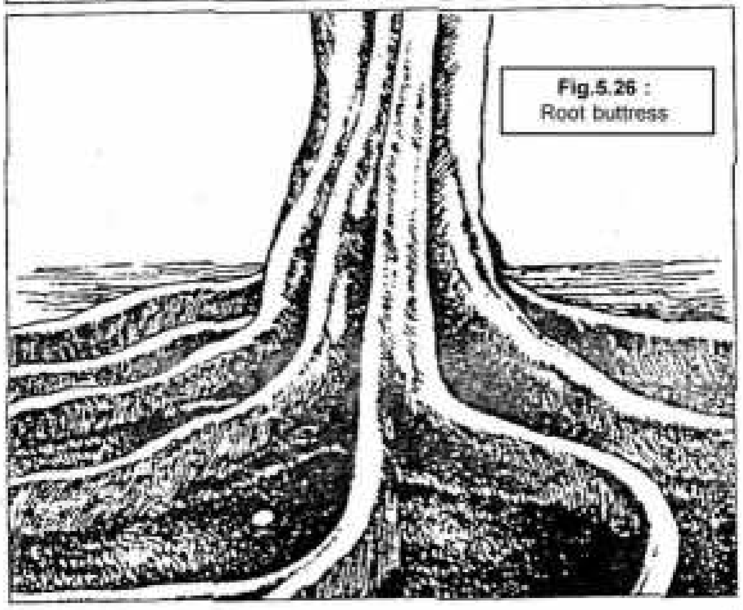


Fig.5.26 : Root buttress

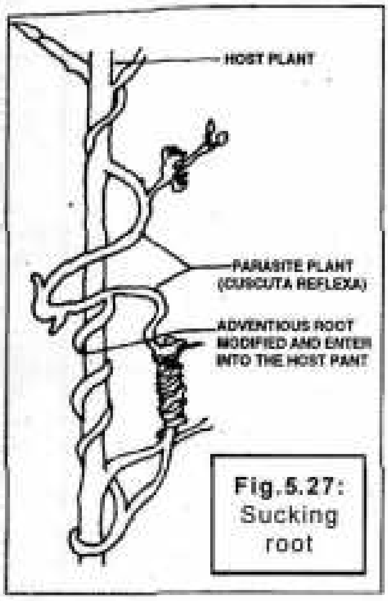


Fig.5.27: Sucking root

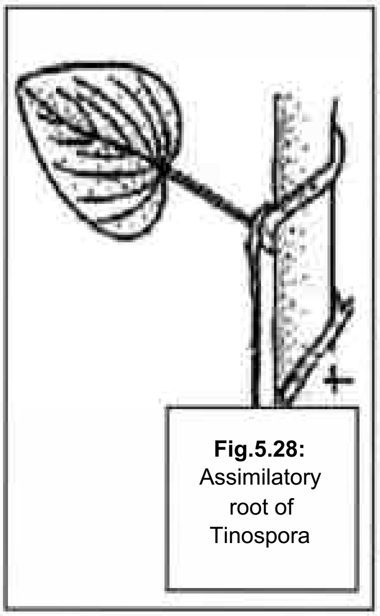


Fig.5.28: Assimilatory root of Tinospora

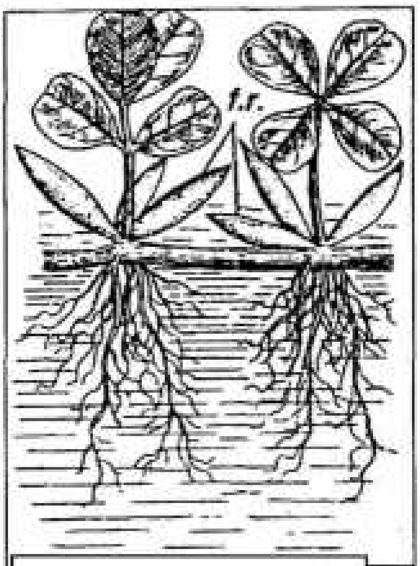


Fig.5.29 : Floating roots of Jussiaea repens

(iv) Clinging roots :

These roots are seen in orchids, which are developed from the stem base and enter the crevices of the support to fix the epiphyte (Fig.5.25). It provides mechanical support to the plant.

(v) Root buttersses : Large trees have great plank-like roots that radiate from the base of the stem. These consist of partly root and partly stem, e.g., *Bombax* (Fig.5.26).

(c) For vital functions :

(i) Sucking roots or haustoria :

Cuscuta, a leafless, nongreen and parasitic plant, always grows in association with other plants. At the point of attachment with the host plant it produces some knob like roots known as haustoria which penetrate into the host plant and draw nourishment (Fig.5.27).

(ii) Epiphytic roots :

Orchids are the plants which grow perched on branches of trees. They firmly attach themselves to the trunk of suitable trees by special roots known as climbing roots. The epiphytes also have aerial absorbing roots. They remain fleshy and grow along with the clinging roots. They have a spongy **velamen** tissue which absorbs atmospheric moisture. They also have chlorophyll and perform photosynthesis (Fig. 5.25).

(iii) Floating roots :

These roots are found in aquatic plants like *Jussiaea* (Fig.5.29). These are adventitious roots developing at the nodes of the floating branches. The roots are spongy and colourless. They remain above the water level. Being soft and spongy they store air which help the plant in floating. They also facilitate respiration.

(iv) Assimilatory roots :

Normally roots are non-green in colour. But the adventitious roots developed from the branches of *Tinospora cordifolia* being green in colour carry out photosynthesis and are called assimilatory roots. These roots are slender, long and in hanging state (Fig. 5.29).

5.2. THE STEM :

The stem is the ascending portion of the plant body developing from the **plumule** of the embryo during germination. The stem with the lateral appendages constitute the shoot system. The skeleton of the shoot is formed by the stem. It is the aerial part of the plant, positively phototropic, negetively geotropic and growing vertically up, while its branches grow horizontally. The young normal stem is generally green. The stem bears leaves and flowers.

FUNCTIONS OF THE STEM :

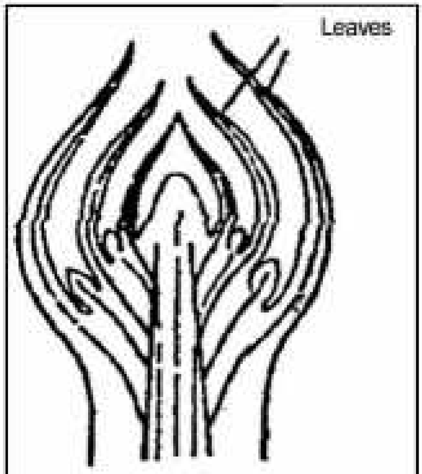


Fig.5.30 : Stem-apex

1. **Conduction :** The water and mineral salts which are absorbed by the root are conducted to the leaf by the stem. Similarly, it conducts prepared food matrial from the leaf to the growing regions and storage organs of the plant body.
2. **Support:** It provides requisite support to the plant. It supports the spread out branches and leaves.
3. **Food manufacture :** The green colouration of young stem is due to presence of cholorophyll which manufacture food material for the plant.

5.2.1. KINDS OF STEM :

There are different kinds of stems to perform diverse functions. They may be aerial or underground. Aerial stems may be erect, rigid or **strong** in order to allow the plant to stand in an upright position. The other category of stem is **weak.** The weak stem either trail on the ground or climb on neighbouring plants or objects.

A. Strong stems :

The strong stem may be of different types. It may be **caudex,** when it is unbranched, erect, cylindrical, stout and marked with scars of fallen leaves, e.g., palms (Fig.5.31). **Culm** type stem with **solid** nodes and **hollow** internodes is found in bamboo (Fig.5.32). Certain plants remain unbranched with a flowering shoot developing from the underground stem. Such plants possess a cluster of leaves only at the base and the remainder of the stem remains leafless. Such special aerial stems are called **scape.**

B. Weak stems :

Plants with weak stem require a support for growth or else they trail on the ground. It is of the following types.

1. **Trailing :** It grows on the surface of the ground without rooting at the nodes. It may be **procumbent** lying prostrate on the ground (e.g. *Basella, Evolvulus,* Fig.5.35) or **decumbent** when after growing on the surface of the ground for some distance, the growing apex rises up (e.g., *Trldax, Lindenbergia,* Fig.5.34). Trailing plants do not try to climb upon any support. A trailing plant is said to be **diffuse,** when the stem is much branched and the branches spread out on the ground in all directions *(e.g., Boerhaavia).*
2. **Creeping :** When the weak plants produce adventitious roots at their nodes and creep on the ground it is said be creeping stem. These do not to climb upon any support. These are said to be creepers, e.g., *Cynodon dactylon,* and *Centella asiatica* (Fig.5.36).

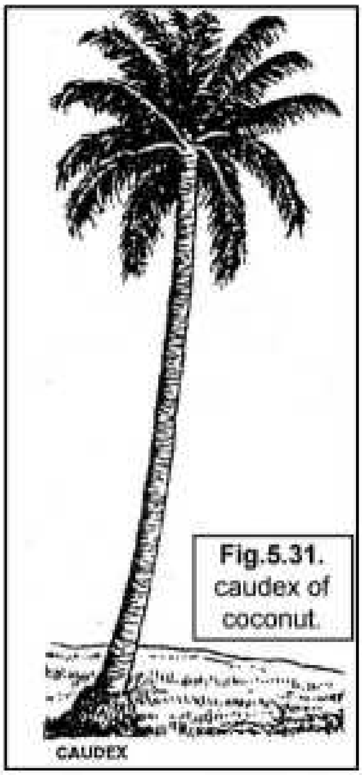


Fig.5.31. caudex of coconut.

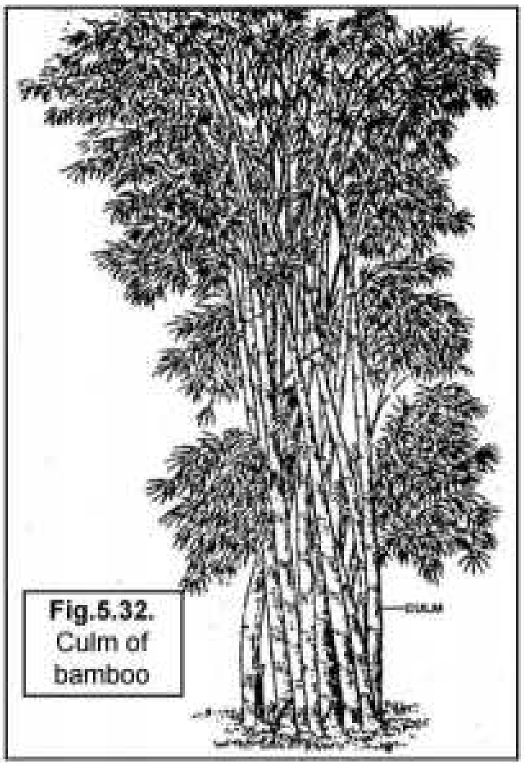


Fig.5.32. Culm of bamboo

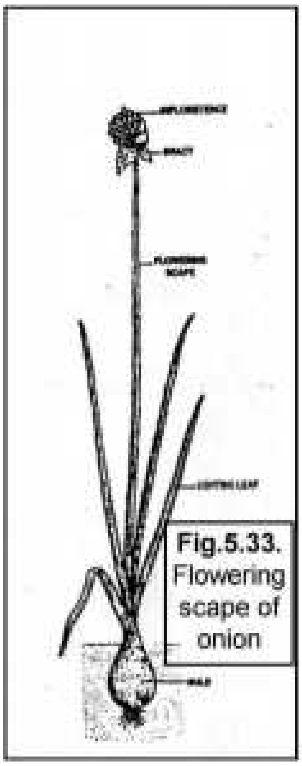


Fig.5.33. Flowering scape of onion

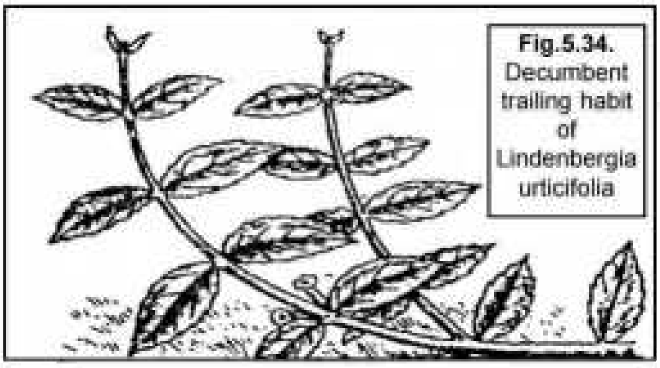


Fig.5.34. Decumbent trailing habit of Lindenbergia urticifolia

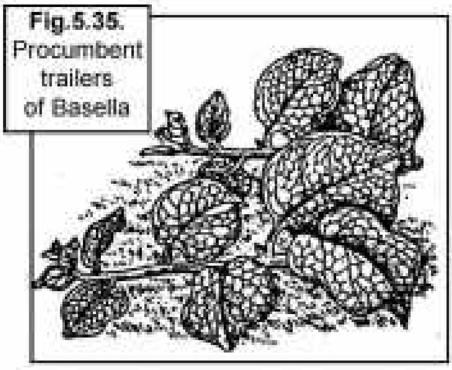


Fig.5.35. Procumbent trailers of Basella

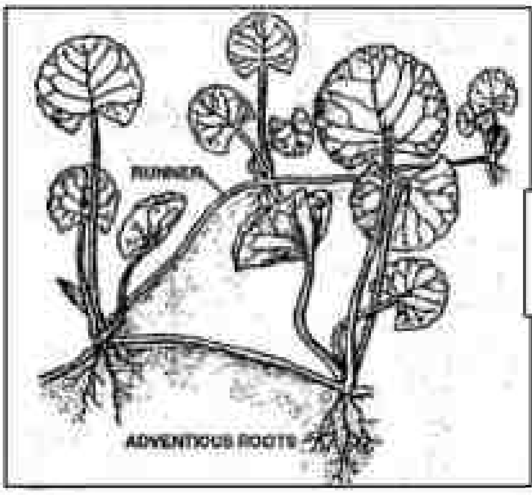


Fig.5.36. Centella asiatica creeping by means of runners.

3. **Climbing :** These are weak stems which grow on support. Usually, they grow up and expose their leaves to sunlight. There are different types of climbers such as : (i) twiners; (ii) tendril climbers (iii) root climbers (iv) ramblers (v) adhesive climbers and (vi) lianas.

   (i) Twiners : These are weak stems which twine round the support. The growing apex circle round the support and such a growth movement is called circumnutation. Normally the growing apex of the stem coils clockwise or anti clockwise around the support, *(dextrose* or *sinistrorse* respectively) as found in *Dioscorea* or *Clitoria.*

   (ii) Tendril Climbers : These make use of specialised climbing organs called tendrils which are soft, wiry and coil like-structures. Tendrils are sensitive and capable of growing spirally around the support when comes in contact with the latter. In many cases, it is the aerial part of the stem modified to form tendrils, e.g., *Cucurbita.*

   (iii) Root climbers : The weak stem can climb up by ad- ventitious roots produced at the nodes as in *Piper betel* which act as holdfast fastening the stem to the support.

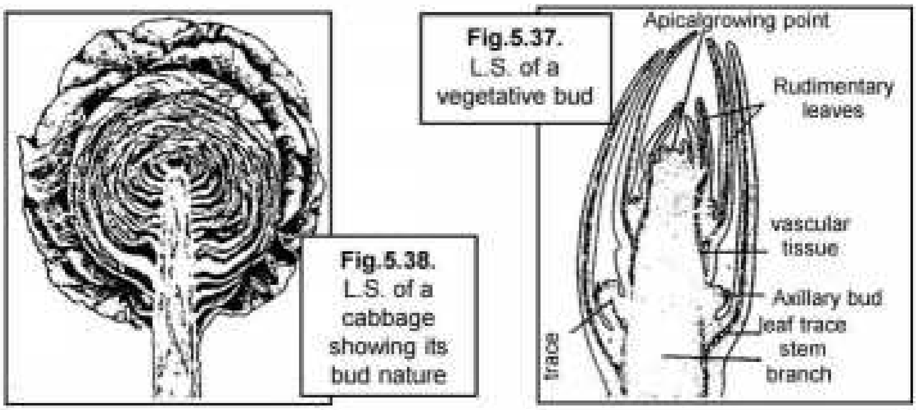


Fig.5.37. L.S. of a vegetative bud

Fig.5.38. L.S. of a cabbage showing its bud nature

   (iv) Ramblers or scramblers and hook climbers : Plants like rose, cane, *Artabotrys* and *Lantana* are having weak stems which do not actually climb, but grow over other bushes. They have superficial outgrowths such as thorns, prickles and curved hooks, etc. for climbing.

   (v) Adhesive climbers : In some *Ficus* species, adhesive discs grow from climbing roots to form carpet like growth covering steep walls. By means of these discs the weak stems adhere to flat walls and grow up.

   (vi) Lianas : These plants grow like ordinary twiners over tall trees. These are perennial woody climbers. Once they reach the topmost part of the supporting tree and their top leaves get sunlight, the weak stem becomes very strong, stout, and woody, e.g., *Tinospora,* species of *Bauhinia* and *Ficus,* etc.

5.2.2. THE BUD :

A bud is a compact and undeveloped young shoot in which the young rudimentary leaves with very short internodes are closely crowded. The plumule in the embryo is the first bud and the shoot system develops from it. The development of the leaves in a bud is in acropetal succession (Fig.5.37). Based on their position, there are different types of bud. Normally it occupies its position at the apex of the stem or branch which is said to be **terminal** or **apical** (Fig.5.37). When its position is in the axil of a leaf, it is known as **axillary.** The elongation of stem depends on the growth of terminal bud. When the axillary bud grows, it gives rise to branches.

The buds may be **vegetative** or **floral.** The former on development, form vegetative shoots and the latter, the flowers. If any extra buds develop by the side of the axillary bud, these

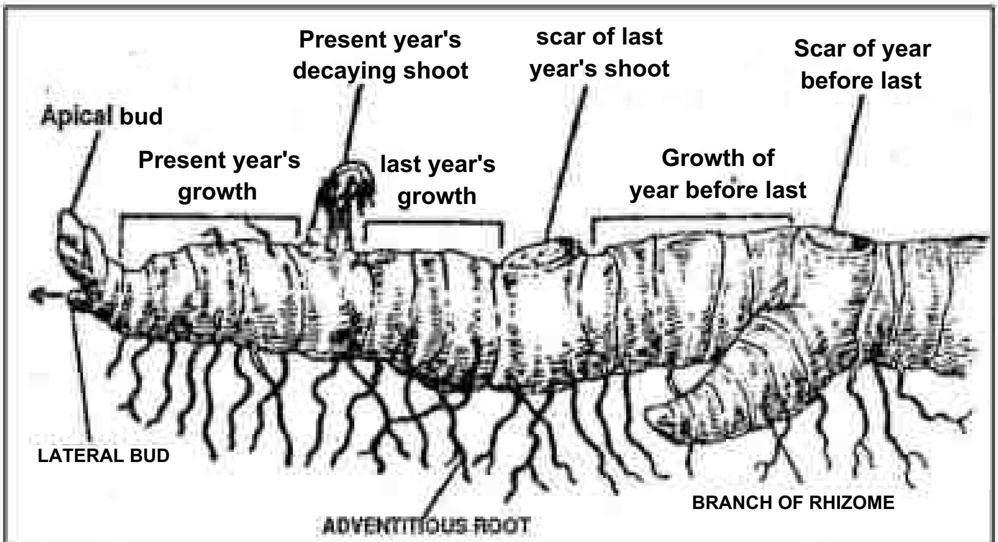


Fig.5.39 : Four-year-old rhizome of a wild plant. The apical bud will develop next year's shoot while growth will be continued by the lateral bud in the direction of the arrow. The stem is therefore, sympodial.

are known as **accessary buds.** Sometimes, **adventitious buds** are developed at various other parts of the plant such as the root **(radical buds),** e.g., sweet potato, or leaf **(foliar buds),** e.g., *Bryophyllum* or at different positions of the stem and the branches **(cauline buds).** The function of all these buds are to gradually develop into new branches, and in some plants into independent plants. Buds, which begin to grow and develop as soon as they emerge from the stem, are called **active buds.** In certain cases, they remain inactive for a period, and are called **dormant buds.**

A cabbage, cut longitudinally, gives a good idea about buds (Fig.5.38). Buds give rise to branches, leaves or flowers. Its protection in plants is provided by various means:

1. Overlapping of the young leaves on the delicate growing point of the bud protect the growing apex against sun and rain.
2. Buds are protected by covering of hairs or in some cases by resinous or gummy secretions.
3. They are protected by **bud scales** in some cases also, e.g., banyan, jack- fruit and *Magnolia,* etc.
4. There may be a coating of wax or cutin on the leaf-surface to check evaporation of water and to prevent it from getting dry.

5.2.3. MODIFICATIONS Of STEMS :

When stems change their form to perform functions other than the normal functions, it is said to be stem modifications. Certain stems or branches of the plant change their shapes or forms to carry on special functions such as perennation (to survive during unfavourable conditions), vegetative propagation, storage of food and specialised functions. There are different types of stem modifications based on their position with respect to soil.

(A) Underground modifications :

For the purpose of storage, perennation and vegetative propagation the stems remain under the ground. During unfavourable season, they remain dormant and when the conditions become favourable they give off new aerial shoots. Although nongreen and are present under the ground, they possess characteristics of stem. These are: presence of nodes and internodes, scale leaves and adventitious roots at the nodes, presence of buds at the axils of scale laves. The following are the different underground modifications of stems based on their shapes or forms:

1. Rhizome:

It is provided with nodes, internodes, scale leaves and buds. The stem part creeps horizotally under the ground and is prostrate and thick. It possesses brown scale leaves with itself being brownish often mistaken for root. Adventitious roots are developed on the lower surface of the node.

In turmeric *(Curcuma domestica- Fig.5.39)* and ginger *(Zingiber officinale- Fig.5.40)* it is fleshy and branched. The apical bud gives rise to new plants on favourable condition. But the rhizome of *Canna* is not fleshy. Here the internodes are long and rhizome grows horizontally by the apical bud.

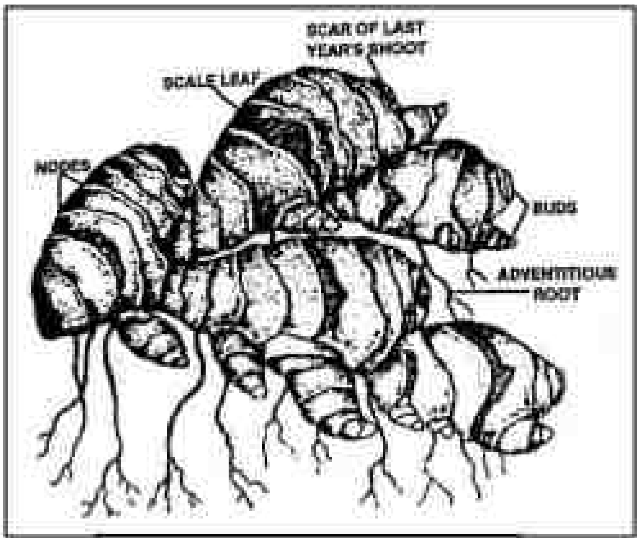


Fig.5.40. Rhizome of ginger

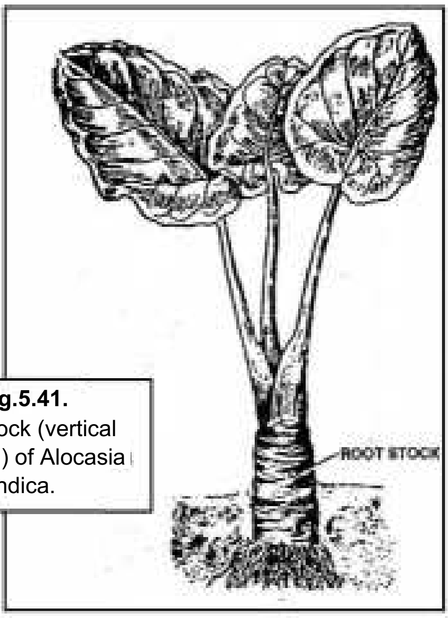


Fig.5.41.
Rootstock (vertical rhizome) of Alocasia indica.

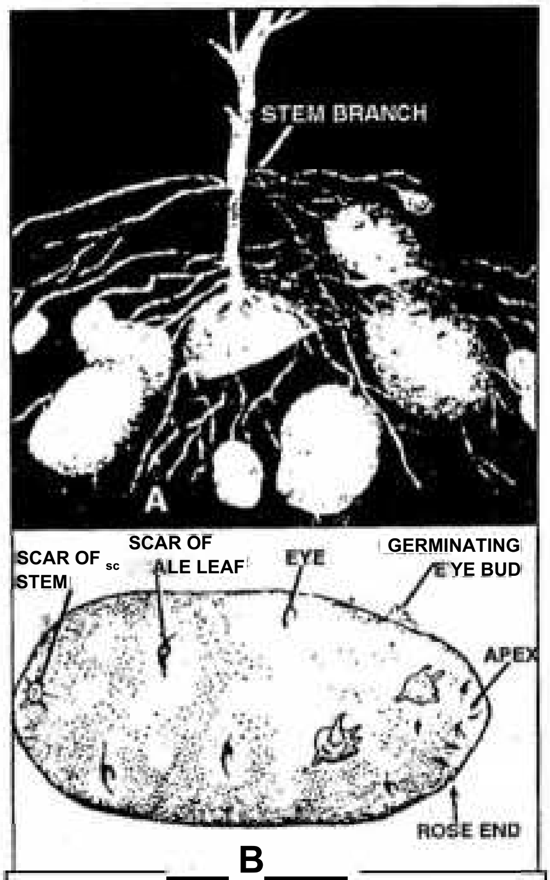
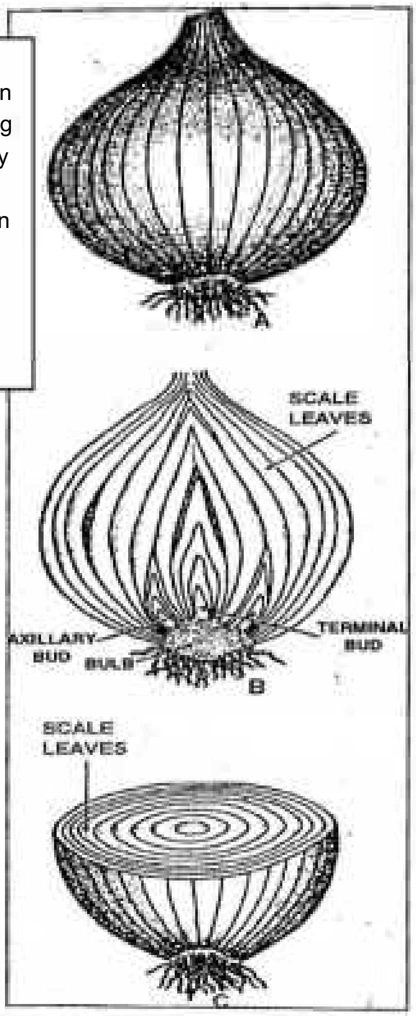


Fig.5.42.
Potato (A) Base of a potato plant showing the development of potato tubers from underground stem branches. (B) A single tuber. Some eyes towards the rose and have commenced development

Fig.5.43.
Bulb of onion, (A) an entire onion showing the lower part of dry scale-leaves with distinct veins, (B) an onion cut longitudinally; and (C) an onion cut transversely.



A special type of rhizome is seen where instead of growing horizontally, it grows vertically down. It is called **rootstock,** e.g., *Alocasia indica* (Fig.5.41).

2. Tuber:

The axil of lower leaf gives rise to underground branches. Its apices swell up into tubers which are without any definite shape, e.g., potato *(Solarium tuberosum)* (Fig.5.42). It is a modified stem due to presence of a number of 'eyes' or buds which can give rise to new plants. The tuber is protected by a corky skin. Adventitious roots are absent. Sometimes, it is very much swollen due to the heavy deposit of food material. Other examples of stem tuber are *Cyperus rotundus* and *Helianthus tuberosus.*

3. Bulb :

Bulb is the underground stem which is conical in shape and gives rise to adventitious roots towards the lower side. It produces fleshy scale leaves surrounding an apical bud. It produces the leafless stem, the scape, in favourable season. In this case, food is stored in the fleshy scale leaves. There are two types of bulbs based on the arrangement of fleshy scale leaves: **tunicated bulb** and **imbricate bulb.** The former possesses a number of concentric scale leaves as found in onion *(Allium cepa)* (Fig.5.43) and in the latter the scale leaves are not concentric but are arranged loosely overlapping one another only at the margins, e.g., garlic *(Allium sativum).* In garlic, the fleshy scale leaves remain separate.

4. Corm :

It is more or less rounded in shape, a condensed vertical stem with a large apical bud. It Is often somewhat flattened from top to bottom, e.g., *Amorphophallus campanulatus* (Fig.5.44). It has nodes, internodes and scale leaves with numerous buds and adventitious roots . It stores up the food material.

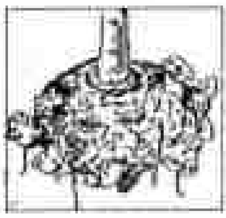


Fig.5.44.Corm of Amorphophallus

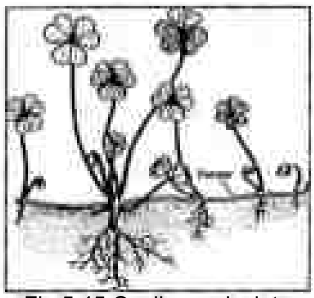


Fig.5.45.Oxalis corniculata propagating by runners.

(B) Sub-aerial modifications :

The sub-aerial stems are weak and unable to stand straight. They may be partially subterranean. The stem is usually modified for the purpose of vegetative propagation. The different types of sub-aerial modified stems are described as follows.

1. Runner:

It is a modified stem produced from axillary bud of the leaf. It is slender, prostrate branched with long internodes that creep on the ground. Adventitious roots develop at the nodes. The interode portion is said to be the runner. Due to the formation of many such runners on all sides the plant spreads out on the ground in all directions. Runners are meant for vegetative propagation, e.g., *Oxalis* (Fig.5.45), *Marsilea,* Dog grass *(Cynodon dactylon)* and *Centella asiatica,* etc.

A special kind of underground runner is known as sobole. It is thin and does not store food material, for which it is not included under rhizome, e.g., creeping grassy weed *(Agropyron)* which grows under the ground in all directions giving rise to numerous runners (Fig.5.46).

Fig.5.46.Sobole of *Agropyron*

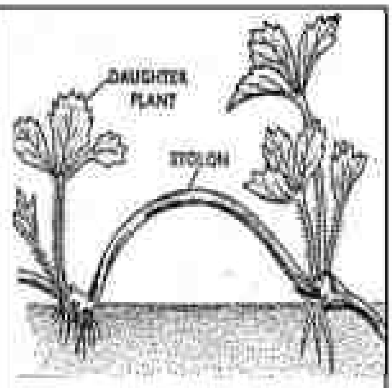


Fig.5.47. Stolon of *Mentha*

2. Stolon :

It is a branch developed at the base of the stem under the soil which at first grows upwards and then arches down to meet the soil. A common example is *Mentha* sp. (Fig.5.47).

3. Offset:

This type of modification is found in aquatic plants like *Pistia* and *Eichhornia* etc. Just like a runner it develops from the leaf axil that grows horizontally up to some extent. It bears a tuft of leaves towards the upper side and adventitious roots towards the lower side. An offset is short, soft, prostrate branch with leaves above and a clusters of roots below. It often breaks away from the mother plant and grows independently again producing offset at the leaf-axil (Fig.5.48 & 49).

4. Sucker:

Like the stolen, it is produced from the underground part of the stem. The lateral branch grows obliquely upwards bearing adventitious roots. It produces leafy shoots when it reaches the soil surface. A sucker is much shorter than a stolon. It strikes roots at the base either before it separates from the mother plant or soon after. A common example is *Chrysanthemum* (Fig.5.50).

C. Aerial modifications :

The above ground part of the stem is known as aerial part. Such aerial stems are modified to carry out certain functions. At times, it is metamorphosed due to extreme modifications. There are various kinds of aerial stem modifications.

1. Stem-tendril:

Tendril is a thin, wiry, leafless, spirally-coiled structure. It occupies the position of a leaf axil or that of a floral bud. It helps in climbing. It is seen in *Vitis,* passion flower *(Passiflara).* In passion flower, it is the axillary branch that is modified into tendrils (Fig.5.51). In balloon vine

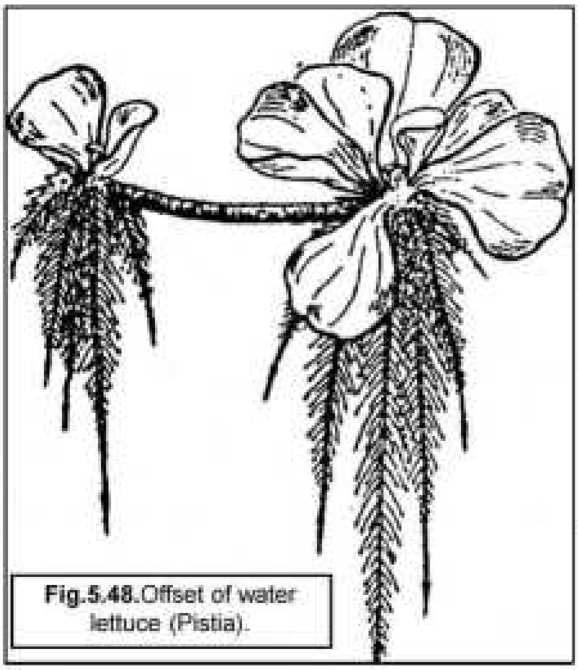


Fig.5.48. Offset of water lettuce (Pistia).

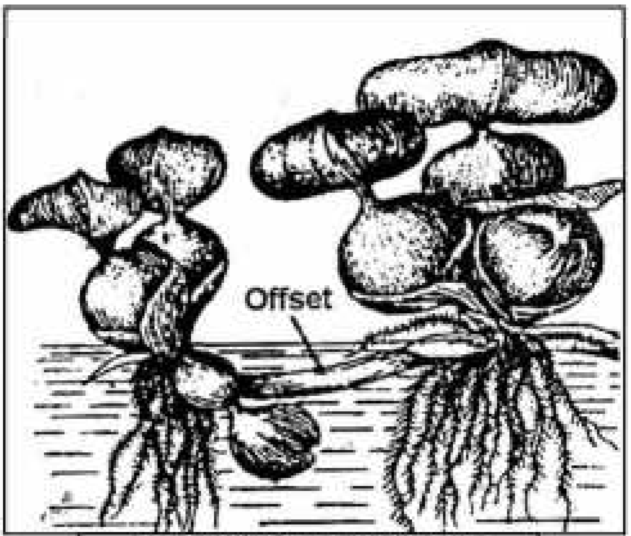


Fig.5.49. Offset of water hyacinth

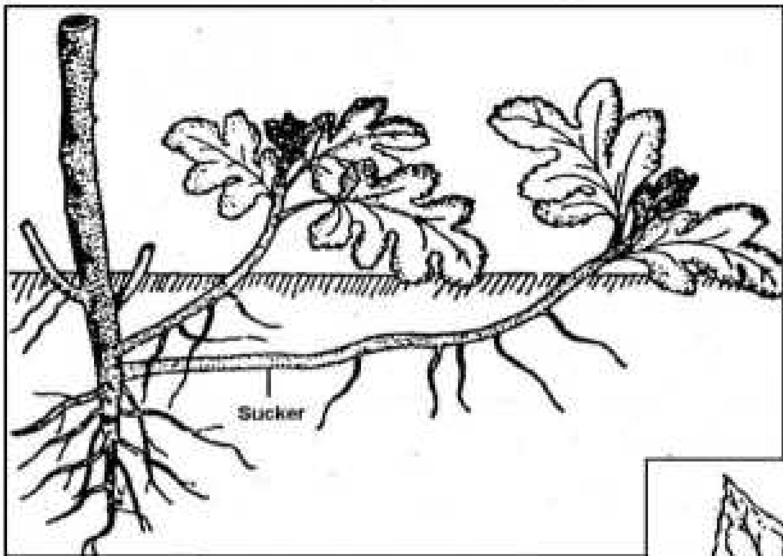


Fig.5.50. Suckers of Chrysanthemum.

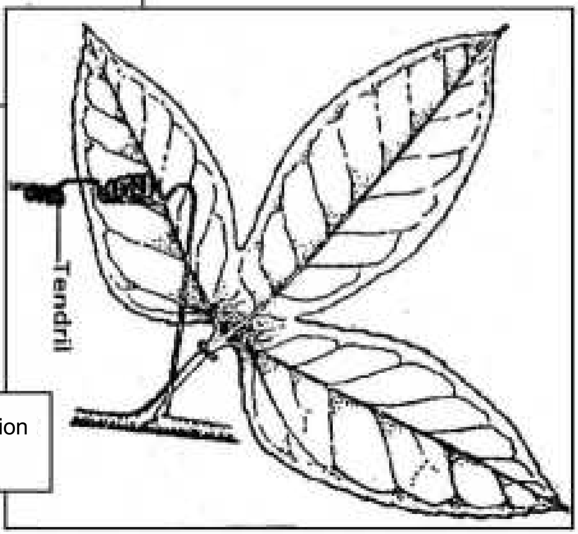


Fig.5.51. Tendril of passion flower (Passiflora)

(Cardiospermum), floral buds are modified to tendril. (Fig. 5.52). In *Antigonon,* it is the floral buds that give rise to tendrils (Fig.5.53). In *Gouania,* the branches end in strong tendrils to provide support to the plant (Fig.5.54).

2. Thorn :

Thorn is a hard, thick, often straight, deep seated and pointed structure. It is a metamophosed stem because it occupies the position of bud. Mostly it arises at the leaf axil. In *Duranta* (Fig.5.55), it is the axillary bud which is modified into thorn. Sometimes thorn also bears small leaves. It is meant to provide protection to the plant. In *Carissa* (Fig.5.56), the terminal bud is modified into a pair of thorns. These are distinguished from spines and prickles being deep seated. In *Flacourtia* (Fig. 5.57) the thorn becomes branched.

3. Phylloclade:

It is a green, flattened or rounded stem provided with nodes, buds and spines. In *Opuntia* (Fig.5.58), the leaves are modified into spines. Being green in structure, it performs the functions of leaves. In *Casuarina* it is green and cylindrical and the leaves are reduced to scale leaves. It is the characteristics of xerophytic plants to check the water loss. The leaves which are mainly responsible for transpiration are either absent or modified. Stem becomes swollen or fattened and green so that it can carry out photosynthetic function of the leaves. They may contain much mucilage for retaining water. Other examples of phylloclades are *Cocoloba* (Fig.5.59) and *Epiphyllum* (Fig. 5.60).

Cladode is a type of phylloclade found in *Asparagus* (Fig.5.61). It consists of one internode only. The ultimate branchlets are of one internode only. These are cylindrical (not fleshy) and are often mistaken for leaves. They are cladodes while leaves are modified or reduced into prickles. These are characteristic adaptations for desert plants.

4. Bulbil :

It develops at the leaf axil due to modification of vegetative bud or floral bud. It is a roundish multicellular structure meant for vegetative propagation. It sheds from the mother plant and grows up into a new independent plant, e.g., *Dioscorea* (Fig.5.62). In *Globba agave* and Onions, bulbils are seen to occur on the inflorescence (Fig.5.63) being modifications of some flowers.

5.2.4. BRANCHING :

An angiospermic plant is differentiated into root, stem, branch, leaf, flower and fruit. The mode of arrangement of branches on the stem is known as **branching.** Branching are of two types: **lateral** and **dichotomous.** These are developed from the axillary or lateral buds. The large branches are called **boughs** while the small ones are known as **twigs.** Branching brings about the shape of the plant. In **caudex** form (Fig.5.31), the stem is unbranched bearing a crown of leaves at the top as seen in palm and coconut. A plant is said to be **excurrent** (Fig. 5.64) where the apical

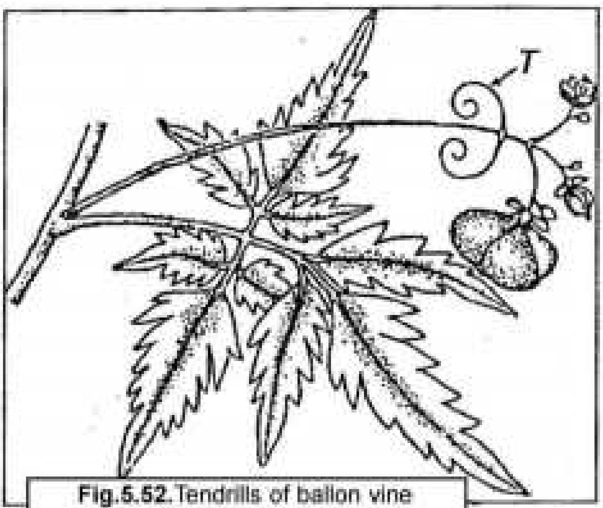


Fig.5.52. Tendrills of ballon vine (Cardiospermum)

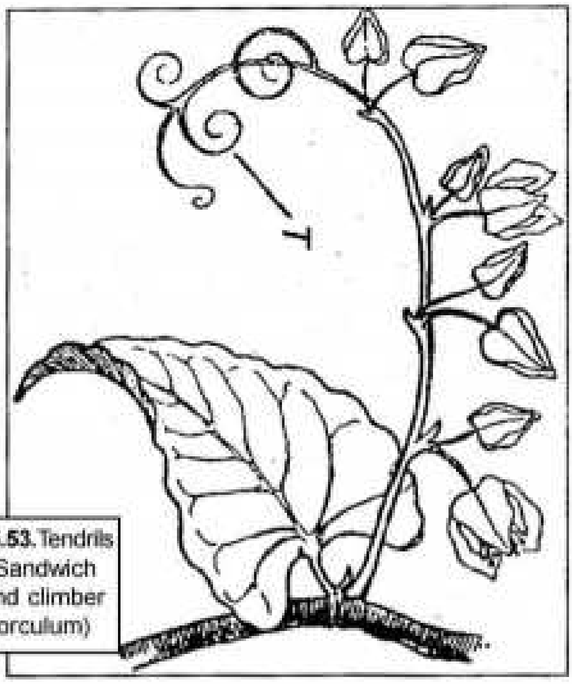


Fig.5.53. Tendrils of Sandwich island climber (Corculum)

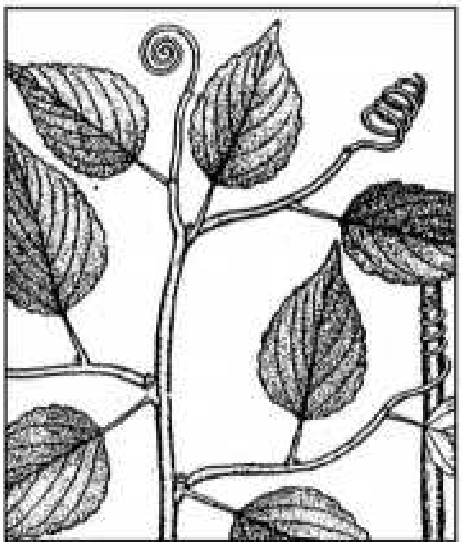


Fig.5.54. Tendrils of Gouania

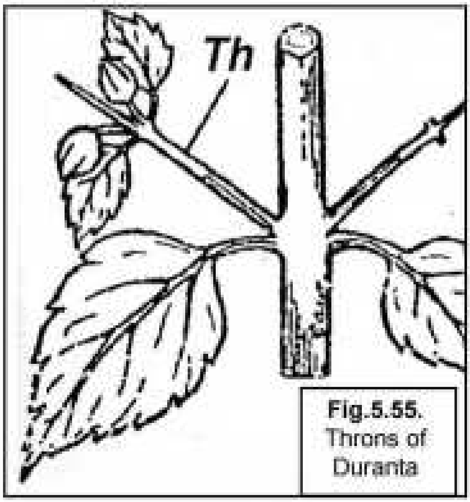


Fig.5.55. Throns of Duranta

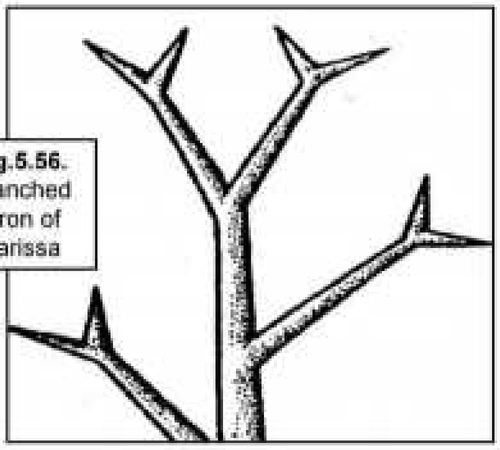


Fig.5.56. Branched thron of Carissa

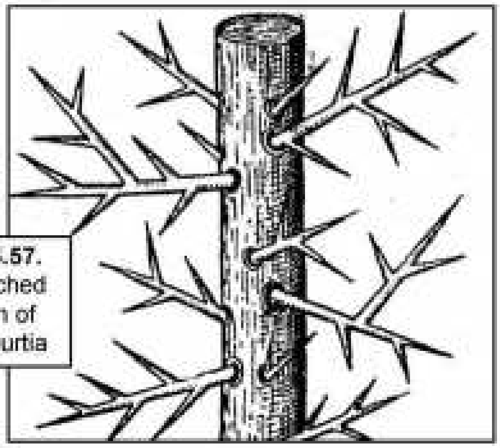


Fig.5.57. Branched thron of Flacourtia

bud grows indefinitely producing branching strictly in acropetalous order as seen in *Polyalthia longifolia.* In **deliquescent** type (Fig. 5.65), the growth of apical bud is suppressed while the lateral buds develop more vigorously, giving a spreading habit to the plant as seen in banyan.

A. Lateral branching :

It is also called axillary branching because it is developed from the axis. It may be racemose (monopodial or indefinite) or cymose (definite).

1. Racemose or monopodial branching :

In this case, the growth of the apical bud is indefinite giving rise to a straight stem. The lateral buds grow on the lateral sides of the straight stem in an acropetal succession. The lowest branch is the oldest and longest. Gradually, it bears shorter branches towards the upper side assuming a pyramidal form or conical shape, e.g., *Polyalthia longifolia* (Fig.5.64), *Casuarina,* etc.

2. Cymose branching :

The growth of the apical bud is checked while the side branches develop and grow forming a spreading habit. When the growth of the apical bud of the plant is checked, the lateral branches grow vigorously and the plant becomes dome shaped. This gives a deliquescent form (Fig.5.67), e.g., Mango or Jackfruit, etc. Based on the number of lateral strong branches produced, there are different types of cymose branching:

(i) Uniparous cyme :

Only one lateral branch is produced. So it is called uniparous or **monochasial cyme.** The uniparous type of branching is a succussion of daughter axes fused together. Therefore, it is otherwise called **sympodial branching.** When successive branches produced on the same side forming a helix, it is called **helicoid cyme** (Fig.5.67) as in *Saraca,* but if these branchings are alternate then it is said to be scorpioid cyme (Fig.5.68) as in *Vitis.*

(ii) Biparous cyme :

Here, two lateral branches develop at a time from the axils of two opposite leaves at each node. This gives rise to a symmetrical shoot, said to be dichasium, e.g., *Ervatamia.* Sometimes, the terminal bud remains undeveloped and the branching looks like a dichotomy. In this case, since there are two opposite leaves at each node, it possesses two opposite axillary buds. Therefore, two symmetrical shoots are developed, e.g., *Mirabilisjalapa, Ervatamia divaricata,* etc. (Fig.5.69).

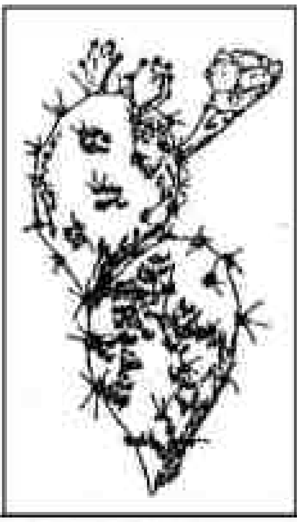


Fig.5.58. Phylloclade of prickly pear (Opuntia)

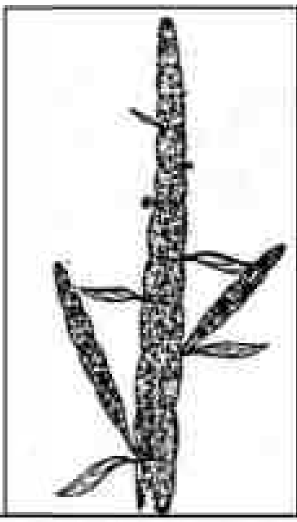


Fig.5.59. Phylloclade of Cocoloba.

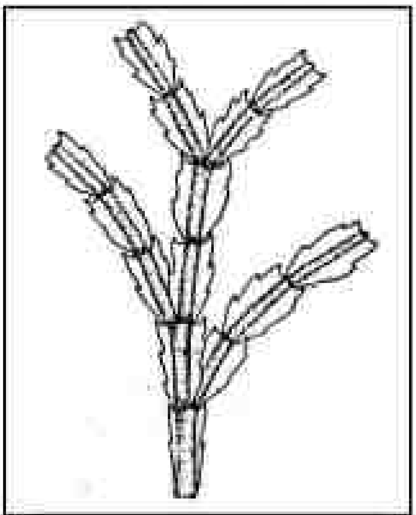


Fig.5.60. Phylloclade of Epiphyllum.

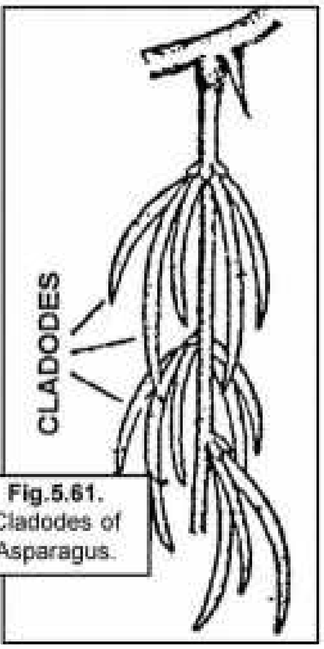


Fig.5.61. Cladodes of Asparagus.

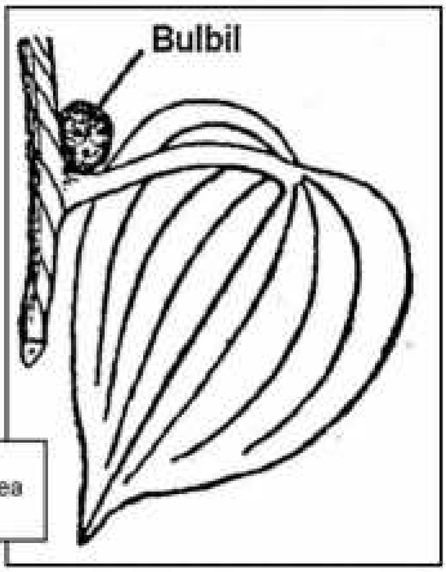


Fig.5.62. Bulbil of Diascorea bulbifera

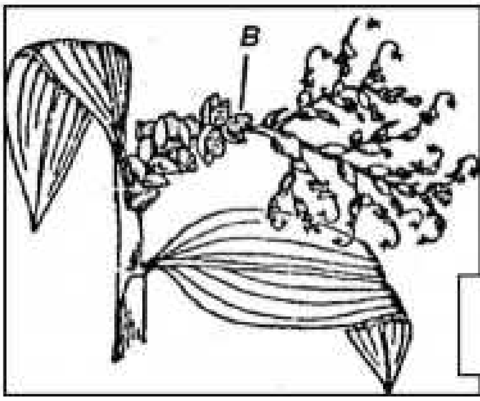


Fig.5.63. Bulbil of Globba agave.

Fig.5.64 (left) : Excurrent habit of *Polyalthia* showing acropetalous branching;
Fig.5.65 (right) : Deliquescent habit of *Ficus* showing branching.

(c) Multiparous cyme :

The plants with more than two leaves at each node upon suppression of development of apical bud produce more than two branches at each node. Such a branching is called polychasial cyme, e.g., *Croton sparsiflorus.*

B. Dichotomous branching :

The terminal bud divides into two, producing two branches in a forked manner. It is common among the nonflowering plants. It may be a **normal or true dichotomy** (Fig.5.70) when two forked branches formed again continue to show similar branching again and again. In some plants, after the bifurcation is made one half grows normally while the other half is suppressed. Successive suppression may be on the same side or on alternate sides. It is said to be **sympodial**

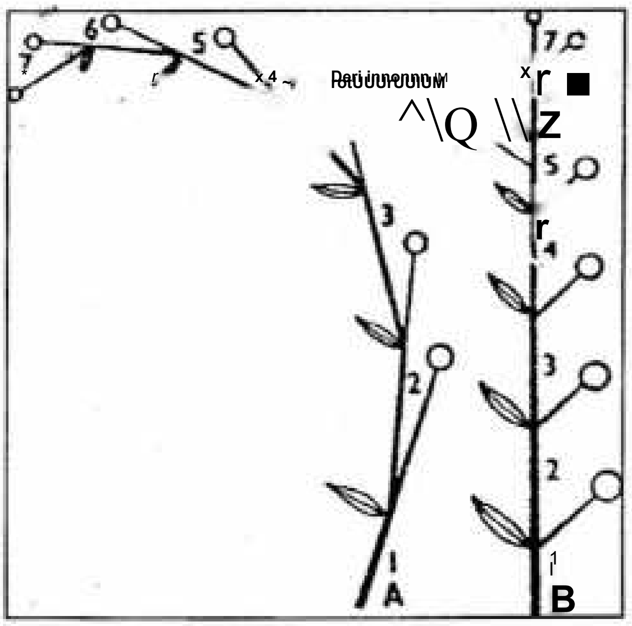


Fig.5.67. Helicoid development of successive branches marked 1,2, 3,4,.... (B) Pseudopodium after straightening up-

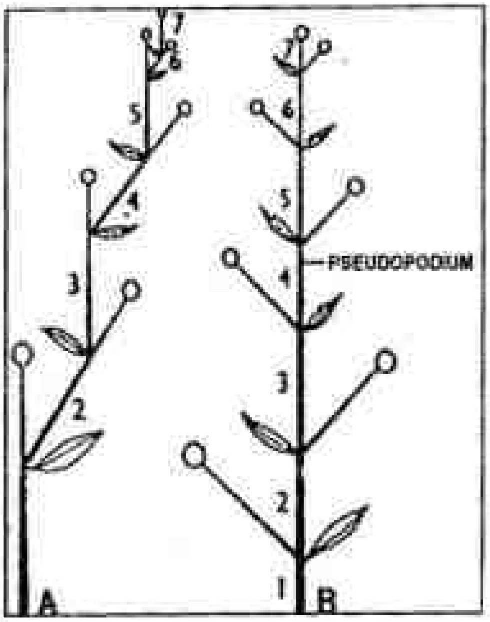


Fig.5.68.Scorpioid cyme. (A) Showing scorpioid development of successive branches marked 1,2,3,4... (B) The pseudopodium after straighting up.

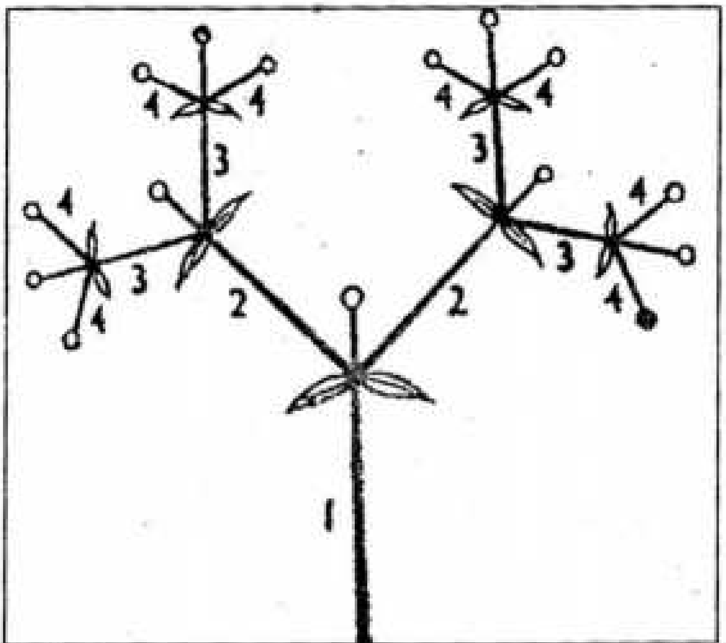


Fig.5.69. Plan to illustrate dichasium. 1,2,3,4,... etc. are the successive branches.

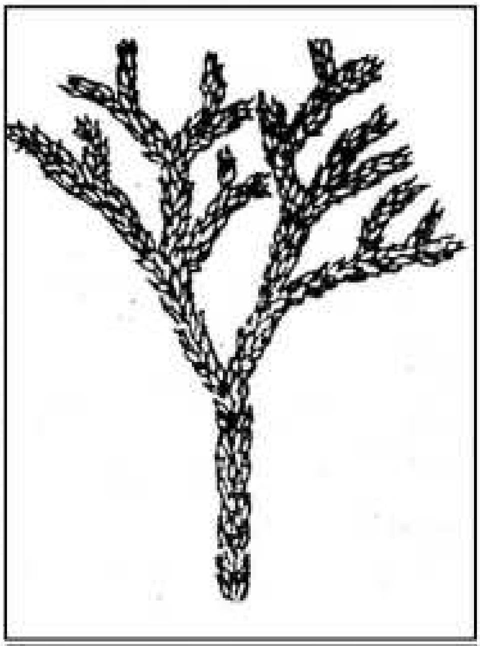


Fig.5.70.A part of the stem of Lycopodium (Pteridophyte) showing true dichotomy.

dichotomy. If the branches on one side only are suppressed, it is called **helicoid dichotomy** and the plants appear coiled (Fig.5.71). If the alternate branches to the left and right are suppressed, it is called **scorpioid dichotomy** (Fig. 5.72).

5.3. THE LEAF:

The leaf is the flattened, lateral outgrowth of the stem or the branch. It develops at the node and possesses a bud at its axil. It is green in colour and a vegetative organ of the plant. It manufactures food material and always develops in an acropetal order on the stem. These are exogenous in origin developing from the swollen growing apex called the **leaf primordia.**

5.3.1. KINDS OF LEAF :

On the basis of origin and function, leaves are of following types.

A. Cotyledonary leaves :

Two cotyledons occur in dicots whereas monocots have one cotyledon. The first leaves on the shoot are represented by the cotyledons. Usually, they contain reserve foods. The cotyledonary leaves are fleshy and non-green, e.g., beans and gram. In monocotyledons, the scutellum represents the cotyledon and its function is the suction of food material from the endosperm. Cotyledonary leaves are thin and flat in *Ricinus* (Fig.5.73).

B. Scale leaves or cataphylls :

Scale leaves are modified leaves. They are usually brown or grey coloured membranous structures that remain either dry, papery or fleshy. Mostly these are found in the underground stems. Scale leaves are also found in the aerial parts of the stem as in *Casuarina, Asparagus* (Fig.5.74).

C. Bract leaves or hypsophylls :

In this case, the leaves are represented by bracts which contain flower or inflorescence in their axils. Special leaves which bear floral buds at their axils are called bract leaves. These are usually small and green but in some, these are large and bright coloured, e.g., *Bougainvillea* (Fig.5.75).

D. Prophylls :

The first few leaves of a branch often differ from the other leaves and are known as prophylls. Usually there is one prophyll in monocots and two in dicots. Single prophyll in *Citrus* and two prophylls in *Aegle* are represented by spines (Fig.5.76).

E. Floral leaves or sporophylls :

The sepals, petals, stamens and carpels of a flower are modified leaves. Of these, the stamens and the carpels are considered as sporophylls as they bear spores.

F. Foliage leaves :

Normal leaves which arise from node of aerial stem as lateral appendages are called the foliage leaves. These are usually green in colour. They perform vital functions such as photosynthesis and transpiration.

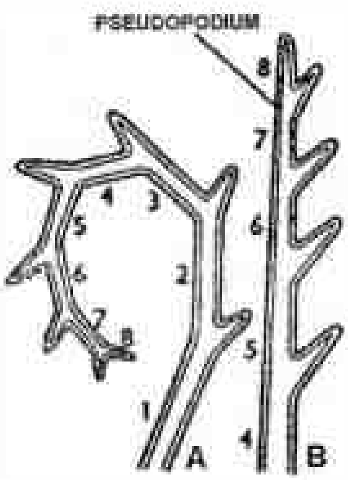


Fig.5.71 .Plan to illustrate helicoid dichotomy. (A) Helicoid development of successive branches marked 1,2,3,4,... (B) The pseudopodium after straightening up.

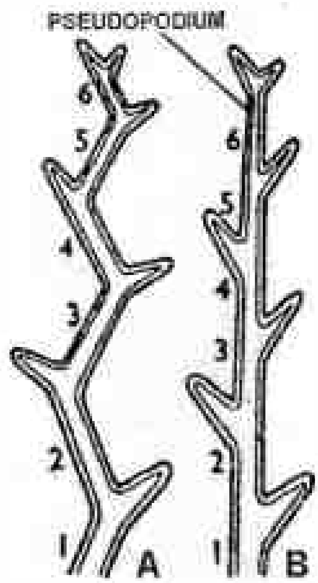


Fig.5.72. Plan to illustrate scorpioid dichotomy. (A) Scorpioid development of successive branches marked 1,2,3,4,... (B) The pseudopodium after straightening up.

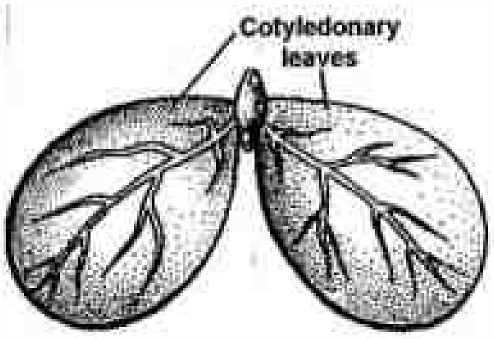


Fig.5.73. Kinds of leaves : Cotyledonary leaves of Ricinus

Fig.5.74. A growing shoot of Asparagus bearing cataphylls.

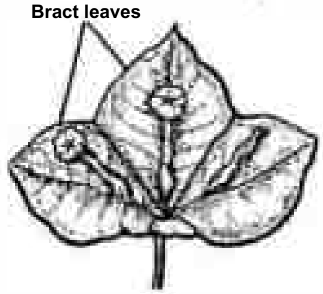


Fig.5.75.Bract leaves of Bougainvillea.

Fig.5.76. Spiny prophylls of *Citrus*

5.3.2. PARTS OF A LEAF :

Atypical leaf consists of three parts: Leaf base or **hypopodium,** petiole or **mesopodium** and leaf lamina or blade or **epipodium.** The entire leaf is said to be phyllopodium. (Fig.5.77)

A. The leaf base (Hypopodium):

The part of the leaf attached to the stem is known as leaf base. In many mononcot plants the leaf base expands into a sheath. When it partially clasps the stem it is called **semiamplexicaul** (e.g., banana, Fig.5.78). If it clasps the stem wholly, it is called **amplexicaul** (e.g., grasses, *Aethusa,* Fig.5.79). In plants like *Caesalpinia, Clitoria* and *Mangifera* (Fig.5.80), the leaf base is swollen and called **pulvinus.** In a few cases, where the leaf bases are winged, they extend down the stem up to the lower node. It is known as a **decurrent** leafbase, e.g., *Symphytum* (Fig.5.81).

B. The petiole (Mesopodium):

It is the stalk of the leaf starting from leaf-base up to the origin of lamina. Sometimes it may not develop at all. A leaf with a petiole is called **petiolate** and one devoid of it is **sessile.** The petiole is commonly a cylindrical structure more or less circular in cross section, or grooved having a longitudinal furrow. Different types of structural outgrowths and modifications are marked on the petiole.

In *Citrus,* it becomes winged and resembles the leaf lamina (Fig.5.82). In *Eichhornea,* it swells into a spongy bulb with numerous air chambers that help the plant to float (Fig.5.83). In *Clematis,* the petioles are tendrillar (Fig.5.84). In *Quisqualis,* the leaf blades sometimes fall off and the petiole becomes hard spines. In *Acaica moniliformis,* it is modified into a sickle-shape lamina, called **phyllode.**

In many monocot plants of the grass family, Gramineae (Poaceae), the sessile leaves develop some peculiar outgrowths at the junction of the sheathing leafbase and the lamina. It looks like a tongue-shaped membranous structure on the inner surface of base and is called the **ligule.** It is further strengthened by two outgrowthe from the two sides of the junction between the sheath and lamina, known as **auricles** (Fig.5.85).

C. The lamina or leaf blade (Epipodium):

The lamina - flattened structure is the most important part of the leaf. It manufactures food and it is the place where all the functions of leaf, like gaseous exchange, transpiration, photosynthesis, etc. are performed. Leaves vary widely, mainly due to different structural aspects of lamina. The structural aspects of lamina can be studied under the following headings:

(i) Shape :

It is the description of the form which is of various types as given below (Fig.5.86):

Acicular: needle-shaped as in pine;

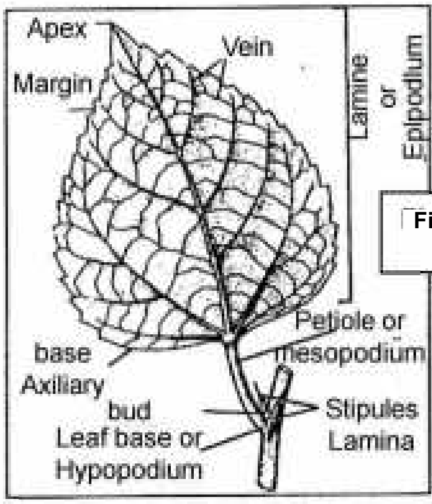


Fig.5.77.Parts of a typical leaf.

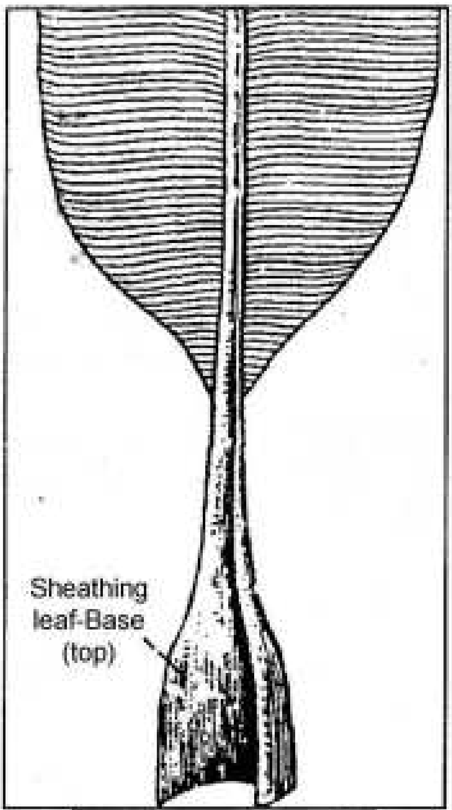


Fig.5.78.Sheathing leaf base of banana

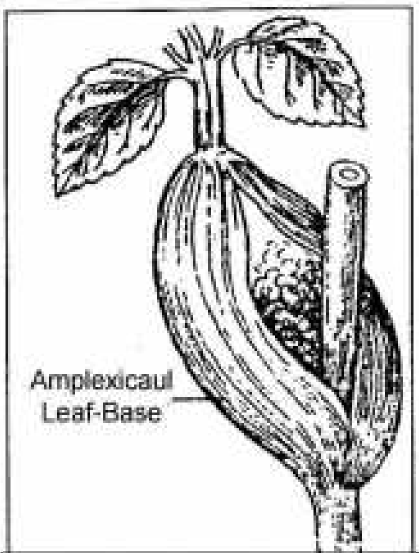


Fig.5.79.Amplexicaul sheathing leaf-base of Aethusa cynapium

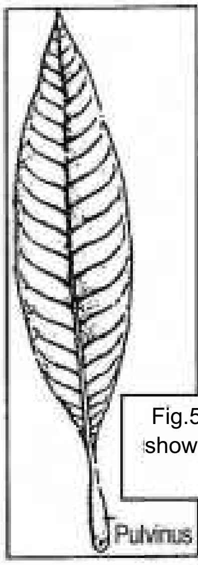


Fig.5.80.Mango leaf showing pulvinus leaf base.

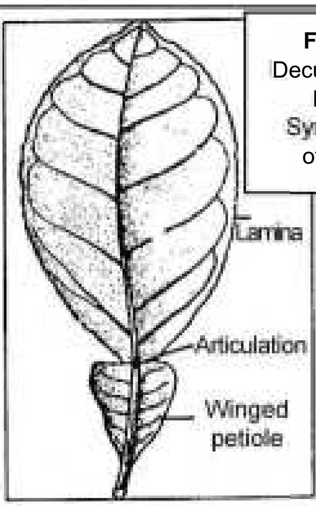


Fig.5.82. Decurrent leaf-base of Symphytum officinale

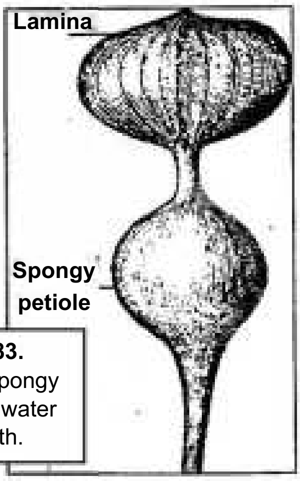


Fig.5.83. Swollen spongy petiole of water hyacinth.

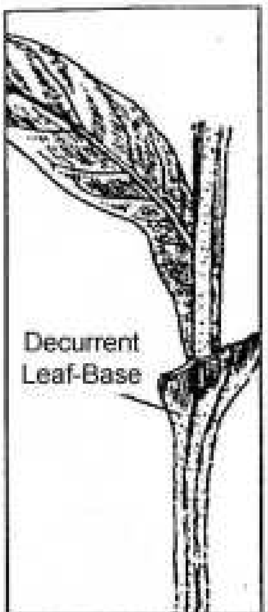


Fig.5.81. Winged petiole of shaddock (Circus grandis).

Linear: Longer and slightly broad as in many grasses, Tuberose, etc.;

Lanceolate : Lens-shaped as in *Nerium* and *Polyalthia;*

Oblong : More or less rectangular as in banana;

Subulate or awl shaped : Wide at the base and narrow towards the apex as in *Isoetes;*

Ovate or egg-shaped : as in China rose and banyan;

Cordate or heart-shaped : as in *Piper betel;*

Sagittate : arrow head-shaped as in *Sagittaria.*

Hastate : sagittate-like, but the two basal lobes directed outwords as in some *sp. of Ipomoea;*

Reniform or kidney-shaped : rounded above with a deep notch at the base as in *Centella asiatica;*

Lunate : Like a half-moon with two pointed basal lobes as in *Adiantum;*

Obovate : wider at the apex and reverse shape of ovate as in jackfruit.

Obcordate : reverse of cordate as in *Bauhinia;*

Spatulate : spatula-like as in *Euphorbia;*

Cuneate : Wedge shaped as in *Pistia;*

Elliptical: Like an ellipse as in *Vinca* and *rotund* or orbicular as in Lotus.

(ii) Base of lamina :

The base of the lamina is generally studied in sessile leaf. When the leaf base surrounds the stem like two flaps as in *Calotropis,* it is called **auricultate** (Fig.5.87). When the auriculate base completely clasps the stem it is called **amplexicaul** (Fig. 5.88). When the basal lobes fuse together after completely clasping the stem, it looks as if the stem has perforated the leaf. This is called **perfoliate** (Fig. 5.89) as seen in *Aloe perfoliata.*

In *Swerita chirayita,* the bases of two opposite leaves fuse together to appear like one leaf, through the centre of which stem has passed. It is called connate leaf base (Fig.5.90).

(iii) Margin of lamina :

The margin of the lamina may be as follows (Fig. 5.91).

(a) **Entire :** Margin is smooth, e.g., Banyan.

(b) **Repand :** Margin is wavy, e.g., *Polyalthia.*

(c) **Serrate** : Margin is toothed with teeth pointed upwards, e.g., China-rose.

(d) **Bi-serrate :** Margin is toothed, but each tooth again serrated, e.g., Elm tree.

(e) **Retroserrate** : Margin is incised like a saw but teeth pointed downwards.

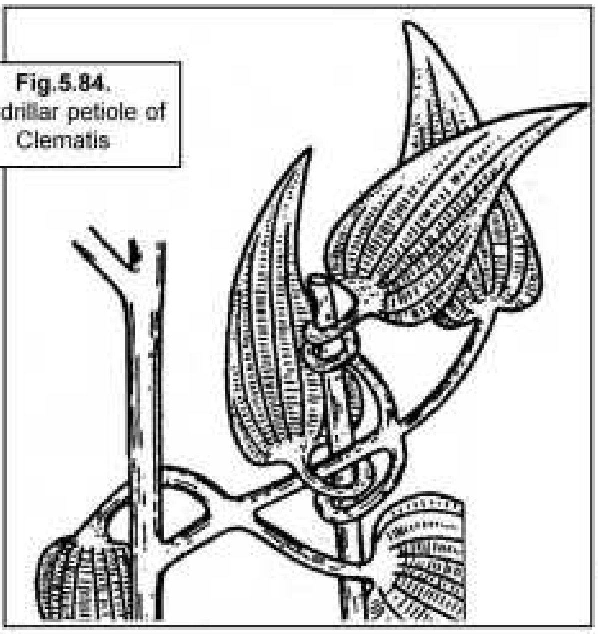


Fig.5.84. Tendrillar petiole of Clematis

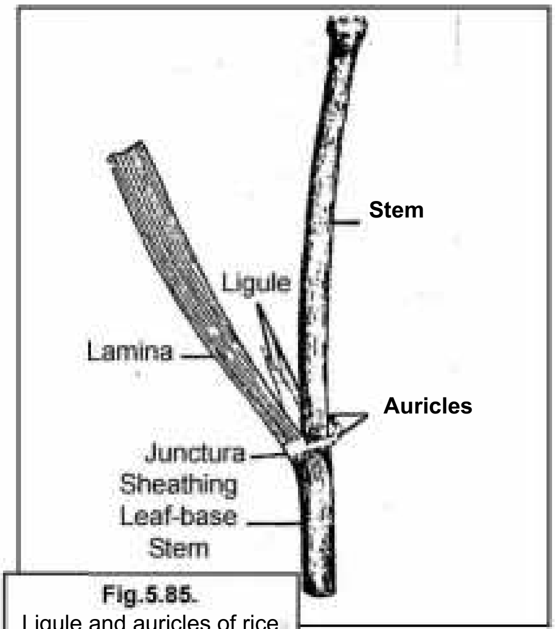


Fig.5.85. Ligule and auricles of rice (Oryza sativa)

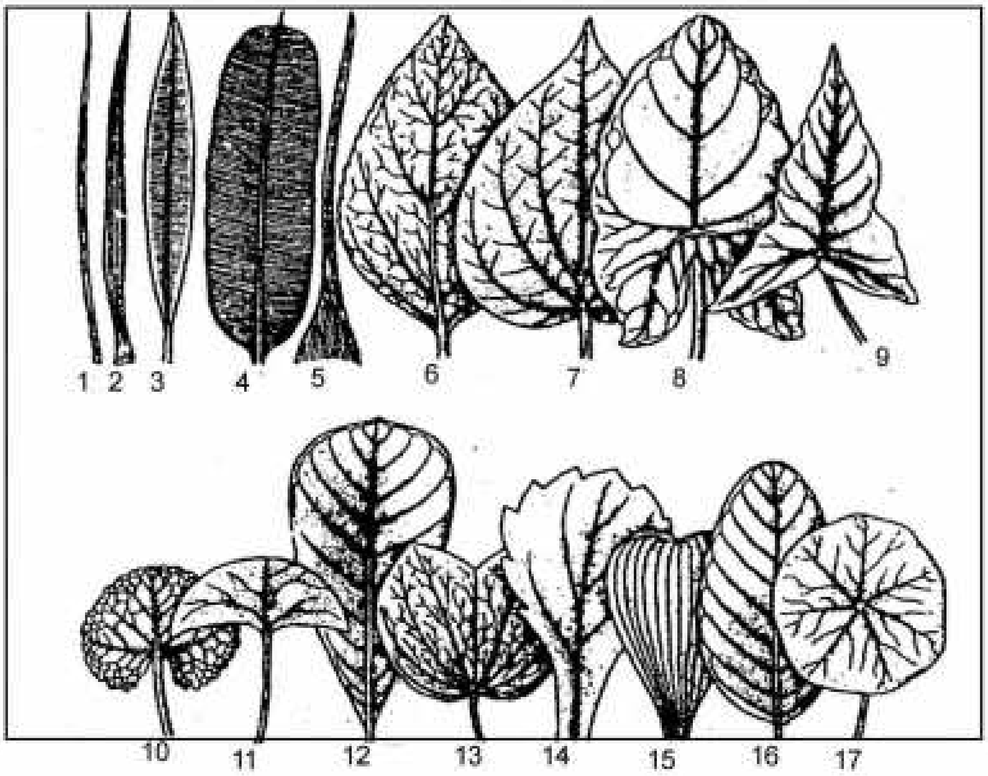


Fig.5.86. LAMINA SHAPES. 1. Acicular in pine; 2. Linear in grass; 3. Lanceolate in Nerium; 4. Oblong in banana; 5. Subulate in Isoeles; 6. Oval in china-rose; 7. Cordate in betel vine; 8. Sagittate in Sagittaria; 9. Hastate in Ipomoea; 10. Reniform in Centella; 11. Lunate in Passaflora lunala; 12. Obovate in jact-fruit; 13. Obcordate in Bauhinia; 14. Spathulate in Lippia; 15. Cuneate in Pistia; 16. Elliptical in guava; 17. Rotund in water-lilly.

(f) **Dentate :** Margin is toothed, the teeth are pointed outwards, e.g., Water lily.

(g) **Bi-dentate :** Margin is toothed and each tooth again dentate.

(h) **Crenate :** Margin is toothed and the teeth rounded, e.g., *Centella.*

(i) **Bi-Crenate :** Margin is toothed and the teeth crenate.

(j) **Spiny :** Margin is pointed to form spines, e.g., Pineapple.

(k) **Lobed or incised :** Margin is incised into various depth and forming small lobes, e.g., Mustard and *Raphamus sativus.*

(iv) Apex of lamina :

The apex of lamina is of following types (Fig.5.92):

(a) **Acute** : Apex is narrow and pointed forming an acute angle, e.g., Mango.

(b) **Obtuse** : Apex is broad angled and blunt, e.g., Banyan.

(c) **Acuminate** : Apex is drawn out into a long tapering tail, e.g., *Ficus religiosa.*

(d) **Mucronate** : Apex is broad but the tip forms sharp point, e.g., *Vinca.*

(e) **Cuspidate or spiny :** Apex forms a spinous structure, e.g., *Phoenix, Pandanus,* palm, etc.

(f) **Tendrillar**: Apex is provided with a thin, wiry, coiling structure known as tendril for climbing, e.g., *Gloriosa.*

(g) **Cirrhose :** The mucronate apex ends in a small, fine thread-like structure, e.g., Banana.

(h) **Truncate** : Apex is cut abruptly, e.g., *Pahs polyphylla.*

(i) **Retuse :** The obtuse apex is slightly notched, e.g., *Pistia Clitoria.*

(j) **Emarginate :** The obtuse apex is deeply notched, e.g., *Bauhinia.*

(v) Surface of lamina :

(a) **Glabrous :** The surface of lamina may be smooth without any hair, e.g., mango.

(b) **Glaucous :** The surface is covered by waxy coating, e.g., lotus, *Calotropis.*

(c) **Scabrous :** The surface is rough.

(d) **Rugose :** The surface is somewhat wrinkled is, e.g., *Rubus rugosus.*

(e) **Viscose :** The surface is sticky because of some excretion, e.g., *Cleome viscosa.*

(f) **Gland-dotted :** The surface is with gland dots, e.g., Lemon.

(g) **Hairy :** The surface is covered with hairs. Based on the different types of hairs, it may be :

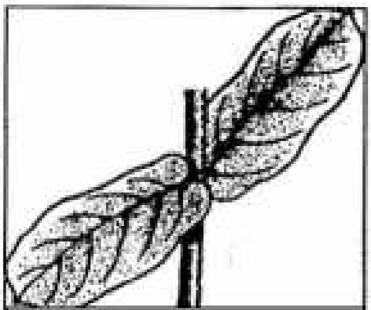


Fig.5.87. Auriculate lamina base in Calotropis.

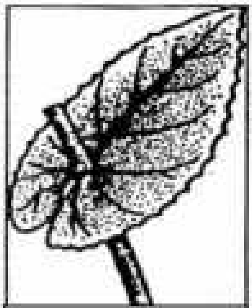


Fig.5.88. Amplexicaul type of lamina base.

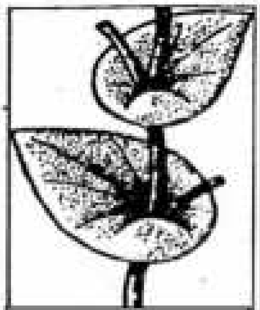


Fig.5.89. Perfoliate base

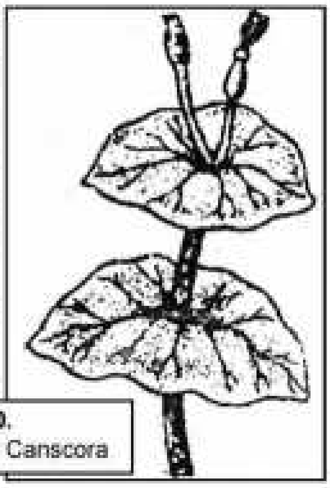


Fig.5.90. Connate base in Canscora

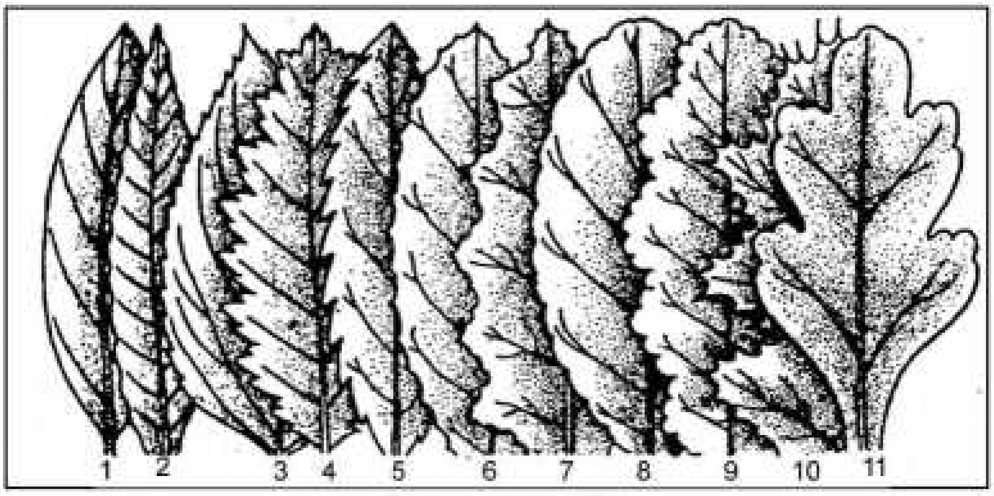


Fig.5.91. LEAF MARGIN :
1.Entire; 2. Repand; 3. Serrate; 4. Bi-serrate; 5. Retroserrate; 6. Dentate; 7. Bi-dentate; 8. Crenate; 9. Bi-crenate; 10. Spiny; 11. Lobed.

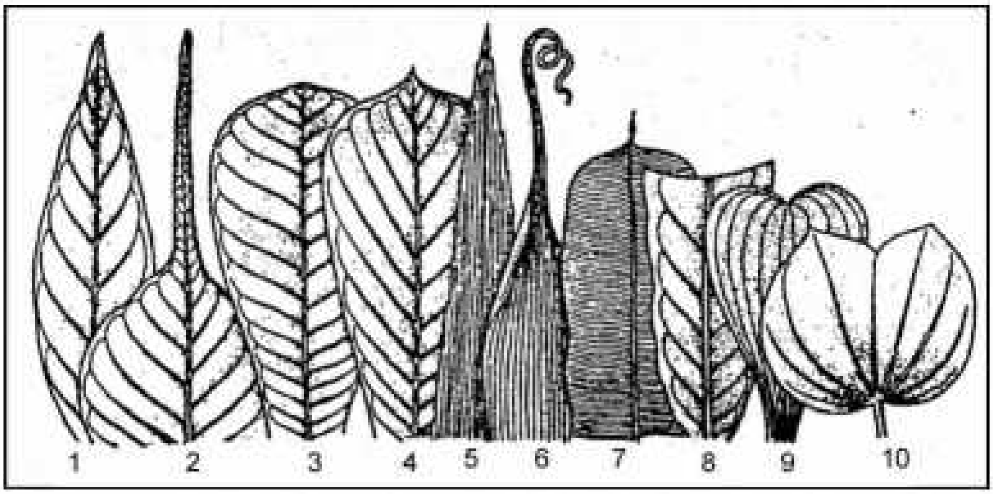


Fig.5.92. LEAF APICES : 1.Acute; 2. Acuminate; 3. Obtuse; 4. Mucronate; 5. Cuspidate; 6. Tendrillar; 7. Cirrhose; 8. Truncate; 9. Retuse; 10. Emarginate.

(i) **Pubescent:** hairs are soft and woolly as in Tomato,

(ii) **Pilose :** hairs are long, distinct and scattered as in *Grewia flavescens,*

(iii) **Villose :** hairs are long, soft and closely arranged as in *Leucas aspera,*

(iv) **Tomentose:** hairs are short, dense and cottony as in *Terminalia* and *Calotropis,* etc.

(v) **Hirsute :** hairs are stiff, fine and scattered as in *Eclipta alba.*

(vi) **Hispid :** hairs are long and rigid as in *Cucurbita.*

(h) **Spinose :** The surface is covered by small prickles as in Brinjal.

(vi) Texture of lamina :

Lamina of the leaves has differeent textures.

(a) **Herbaceous :** The leaf lamina is thin and membranous as in China-rose and Rose.

(b) **Coriaceous :** The leaf lamina is firm and leathery as in Mango.

(c) **Succulent:** The leaf lamina is soft and juicy and more or less brittle as in *Kalanchoe.*

5.3.3 THE STIPULES :

Stipules are the appendages or outgrowths from the leaf base. It protects the young axillary buds. Leaf is said to be **stipulate** when the stipule is present, while in its absence the leaf is **exstipulate.** Stipules are very common in dicotyledons but rare in monocotyledons. In some leaves they remain as long as the lamina persists **(persistent)** or fall off soon after the lamina unfolds **(deciduous).** Stipules may remain as a normal appendage or may be modified to give different structures.

According to their shape, position and size, stipules are of following types :

A. Normal stipules :

(i) Free-lateral:

These are two in number, free, laterally placed at the leaf base and green in colour, e.g., China rose (Fig.5.77).

(ii) Adnate :

In this case, two lateral stipules grow along the petiole up to a certain height forming two winged appearance, e.g., *Rosa* (Fig.5.93).

(iii) Interpetiolar:

This type of stipule is seen in plants having opposite leaves. The stipules lie between the petioles of opposite leaves, alternating with the latter, e.g., *Ixora* (Fig.5.94).

(iv) Intrapetiolar:

In this case, stipules present at the base of the opposite leaves, each being at the axil of a leaf, e.g., *Ervatamia* and *Gardenia* (Fig.5.95).

(v) Ochreate :

It forms a hollow tube like structure encircling the internode of the stem up to a certain height along with the some part of the petiole. The stipule is membranous, e.g., *Polygonum* (Fig.5.96).

B. Modified stipules :

(i) Foliaceous :

At the base of the rachis of a compound leaf, there are two large, green, leafy structures known as foliaceous stiplue, e.g., *Pisum* (Fig.5.97).

(ii) Bud-scales or convolute :

These are two scaly stipules present on the two lateral sides of the leaf bases enclosing the bud and becoming convolute in shape. When the leaves unfold, these scaly stipules fall off, e.g., *Ficus, Artocarpus* (Fig. 5.98), and *Magnolia,* etc.

(iii) Spinous :

In this case, the stipules appear as two sharp pointed strucutres that provide protection to the plant, e.g., *Acacia, Mimosa, Zizyphus* (Fig. 5.99 A,B).

(iv) Tendrillar:

The stipules develop on two sides of the petiole and becomes thin, wiry, coil like structures helping the plant to climb;, e.g., *Smilax* (Fig.5.101).

(v) Stipe l:

Sometimes in compound leaf the outgrowths are found at base of the leaflets. These are known as stipels, e.g., *Clitoria, Dolichos lablab* (Fig. 5.100),

5.3.4 VENATION :

Veins are rigid, linear structures. These arise from the petiole and the midrib and traverse the leaf lamina in different directions. The veins divide and redivide to form the skeletal structure of leaf lamina. Such ramification shows different types of arrangements in different leaves. The ramifications are the **veins** and the **veinlets** while their arrangement is known as **venation.**

It serves to distribute the water and dissolved mineral salts throughout the expanded lamina and carries the prepared food from It. It gives mechanical strength to lamina and helps in conduction.

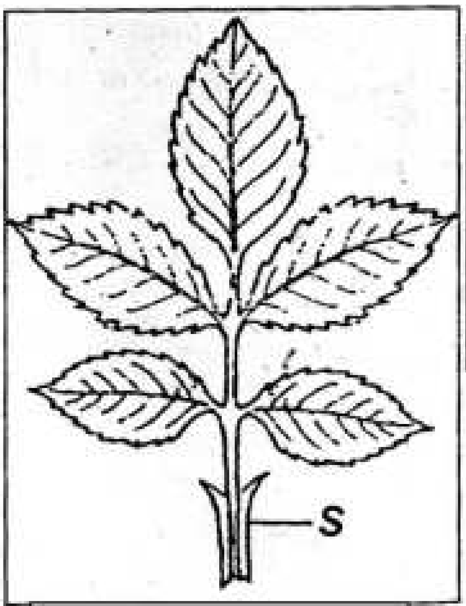


Fig.5.93.Adnate stipule (S) of rose.

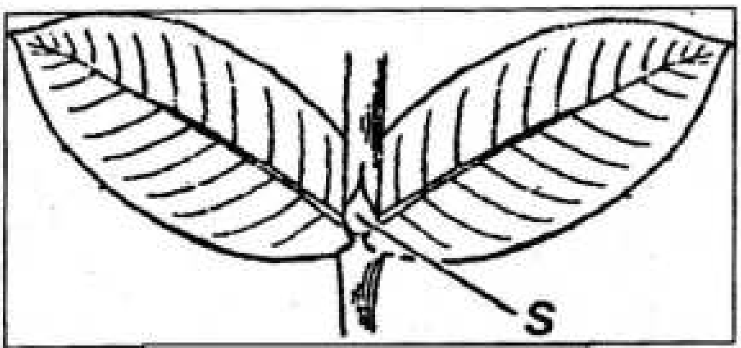


Fig.5.94.Interpetiolar stipule (S) of Ixora.

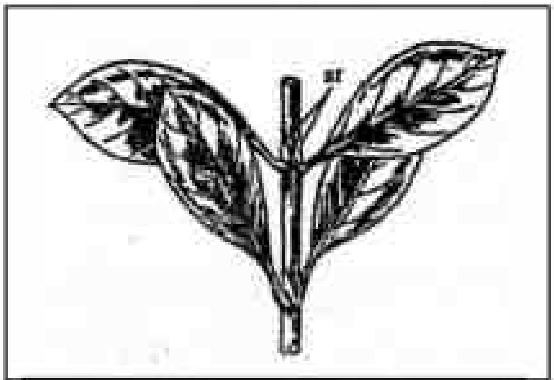


Fig.5.95.Intrapetiolar stipule in Gardenia with opposite leaves

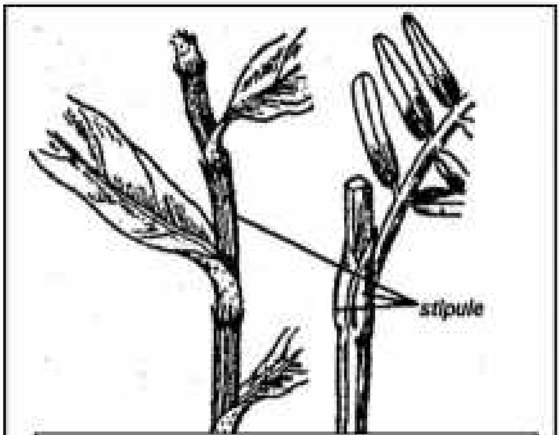


Fig.5.96.Ochreate stipule of Polygonum and Astragalus.

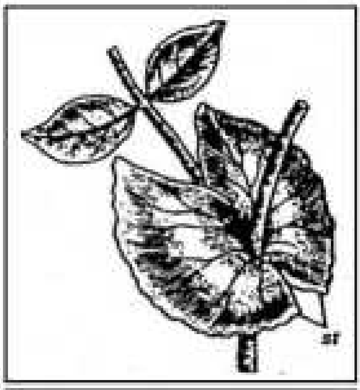


Fig.5.97.Foliaceous in pea

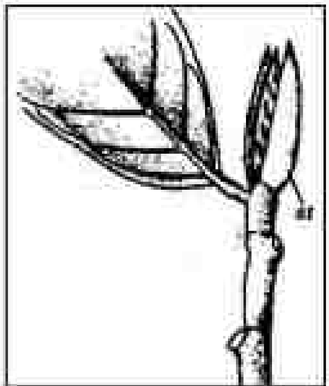


Fig.5.98.Convolute (Bud-scale) in Artocarpus.

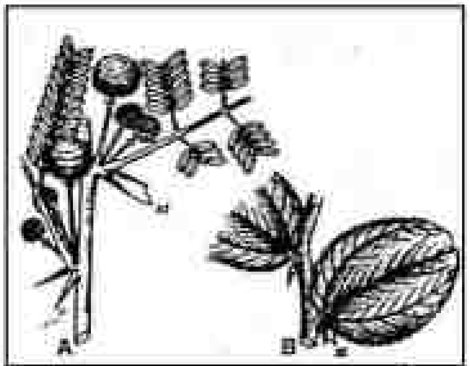


Fig.5.99.Spiny Stipules: (A) Acacia nilotica; (B) Zizyphus mauritiana

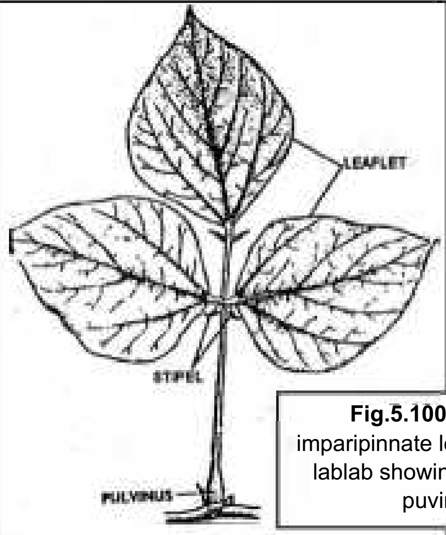


Fig.5.100. Trifoliate imparipinnate leaf of Dolichos lablab showing stipels and puvinus.

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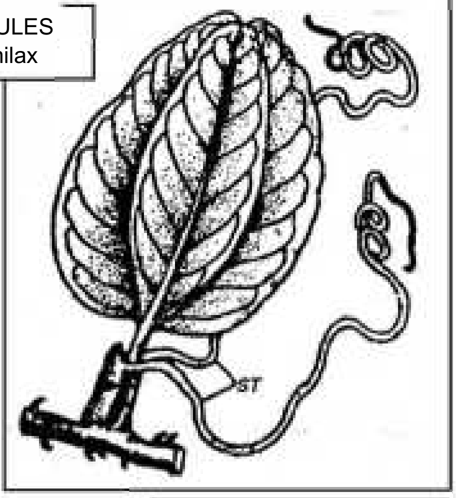
Fig.5.101. STIPULES Tendrillar in Smilax



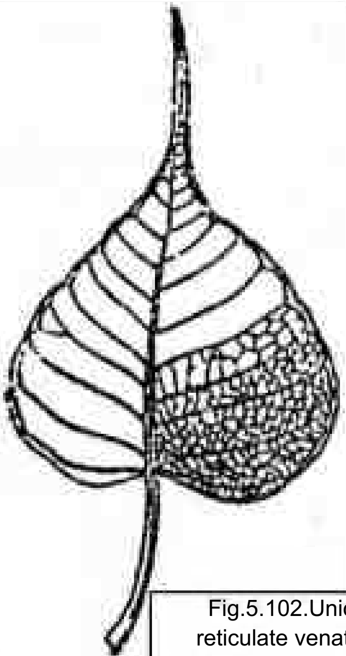


Fig.5.102.Unicostate reticulate venation in the leaf of Ficus religiosa

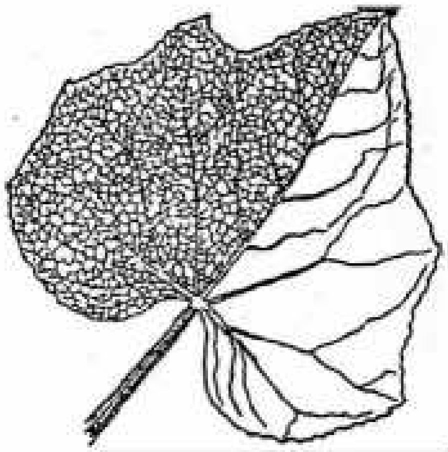


Fig.5.103. Multicostate divergent reticulate venation M in cucumber.

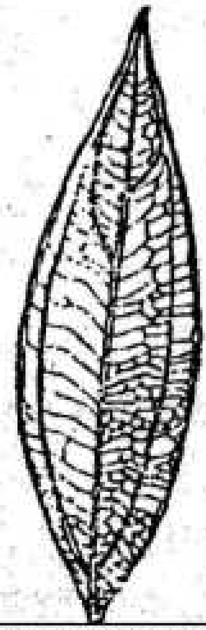


Fig.5.104. Muiticostate convergent reticulate venation in cinnamon

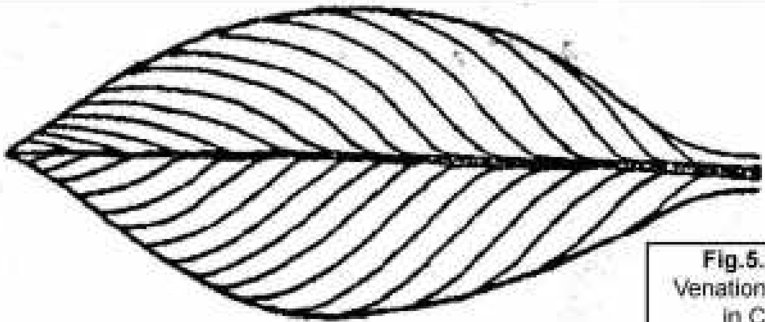


Fig.5.105. Parallel Venation : Pinnate type in Canna leaf.

Angiosperm leaf shows two principal types of venation. When veins and veinlets are irregularly arranged forming a net like reticulate structure, it is called **reticulate venation.** When they run parallel to each other, it is said to be **parallel venation.** Reticulate venation is characteristic of dicotyledons, while the parallel venation is found in monocotyledons. However, there are some exceptions. Among monocotyledons, *Smilax, Dioscorea* and a few others show reticulate venation and among dicotyledons *Calophyllum* and a few others show parallel venations.

A. Reticulate venation :

1. Unicostate or pinnate :

The strong nerve that passes from the base of the petiole to the leaf apex is known as midrib or costa. It bears a large number of laterally placed veins. Further branching of veins are known as veinlets. It resembles the general plan of a feather. Hence, it is called **pinnate.** Since it possesses a single prominent vein, it is called **unicostate.** This type of venation is common in dicotyledons like *Ficus,* mango, etc.(Fig.5.102)

2. Multicostate or palmate :

In this case, strong veins are more than one. These costa arise from the tip of the petiole and proceed outwards. So, it is called multicostate or **palmate** type of reticulate venation. When costa arising at the base of the leaf-blade diverge from one another towards the margin of the leaf, never meeting with each other the venation is called reticulate, palmate and **divergent** type, e.g., China rose, Castor, Cucumber (Fig.5.103). But when the costa run in a curved manner from the base and converge towards apex, it is called reticulate, palmate and **convergent** type, e.g., cinnamon, camphor (Fig.5.104).

B. Parallel venation :

In this case, the leaf has one or more prominent midribs, which gives off lateral veins that proceed parallel to each other towards the margin or apex of the leaf-blade as in banana, *Canna,* turmeric etc. (Fig. 5.105).

Parallel venation may be **unicostate** when there is a single prominent midrib or may be **multicostate** when there are more than one. In **multicostate** or **palmate** venation, if prominent veins (costa) originate from the base of the leaf lamina and spread out or diverge towards the distal end of the leaf, it is known as **divergent** type e.g. Palm (Fig.5.107).

If the prominent veins (costa) coming out from the base of the leaf lamina and converge towards apex, it is called **convergent** type e.g. grasses, rice, bamboo (Fig.5.106).

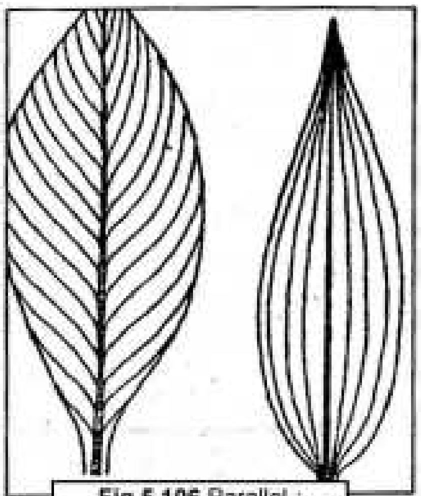


Fig.5.106. Parallel : Palmate (convergent) type in bamboo leaf.

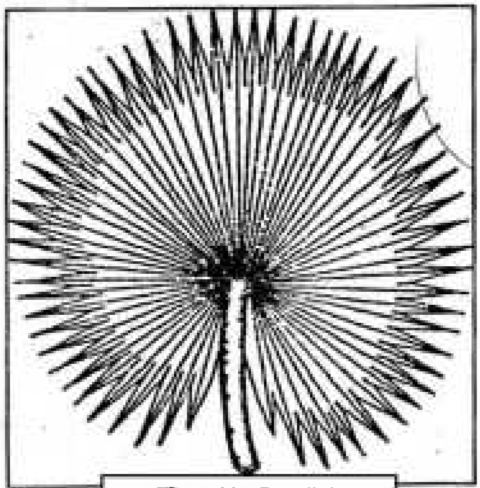


Fig.5.107. Parallel Venation Palmate (divergent) type in palmyra-palm leaf.

5.3.5. SIMPLE AND COMPOUND LEAF :

A simple leaf consists of a single lamina which may be entire or incised. Such incision does not proceed up to the mid-rib or the petiole. In a compound leaf the incison of the leaf blade proceeds to the mid-rib or to the petiole so that the leaf lamina gets divided into several segments called **leaflets.** Here the midrib is converted into **rachis** at the base of which there is axillary bud like that as a simple leaf. There are two types of compound leaves such as **pinnate and palmate.**

Compound leaf and branch :

A compound leaf looks similar to the branches, yet it is distinguished by the following points:

(1) A compound leaf never bears a terminal bud which is found in case of a branch.

(2) A compound leaf, like a simple leaf always bears a bud at its axil (axillary bud) but branches themselves occupy the axillary position of a leaf.

(3) The leaflets of a compound leaf have no axillary buds whereas the leaves borne on a branch have axillary buds one for each.

(4) A branch consists of nodes and inter nodes, while the rachis of a compound leaf is devoid of them.

A. Pinnately compound leaf:

A compound leaf, that bears the leaflets on lateral sides of the rachis is called pinnate. The rachis bears the leaflets either in alternate or opposite manner. It may be of the following types:

(i) Unipinnate :

In this case, the rachis bears the leaflets directly along its two sides as in a feather., e.g., *Cassia, rose, Margosa,* etc. When the leaflets are even in number it is said *to* be **paripinnate,** e.g., *Cassia* (Fig:5.108). But if the number of leaflets is odd, it is said *to* be **imparipinnate,** e.g., rose. (Fig.5.108), potato, *Clitoria,* etc.

(ii) Bipinnate :

The main rachis is branched to give secondary rachis. The leaflets are borne on secondary rachis, e.g., *Caesalpinia,* (Fig. 5.109) *Mimosa, Acacia* and *Albizia* etc. All the bipinnate compound leaves are paripinnate.

(c) Tripinnate:

In this case, the leaf is thrice pinnate. The secondary rachis again bears tertiary rachis that bears the leaflets. Tripinnate compound leaves are imparipinnate, e.g., *Moringa* (Fig. 5. 110),

(d) Decompound :

When the leaf is more than thrice pinnate, it is said to be decompound as in Carrot, Fennel *(Foeniculum vulgare)* and *Coriandrum,* etc. (Fig. 5.111).

B. Palmately compound leaf :

In palmately compound leaf, the rachis does not develop at all so that all the leaves are articulated to a point on the top of the petiole. The leaflets diverge from a common point like the fingers from the palm. According to the number of leaflets, it may be of following types:

(i) Unifoliate:

In this case, a single leaflet is articulated to the winged petiole, e.g., lemon, orange and other citrus plants (Fig.5.112).

(ii) Bifoliate:

Two leaflets articulated to the rachis, e.g., *Balanites, Bignonia* etc.

(c) Trifoliate:

When three leaflets are articulated to the rachis *e.g.,Oxalis, Aegle* (Figs. 5.113 and 114), etc.

(d) Quadrifoliate:

Four leaflets are articulated at the tip of the petiole, e.g., *Paris quadrifolia* and *Marsilea.*

(v) Multifoliate or digitate:

Five or more leaflets are articulated to the rachis and look like spreading of fingers from the palm, e.g., *Bombax, Gynandropsis,* etc.

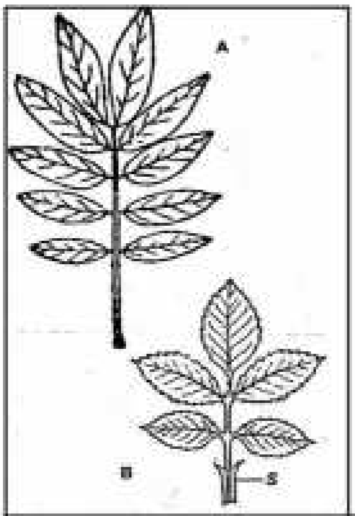


Fig.5.108.(A) Unipinnate (Paripinnate) (B) Unipinnate (imparipinnate)

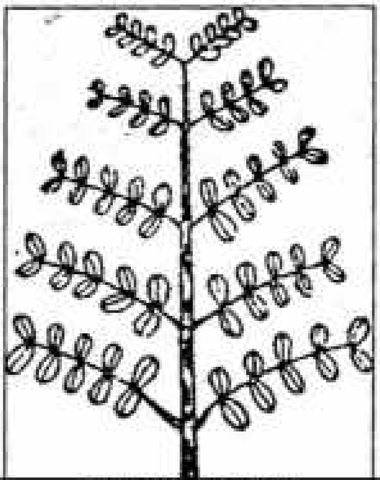


Fig.5.109. Bipinnate

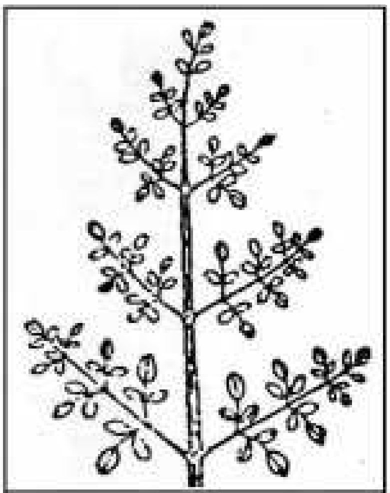


Fig.5.110. Tripinnate

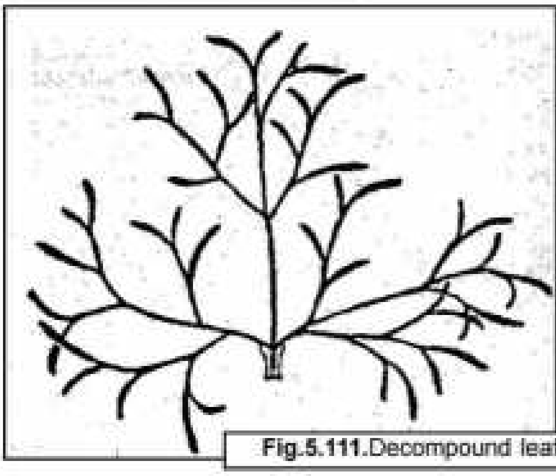


Fig.5.111. Decompound leaf

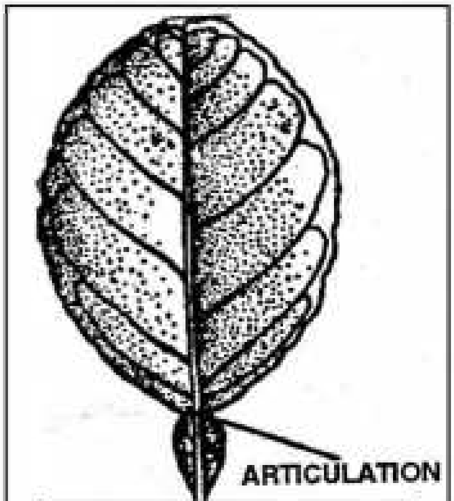


Fig.5.112. Unifoliate

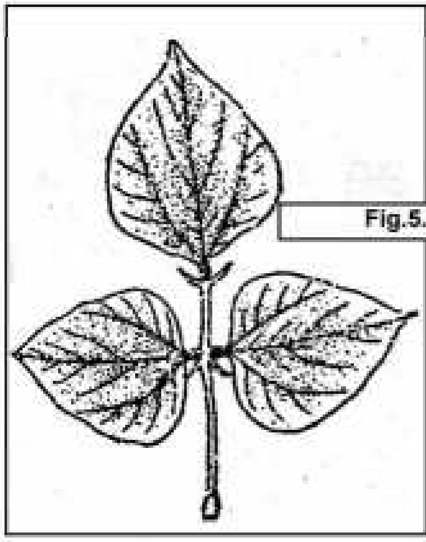


Fig.5.113. Trifoliate

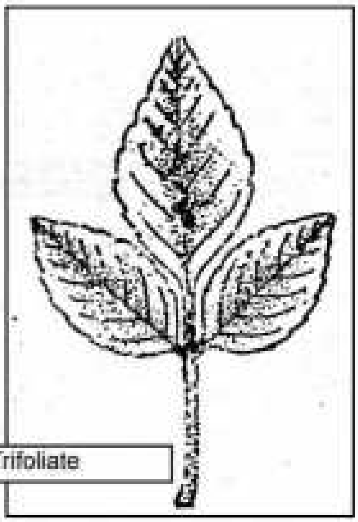


Fig.5.114. Trifoliate

5.3.6. MODIFICATIONS OF LEAVES :

Any change in the form of leaf or its parts- such as petiole, leaf lamina, margin, and apex, etc. to perform some functions other than their normal functions is called modification of leaf. Leaves of many plants are modified or metamorphosed into various structures. These are as follows:

A. Leaf-tendrils:

Tendrils are slender, wiry, closely coiled structures which help the plant in climbing. These are sensitive to contact with a foreign body. The terminal leaflets of *Pisum* or the entire leaf lamina in *Lathyrus* (Fig.5.115) are transformed into tendrils. The terminal leaflet is also transformed into leaf-tendril in *Naravelia* (Fig.5.117) *and Bignonia.* The leaf apex becomes a tendril in *Gloriosa superba* (Fig.5.116). The tendril of *Cucurbita* is considered as a modified prophyll.

B. Hooks :

In some species of *Bignonia,* (Fig:5.118), the terminal leaflets become modified into three, very sharp and curved hooks like the nails of a cat. The leaf spines on the main branches of *Asparagus* also act as hooks.

C. Leaf spines :

The leaf margin or leaf apices or entire leaf lamina may be modified to pointed structures known as spines. These spines may be small and at the margin as in *Argemone mexicana,* Pineapple, *Agave, Aloe,* etc. (Fig.5.119). In *Opuntia,* ordinary leaves are feebly developed and soon fall off, but the minute leaves of the axillary bud are modified into spines. The entire leaf becomes modilied into spine in barberry. In date palm, the leaf apex becomes sharp and pointed transforming into spines. Spines provide protection to the plants.

D. Scale-leaves:

It is the characteristic feature of underground modified stems. These are thin, dry, stalkless, membranous structures, which protect axillary buds. In Onion, these are thick and fleshy to store water and food. In *Casuarina,* the scale leaves (Fig. 5.120) occur in a whorl at each node.

E. Phyllode:

The plant Australian *Acacia* possesses bipinnate compound leaves when in young seedling stage. It is found that gradually the petiole or rachis becomes flattened, sickle shaped taking the shape of a leaf with the falling of leaflets (Fig.5.121). This flattened winged petiole or rachis is known as **phyllode.** It carries on all the functions of a leaf.

F. Pitcher:

It is found in one kind of insectivorous plant. Here, the leaf becomes modified into a **pitcher.** The slender petiole coils like a tendril holding the pitcher vertically up. Its basal portion is flattened like a leaf. The tip of the leaf is motdified to a lid which covers the mouth of the pitcher. The function of the pitcher is to capture a insects and digest them. E.g., *Nepenthes* (Fig.5.122).

G. Bladder:

Bladders are modified leaf, found in certain aquatic plants commonly known as bladderwort. The leaf of the plant is very much segmented. Some of these segments are modified to form

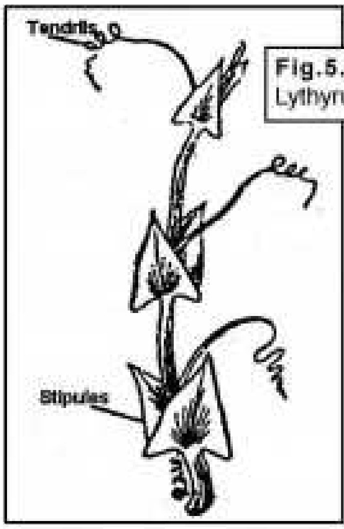


Fig.5.115.: Leaf tendril of Lythyrus

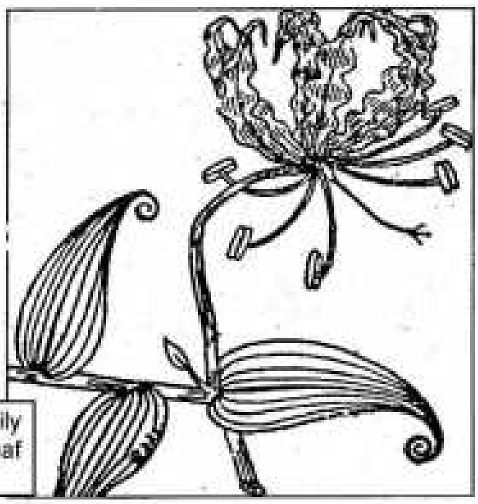


Fig.5.116.: Portion of glory lily (Gloriosa) stem with the leaf apex modified into a tendril

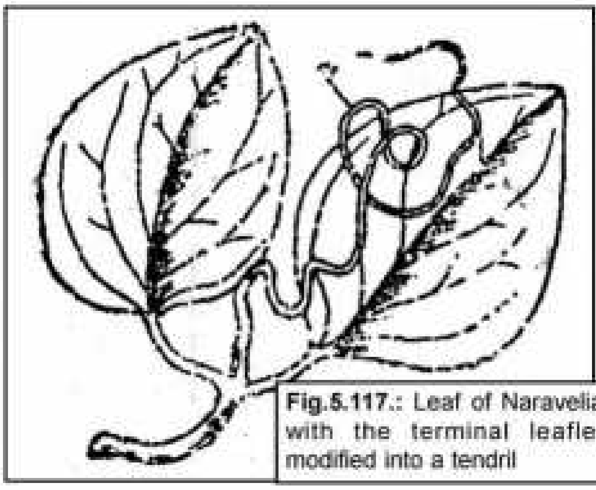
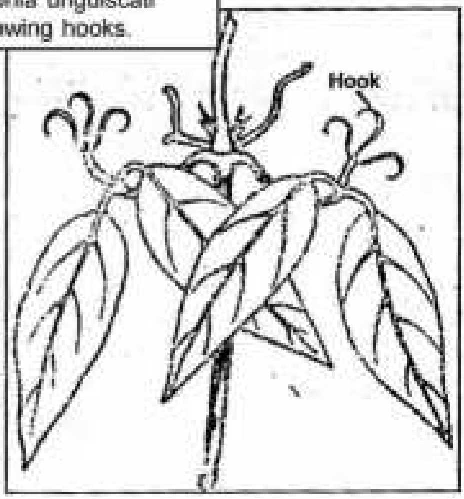


Fig.5.117.: Leaf of Naravelia with the terminal leaflet modified into a tendril

Fig.5.118.: Stem of Bignonia unguiscati showing hooks.



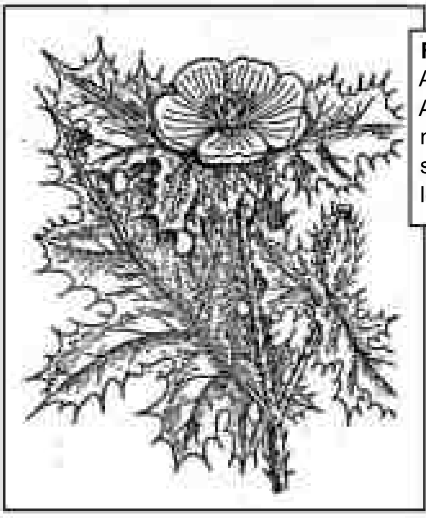
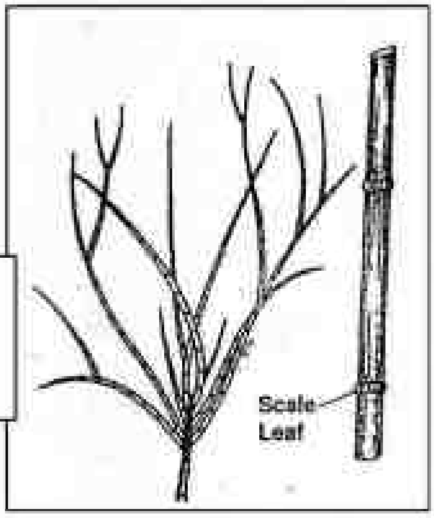


Fig.5.119.: A twig of Argemone mexicana showing leaf spines

Fig.5.120.: Casuarina stem showing scale leaf.



bladder like structures provided with lids. The structure is such that the aquatic animalcules can get into the bladders but cannot come out. So, it acts as a trap-door entrance, e.g., *Utricularia* (Fig. 5.123).

5.3.7. PHYLLOTAXY :

The mode of arrangement of leaves on the stem is known as phyllotaxy. There is a definite law according to which the leaves are arranged on the stem of a particular species. There are three categories of phyllotaxy which fall under two principal types known as cyclic and acyclic.

In acyclic phyllotaxy a single leaf is present at each node. Acyclic phyllotaxy may also be as **spiral** or **alternate** phyllotaxy. In cyclic type, at each node there are more than one leaf. In cyclic type, the leaves are arranged in a cycle in which the angle between adjacent leaves known as angular divergence is the same. If there are two leaves at the node, two will be placed opposite (i.e. at an angular distance of two right angles). If there are three leaves, the angle between leaves in the same whorl is 120° (i.e. one third of a circle). If four, it is 90° and so on. Cyclic type shows two distinct categories of phyllotaxy: *opposite* and *whorled* depending on presence of two or more than two leaves at each node respectively.

(i) Alternate:

Here, a single leaf arises at each node. These alternate to each other. It is the commonest type of phyllotaxy, e.g., mustard, sunflower, China rose, etc. (Fig.5.124). If an imaginary line is drawn from the base of one particular leaf through the bases of the successive leaves, it forms a spiral. This imaginary spiral line is known as **genetic spiral** (Fig.5.125). When looked from top, one finds in each cycle of spiral one leaf comes to lie directly on another leaf which is placed on a vertical line. So, on the stem one finds definite number of rows of leaves, known as orthostichy. Alternate phyllotaxy is classified further on the basis of number of leaves in relation to spirals. These are as follows (Fig.5.126).

1. Distichous or two ranked or 1/2 phyllotaxy :

In this case, leaves are arranged in two vertical rows. It is found that the third leaf remains over the first while completing one spiral. Fourth leaf also stands over the second. So, there are two leaves in each spiral. The fifth leaf stands over the first and the third and so on, e.g., wheat, rice. In this case, the angular divergence is 180° (360° * '$/_2$).

2. Tristichous or three-ranked or 1/3 phyllotaxy :

In tristichous phyllotaxy, there are three leaves in one spiral. The fourth leaf stands vertically over the first one, and one cycle of the genetic spiral involves three leaves. The fifth leaf stands over the second, the sixth over the third, and the seventh remains over the fourth and the first. There are three orthostichies, i.e., leaves are arranged in three rows or ranks. The mode of arrartgement in the first, fourth, seventh and tenth leaf remains in one row while the third, sixth, ninth and twelveth in the second row and second, fifth, eighth and eleventh in the third row, e.g., *Cyperus.* Here the angular divergence is 120°. (360°.x'$/_3$).

3. Pentastichous or five-ranked or 2/5 phyllotaxy :

In this case, the leaves are arranged in five vertical rows. There are five leaves in two spirals. The mode of arrangement is first and sixth leaf on the first orthostichy, second and

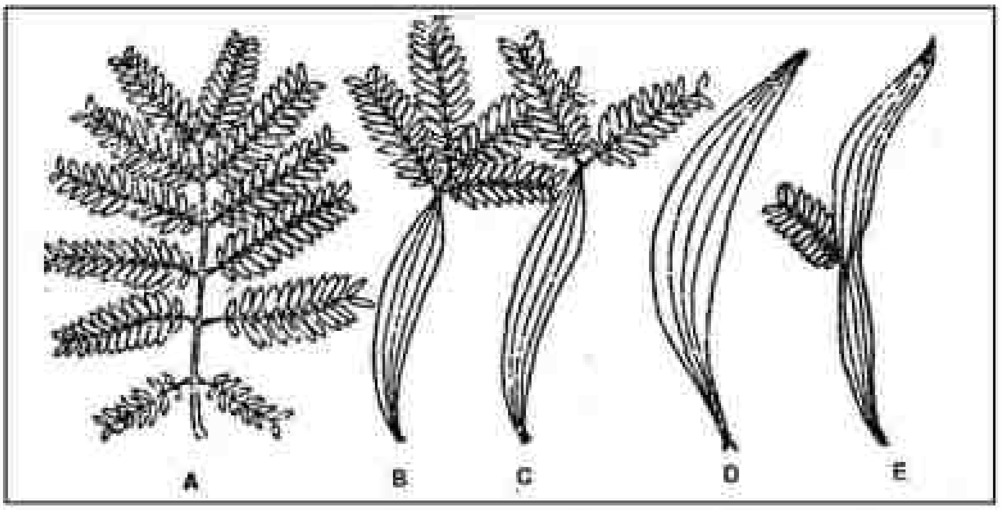


Fig.5.121. Development of phyllode in Australian Acacia. (A-D); petiole modified into phyllode; (E), rachis and petiole together modified into a phyllode.

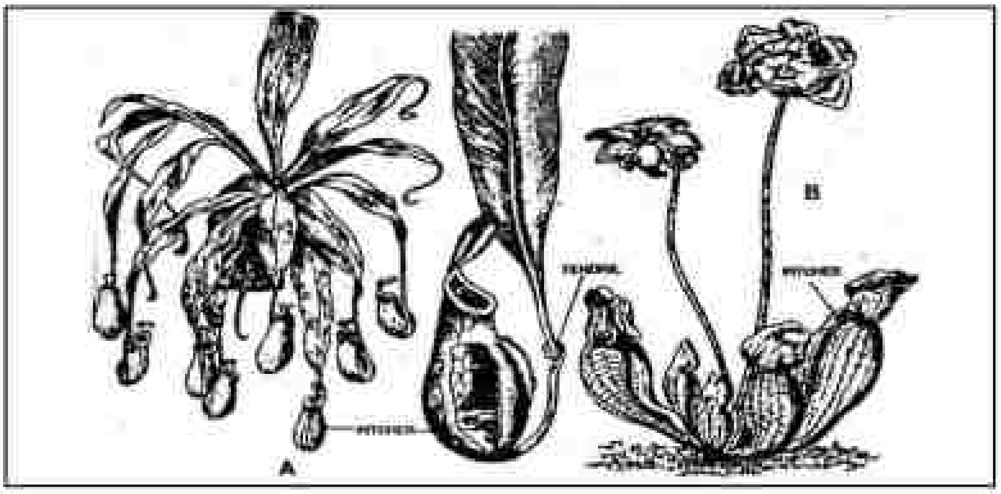


Fig.5.122. PITCHER PLANTS.(A) Nepenthes (the Asiatic Pitcher Plant) - One enlarged leaf showing the pitcher; (B) Sarracenia purpurea-the North American Pitcher Plant.

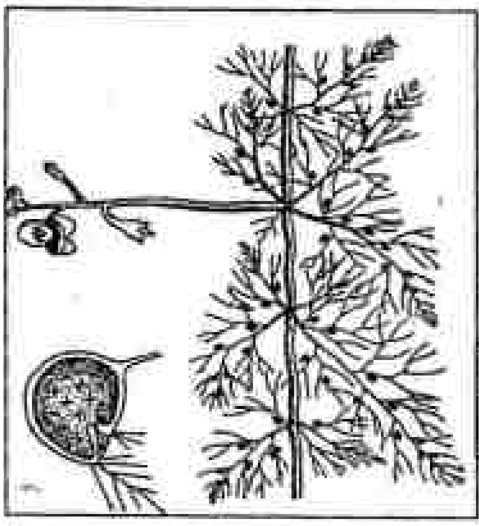


Fig.5.123. Bladderwort (Utricularia) with many small bladders, top, a bladder in section (magnified)

seventh on the second, three and eighth on the third, fourth and ninth on fourth orthostichy. Hence, It is called 2/5 phyllotaxy, making an angular divergence of 144° (3600x2/5). A common example is China rose.

4. Octastichous or eight-ranked or 3/8 phyllotaxy :

The arrangement of leaves is found along eight vertical rows. The mode of arrangement is first and ninth leaf on first row, second and tenth on second row, third and eleventh on fourth row and so on. In this case, there are eight leaves in three spirals. Here, the angular divergenre between two consecutive leaves is 135° (360°x3/8). A common example is Papaya.

(ii) Opposite :

When, two leaves arise at each node, and are opposite to each other, it is opposite phyllotaxy. When one pair of leaves stand at right angle to the next upper or lower pair, the phyllotaxy is called opposite **decussate,** e.g., *Ocimum, Ixora, Calotropis* (Fig.5.127). In some other plants, the successive pairs are placed exactly on top of each other so that all the leaves lie in one plane. A pair of leaves is seen to stand directly over the lower pair in the same plane. Such an arrangement is said to be opposite superposed, e.g., *Quisqualis* (Fig.5.128).

(iii) Whorled or Verticillate :

Here three are more leaves, which form a whorl at each node, are arranged in a circle or whorl, e.g., *Alstonia, Allamanda, Nerium* (Fig.5.129).

Leaf mosaic :

Phyllotaxy is the arrangement of leaves on the stem in such a manner that each leaf gets adequate amount of sunlight for manufacture of food material. The arrangement allows the leaves to secure maximum amount of sunlight with minimum amount of overlapping. Such a condition is also obtained by a differential growth of the stalk of different leaves on the twig so that all the leaves are brought to the same level. It resembles with a flat mosaic surface. The leafstalks are unequal and leaves originating lower down have longer stalks. Leaves twist and turn to fill up all the gaps where light is available, -e.g., *Acalypha* (Fig.5.130).

5.3.8. FUNCTIONS OF LEAF :

A. Manufacture of food :

It is the primary function of green leaves. The process is called photosynthesis by which leaf produces food material using water and carbon dioxide in the presence of sunlight and green pigment, chlorophyll.

B. Interchange of gases :

It takes place both for respiration and photosynthesis. There are numerous, minute openings present on the leaves, called stomata, through which gaseous exchange takes place between the atmosphere and the plant body.

C. Evaporation of water:

Water absorbed by the root is evaporated from the leaf surface during the day time. It generally takes place through the stomatai openings. The phenemenon is known as transpiration. This process allows the plant to absorb water and minerals from the soil and conduct the same to the top of the plant.

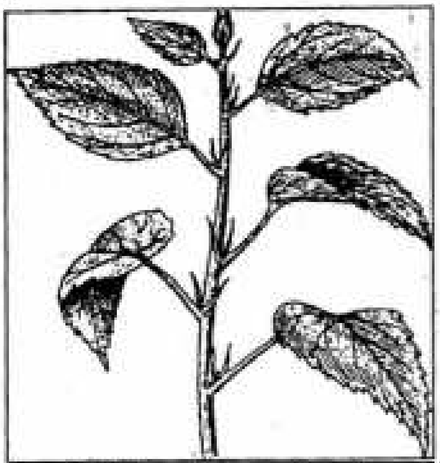


Fig.5.124. Alternate (Spiral)

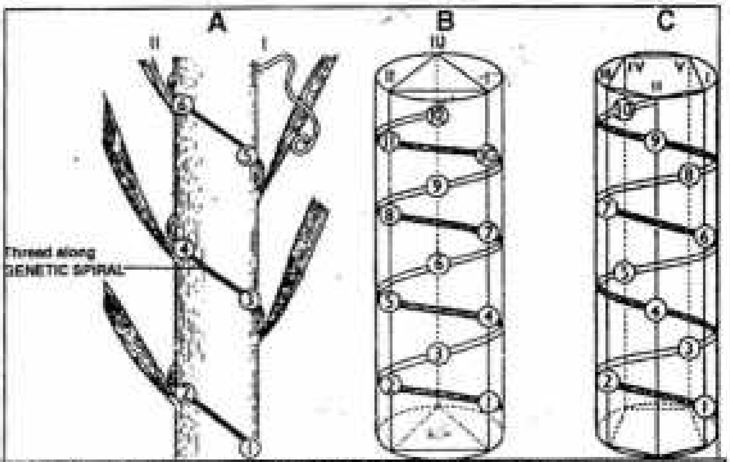


Fig.5.125. The genetic spiral (A) shows a thread tracing the genetic spiral. Nos.1,2,3... etc.. are the consecutive leaves. (B) Tristichous or three-ranked (I,II &III) phyllotaxy. (C) Pentastichous or five-ranked (I-V) phyllotaxy

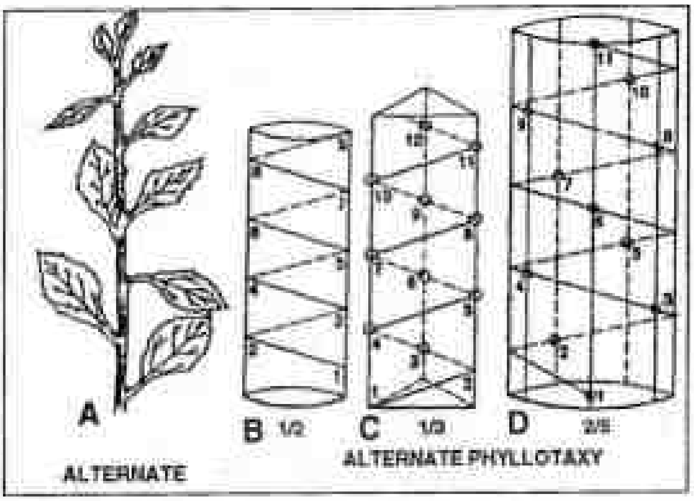


Fig.5.126.Phyllotaxy : (A) Alternate; (B) Distichous (1/2); (C) Tristichous (1/3); (D) Pentastichous (2/5)

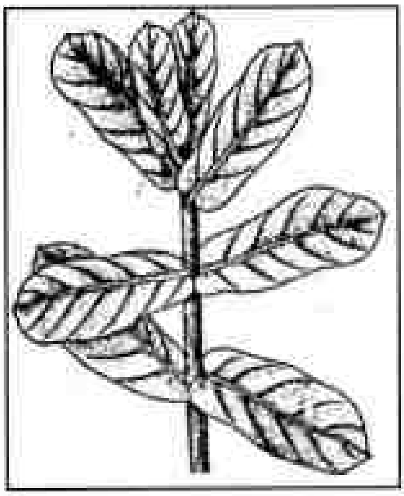


Fig.5.127.Opposite superposed in Quisqualis.

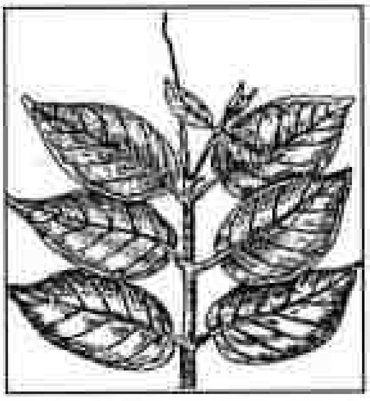


Fig.5.128.Opposite superposed in Quisqualis.

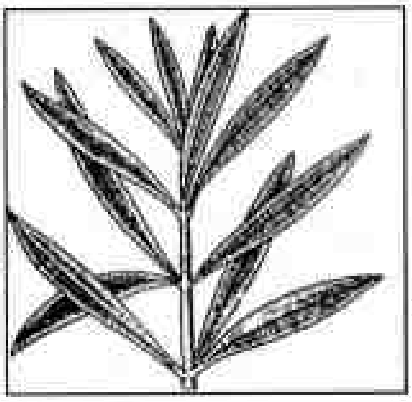


Fig.5.129.Verticillate (whorls of three) in Nerium odorum.

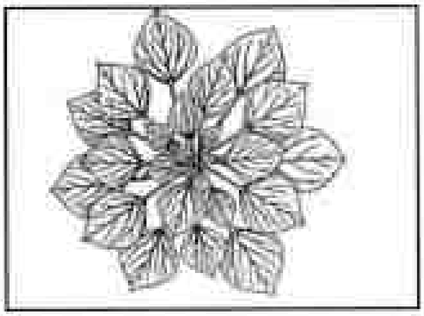


Fig.5.130.Leaf mosaic in Acalypha. The lower leaves have longer petioles so that all leaves are brought to the same level and are not shaded by one anothe.

5.4. INFLORESCENCE :

The shoot of angiospermic plant may have two distinct parts: vegetative and reproductive. Generally, the reproductive part is identified as flower. The reproductive part of the shoot may bear one or many flowers. The group of flowers present on a shoot transforms the shoot into an axis with flowers (flowering axis). The mode of arrangement of flowers along the flowering axis is known as inflorescence or anthotaxi.

The floral buds are developed in the reproductive phase. If the floral bud is single and develops into a flower it is called **solitary.** It may either be developed at the leaf axis or at terminal part of the plant. In former case, it is said to be **solitary axillary;** while in the latter, it is termed as **solitary terminal.** But in many cases a cluster of flowers develop on an axis, known as **floral axis.**

The floral axis bearing the flowers is known as peduncle or rachis and the stalk of individual flower is called pedicel. The inflorescence consisting of a collection of flowers may be different depending on the mode of arrangement of flowers- pedicellate or sessile; length of the floral axis; and sexuality of the flower. Mainly, there are two types of inflorescences: racemose and cymose. In some cases, special cymose and mixed racemose and cymose types of inflorescences are marked.

5.4.1. RACEMOSE INFLORESCENCE :

In this case, floral axis never terminates by a flower. The growth of floral axis is continuous or indefinite. The arrangement of flowers is acropetalous,. i.e., the older flowers remain towards the base while younger flowers are found towards the apex. The opening of flowers is centripetal. The basal or marginal older flowers open first which is followed by the upper or centrally placed flowers.

There are various types of racemose inflorescences in which floral axis is elongated or shortened or flattened being concave or convex. Racemose inflorescence is of the following types.

(A) Main axis elongated :

(a) Flowers pedicellate :

(i) Raceme :

The main axis is elongated and the flowers are borne laterally. All the flowers are pedicellate and borne acropetally. The lower older flowers in the rachis have longer pedicels, whereas, the pedicels of upper younger flowers are comparetively shorter. This type is seen in many plants such as *Brassica* (Fig. 5.1.1), *Raphanus, Crotalaria, Cleome,* etc.

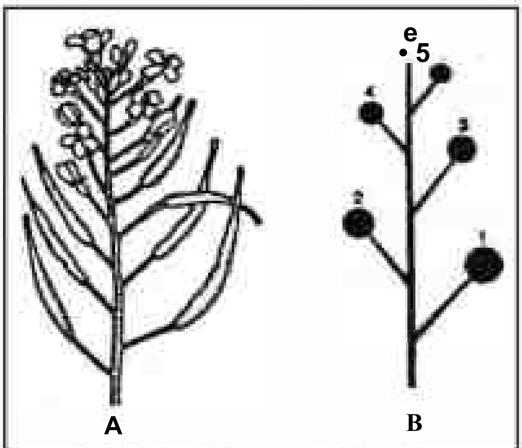


Fig.5.1.1. (A) Raceme of Brassica; (B) Raceme (diagrammatic presentation)

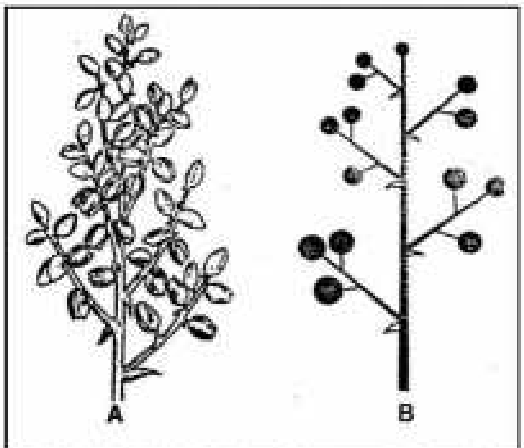


Fig.5.1.2. (A) Panicle of Yucca; (B) Panicle (diagrammatic presentation)

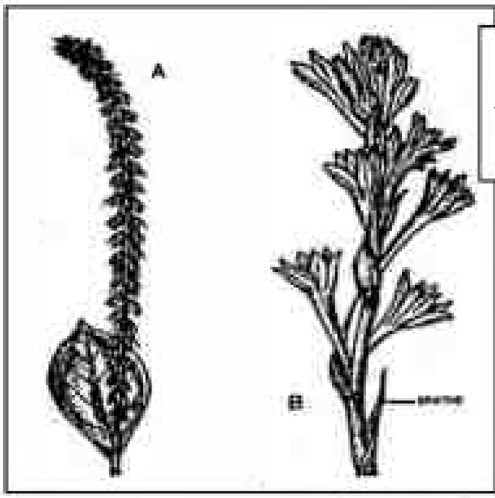


Fig.5.1.3. (A) Spike of Achyranthes (B) Spike of Polyanthes.

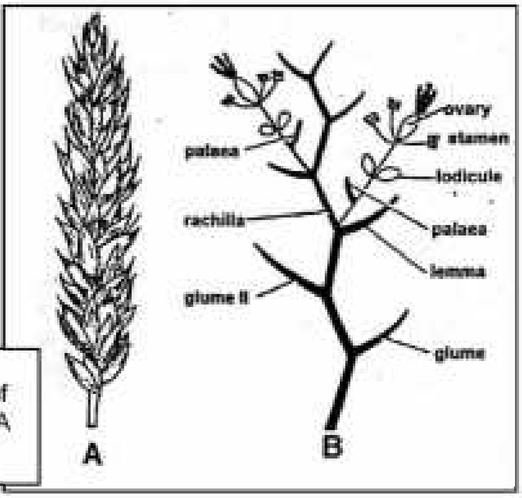


Fig.5.1.4. (A) Spike (of wheat; (B) A spikelet.

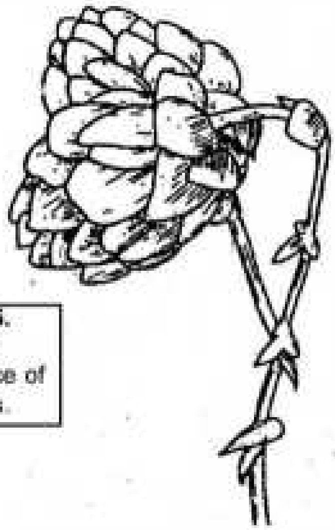


Fig.5.1.5. Strobile inflorescence of Humulus.

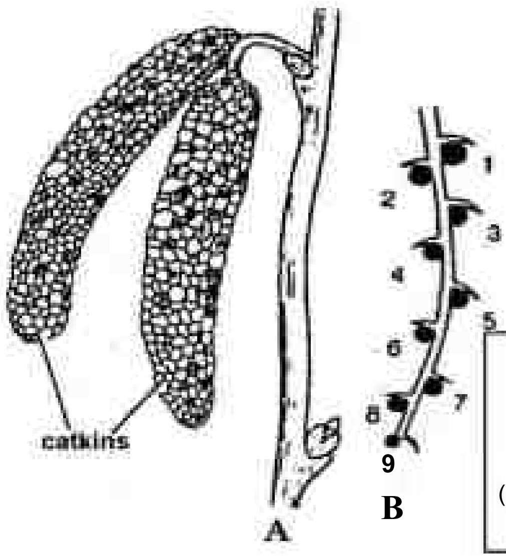


Fig.5.1.6. (A) Female catkin of Morus; (B) Catkin (diagrammatic presentation)

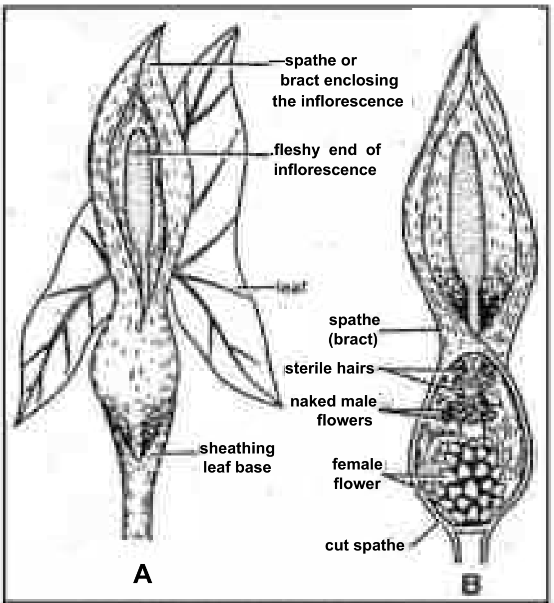


Fig.5.1.7. (A) Spadix of Colocasia;
(B) Spadix (diagrammatic presentation)

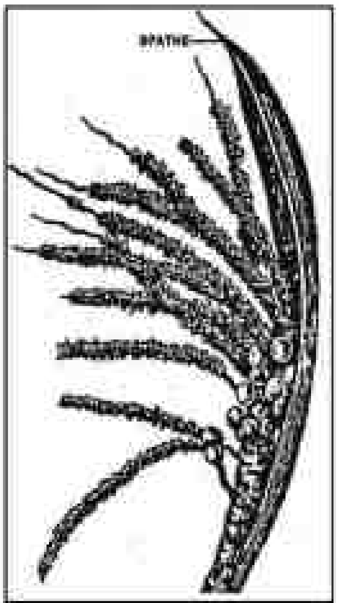


Fig.5.1.8. Compound spadix of coconut

When the main axis is branched and the branches bear the flowers as in raceme it is called **compound raceme** or **panicle.** These are found in *Caesalpinia, Yucca* (Fig.5.1.2), *Litchi, Andrographis paniculata,* etc.

(b) Flowers sessile

(ii) Spike :

It is similar to raceme, excepting that the flowers are sessile (without pedicel). Examples: *Achyranthes* (Fig.5.1.3), *Piper longum,* tuberose *(Polyanthes), Adhatoda vasica,* etc. In case the floral axis is branched and sessile flowers are borne on these branches as in spike then the inflorescence is called **compound** spike as seen in *Amaranthus.*

(iii) Spikelet or Locusta :

In the spikelet type of inflorescence, it is subtended by two bracts or glumes at the base. It consists of one to many flowers. Each flower is borne in the axil of a bract called **lemma** and a bracteole called **palea.** In rice, each spikelet is composed of one flower only and whole inflorescence is like a **panicle.** So it is called panicle of spikelets. In wheat (Fig.5.1.4), the multiflowered spikelets on an unbranched axis, looking like a compound spike called spike of spikelets, are seen. Panicle of spikelets is also found in many grasses.

(iv) Strobile :

It is a type of spike consisting of sessile flowers borne on the main axis. Each flower is borne in the axil of a persistent membranous bract, e.g., *Humulus lupulus* (Fig. 5.1.5).

(v) Catkin or Amentum :

It is a spike in which the floral axis is thin and weak. So the whole inflorescence is a drooping one (hanging downward). The inflorescence axis is long and pendulous and the flowers are unisexual, e.g., *Morus* (Fig.5.1.6), *Acalypha.* Sometimes, the pendulous axis is erect as in the male and female catkins of *Salix.*

(vi) Spadix :

The floral axis is thick and fleshy and the flowers are covered by one or several brightly coloured bracts, called *spathe,* e.g., *Colocasia esculanta* (Fig. 5.1.7), *Amorphophallus titanum.* In *Colocasia* the female flowers are borne towards the base of the axis. Above the female flowers some sterile flowers are borne followed by the male flowers. The top of the axis is without flowers and is known as appendix. When the axis of spadix is branched and sessile flowers are borne on these branches as in spadix, it is called **Compound spadix,** e.g., coconut (Fig. 5.1.8).

B. Main axis is shortened :

(vii) Corymb :

Here, the main axis is short. The flowers have unequal pedicels. The lower flowers have longer pedicels than the upper ones so that all the flowers remain more or less the same level, e.g., *Iberis, Prunus cerasus* (Fig. 5.1.9). **Compound corymb** is seen in the inflorescence of *Pyrus terminalis* (Fig. 5.1.10).

(viii) Umbel :

It is racemose type in which main axis is shortened. The flowers are borne at the tip of the axis. The flowers have more or less equal pedicels and appear to form a cluster. This type of umbel is called simple umbel, e.g., *Centella asiatica* (Fig.5.1.11) *Generally the* umbel is branched and the branches arise from a single point with a whorl of bracts known as **involucre.** These branches bear flowers in umbel like manner. This type of umbel is known as **compound umbel,** e.g., *Coriandrum* (Fig.5.1.12), *Foeniculum, Daucus carota* and other members of the family Umbelliferae (Apiaceae). The involucres of the secondary umbels are called **involucels.**

(ix) Capitate :

The rachis is shortened. Large number of sessile flowers grow from the suppressed floral axis appearing like a globose structure. Capitate type of inflorescence is seen in many leguminous plants like *Mimosa* (Fig.5.1.13), *Acacia, Albizia,* etc.

C. With main axis flattened to form receptacle :

(x) Capitulum or head or anthodium :

The floral axis is very much flattened forming a convex receptacle. The flowers are arranged on the receptacle. A large number of sessile flowers(called florets) are borne on the flattened axis (receptacle). The arrangement of flowers is in centripetal order. The whole inflorescence is

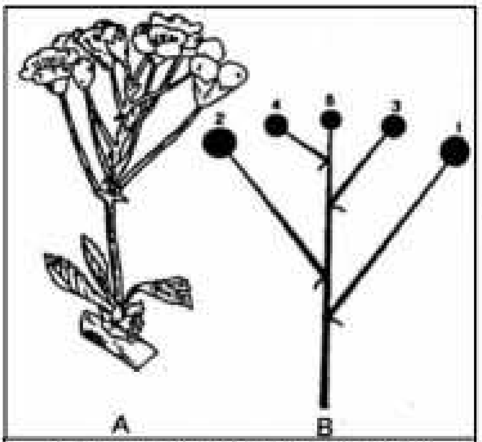


Fig.5.1.9.: (A) Corymb of cherry; (B) Corymb (diagrammatic)

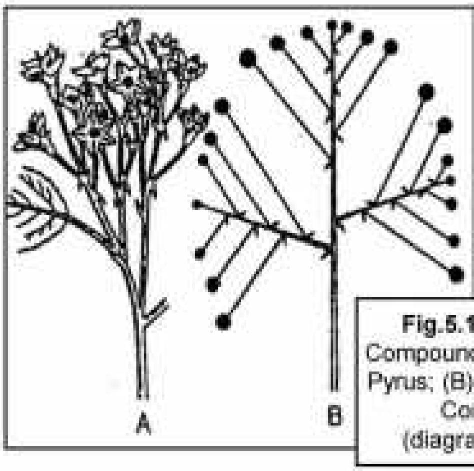


Fig.5.1.10.: (A) Compound Corymb of Pyrus; (B) Compound Corymb (diagrammatic)

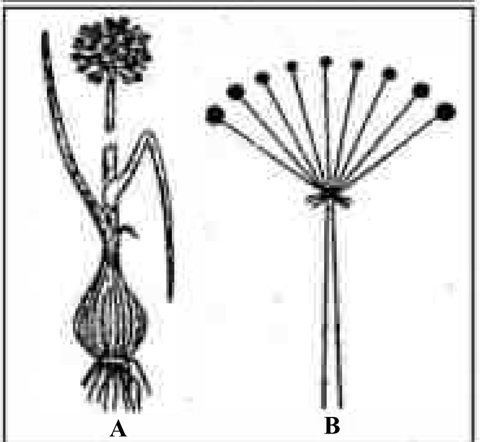


Fig.5.1.11.:(A) umbel of onion; (B) Umbel (diagrammatic)

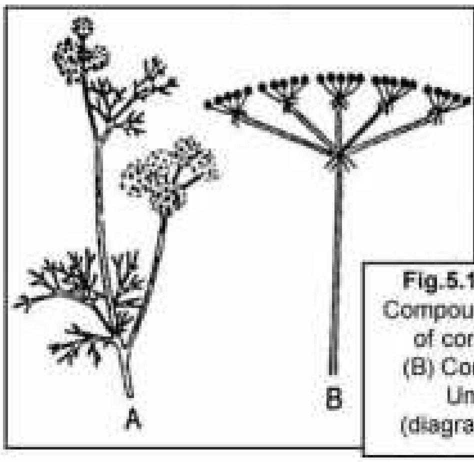


Fig.5.1.12.:(A) Compound Umbel of coriander; (B) Compound Umbel (diagrammatic)

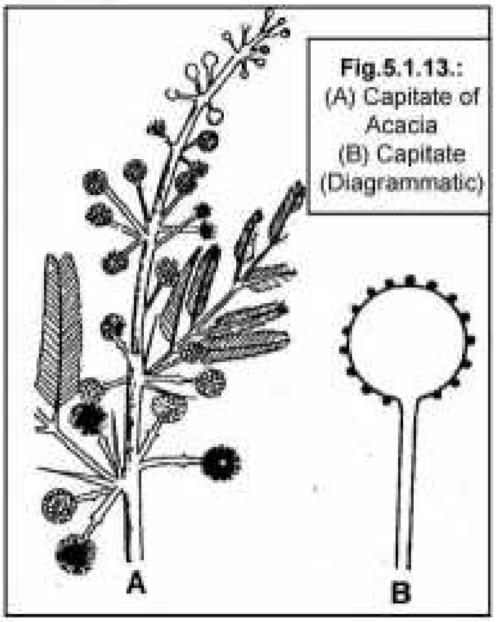


Fig.5.1.13.: (A) Capitate of Acacia (B) Capitate (Diagrammatic)

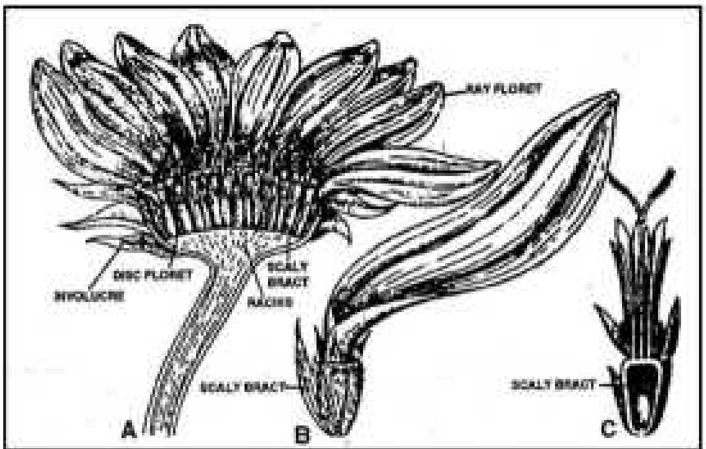


Fig.5.1.14.: (A) Capitulum of sunflower; (B) A ray floret; (C) A disc floret (partly dissected).

surrounded by a whorls of bracts (involucre), e.g., sunflower (Fig.5.1.14), marigold, and all members of the family Compositae (Asteraceae). In some of this type of inflorescence the marginal flowers differ from the central flowers and are known as ray florets and disc florets, respectively. But in *Chrysanthemum,* the florets are of same type (homomorphic). Compound capitulum consists of several capitula, is found in *Echinops echinatus* of family Compositae.

5.4.2. CYMOSE INFLORESCENCE :

The floral axis terminates with a flower. So, the growth of the floral axis is checked and the inflorescence is limited. The arrangement of flowers is basipetalous, i.e., the terminal flower is the oldest and younger flowers are found below it. Where the rachis is flattened, the order of opening of flowers is centrifugal.

Solitary axillary flowers in *Hibiscus* and *Datura* are placed under cymose inflorescence. Cymose is grouped under the following types.

(i) Uniparous or monochasial cyme :

The inflorescence axis terminates with a flower. From the base of the flower only one lateral branch comes out which also terminates by a flower. Depending on the branching, it is of following two types.

(a) Scorpioid cyme :

In this case, the axis terminates in a flower. The successive lateral branches develop in a zig-zag-manner on alternate side, each of which also ends in a flower, e.g., *Ranunculus bulbosus* (Fig.5.1.15), *Heliotropium indicum,* etc.

(b) Helicoid cyme :

The floral axis ends in a flower. The successive lateral branches develop on the same side forming a helix, e.g., *Myositis palustnis, Juncus* (Fig.5.1.16), *Begonia, etc.*

(ii) Biparous or dichasial cyme :

The main axis terminates in a flower. Two lateral branches develop on the two sides below the terminal flower of the main axis, each one being terminated by flower. The lateral branches may again branch similarly on two sides in biparous manner, e.g., *Ixora, Jasminum, Nyctanthes, Clerodendron* and *Dianthus,* (Fig.5.1.17).

(iii) Multiparous or polychasial cyme :

In this case, the main axis ends in a flower. It produces more than two lateral branches below the base of the terminal flower, each terminating in a flower. Here the middle or central flower opens first, e.g., *Calotropis* (Fig.5.1.18).

5.4.3. SPECIAL CYMOSE :

(i) Cyathium :

It consists of a cup-shaped green involucre with nectar glands on it. The central single female flower is surrounded by a number of male flowers each represented by a single stamen. These reduced male florets, along with a long stalked centrally placed female floret on a convex receptacle, represent the inflorescence, e.g., *Poinsettia (Euphorbia)* (Fig.5.1.19).

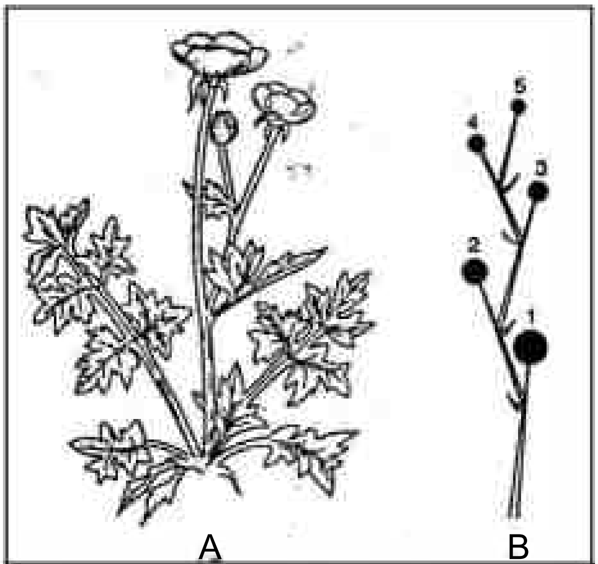


Fig.5.1.15. (A) Scorpioid of Ranunculus bulbosus; (B) diagrammatic

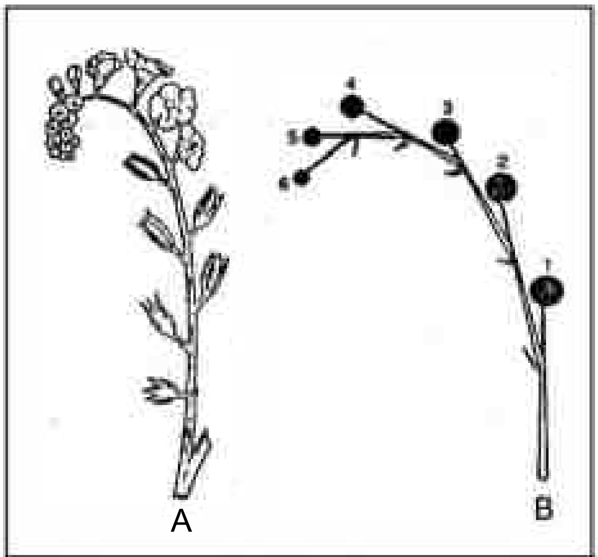


Fig.5.1.16. (A) Helicoid Cyme of Juncus; (B) diagrammatic

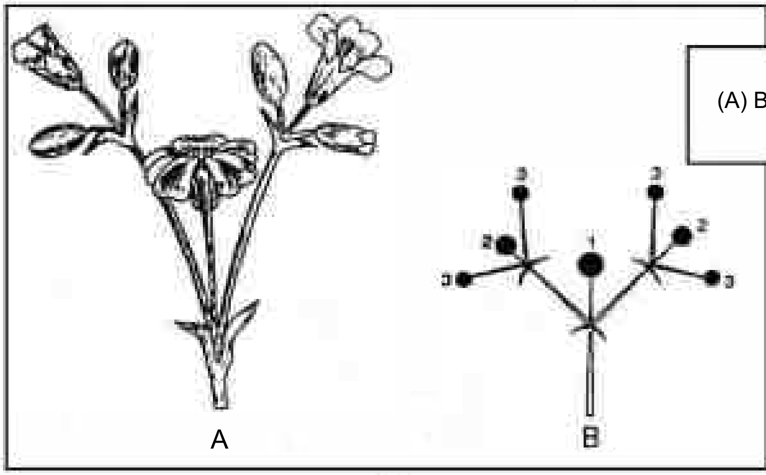


Fig.5.1.17.
(A) Biparous cyme of Dianthus;
(B) Diagrammatic

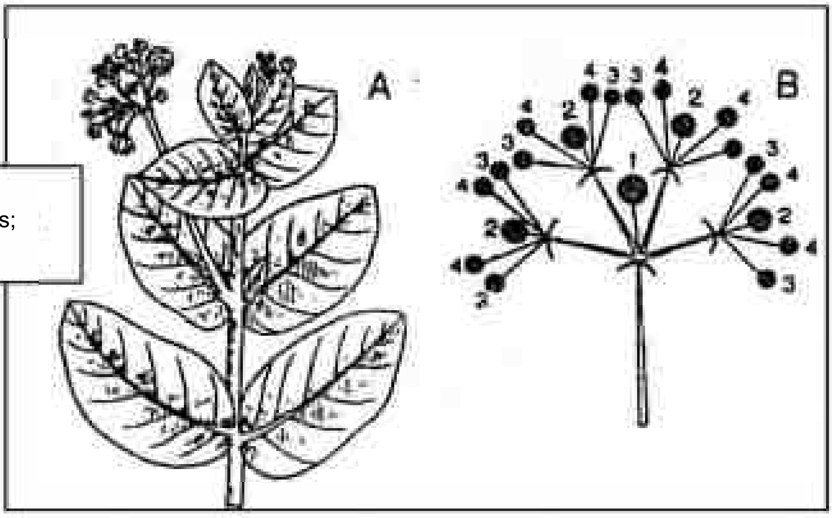


Fig.5.1.18.
(A) Polychasial cyme of Calotropis;
(B) Diagrammatic

(ii) Verticillaster:

Here is a long floral axis differentiated into several nodes. At each node, there are opposite leaves acting like bracts. Inflorescence develops at each of the two opposite axils. Each inflorescence is a condensed form of dichasial cyme, presence of which at two opposite sides of the node forms a false whorl. The dichasial cyme subsequently is reduced to two scorpioid cymes, e.g., *Asteracanatha longifolia, Leucas aspera* and *Leonurus sibiricus* (Fig.5.1.20).

(iii) Hypanthodium :

The floral axis forms a cup-shaped receptacle which is fleshy, almost closed and with an apical opening known as **ostiole.** Flowers are arranged in the inner wall of the cup in cymose manner, such that, flowers are not visible to outside. They are unisexual in which male flowers are near the ostiole and female flowers are found at the base of the cup, e.g., *Ficus* (Fig.5.1.21).

(iv) Coenanthium :

It is just like hypanthodium. But it shows a different type of receptacle. Instead of forming a closed structure, it becomes saucer-shaped with the margins slightly curved up, e.g., *Dorstenia* (Fig. 5.1.22).

(v) Cymose capitate :

In *Anthocephalus indica,* although the inflorescence looks like a racemose capitate type, the pattern of arrangement of flowers is cymose type. So it is cymose capitate type.

5.4.4. MIXED INFLORESCENCE :

The inflorescence showing both racemose and cymose pattern of arrangement of flowers is known as mixed inflorescence. These are as follows:

(i)Mixed panicle :

In this case, the general pattern of arrangement of flowers on the main axis is like panicle, but the top flower opens first- a characteristic feature of cymose, e.g., *Ligustrum* (Fig.5.1.23).

(ii) Mixed spadix :

The floral axis is elongated like racemose and covered by spathe like bracts as in spadix. But in this case, the individual group of flowers present at each node shows cymose arrangement, e.g., *Musa* (Fig.5.1.24).

(iii) Cymose umbel:

In this case, it looks like a simple umbel of racemose inflorescence but on closer observation, it is found that the umbel is formed by the grouping together of a number of smaller cymose inflorescences, e.g., *Allium cepa, Crinum, Lantana,* etc.

(iv) Cymose corymb :

Here, a number of smaller cymose clusters are arranged at the same level in a corymbose manner, e.g., *Alstonia scholaris, Holarrhena antidys.entrica, Oldenlardia corymbosa, Ixora parvifolia* (Fig.5.1.25).

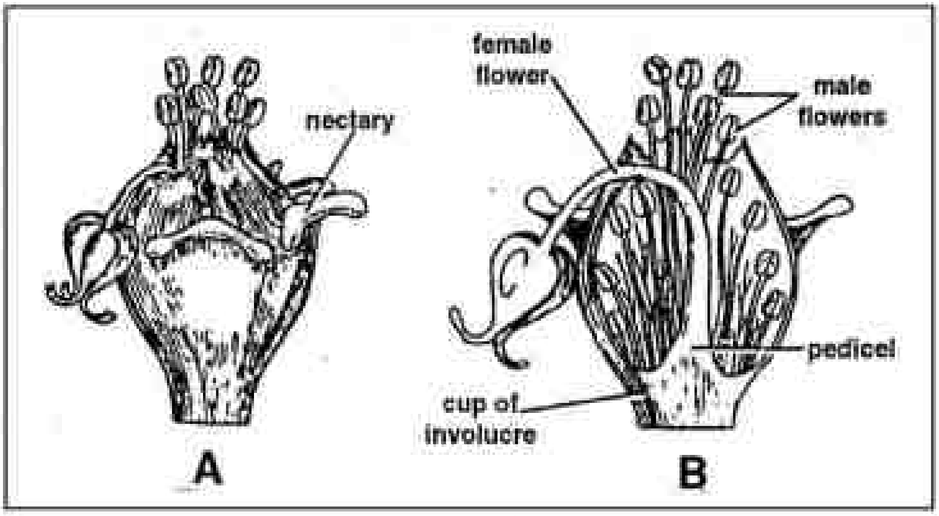


Fig.5.1.19. (A) Cyathium of Euphorbia (external view); (B) Longitudinal section

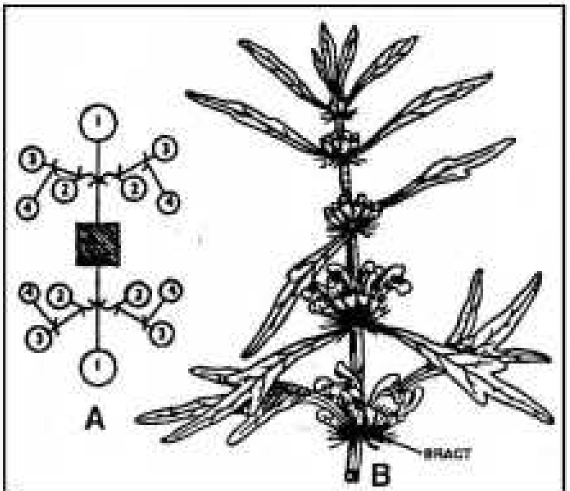


Fig.5.1.20. Verticillaster; (A) Ground plan (B) Leonurus sibiricus

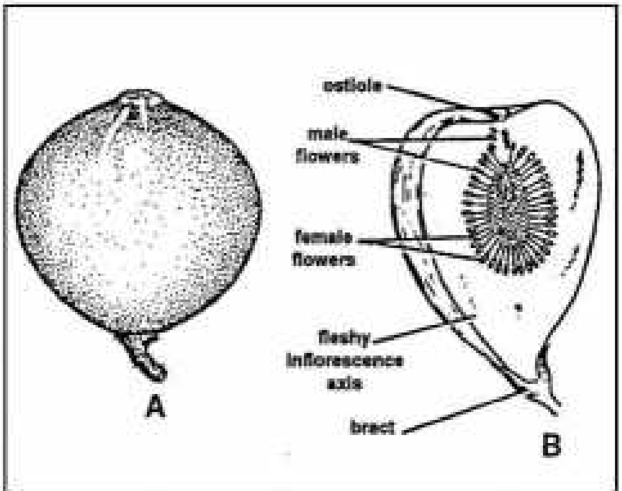


Fig.5.1.21. Hypanthodium of fig (A) External view (B) Longitudinal section

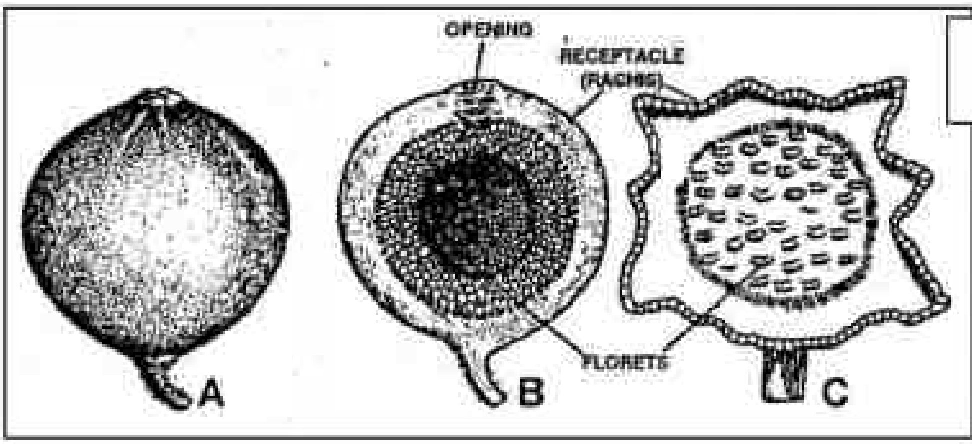


Fig.5.1.22. Coenanthium of Dorstenia cordifoila.

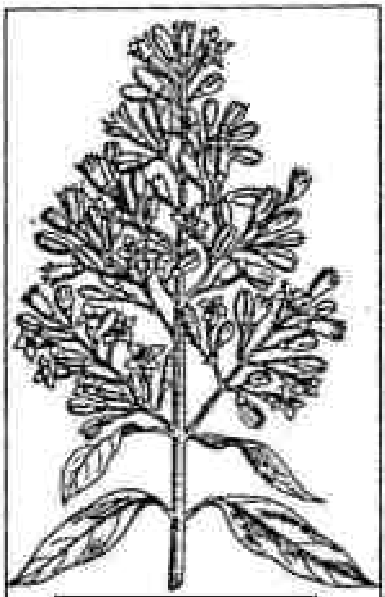


Fig.5.1.23.
Mixed panicle of
Ligustrum vulgare.

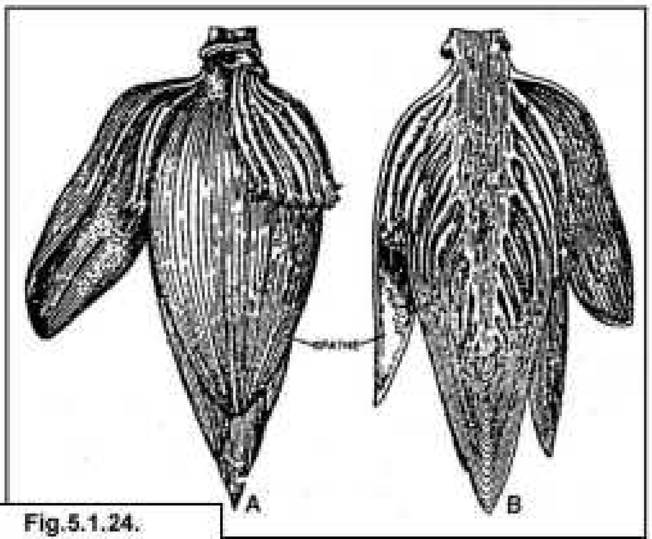


Fig.5.1.24.
Mixed spadix of banana
(A) External view
(B) L.S.

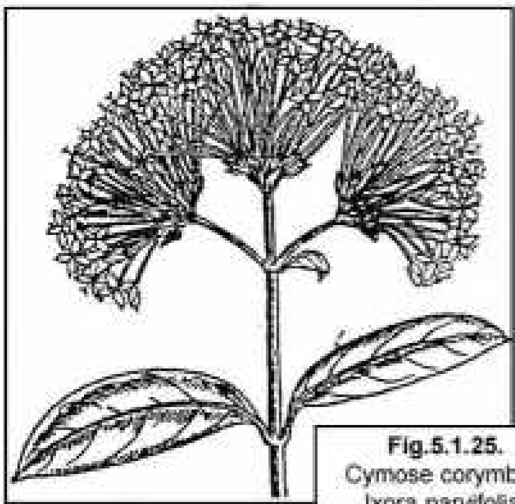


Fig.5.1.25.
Cymose corymb of
Ixora parvifolia.

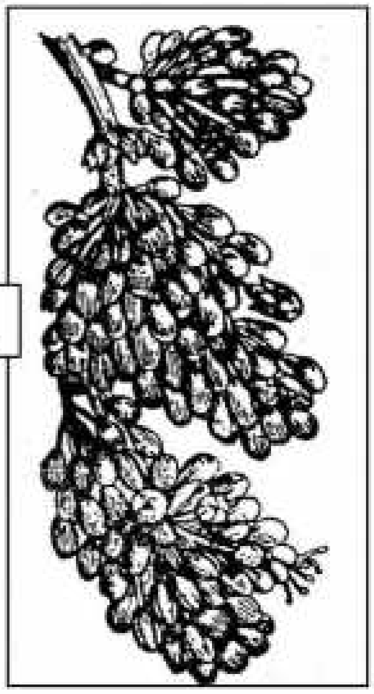


Fig.5.1.26.
Thyrsus of grape.

(v) Thyrsus :

A number of cymose clusters borne acropetally (characteristic feature of racemose) on an unlimited axis gives rise to thyrsus type inflorescence, e.g., grape vine (Fig.5.1.26).

5.5. FLOWER AND FLORAL PARTS :

Flower is the reproductive part of the plant. It is the most conspicuous structure of the angiospermic plants. Morphologically, it represents a short and compact branch, the growth of which is ceased. It develops from the floral bud. It is regarded as a metamorphosed shoot meant essentially for reproduction of the plant.

5.5.1 PARTS OF A FLOWER :

There are four different parts of a flower such as calyx, corolla, androecium and gynoecium. In some cases, it grows in the axil of a small appendage or leaf like structure known as **bract.** Flower having a bract is termed as **bracteate** and the flower without a bract is said to be **ebracteate.** The stalk that supports the flower is known as *pedicel.* Presence of a pedicel makes the flower **pedicellate** and its absence makes it sessile. The swollen portion of the pedicel that bears different parts of the flower is known as **receptacle** or **thalamus.** The floral parts are arranged on the thalamus as the leaves are arranged on the stem. It may be **spiral** or **cyclic.** Atypical flower shows cyclic or whorled type of phyllotaxy. The members of the consecutive whorls alternate with one another. The plants like lotus, *Magnolia,* etc., show spiral type of arrangement of floral whorls. In rose, it is spirocyclic or hemicyclic in which the floral phyllotaxy is partly spiral and partly cyclic.

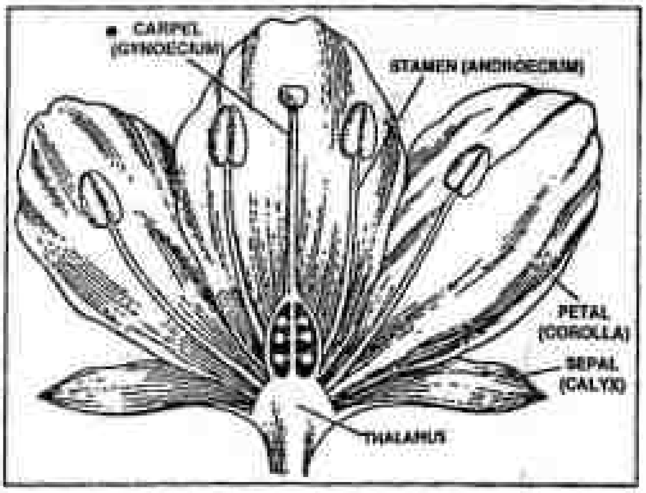


Fig.5.1.27. L.S. of a typical flower.

Atypical flower consists of four sets of members arranged in four successive whorls on the thalamus (Fig. 5.1.27). The **calyx** is composed of **sepals, corolla** of **petals, androecium** of stamens and **gynoecium** or **pistil** of **carpels.** Of these, **calyx** and **corolla** are known as **helping whorls** or accessory **whorls** while **androecium** and **gynoecium** are called the essential **whorls** or **reproductive whorls.** Calyx and corolla are the two outermost whorls which serve secondary purposes like giving protection to the reproductive parts and in making the flower attractive.The stamens of androecium are the **microsporophylls** and the carpels are the **megasporophylls.** These are the male and female sex organs, respectively. When the calyx and corolla cannot be distinguished and is represented only by one set of accessory members, the whorl of such members is termed as **perianth.** Androecium is the third floral whorl consisting of stamens. It is the male reproductive organ of the flower. Each stamen consists of a long stalk-like **filament** and two **anther lobes** bearing pollen grains. The tissue that joins filament with the anther lobes is called **connective.** Each anther lobe is made of two chambers called pollen sacs or **microsporangia.** Thus, generally there are four microsporangia in one anther. Similarly, the fourth and the last floral whorl, **gynoecium** consists of carpels (megasporophylls). It is differentiated into ovary, style and stigma. Ovary contains some small egg shaped structures within it, called ovules. Some of the terms used in connection with flower are given in the Table-5.1.1

Table-5.1.1
Terms used for description of flowers

TERM	MEANING	EXAMPLES
Complete	All the members are present in a flower	China rose
Incomplete	One or more of the floral members are absent	*Luff a*
Bisexual (Perfect)	Both male and female sex organs are present.	Chinarose
Unisexual (imperfect)	Only one reproductive whorl is present	—
i) Pistillate	Only gynoecium is present.	*Luff a*
ii) Staminate	Only androecium is present	*Luff a*
Monoecious	Both male and female flowers are present on the same plant.	Castor, Maize *Cucurbita*
Dioecious	Male and female flower are borne on two different plants.	Mulberry, Betel *Phoenix, Papaya*
Neuter	A flower which does not bear the androecium or gynoecium	Ray florets of sunflower
Gynomono-ecious	Bisexual and female flowers are present on the same plant.	Some members of Asteraceae
Andromono-ecious	Both bisexual and male flowers are present on the same plant.	Veratrum of liliaceae
Gynodio-ecious	Some plants are completely female while others bear bisexual flowers.	Thymus
Androdio-ecious	Some plants are completely male while others bear bisexual flowers.	—
Polygamous	Staminate, pistillate and bisexual flowers develop on the same plant.	Mango
Trioecious	Separate plants bear male, female and bisexual flowers.	Silene
Achlamydous	Flowers are without sepals or petals	Piper
Monochlamy-dous	Flowers have only one accessary whorl.	Tuberose
Dichlamy-dous	Flowers have both calyx and corolla.	Pea and Rose

Regular or Actinomorphic	The flower is divided into two equal and symmetrical halves when cut through any vertical plane passing through the axis.	Rose
Irregular and Zygomorphic	Flower can be cut into two equal halves only through one vertical plane passing through the centre	Pea, Bean, *Cassia*
Irregular and asymmetrical	Flowers cannot be cut into two symmetrical halves along any plane.	*Canna*
Isomerous	Sepals, petals, stamens and carpels number is uniform,i.e., they are same or multiple of a base number (2,3,4, or 5)	*Papaver, Argemone Brassica, Hibiscus*
Hetero-merous	The numbers of members of different whorls are different	—
Tetracyclic	Flowers have one whorl each of calyx, corolla, androecium and gynoecium	—
Pentacyclic	When there is two whorle of stamens or two whorls of petals.	—
Polycyclic	If the number of whorls increases more than pentacyclic condition	Wild rose.

5.5.1. THALAMUS :

Thalamus is the direct prolongation of the pedicel and is also called **torus** or **receptacle.** It may be elongated and conical or like an inverted cone with a spongy flat top as in lotus. It may be slightly convex as in brinjal or as in *Artabotrys, Michelia,* etc. and cup-shaped as in epigynous flowers.

In most of the flowers, thalamus has three internodes which are condensed. When it is elongated, the first internode (between calyx and corolla) is called **anthophore,** the second internode (between corolla and androecium) is called **androphore** or **gynandrophore** and the third internode (between androecium and gynoecium) is known as **gynophore.** Gynophore is seen in the flower of *Capparis sepiaria* (Fig.5.1.28). Androphore or gynandrophore is found in *Passiflora suberosa* (Fig.5.1.29). Sometimes the thalamus projects into the ovary and the carpels remain attached to it which a separated at maturity. This type thalamus is called **carpophore,** e.g.. *Foeniculum vulgare* (Fig.5.1.30).

The floral leaves are inserted on the thalamus. If it is inserted successively such as calyx, corolla, androecium and gynoecium and it is terminated by the gynoecium the flower is termed

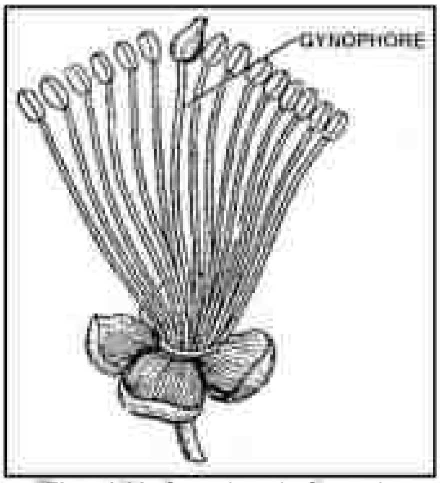


Fig.5.1.28. Gynophore in Capparis sepiaria

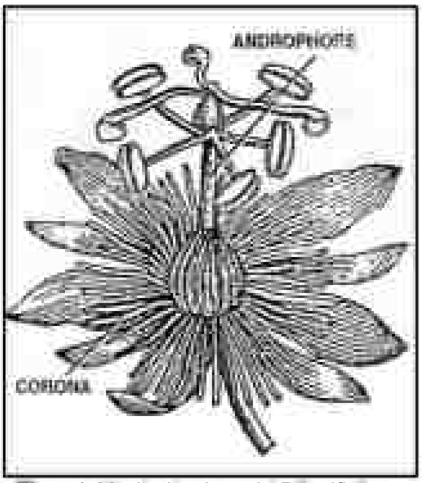


Fig.5.1.29. Androphore in Passiflora suberosa

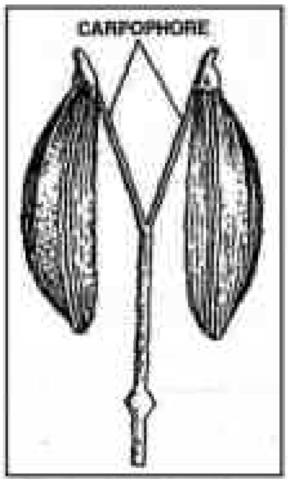


Fig.5.1.30. Carpophore in Foeniculum vulgare.

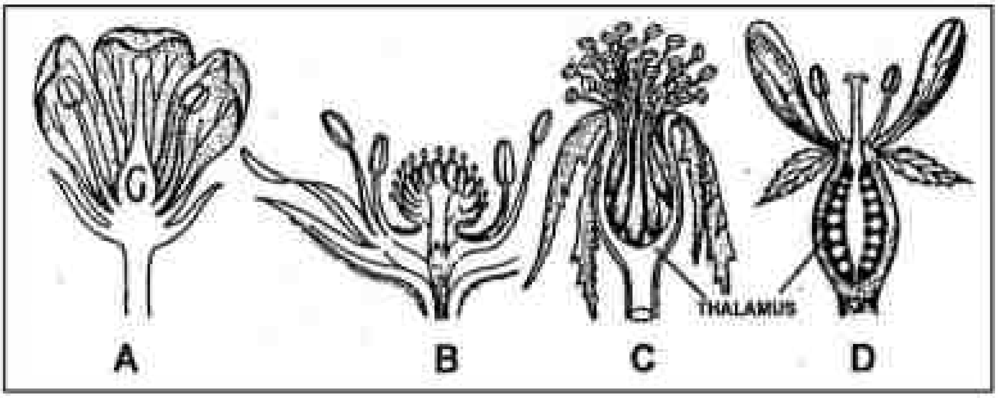


Fig.5.1.31. INSERTIONS OF FLORAL LEAVES : (A) Hypogynous; (B) Perigynous with flat receptacle in strawberry; (C) Perigynous with concave receptacle in rose; (D) Epigynous.

as **hypogynous,** i.e, ovary is superior. It is very common and found in *Magnolia,* mustard brinjal, etc. In case of cup-shaped concave thalamus, the gynoecium is placed at the centre of the cup. It is , called **perigynous** and here ovary is half superior and half inferior. The other three whorls are inserted on the rim of the flat or the concave thalamus, e.g., peas, strawberry, rose, etc. In the third type of insertion of the floral whorls on the thalamus, it is found that the cup shaped thalamus may fuse with the wall of the ovary giving it the lowest position. The other floral whorls remain above the ovary and in this case, the ovary is said to be **inferior.** This condition of insertion of floral whorls, in relation to the thalamus is called **epigynous,** e.g., sunflower, guava and the unisexual pistillate orfemale flowers of *Cucurbita* (Fig. 5.1.31).

Table-5.1.2

Different types of bracts with examples

Type	***Character***	***Examples***
Leafy bracts	leaf like appearance	*Adhatoda*
Scaly bracts	bracts membranous	disc-florets of Sunflower
Spathe	large, brightly coloured enclosing infloroscence	Banana, maize
Involucre	bracts in one or more whorls around a flower or a group of flowers	Marigold, Sunflower
Petaloid	bracts coloured and showy	*Bougainvillea,*
Glumes	small, dry, scaly bracts	Rice

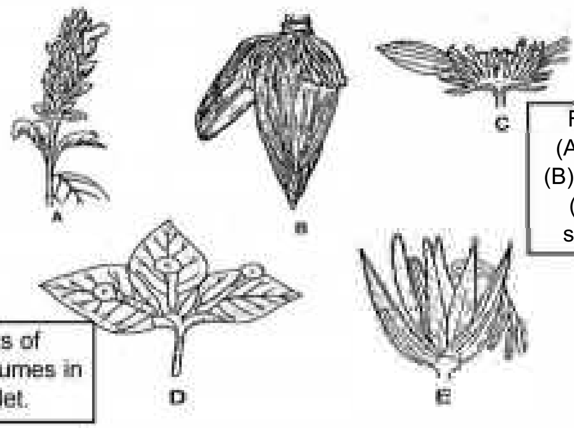


Fig.5.1.34.Types of bracts :
(A) Leafy bracts of Adhatoda;
(B) Spathe of spadix of banana;
(C) Capitulum of sunflower showing involucre of bracts;

(D) Petaoid bracts of Bougainvillea; (E) Glumes in the maize spikelet.

Fig.5.1.32. Different types of bracts and bracteoles

5.5.2. BRACTSAND BRACTEOLES :

Bracts are special leaves from the axil of which a solitary flower or a cluster of flowers arise. Its position is at the base of the pedicel (Table-5.1.2). Besides, bract-like or scaly appendages are found on the pedicel. These are known as **bracteoles.** The bracteoles may form a whorl just below the calyx as in China rose, in which such a whorl is known as **epicalyx.** Bracts vary in size, colour and longevity. Their main function is to protect the floral bud (Fig. 5.1.32). For this purpose, sometimes they become very much enlarged enclosing the whole cluster of flowers. When green in colour, they also manufacture food. Sometimes they become brightly coloured in order to attract insects for pollination.

5.5.3. CALYX:

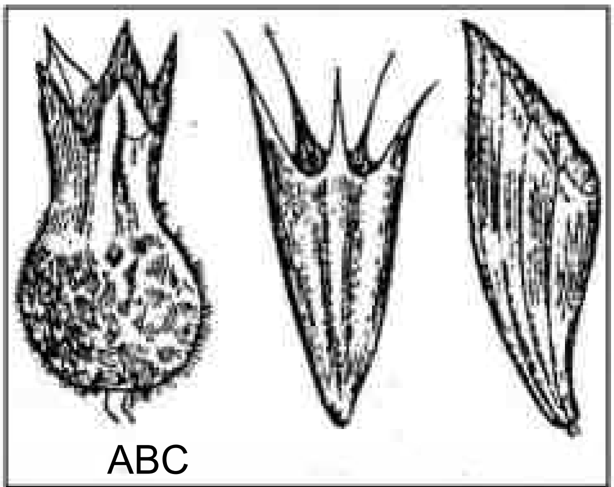


Fig.5.1.33. (A) Ureceolate in Hyoscyamus, Bilabiate in (B) Leonurus; (C) Leucas.

It is the lower most (or outermost) whorl of the flower, consisting of a number of sepals. These are usually green, somewhat resembling small leaves. Below the calyx, in some plants, there may be presence of epicalyx which is regarded as bracteoles rather than parts of a flower. In the bud stage, flower is protected by the calyx. Like symmetry of flower, it may be regular or irregular. If the members are free from one another, it is termed as **polysepalous** or **dialysepalous,** as seen in mustard. If the sepals are wholly or partially united with one another forming a tube like structure, it is called **gamosepalous. Regular gamosepalous** calyx may be tubular, bell shaped, or urceolate, etc. Irregular gamosepalous calyx is generally bilabiate (Fig.5.1.33 A, B and C)

In some, the sepals may be coloured like petals and are called petaloid. These attract insects for pollination.

Duration of calyx :

On the basis of the length of time that the calyx remain attached to flower or fruit, the calyx may be of different types, as shown in Table 5.1.3.

Table - 5.1.3

Types of calyx on the basis of duration attached to flowers

Type	***Character***	***Examples***
Caducous	Calyx drops off as soon as the flower opens	*Papaver, Argemone,* etc.
Deciduous	Calyx falls off along with the petals (corolla)	*Brassica*
Persistent	Calyx remain attached to the fruit	*Solanum, Datura,* etc.
Marcescent	Persistent calyx assumes a shrivelled dry-up appearance	*Guava*
Accrescent	Persistent calyx grows with the fruit	*Physalis, Shorea*

Modification of calyx :

The sepals of calyx in some cases appear in different forms to serve different functions other than the normal. It is due to modification of calyx. It is **petaloid** or petal-like in *Sterculia roxburghii* due to scarlet colour of calyx. Petaloid calyx is also seen in *Saraca asoca* and *Caesalpinia pulcherrima.* The calyx is modified into hairy, scaly or feathery structure known as **pappus** as in *Tridax,* Sunflower, etc. It is **spinous** in *Trapa.* In *Musaenda* out of five sepals, four sepals are normal, but the fifth one is large and **petaloid.** In some other cases, the sepal is prolonged downwards forming **spurred** sepals, e.g., *Delphinium, Impatiens.* Different types of modified calyx are shown in Fig.5.1.34.

5.5.4. COROLLA :

It is the second (accessory) whorl of flower. Its members are called *petals.* The corolla also protects the stamens and carpels in bud condition like does calyx. It is generally brightly coloured due to the presence of anthocyanin and anthoxanthin pigments. The primary function of corolla is to attract the insects for pollination. It is possible due to the bright colour of the petals combined with the scent of essential oils present in it. Like calyx, the corolla may be polypetalous or gamopetalous in which the petals may be free or united. Petals may sometimes be green and may look like the sepals. In this case, it is termed as **sepaloid** as in *Annona, Polyalthia, Artabotrys,* etc. In general the lower part of a petal is narrow known as **claw;** and the upper part is wide, called **limb.** It is seen in polypetalous corolla. The claw corresponds to the petiole, and the limb to the blade of a leaf. The polypetalous corolla is also known as **dialypetalous,** while gamopetalous corolla is called **sympetalous.** When united, the united portion is the **corolla tube** and the portion above is known as the **corolla lobes.** The junction of the portion of the tube which opens into the limb is called **throat.**

Forms of corolla :

The form of corolla may be of various types. It depends on symmetry of corolla, free or united condition of petal and shapes of petals. The different forms of corolla are given below.

(a) Polypetalous and regular corolla :

- **(i) Cruciform:** It consists of four free petals, each having differentiated into claw and limb. These are arranged in the form of a cross, e.g., mustard, radish, cabbage, etc. (Fig.5.1.35 A).
- **(ii) Caryophyllaceous:** This form of corolla consists of five petals. The claws are long while the limbs of the petals are placed at right angles to the claws, e.g., *Dianthus,* (Fig.5.1.35.B).
- **(iii) Rosaceous:** It consists of five petals with very short claws or none at all. The odd petal is anterior and the limbs spread regularly outwards, e.g., wild rose, tea etc. (Fig.5.1.35 C).

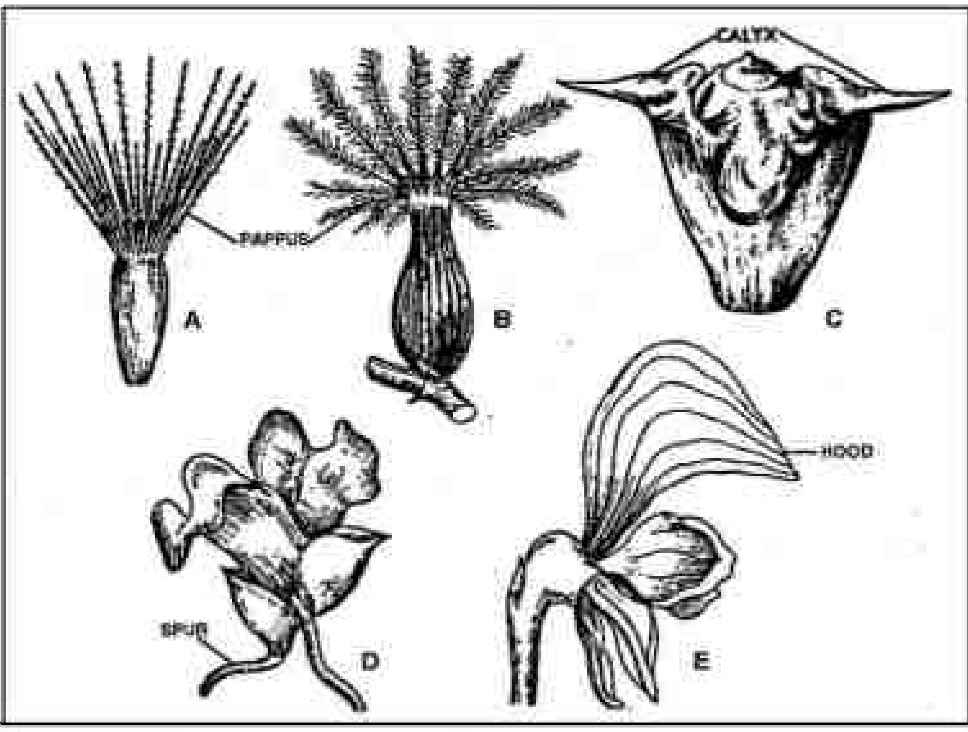


Fig.5.1.34. Pappus in (A) Mikania scandens (Compositae); (B) Valeriana (Valerianaceae); (C) Spinous calyx in Trapa bispinosa; (D) Spurred calyx of Impatiens balsamina; (E) Hooded calyx of monkshood (Aconitum napellus).

(b) Polypetalous and irregular corolla :

(i) Papilionaceous : Its general appearance resembles a butterfly. Out of five petals, the posterior petal is larger than others and termed as **standard** or **vexillum,** the two lateral ones are known as **wings** or **alae,** and the two innermost are known as the **keel** or **carina.** These two innermost are united to form a boat-shaped cavity, e.g., pea, bean, gram, etc. (Fig.5.1.35 D).

(c) Gamopetalous and regular corolla :

(i) Tubular: The corolla tube is cylindrical throughout and the limbs are not spreading. Tube is more or less equally expanded from base to apex, e.g., central florets of sunflower (Fig.5.1.35 E)

(ii) Campanulate:

The petals are united forming a bell-shaped structure, e.g., *Cucurbita* (Fig.5.1.35 .F), *Physalis,* etc.

(iii) Infundibuliform: The corolla is funnel shaped looking like an inverted cone, e.g., *Datura, Ipomoea,* etc. (Fig.5.1.35.G).

(iv) Hypocrateriform : Gamopetalous corolla is found with a long slender tube and expanded flat limbs placed at right angles. It is also known as salver shaped, e.g., *Vinca rosea.* (Fig.5.1.35 H).

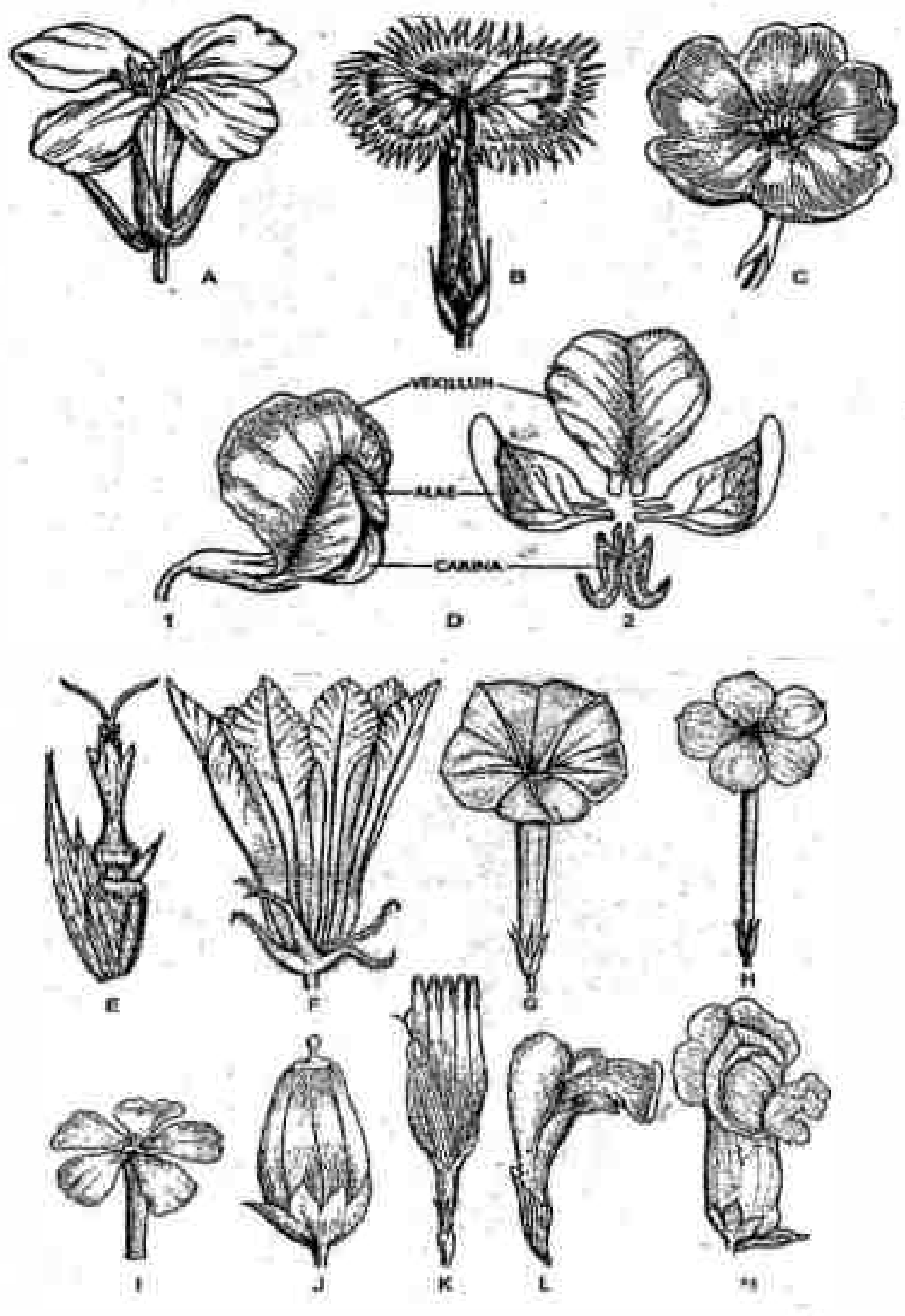


Fig.5.1.35. Polypetalous corolla forms. (A) Cruciform in mustard (Brassica nigra); (B) Caryophyllaceous in pink(Dianthus chinensis); (C) Rosaceous in wild rose; (D) Papilionaceous in pea; (1) Complete; (2) Corolla dissected to show arrangement and forms of petals;
Gamopetalous corolla forms : (E) Tubular in sunflower disc floret; (F) Campanulate in Cucurbita; (G) Infundibuliform in Ipomoea; (H) Hypocrateriform in Vinca; (I) Rotate in Nyctanthes; (J) Urceolate in Kalanchoe; (K) Ligulate in marigold ray floret; (L) Bilabiate in Leucas; (M) Personate in snapdragon

(v) Rotate: Gamopetalous wheel shaped corolla, the tube of which is shorter than the hypocrateriform. It has petals with a circular limb at right angles to the tube, e.g., *Nerium, Nyctanthes* (Fig.5.1.35.1).

(vi) Urceolate: The corolla tube is swollen in the middle, tapering towards both base and apex like a spindle, e.g., *Kalanchoe*

(d) Gamopetalous and irregular corolla :

(i) Ligulate or strap-shaped : Here five petals are united to form a short tube at base which is flattened on one side like a strap or tongue, e.g., the ray florets of *Tagetes Patula* (Fig.5.1.35K).

(ii) Bilabiate: The corolla is gamopetalous, zygomorphic and divided into two lips upper and lower. The mouth of corolla is wide open. The upper posterior part is formed by the union of corolla lobes while the unequal lower anterior part is formed by the union of three lobes. It is mostly seen in *Ocimum, Leucas* (Fig.5.1.35 L) and in *Asteracantha.*

(iii) Personate: It is also bilipped but here the lips are placed so near to each other that the mouth of corolla is closed. The projection of the lower lip closing the mouth is called **palate,** e.g., *Antirrhinum* (Fig.5.1.35M).

Fig.5.1.36.Polyphyllous petaloid perianth of Gloriosa superba

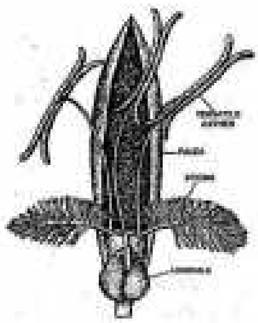


Fig.5.1.37.Flower of Festuca pratensis

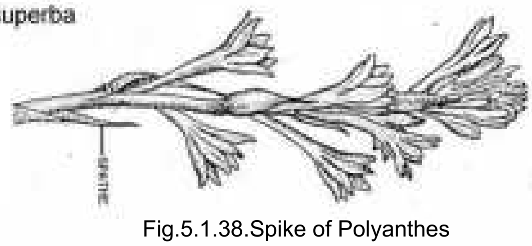


Fig.5.1.38.Spike of Polyanthes

In most of the monocots the accessory whorls look alike. They are not differentiated into green calyx and coloured corolla. These are collectively known as **perianth,** and the individual member are called tepal. When the tepals are green like sepals, perianth is called **sepaloid,** e.g., date palm and when these are brightly coloured, it is known as **petaloid,** e.g., *Gloriosa* *superba* (Fig.5.1.36). In grasses the perianth is represented by two lodicules, e.g., *Rice* (Fig.5.1.37). If the perianth members are free from one another as in *Gloriosa,* it is termed as **polyphyllous,** but when united it is called **gamophyllous,** e.g., *Polyanthes tuberosa* (Fig. 5.1.38).

Aestivation :

The arrangement of petals (and also of sepals) in bud condition with respect to its sister segments is known as aestivation. It is of following types.

(i) Valvate: The sepals or petals meet by their edges only, e.g., sepals of *Solarium.* (Fig.5.1.39A)

(ii) Twisted or **contorted :** When the margin of petal is overlapped by the next one and the other margin is overlapped by the succeeding one, it gives a twisted aestivation (Fig.5.1.39B).

(iii) Imbricate: When anyone of the petal or sepal is completely inner, one completely outer and each of the remaining members overlap with each other, it is known as imbricate aestivation. It is of two types:

(a) Ascending imbricate :

The posterior petal is innermost, i.e., its both margins are overlapped (Fig.5.1.39 C), e.g., *Cassia, Bauhinia, Caesalpinia,* etc.

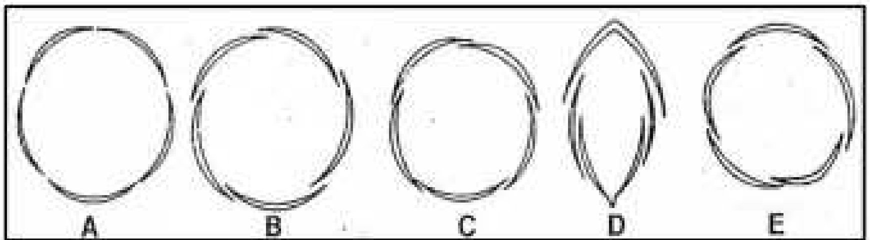


Fig.5.1.39. Schematic presentation of aestivation (A) Valvate (B) Twisted (C) Ascending imbricate (D) Descending inbricate (E) Quincuncial

(b) Descending imbricate/vexillary :

The posterior petal is the largest and outer most known as **vexillum** while the anterior petal is innermost, is known as keel, e.g., pea, beans (Fig.5.1.39 D), etc.

(iv) Quincuncial: It is a modification of imbricate type. Out of the five petals, two are completely internal, two completely external while the remaining one is overlapped, e.g., *Murraya* (Fig.5.1.39 E)

5.5.5. ANDROECIUM :

The androecium is the **male reproductive whorl** of the flower. It is composed of **stamens.** Each stamen consists of **filament, anther** and **connective** (Fig.5.1.40). It is the microsporophyll consisting of **anther lobes** or pollen sacs. The pollen sacs are grooved longitudinally along the ventral face of the anther forming the pollen chambers. Each pollen chamber is a microsporangium

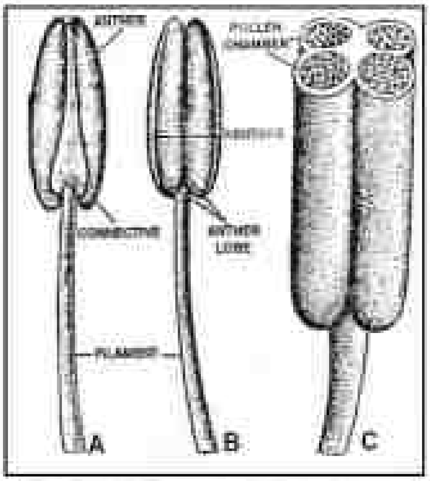


Fig.5.1.40. Stamen (A) Dorsal view; (B) Ventral view; (C) T.S. of anther

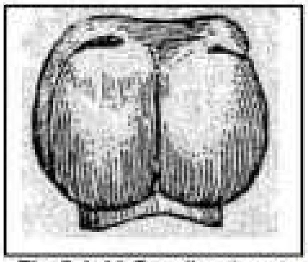


Fig.5.1.41. Sessile stamen of Arum maculatum.

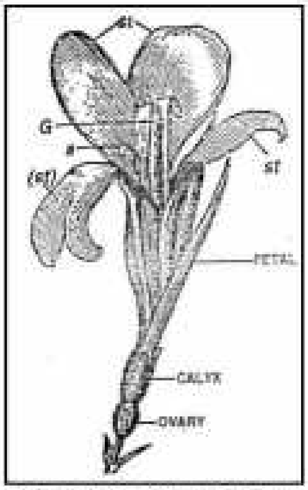


Fig.5.1.42. Canna indica st=staminode; a=another; g=pistil

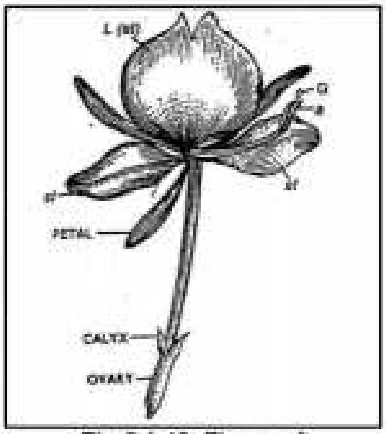


Fig.5.1.43. Flower of Hedychium coronarium L = labellum

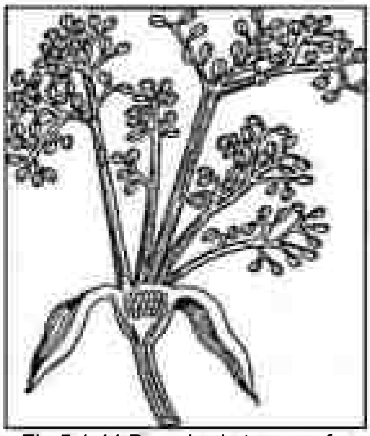


Fig.5.1.44.Branched stamen of castor (after Van Tieghem)

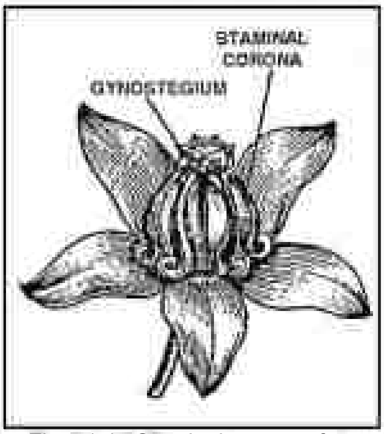


Fig.5.1.45.Staminal corona of Calotropis procera

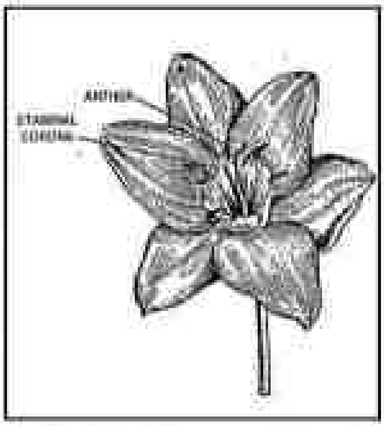


Fig.5.1.46. Staminal corona of Eucharis amazonica

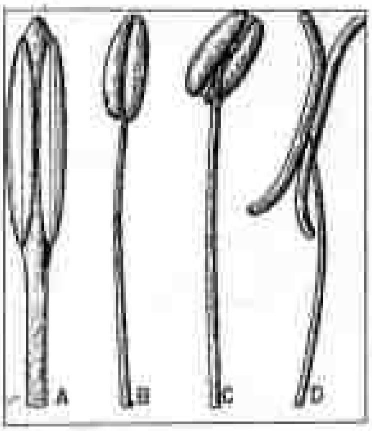


Fig.5.1.47. Attachment of anthers (A) Adnate (B) Basifixed (C) Dorsifixed (D) Versatile

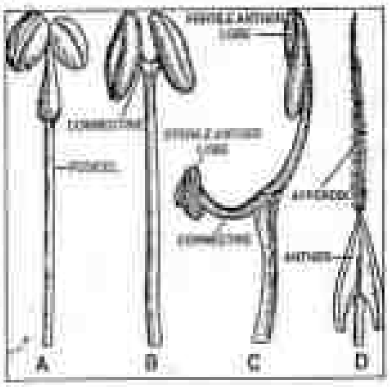


Fig.5.1.48. Different types of connectives (A) Discrete (B) Divaricate (C) Distractile (D) Appendiculate

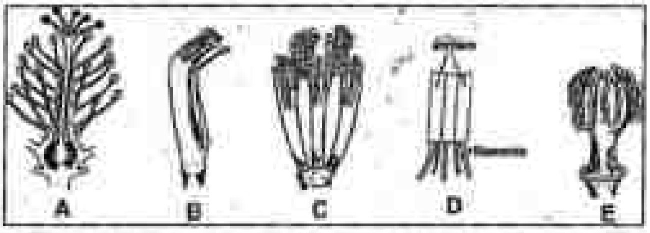


Fig.5.1.49. Cohesion of stamens : (A) Monadelphous; (B) Diadelphous; (C) Polyadelphous; (D) Syngensious; (E) Synandrous

and contain numerous pollens or microspores. A typical anther is dithecous having two elongated lobes. The stamen, therefore, bear four microsporangia or pollen chambers. But in many cases there are only two and sometimes these two pollen chambers fuse forming a mature unilocular anther, e.g., China rose, lady's finger, cotton, etc. In *Calotropis* and orchids, the pollen grains are aggregated in a mass within a membranous sac called **pollinium.** According to the number of stamens present in a flower, it may be **monandrous** *(Poinsettia),* diandrous (Acanthaceae), **triandrous** (many monocots), tetrandrous (Lamiaceae), **Pentandrous** (most dicots), *hexandrous* (rice, bamboo, etc.) or *polyandrous* (Rosaceae).

(a) Filament:

The filament is a slender stalk of the stamen which bear anthers. In rare cases a stamen may be devoid of filament **(sessile),** e.g., *Arum maculatum* (Fig.5.1.41). In some cases a stamen may not develop any fertile anther and it is termed as **staminode** e.g.. *Cassia* and *Canna.* In the flower of *Canna,* the showy **labellum** is formed of staminodes (Fig.5.1.42 & 5.1.43). When the filament is very long, stamens come out of the flower and are termed as **exserted.** But, if it remains within the flower, it is termed as **inserted.** The filament is ordinarily simple, but it is branched in *Ricinus* (Fig.5.1.44). Filaments bearing appendages are called staminal corona. It is horny in *Calotropis* (Fig.5.1.45) and cup shaped in *Eucharis* (Fig.5.1.46), *Pancratium,* etc. The mode of attachment of filament to the anther varies. When it is attached throughout the length at the back of the anther, it is called **adnate,** e.g., *Magnolia* and waterlily. If the filament ends just at the base of the anther, it is called **basifixed ,** or **innate,** e.g., mustard, *Carex,* etc. The attachment is called **dorsifixed** when the filament is attached to the back of the anther, e.g., passion-flower and *Sesbania,* etc. In the members of family Cyperaceae or in many grasses the attachment is **versatile** in which the filament is attached at a point about the middle part of the connective and the anthers seem to swing freely on the filament. The above types of attachment is shown in the Fig.5.1.47. The stamens may be **tetradynamous** or **didynamous** based on the length of filaments. In the former out of six stamens, four inner are long and two outer are short while in the latter, two are long and two are short.

(b) Anther:

In all angiosperms, the anthers are generally bilobed and formed of four microsporangia. It is rarely unilobed or one-chambered either by the abortion of one lobe or by the destruction of the partition tissue separating the four chambers. The grooved ventral side of the another if faces the gynoecium or the centre of the flower, the anther is **introse** but in few cases as in *Gloriosa superba, Iris, Colchicum,* etc. the anther faces the petals and such an anther is termed as **extrose.**

(c) Connective :

It is a patch of tissues connecting the parallel anther lobes. It may be extremely small or not well marked and termed as **discrete,** e.g., sps. of *Euphorbia* and *Adhatoda zeylanica.* The condition is **divaricate** when connective separates the two anther lobes from one anther, e.g., *Tilia* and *Justicia gendarussa.* In *Salvia,* the connective separates two another lobes, of which the upper one is fertile and lower sterile. This condtion is termed as **distractile.** The condition is also called **appendiculate,** when it bears appendages as seen in *Thevetia.* Different types of connectives are shown in Fig.5.1.48.

Cohesion and adhestion of stamens :

Cohesion is defined as the fusion of the members amongst the same whorl while adhesion is the fusion of the members with respect to the different whorls.

(a) Cohesion of stamens :

Following terms are used to describe the different conditions of cohesion of stamens confined to different parts of stamens only.

(i) Polyandrous : The statmens are free from one another. Anthers and filaments remain completely free.e.g, *Papaver, Ranunculus,* etc.

(ii) Adelphous : In this case, the filaments are fused and anthers remain free. Depending on the bundles (fused filaments) formed; these may be of different types (Fig.5.1.49A, B, C).

(a) Monadelphous : The filaments of stamens are fused to form one bundle while anthers remain free, e.g., *Hibiscus, Abutilon, etc.*

(b) Diadelphous : The filaments are united into two bundles, anthers remaining free, e.g., *Pisum* (Fig. 5.1.49 B).

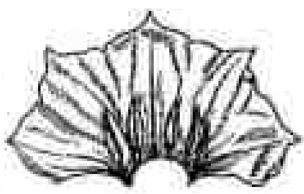


Fig.5.1.50.Epipetalous stamens in brinjal.

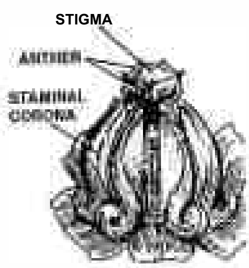


Fig.5.1.51.Gynostegium in Calotropis.

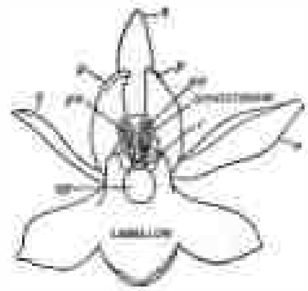


Fig.5.1.52.Flower showing gynostemium sp=opening into spur; r=rostellum; po=pollinia; s=sepal; p=petal; c=caudicle; d=disc.

(c) Polyadelphous : The filaments are united to form many bundles, anthers being free, e.g., *Bombax, Citrus,* etc. (Fig. 5.1.49C).

(iii) Syngenesious : In this case, stamens are united by their anthers (Fig.5.1.49.D) while filaments are free as in Asteraceae, e.g., *Tridax, Helianthus,* etc.

(iv) Synandrous : Here both filaments and anthers of the stamens are united (Fig. 5.1.49 E) throughout their length, e.g., *Cucurbita, Lagenaria,* etc.

(b) Adesion of stamens : It is the union of stamens with respect to the different whorls of the flower (such as stamens and petals, stamens and carpels). These are of following types.

(1) Epipetalous : When stamens adhere to petals, it is called epipetalous condition e.g., *Datura, Solanum* and many other flowers (Fig.5.1.50). If it adheres to the tepals it is termed as **epiphyllous,** e.g., *Polyanthes tuberosa.*

(2) Gynandrous : In this case, the adhesion is between stamens and carpels as seen in the **gynostegium** of family Asclepiadaceae (Fig.5.1.51) and the **gynostemium** of family Orchidaceae (Fig.5.1.52).

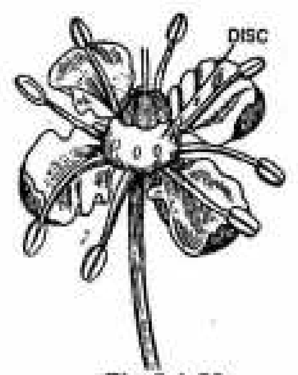


Fig.5.1.53. Obdiplostemonous condition

Insertion of stamens :

Several cases arise with respect to the insertion of stamens.

When the stamens form a single whorl and the number of stamens is equal to the number of sepals and petals, the flower is **isostemonous.** Sometimes there are two whorls of stamens, the first whorl alternating with petals and the second whorl alternating with sepals. This condition is termed as **diplostemonous.** When there are two whorls of stamens of which the first whorl is alternating with sepals and the second whorl is alternating with petals, the condition is termed **obdiplostemonous,** e.g., some members of family Rutaceae (Fig.5.1.53).

5.5.6. GYNOECIUM OR PISTIL :

It is the innermost and the **female reproductive whorl** of the flower. It is composed of one or more **carpels** or **megasporophylls.** A carpel is **simple** or **monocarpellary** when it consists of a single carpel. This condition is the characteristics of family Fabaceae. But when it is made up of more than one carpel it is termed as **compound or multicarpellary.** Multicarepllary gynoecium may be **apocarpous** in which each carpel is free from the other or **syncarpous** when all the carpels are united forming a compound gynoecium. Apocarpous condition is found in *Clematis, Ranunculus, etc.,* while syncarpous condition is seen in most angiosperms such as *Brassica, Hibiscus, Datura,* etc. (Fig.5.1.54). Among multicarepllary conditions, there are five types. This is based on the number of carpels. It may be **bicarpellary** (e.g., *Mussaenda, Coriandrum)* with two corpels, **tricarpellary** *(e.g., Allium cepa)* with three, **tetracarpellary** (e.g.,

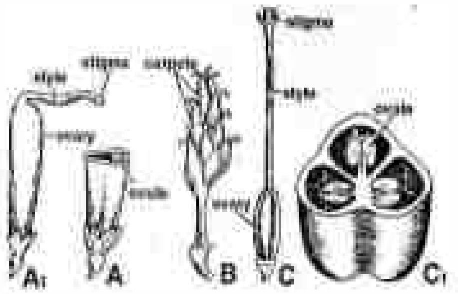


Fig.5.1.54. Carpels forming Gynoecium (A) External view of simple gynoecium. (A1) Simple ovary in T.S. (B) Compound apocarpous gynoecium (C) Compound syncarpous gynoecium. (C1) Compound syncarpous gynoecium in T.S.

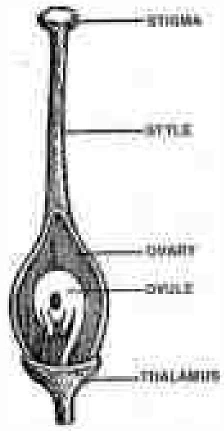


Fig.5.1.55. Atypical carpel.

Datura, Berberis) with four, **pentacarpellary** (e.g., *Melia, Hibiscus)* with five and **multicarpellary,** number of carpels more than five (e.g, *Papaver).* A typical carpel has three parts - **ovary, style** and **stigma** (Fig.5.1.55)

Fig.5.1.56. Position of ovary on thalamus as seen in L.S. of flower (A) Superior; (B) Semi-inferior; (C) Inferior.

(a) Ovary :

It is the lowermost swollen part containing one or more egg like bodies known as **ovule.** After fertilisation, ovary transforms into fruit while ovules into seeds. So, ovules are the predecessor of seeds.

The position of the ovary with respect to other floral whorls and classified as **superior, semi-inferior** and **inferior** has already been discussed under thalamus (Fig.5.1.56).

Chambers in the ovary :

The ovary is only one chambered or unilocular in monocarepllary condition. Thus, in apocarpous ovary each free carpel would be unilocular. In syncarpous ovary, it may be **bilocular**

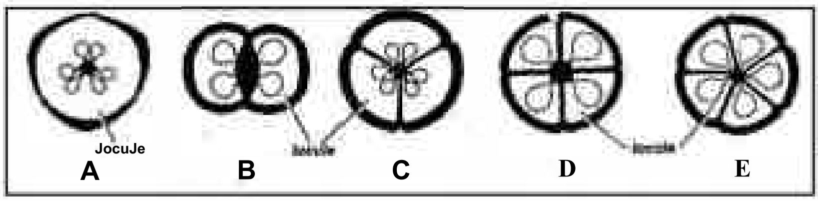


Fig.5.1.57.Chambers in ovary

(e.g., *Solunum, Murraya,* etc.), **trilocular** (e.g., *Euphorbia, Musa,* etc.), **tetralocular** (e.g., *Ocimum, Salvia,* etc.), **Pentaiocular** (e.g., *Hibiscus, Geranium* etc.) or **multilocular** (eg., *Citrus, Melia,* etc.) (Fig.5.1.57)

Table 5.1.4
PLACENTATION

Type	Character	Examples
(A) Marginal	The gynoecium is monocarpellary. The placenta develops along the fused margin (ventral suture) of the carpel.	*Pisum*
(B) Axile	The number of carpels is two or more. The ventral suture of the carpels meet at the centre of the ovary. So, the ovary is multichambered. The placentae arise from the central axis.	*Hibiscus, Citrus, Solarium,* etc.
(C) Parietal	The ovary is one-chambered. The placentae bearing the ovules develop on the inner wall of the ovary. Their position corresponds to the confluent margins of carpels and their number corresponds to the number of carpels.	*Brassica, Vanda,* etc.
(D) Free-Central	The placenta arises from the base of the ovary, projects far into its cavity as a swollen central axis and bears ovules all over its surface. The ovary is single chambered.	*Primula, Dianthus,* etc.
(E) Basal	The ovary is simple and unilocular. A single ovule is developed at the base. The placenta is placed on the tip of the thalamus at the floor of the ovary.	Members of family *Asteraceae*
(F) Superficial	The ovary is multicarpellary and multilocular. In this case, the whole inner walls of the chambers are lined with placental tissue so that ovules develop all around. It is similar to axile placentation but the ovule bearing placentae are brone on the inner surface of the partition walls.	*Nymphaea*

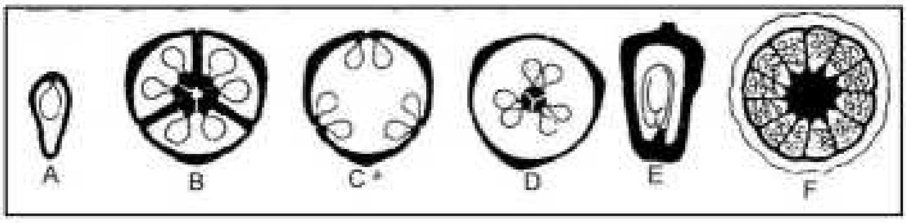


Fig.5.1.58

The ovary contains ovules and the stalk of the ovule that attaches with the carpel is known as **placenta.**

Arrangement of ovules :

In different flowers the ovules are arranged differently with their placenta in the ovary in a characteristic definite manner which is called **placentation.** Different types of placentations as mentioned in Table 5.1.4 are shown in Fig.5.1.58.

(b) Style :

The ovary protrudes to a small or long style. Style connects the ovary below and stigma above. It is usually **terminal** as it originates from the top of the ovary. In some cases, the ovary apex is deflected and the style appears to orginate from near the base **(basal)** or from the side

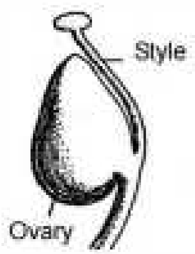


Fig.5.1.59.Lateral style

Fig.5.1.60.Gynobasic style

Fig.5.1.61.Branched styles

(lateral), *e.g., Alchemilla* and mango (Fig.5.1.59). Style may originate from the central depressed portion of the ovary and such condition is known as **gynobasic** (Fig.5.1.60) as seen in the members of family Lamiaceae. The style is usually deciduous, but in some cases it is persistent, e.g., *Naravelia, Clematis.* The style of *Canna* is **petaloid.** The base of the style may be swollen forming **stylopodium** as in the members of family Apiaceae. Sometimes, the style may be branched, e.g., members of family Euphorbiaceae (Fig.5.1.61).

(c) Stigma :

Stigma is present at the top of the style. Sometimes, when there is no style, the stigma is placed on the top of the ovary (e.g., *Sambucus, Berberis,* Lotus, etc.). In this case, it is termed as **sessile.** The stigma is commonly rough or hairy and sticky due to secretions. In China rose, stigmas are separated while it is bifid in Asteraceae. The number of lobes of stigma may correspond to the number of carpels. Monocarellary flower of family Poaceae shows exceptions having bifid and feathery stigmas. The stigma of *Papaver* is sessile as well as **striate** giving star like appearance. The stigma is branched in *Begonia.* The three stimgas of *Crocus* have funnel shaped foms. The different types of stigmas as discussed above are given in Fig.5.1.62 (A-F).

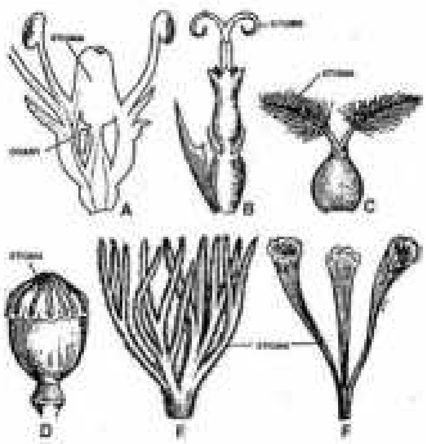


Fig.5.1.64. Stigma (A) Sessile in Sambucus nigra; (B) Bifid in sunflower; (C) Bifid and feathery in rice; (D) Striate and sessile in poppy; (E) Highly branched in Begonia; (F) Funnel shaped in Crocus sativus

Ovule is considered to be an **integumented megasporangium** (Fig.5.1.63). It is attached to the placenta by a slender stalk known as **funicle.** The other end of the funicle is attached to the body of the ovule and

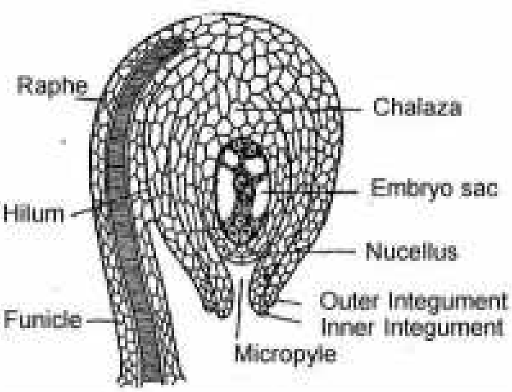


Fig.5.1.63. L.S. of typical anatropous ovule

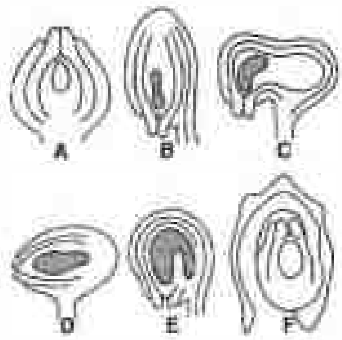


Fig.5.1.64. Ovules (A) Orthotropous (B) Anatropous (C) Campylotropous (D) Hemianatropous (E) Amphitropous (F) Circinotropous.

the point of attachment is called **hilum.** An ovule which is attached to the placenta directly, without the funicle is known as **sessile** ovule. The funicle continues beyond the hilum and may extend up to the base of the ovule **(chalaza)** forming a short ridge, called **raphe.** The main body of the ovule is called **nucellus.** It is surrounded by two coats, the **integuments.** There is no integument (ategmic) in parasitic plants like *Santalum* and *Loranthus.* A small opening is found at the apex of of the integuments which is called **micropyle.** The ovule may be **unitegmic** with single integument (e.g., gymnosperms, family Asteraceae and sympetalous or gamopetalous dicotyledons), **bitegmic** with two integuments (e.g., monocotyledons and polypetalous dictyledons). In addition there may be extra outgrowths in a few cases, known as **Aril,** a collar-like outgrowth from the base Of the ovule often form the third integument (e.g., litchi, nutmeg, etc.) and **Carcuncle,** an outgrowth of the outer integument is present in the micropylar region of some plants (e.g., castor and other members of Euphorbiaceae).

There is a large oval cell, embedded in the nucellus towards the micropylar end which constitute the most important part of the ovule, the **embryo sac.**

Based on the mutual position funicle, chalaza and micropyle, the ovules may be **orthotropous, anatropous, campylotropous, hemianatropous, amphitropous or circinotropous** (Fig.5.1.64). The most common type of ovule is anatropous or reversed type as shown in Fig.5.1.64B. In orthotropous, the ovule remains straight (e.g., family Polygonaceae, Piperaceae, Urticaceae, etc.) In amphitropous condition, the ovule is placed at right angle to the funicle (e.g., *Ranunculus, Lemna* and poppy). In campylotropous condition it is bent like a horse-shoe, so that micropyle is brought to the chalaza (e.g., many plants of family Cruciferae, Chenopodiaceae, Caryophyllaceae and other plants like *Mirabilis).*

5.6. FRUITSAND SEEDS :

The post-fertilization changes in angiosperm results in the formation of fruits and seeds. It is found that out of two male gametes in the pollen tube, one fuses with the egg cell forming a zygote which develops into an embryo, and the latter undergoes a series of changes to form the seeds. Other male gamete fuses with the secondary nucleus of the embryo sac forming a triploid endosperm. In the meantime, other parts of the ovary get transformed into the fruit. The fruit provides necessary protection to the seed and helps in its dispersal from the mother plant to outside, where the seed can germinate to give rise to new plant of its own kind.

5.6.1. FRUITS :

Fertilisation leads to the development of embryo inside the embryo sac of the ovule. Along with series of changes in the embryo, the ovule is converted into the seed while the wall of the ovary and other parts of the flower connected to it change into a fruit. Thus, fruit is defined as **ripened ovary.** Its biological need is to protect the seeds by forming a case or vessel around it. It also assists in the dispersal of seeds. Sometimes the fruits may be formed without fertilisation. This condition is called **parthenocarpy** and the fruit is known as **parthenocarpic fruit.**

5.6.2. PARTS OF A FRUIT:

A fruit consists of seeds and its wall is called **pericarp.** The pericarp is distinguished into three parts such as outer **epicarp** (the skin of ovary), the middle **mesocarp** which may be pulpy (e.g., Mango, peach, palms, etc.) and the inner **endocarp** which is often very thin and membranous (e.g., Orange) or very hard and stony (e.g., Palms, Mango) (Fig.5.2.1). In many cases pericarp is not differentiated into three parts. When the fruit is developed only from the single ovary of a flower it is called true fruit. But sometimes, the thalamus, receptacle or calyx may also grow and form a part of the fruit. In such cases, it is known as false fruit or spurious fruit (Pseudocarp). Some of the spurious fruits, developed involving different parts of the flower, are described in Table 5.2.1. and deplicted in Fig. 5.2.2.

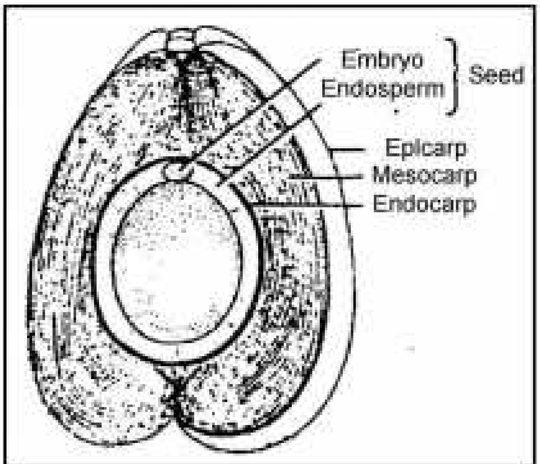


Fig.5.2.1. Parts of a fruit

Table - 5.2.1

Spurious or false fruits

Parts of the flower other than ovary in fruit formation	***Example***
1. Calyx is fleshy and form the prominent part of the fruit.	*Dillenia*
2. Thalamus grows round the ovary and becomes fleshy.	Apple and pear
3. Thalamus swells up bearing the number of small fruits on its outer convex surface.	Strawberry
4. Thalamus is elongated and bears small true fruits on its inner concave surface.	Rose
5. The inferior fruit is surrounded by the dry thalamus and often crowned by hairs or **pappus.**	Sun flower
6. The peduncle and the thalmus grow and become swollen and fleshy bearing below the reniform fruit developed from the ovary.	Cashew-nut *(Anacardium)*
7. The peduncle becomes fleshy with the actual nut type of fruit on its top.	*Semecarpus*
8. A number of small true fruits are fused together to form aggregate fruit.	Custard apple
9. The fruit is developed from an inflorescenc	Mulberry, pineapple jackfruit, fig and bayan

5.6.2. DIFFERENT TYPES OF DEHISCENCE :

Fruits, when ripe, may become fleshy and pulpy or dry up becoming papery or stony. The fruits split open at maturity in order to discharge the seeds to outside. Such fruits are dry and are called **dehiscent fruits.** The fruits which do not open at maturity are called **indehiscent fruits.** There are various ways by which dehiscence of fruits take place. According to the mode of opening, the different types of dehiscence marked in the fruit are given in Table - 5.2.2.

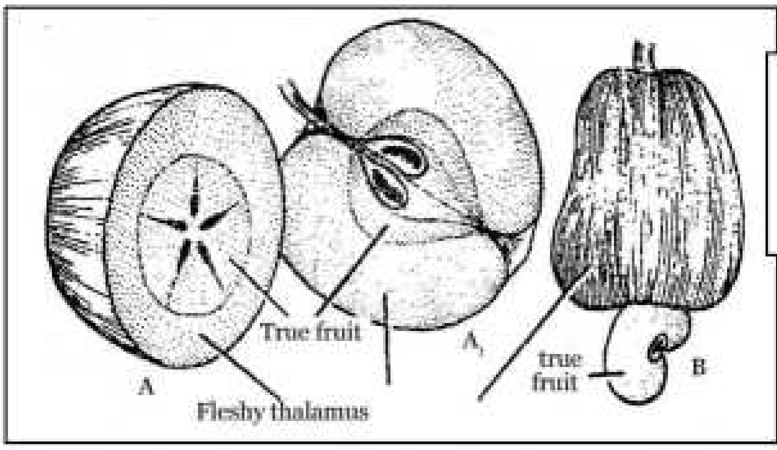


Fig.5.2.2.
False fruit
(A)T.S. of an apple. (A1) L.S. of an apple;
(B) Cashew nut

Tale - 5.2.2.

Dehiscence of fruits

TYPES OF DEHISCENCE	*Example*
1. **Sutural:** Fruits split by the margin either ventral or dorsal or by both. The fruits are developed from monocarpellary ovary.	*Calotropis, Magnolia,* Members of Fabaceae (pea, bean, etc.)
2. **Loculicidal:** Splitting takes place through the back of the loculus (or chamber) and the valves separate from the axis. So the number of valves are the same as that of ovary chamber. Fruit is developed from polycarpellary ovary.	*Hibiscus, Gossypium, Abelmoschus, Adhatoda, Rueilia, Andrographis,* etc.
3. **Septicidal:** Dehiscence takes place through the partition walls of the multicarpellary fruits.	*Brassica, Raphanus, Abroma,* etc.
4. **Septifragal:** Splitting of multilocular fruit takes place septicidally. In this case, septa or partition walls break so that the valves fall away. The seeds are attached to the central axis of the fruit.	*Cedrela, Pterospermum, Datura,* etc.
5. **Porous:** Fruits split by number of little pores. Through these pores the seeds are set free.	*Papaver* (Poppy)
6. **Transverse:** The fruit bursts transversely so that the upper part separates away from the lower. Upper cap like part is blown away by wind living the seeds exposed.	*Portulaca, Celosia,* etc.

5.6.3. TYPES OF FRUITS :

All the fruits (true or spurious) are classified into three main groups- **simple, aggregate** and **multiple** or **composite.**

A. Simple fruits :

A fruit developing from a single ovary (monocarpellary or polycarpellary syncarpous gynoecium) of a flower is known as simple fruit. It may be dry or fleshy. The dry fruit again is divided into dehiscent, indehiscent and schizocarpic (splitting) fruits.

I. Dehiscent or Capsular fruits :

The fruits of this category burst automatically on ripening, discharging the seeds. The types of dehiscence are given in table 5.2.2. This may be of following types.

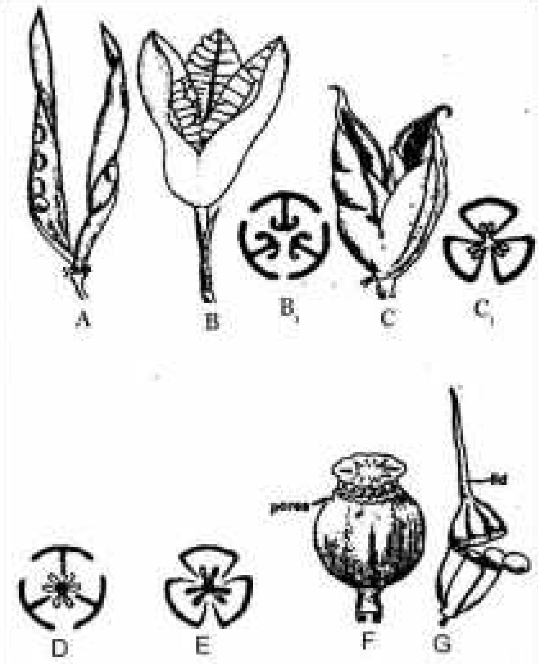


Fig.5.2.3. Types of dehiscence : (A) Sutural; (B,B1) Loculicidal; (C,C1) Septicidal; (D-E) Septifragal; (F) Poricidal; (G) Transverse.

(i) **Legume or pod :** It is a simple, dry, dehiscent fruit. It develops from a monocarpellary, superior, one chambered ovary. It dehisces by both the sutures from apex to the base, e.g., members of Fabaceae such as *Pisum, Cicer;* etc. (Fig.5.2.4A).

(ii) **Follicle :** It resembles legume type of fruits being developed from monocarpellary, unilocular, superior ovary but differs from the legumes as it dehisces along one suture (usually ventral) only, e.g., *Calotropis.* In *Calotropis,* it shows a paired follicle developing from bicarpellary ovary (Fig.5.2.4B).

(iii) **Siliqua :** The fruit is developed from a bicarpellary, syncarpous, superior ovary which is one chambered but appears two chambered due to the development of a false partition wall known as **replum.** The fruit of

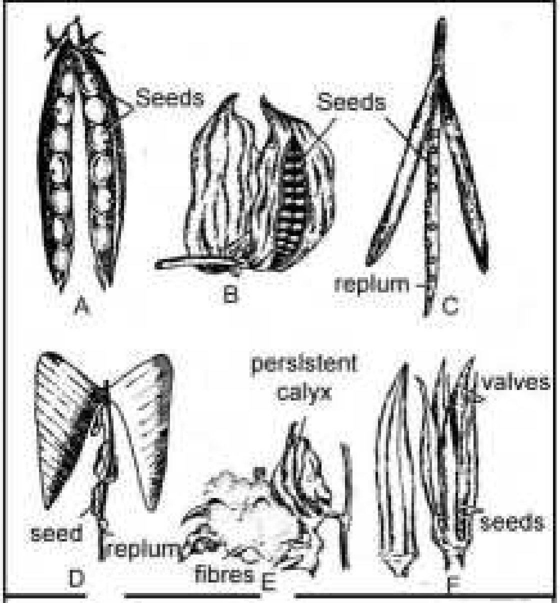


Fig.5.2.4. (A-F) Simple, dry, dehiscent fruits; (A) Legume of pea; (B) Follicle of madar; (C) Siliqua of mustard; (D) Silicula of Capsella; (E) Capsule of cotton; (E) Capsule of cotton; (F) Capsule of lady's finger

this type dehisces along both the sutures from the base upwards, the seeds remaining attached to the replum, e.g., fruits of Brassicaceae such as *Brassica, Raphanus,* etc. (Fig.5.2.4C).

(iv) Silicula : It resembles the siliqua type of fruit but much shorter and flattened, being nearly as broad as its length and contains only a few seeds, e.g., *Capsella bursa-pastoris, Iberis amara* etc. (Fig. 5.2.4D).

(v) Capsule : It is a many-seeded, uni-or multilocular fruit. This kind of fruit develops from a superior (or sometimes in- ferior) bi-or polycarpellary ovary. It dehisces in various ways. It may dehisce by pores (e.g., *Papaver)* or transversely (e.g., *Celosia)* or loculicidally (e.g., *Abelmoschus esculentus)* or septicidally (e.g., Linseed) or septifragally (e.g., *Datura)* (Fig. 5.2.4E.F).

(vi) Pyxis : It is a capsule type of fruit which splits open transversely along a circular line. The upper valve serves as cap, e.g., *Celosia, Portulaca.*

II. Indehiscent fruit or Achene fruits :

This type of fruit is simple; dry and indehiscent. Based on its development, it is divided into the following types:

(i) Caryopsis : A small, dry, one seeded fruit, it develops from a superior, monocarpellary ovary. In this case, the pericarp is fused with the seed-coat, e.g., members of Poaceae such as Rice, Maize, etc., (Fig.5.2.5A).

(ii) Achene : It is similar to caryopsis but the pericarp is not completely fused. It develops from a superior, monocarpellary ovary with the pericarp free from the seed-coat, e.g., *Mirabilis,* Potentilla, etc., (Fig.11.2.5B).

(iii) Cypsela: It is a one seeded fruit developing from bicarpellary, syncarpous, one chambered, epigynous or inferior ovary. In this case, pericarp and seed-coat are separate, e.g., members of Asteraceae, such as *Helianthus, annus* (sunflower), *Tagetespatula* (Marigold) and Dahlia, etc. (Fig.5.2.5C).

(iv) Samara : It is a simple, dry, indehiscent, one or two seeded fruit, developing from a supe- rior, bortricarpellary ovary, with flat- tened wing-like outgrowths, e.g., *Hiptage, Dioscorea,* Acer (Fig.5.2.5 D,E). Wing-like samara is also found in the fruit of *Shorea robusta.* But here the wings are dry, per- sistent sepals. *Winged* fruit of this nature is known as samaroid.

(v) Nut: It is a dry, one-chambered and one- seeded fruit developing from a superior, bi-or polycarpellary ovary. In this case, the pericarp is hard and woody, e.g., Chestnut, *Anacardium occidentale* (Cashew-nut), Trapa *bispinosa* (Water chestnut), *Litchichinensis,* etc. (Fig.5.2 F,G). However, Coconuts and Palmyra-palms fruits are not nuts because in

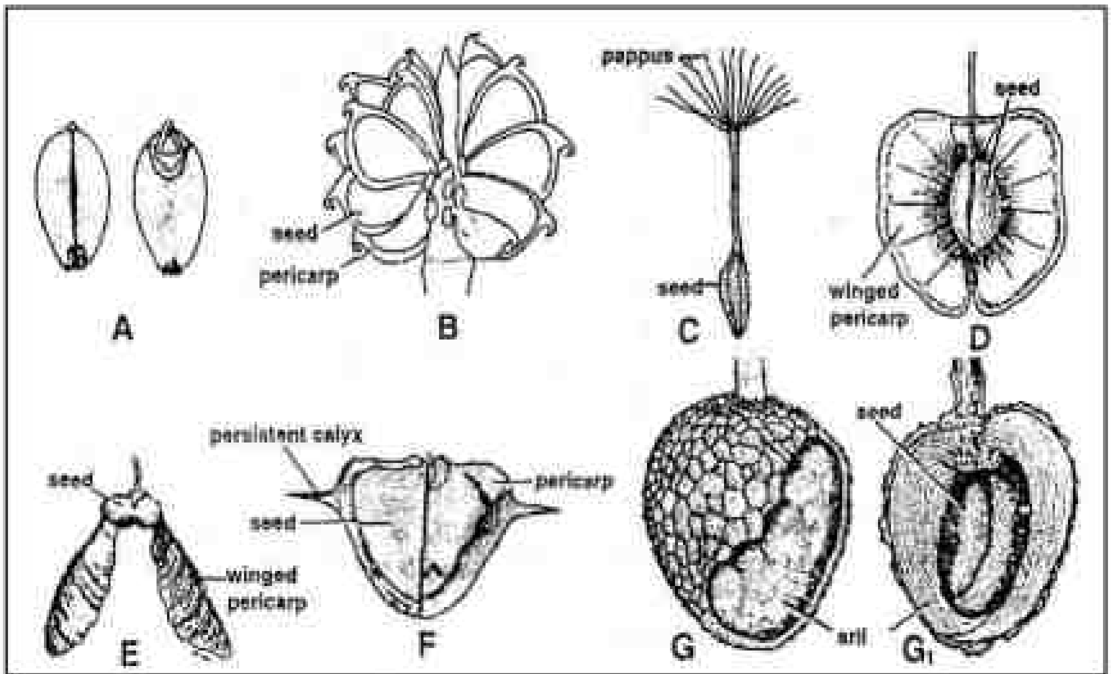


Fig.5.2.5. Simple, dry indehiscent fruits : (A) Caryopsis of wheat; (B) Achene of Ranuncuius; (C) Cypsela of sunflower; (D) Samara of Hiptage; (E) Samara of Maple; (F) Nut of water chestnut; (G) Nut of litchi; (G1) L.S. of nut of litchi.

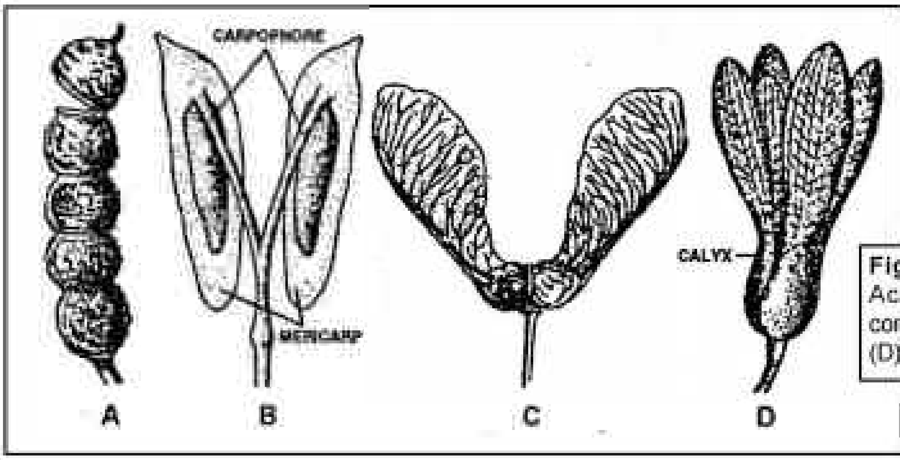


Fig.5.2.6. (A) Lomentum of Acacia; (B) Cremocrap of coriander; (C) Samara of maple; (D) Samaroid fruit of shorea.

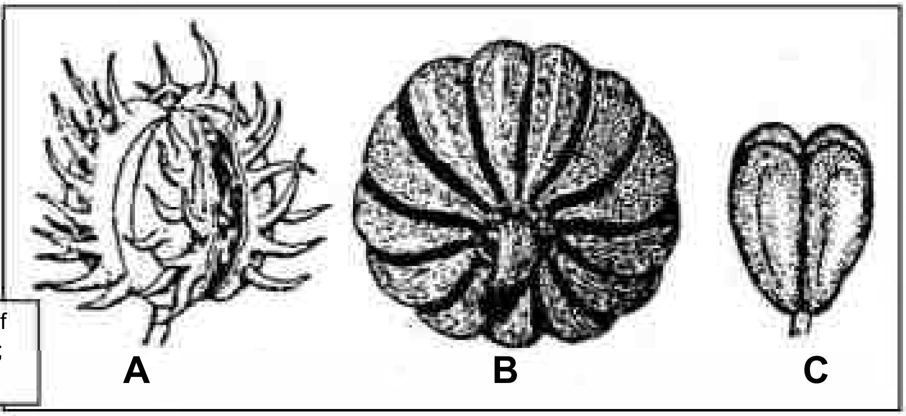


Fig.5.2.7. (A) Regma of castor; (B) Regma of Hura; (C) Carcerule of Ocimum.

them endocarp becomes hard and woody. In *Areca* or Betel-nuts and date-palms, the pericarp is *soft* (fibrous in areca-nuts and pulpy in Date-palms). It is the seed, that is stony and not pericarp as described above. So, these fruits do not come under nut.

III. Schizocarpic or Splitting fruits :

This type of fruit breaks up into a umber of indehiscent bits called mericarp. So it is in between dehiscent and indehiscent dry fruits since each of the mericarp discharges the seed only on the rotting of the pericarp. There are several types of schizocarpic, dry, simple fruits.

(i) Lomentum : The fruit is legume type, but constricted or partitioned between the seeds into a number of one-seeded parts. It usually breaks up into bits containing one or more seeds, (e.g., *Acacia, Mimosa,* etc.) (Fig.5.2.6.A).

(ii) Cremocarp : It is a dry, two-seeded indehiscent, schizocarpic fruit, developed from the inferior, bicarpellary ovary. When ripe, it splits into two mericarps. These are attached to the carpophore (prolonga- tion of the thalamus), e.g., Coriander, Cumin, Carrot, etc. (Fig.5.2.6B).

(iii) Double samara : It is a type of two or more chambered winged fruit developing from syncarpous ovary. The wings are formed out of the pericarp and the fruit breaks up into two component parts, each enclosing a seed, e.g., Maple (Fig.5.2.6C).

(iv) Regma : It develops from polycarpellary ovary. The fruit breaks up into many components equal to the number of carpels. Each one is called cocci, e.g., Castor (Fig.5.2.7.A), *Jatropha, Hura* (Fig.5.2.7B) and *Geranium,* etc.

(v) Carcerulus : It is the fruit developed by the superior, bicarpellary ovary with falsely formed four chambers and having a gynobasic style. The seeds are liberated by the decomposition of the pericarp, e.g., *Ocimum, Salvia, Abutilon, Althaea,* etc. (Fig.5.2.7C).

(vi) Utricle : The fruit is one seeded developing from a bicarpellary, syncarpous, unilocular, superior ovary. It has thin pericarp which splits open by a lid, e.g., *Achyranthes, Amaranthus,* etc.

B. Fleshy fruits :

The fruits which become fleshy, remain succulent and juicy, are called fleshy fruits. Normally, they are indehiscent, so that seeds are set free only after the decay of the pulp. This includes the following types:

(i) Drupe (stone fruits) : It is a fleshy, one-or more-chambered and one-or more-seeded fruit. Normally, it is one-seeded with a skinny epicarp, a fibrous and juicy mesocarp and stony hard endocarp, e.g., Mango (Fig.5.2.8.A), Peach, and Indian plum' (Fig.5.2.8.B). These are called **'stonefruits'** because of the stony hard endocarp. In case of more-seeded drupe, every seed has got a separate endocarp around, e.g., *Borassus flabellifer* (Fig.5.2.8.C), It is a true

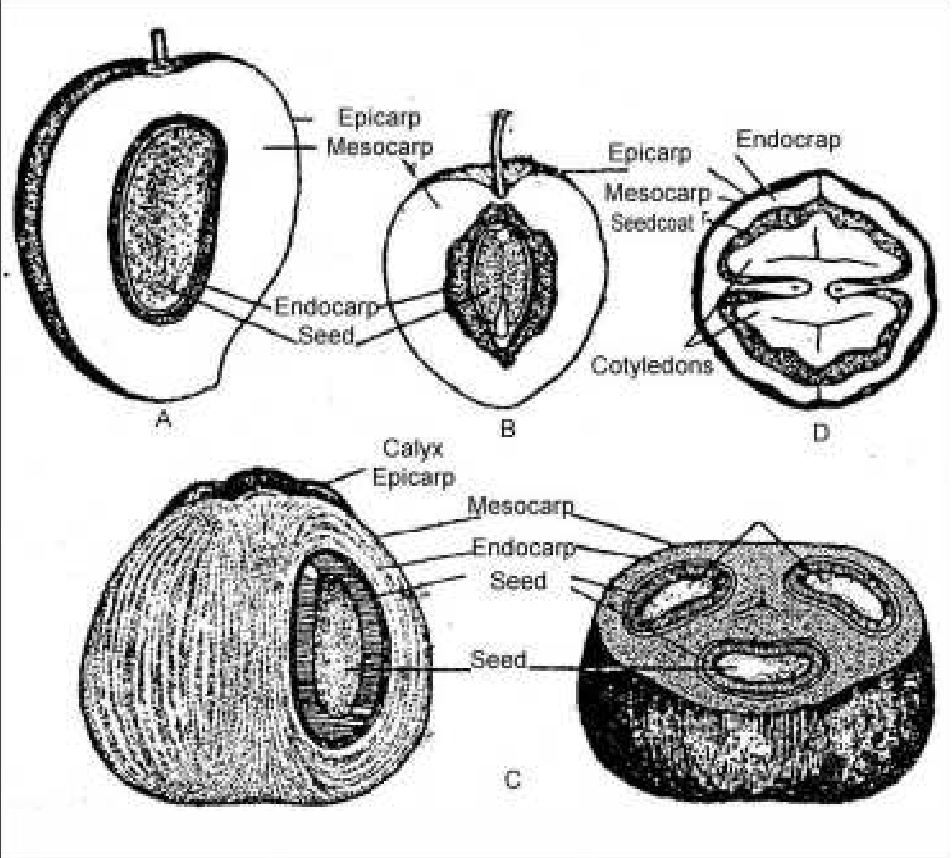


Fig.5.2.8. Drupe. (A) Mango; (B) Indian plum (Zizyphus); (C) Palmyra palm with three shown in I.S. and T.S.; (D) T.S. of walnut fruit. Epicarp and mesocarp are not seen in market walnut as they get peeled off.

fruit since it develops from monocarpellary or polycarpellary syncarpous and superior ovary. In Coconut, the mesocarp is fibrous (not fleshy as in other drupes) and the edible part is the endosperm of seed. Other examples of drupe are peach *(Prunus)* and country almond, etc,

(ii) Bacca or berry : It is a one or many seeded pulpy fruit. It develops from a single carpel or more commonly from a syncarpous ovary with axile or parietal placentation. Any fleshy fruit in which there is no hard part excepting the seeds as considered as bacca. The pericarp is differentiated into epicarp, mesocarp and endocarp or all of these may form a pulp in which the seeds are embedded. In the begining, the seeds are attached to the placenta; but at maturity they are found loose in the pulp, e.g., Tomato, Grapes, Brinjal, Plantain, Guava, Papaya, etc. One seeded berry is found in Date-palm, *Artabotrys.,* etc. (Fig.5.2.9 A-D). There are a number of fruits of the berry or bacca type which show some variations from the normal type. These are noted in Table 5.2.3.

Tale - 5.2.3

Different types of berry fruits

TYPES WITH CHARACTERISTICS	***Example***
(i) **Pepo:** It is a fleshy, many seeded fruit, like the berry. It develops from an inferior, one-celled or spuriously three-or more-celled syncarpous pistil with parietal placentation. The seeds are attached to the placenta. The epicarp forms a tough rind.	Member of Cucurbitaceae such as Gourd, Cucumber, Melon, Squash, etc. (Fig.5.2.10 A, B and D).
(ii) **Hesperidium:** It is a many-celled, fleshy fruit developing from a superior, multicarpellary, syncarpous, Multilocular ovary with axile placentation Here the endocarp projects inwards forming distinct chambers. The epicarp and mesocarp are fused together. The epicarp is leathery having aromatic oils while the mesocarp is represented by white fibers. The fused epicarp and mesocarp form the rind. The endocarp is thin and papery. The juicy, unilocular, succulent hairs are outgrowht of the endocarp and form the edible part of the fruit.	Members of Rutaceae such as Oranges and Lemons, etc. (Fig. 5.2.10C)
(iii) **Balausta :** It is an inferior, many-celled and many-seeded fruit developing from a multicarpellary, syncarpous ovary. The pericarp is tough. The two of carpels are placed one above the other. Calyx is persistent and found on the top. The edible part is succulent seed-coat (testa).	Pomegranate *(Punica granatum)* (Fig5.2.10E and Fig.11.2.11)
(iv) **Amphisarca :** The fruit is formed from a superior, many chambered and many-seeded ovary. The pericarp is woody. The edible part of the fruit is the inner fleshy layer of pericarp and the placenta.	*(Aegle)* *Feronia limonia, etc.* (Fig.5.2.12)
(v) **Pome:** It is a fruit developing from an inferior, syncarpous ovary. It is a spurious or false as it is surrounded by a **fleshy thalamus** which is edible. The actual fruit lies within.	Apple *(Malus sylvestris)* and Pear *(pyrus communis)* (Fig.5.2.13 A, B)

A comparative account between drupe and berry is given below in table 5.2.4.

Table - 5.2.4

Comparison between drupe and berry

Drupe	Berry
1. Pericarp is differentiated into epicarp, mesocarp and endocarp	Pericarp is same as in drupe, but endocarp is sometimes absent.
2. It is called stone-fruit since endocarp is hard.	If endocarp is present, it is thin and membranous.
3. Seed is enclosed by endocarp.	Seed is enclosed by mesocarp.
4. Exmaples are Mango, Coconut, Peach, Almond, Chestnut, etc.	Examples are Brinjal, Banana, Tomato, Chillies, etc.

C. Aggregate fruits :

When a fruit develops from a single flower with an apocarpous pistil, it is called aggregate fruit. Since the carpels are free, each carpel gives rise to a simple fruitlet. Sometimes these fruitlets join together giving the appearance of a single fruit. In many other cases the fruits remain free from one another forming a bunch of fruits known as etaerio of fruitlets. Each fruitlet, an etaerio may be a follicle, an achene drupe or berry.

(i) Etaerio of follicles : Etaerio of follicles are developed from apocarpous, muiticarpellary flower. It may be the development of paired fruits (e.g., *Calotropis* and *Vinca),* three fruits (e.g., *Λconitum),* five fruits *(e.g., Sterculia)* and many fruits *(e.g., Michelia* and *Magnolia* from a single flower with free or apocarpous pistil. In *Michelia* and

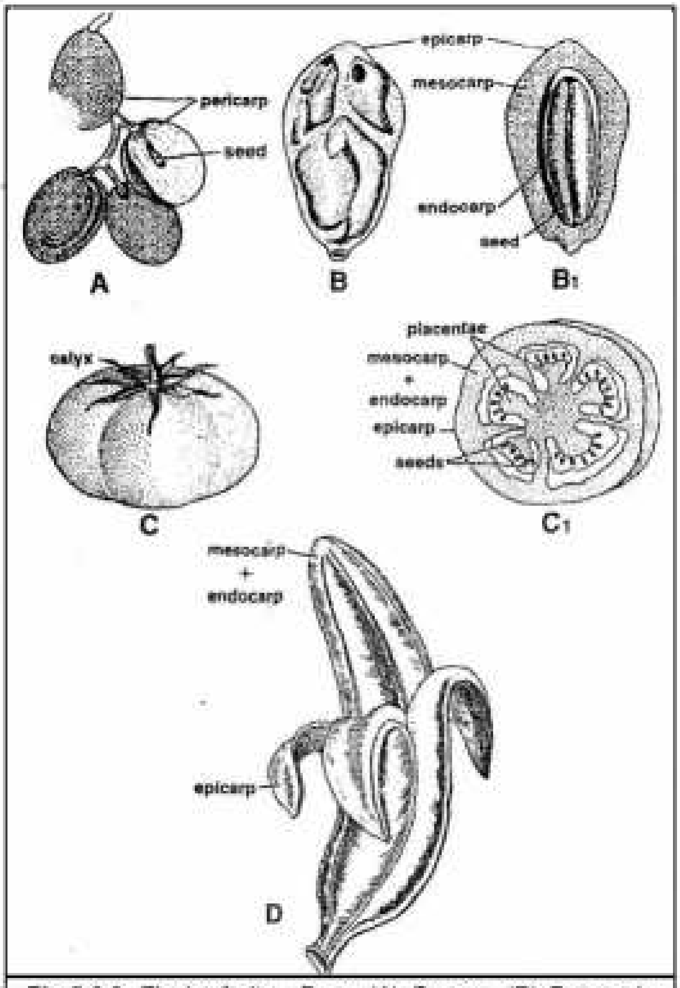


Fig.5.2.9. Fleshy fruits : Berry (A) Grapes. (B) Date palm (entire); (B1) L.S. date palm fruit; (C) Tomato entire; (C1) L.S. tomato; (D) Banana.

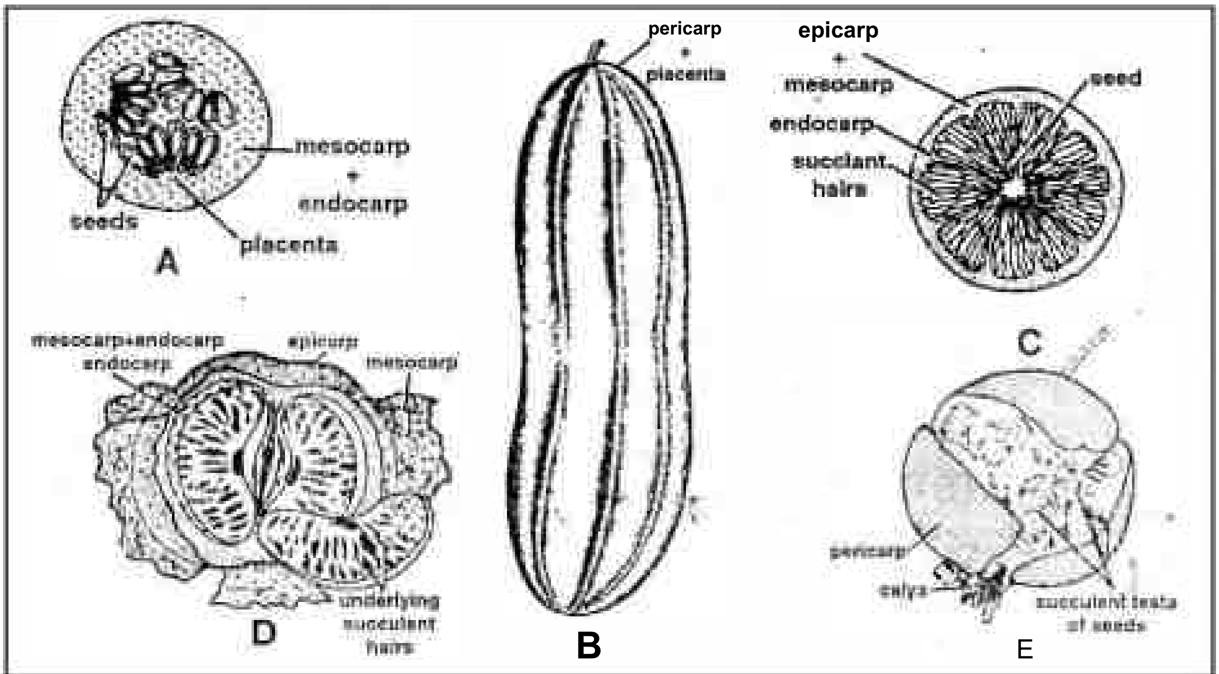


Fig.5.2.10. Fleshy fruits : (A) T.S. of cucumber; (B) Entire cucumber; (C) Hesperidium of lemon; (D) Hesperidium of orange; (E) Balausta of pomegranate;

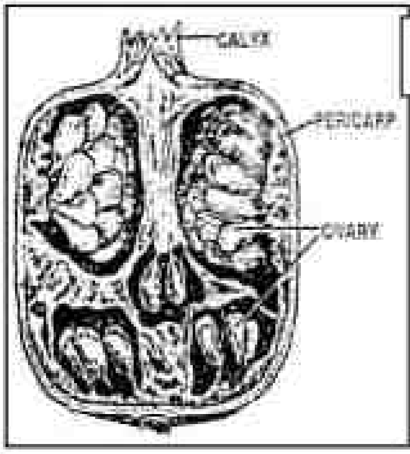


Fig.5.2.11. L.S. of pomegranate.

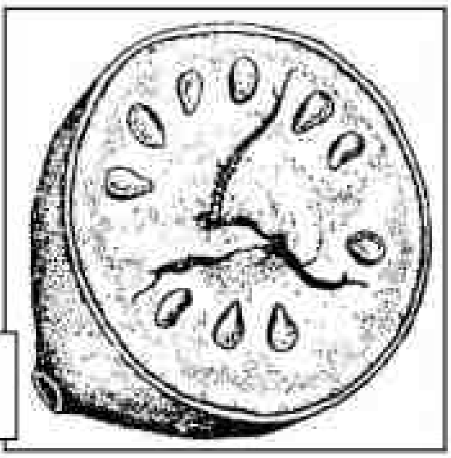


Fig.5.2.12. Wood-apple (Aegle marmelos)- an amphisarca in T.S.

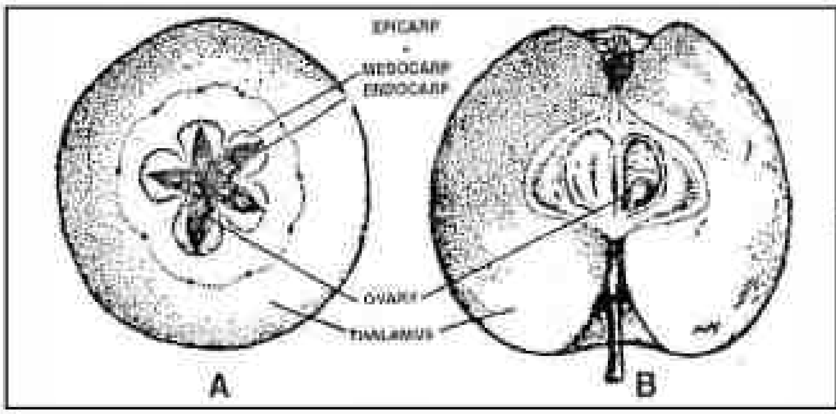


Fig.5.2.13. Pome of apple : (A) T.S.; (B) L.S. the real fruit with its pericrap is surrounded by a fleshy edible thalamus. The pericarp the epicarp and mesocarp are fleshy while the endocarp is cartilaginous.

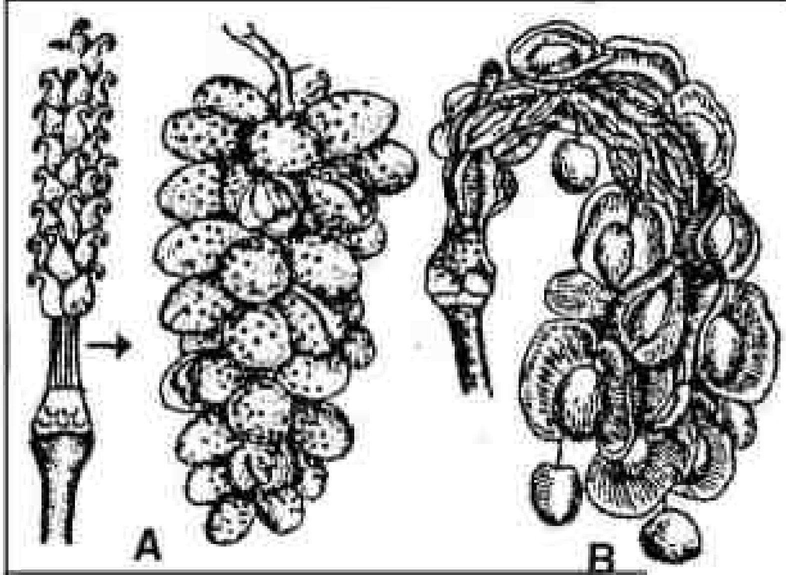


Fig.5.2.14. Etaerio of follicles : (A) Michelia cham-paca. The pistil (left) develops into the aggregate fruit (right); (B) Magnolia grandiflora fruit.

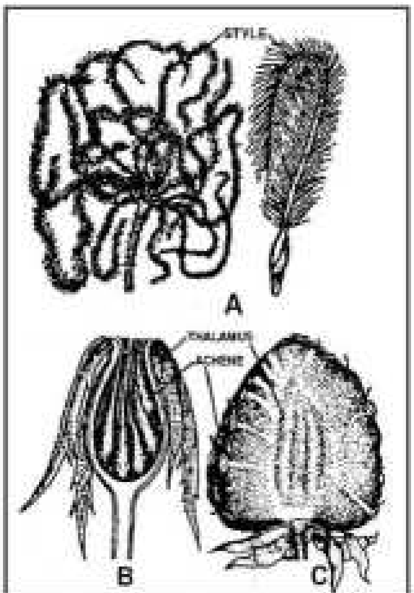


Fig.5.2.15. Etaerio of achenes; (A) Achenes of Naravelia. An achene fruitllet is shown separately; (B) Hip of rose; (C) The achenes of strawberry are on the surface of the fleshy halamus.

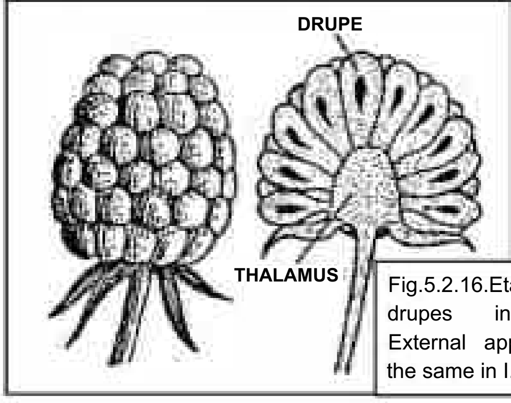


Fig.5.2.16.Etaerio of drupes in raspberry. External appearance and the same in I.S.

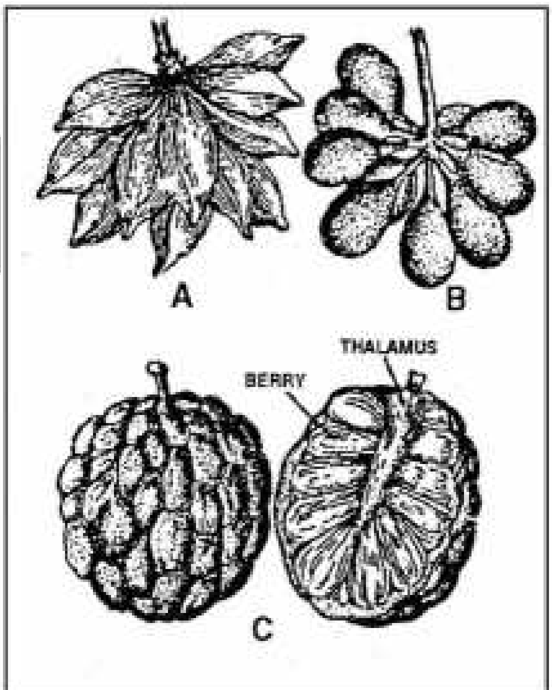


Fig.5.2.17. Etaerio of berries : (A) Artabotrys; (B) Polyalthia longifolia; (C) External view and I.S. of the Anona squamosa fruit.

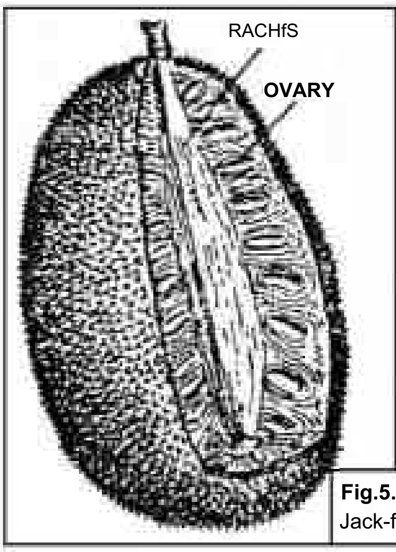


Fig.5.2.18. Sorosis; Jack-fruit

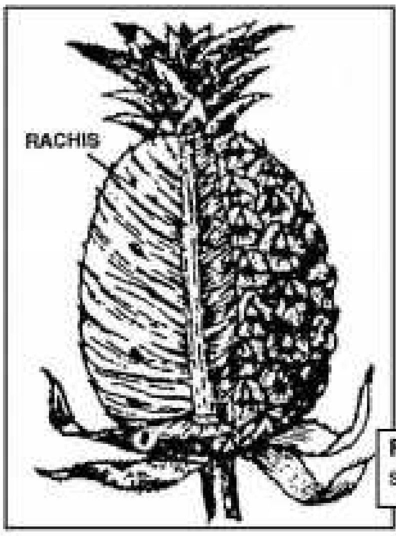


Fig.5.2.19. Pineapple : a portion has been taken out to show rachis of inflorescence.

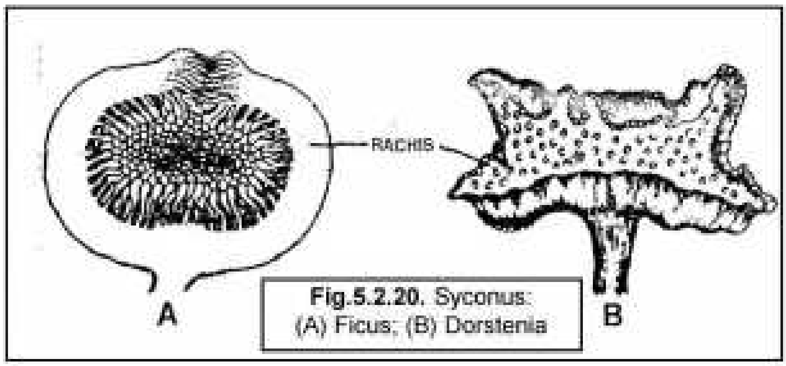


Fig.5.2.20. Syconus: (A) Ficus; (B) Dorstenia

Magnollia, there are infinite number of carpels. As the flower matures, the thalamus elongates and the aggregate fruit looks like a branch of fruits (Fig. 5.2. 14A&. B). In the fruit of *Asclepias,* a special name has been given the **conceptaculum.** Here, the two follicles are united at the base.

(ii) Etaerio of achenes : This type of fruit is very common. These fruits are clustered together on a common thalamus. The fruitlets are provided with feathery persistent styles (e.g., *Naravelia, Clematis)* and occur in a group. The achenes remain enclosed in a hollow, receptacular thalamus (e.g., rose) and occur on a flattop-shaped spongy thalamus (e.g., Lotus). The minute achenes are buried as small brown specks on a fleshy edible thalamus of Strawberry.

(iii) Etaerio of drupes : In this case, a number of small drupes or drupels, developing from separate carpels of a flower, are aggregated together on a fleshy thalamus, e.g., Raspberry (Fig.5.2.16).

(iv) Etaerio of berries : It develops from an apocarpous pistil lying embedded in the fleshy thalamus and grows into a single fruit (e.g., *Anona).* On the other hand, a group of distinct and separate berries are produced in *Artabotrys* and *Polyalthia* (Fig. 5.2. 17).

D. Multiple or composite fruits :

A multiple or composite type of fruit develops from a number of flowers (inflorescence). Such a fruit is also known as infructescence. Whole inflorescence with its component parts takes part in the production of fruit. These fruits are of two types.

(i) Sorosis : It is a multiple fruit developing from a spike or spadix. The whole inflorescence forms a compact mass. The flowers fused together by their succulent tepals and arranged on a thick club-shaped rachis. The fertile fruits have edible juicy perianth leaves and the bracts form more or less juicy chaffs around them. The spine like structures on the tough rind represent the stigmas of the carpels. The seed is covered by a membranous testa (e.g., *Artocarpus, Morus and Pandanus).* The edible part of the fruit is the fleshy and succulent perianth, flower and bracts (Fig.5.2.18). In *Morus,* fleshy perianth enclose dry achenes.

There are similar structures found in other cases, but the ovaries are not conspicuous, e.g. *Ananas comos* (Pineapple). The polygonal areas present on the surface represent united ovaries of the constituent flowers of the inflorescence. The sterile bracts present on the top of the fruit look like crown of small leaves (Fig. 5.2.19).

(ii) Syconus :

The fruit is formed from the **hypanthodium** type of inflorescence. It is a hollow or pear-shaped fleshy receptacle that forms the edible part of the fruit. The inflorescence giving rise to the fruit is also known as coenanthium. The female flowers within the closed receptacle of the inflorescence develop achenes, forming a multiple fruit of achenes, e.g., *Ficus,* (Fig.5.2.20A). A similar fruit is formed in which the coenanthium develops achenes on the open receptacle, e.g; *Dorstenia* (Fig.5.2.20B).

Different parts of fruits are used as human food as noted in Table - 5.2.5.

Table - 5.2.5

Edible parts of some common fruits

Common English name	***Botanical name***	***Type of fruit***	***Edible parts***
Cashew-nut	*Anacardium occidentale*	nut	Fleshy peduncle and cotyledons
Mango	*Mangifera indica*	drupe	Mesocarp
Custard apple	*Anona reticulata* *Anona squamosa*	etaerio of berries	Pericarp (except apices)
Apple	*Malus sylvestris*	pome	Fleshy thalamus
Banana	Musa spp	berry	Mesocarp and endocarp
Fan-palm	*Borassus flabelifer*	fibrous drupe	Endosperm
Coconut	*Cocus mucifera*	fibrous drupe	Endosperm
Cucumber	*Cucumis sativus*	pepo and placentae	Mesocarp, endocarp
Date-plam	*Phoenis octylifera*	one-seeded berry	Pericarp

Common English name	*Botanical name*	*Type of fruit*	*Edible parts*
Dillenia	Dillenia indica	pseudocarp;	Accrescent calyx
Fig	*Ficus* sps.	syconus	Fleshy receptacle
Jack-fruit	*Artocarpus infegrifolia*	sorosis	Bracts, perianth and seeds
Grape	*Vitis vinifera*	berry	Pericarp and placentae
Guava	*Psidium gujava*	berry	Thalamus and pericarp
Indian plum	*Zizyphus mauritiana*	drupe	Mesocarp including epicarp
Litchi	*Litchi chinensis*	one-seeded nut	Starchy endosperm
Maize, rice wheat	*Zea mays, Oryza sativa,* Tritium aestivum	caryopsis	Starchy endosperm
Melon	*Citrullus sps.*	pepo	Mesocarp
Orange	*Citrus sps.*	hesperidium	Juicy placental hairs
Pea	*Pisum sativum*	legume	Cotyledons
Pear	*Pyrus communis*	pome	Fleshy thalamus
Pineapple	*Anans comosus*	sorosis	Outer-portion of receptacle, bracts and perianth
Pome-granate	*Punica granatum*	balausta	Juicy outer coat of the seed or succulent testa
Shaddock	*Pummelo sps.*	hesperidium	Juicy placenta: hairs
Strawberry	*Fragaria vesca*	etaerio of achenes	Succulent thalamus
Tomato	*Lycopersicum sps.*	berry	Pericarp and placentae
Wood-apple	*Aegle sps.*	berry	Mesocarp, endocarp and placentae
Walnut	*Juglans regia*	drupe	Lobed cotyledons
Groundnut	*Arachis hypogea*	lomentum	Seed (mainly cotyledons)
Tamarind	*Tamanindus indica*	lomentum	Mesocarp
Lotus	*Nelumbo nucifera*	eataerio of achenes	Thalamus and seeds
Plum	*Prunus domestica*	drupe	Epicarp and mesoscrap

II. ANATOMY OF FLOWERING PLANTS (ANGIOSPERMS)

5.7. TISSUES :

In multicellular organisms, different parts of the body like leaves, branches, fruits, flowers carry out different functions. However, they originate from the cells. Cells after their origin get differentiated and also associate with similar cells to carry out specific functions. A group of cells more or less alike in form, origin and development, performing common functions, is called a tissue. This definition may not be quite sufficient to describe the complex tissues like xylem and phloem in higher plants. In this regard tissue can be considered from two view points.

1. From a general anatomical point of view tissue is considered as a group of contiguous cells and form a structural part of a plant.

2. From physiological point of view even widely different cells can constitute a tissue, for example, xylem consists of conducting elements, supporting elements and storage elements together forming a complex tissue.

Thus, a tissue may be defined as "a group of similar or dissimilar cells performing or help to perform a common function or a set of related funtions, having a common origin and development. "

Classification of Plant Tissue

Plant tissues may be classified from the structural and funtional point of view. However, on the basis of stages of development, plant tissues are broadly classified into two fundamental types : Meristematic tissue and Permanent tissue.

5.7.1. Meristematic tissue :

Meristematic tissue is a group of young, immature, undifferentiated and thin walled living cells which retain the power of continuous division. It is commonly referred to as a meristem and occurs in the growing regions of the plant body.

5.7.1.1. Characteristic features of meristematic tissues :

The cells of the meristematic tissues are quite distinct in their cytological and physiological characteritics from other cells. The following are the characteristics of the meristematic tissues.

(i) The constituent cells of meristematic tissue are in a state of continuous and active division.

(ii) The cells are more or less undifferentiated.

(iii) They are compactly arranged without intercellular spaces.

(iv) They are usually isodiametric in shape.

(v) They are living with abundant cytoplasm and a prominent nucleus for each.

(vi) The cell wall is thin and homogenously cellulosic.

(vii) The vacuoles are either small or absent.

(viii) Endoplasmic reticulum and mitochondria are not fully developed.

(ix) Plastids occur in proplastid stage.

(x) They show greater enzymatic activity and hence are metabolically more active.

CLASSIFICATION OF MERISTEMS

I. Meristems based on the stage or method of development:

Promeristem :

It is the first formed meristem representing the foundation stage of formation of new developing organ. It consists of young initials and their derivatives. It is present at the of root and stem apices. It is also known as primordial meristem or embryonic meristem.

II. Meristems based on origin :

On the the basis of origin, meristems are of two types : Primary meristem and Secondary meristem

Primary meristem : It is derived directly from promeristem. It builds up the primary part of the plant body. It occurs at the apices of stem, roots and primordia of leaves etc. It continues to divide and the derivatives differentiate into permanent tissues.

Secondary meristem : It develops from primary permanent tissues which regain the power of division i.e. it becomes meristematic at a later stage. The secondary meristem add new cells to the primary body effecting secondary growth in thickness. Cork combium, inter fascicular cambium, accessory cambium etc. are examples of secondary meristem.

III. Meristems based on position (Fig. 5.1):

On the basis of position in the plant body, meristems are calssified as apical meristem, intercalary meristem and lateral meristem.

Apical meristem : The meristem that occurs at the apices of the root, stem and leaves is known as apical meristem. It comprises either of a single apical cell or group of apical cells. The activity of this meristem results in longitudinal growth (height) of the plant. Apical meristem includes promeristem and primary meristem.

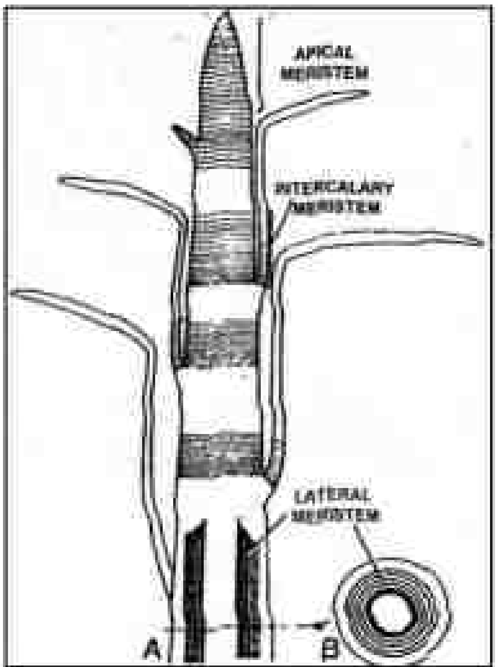


Fig.5.1. Position of meristems : (A) Longitudinal view; (B) Cross-section.

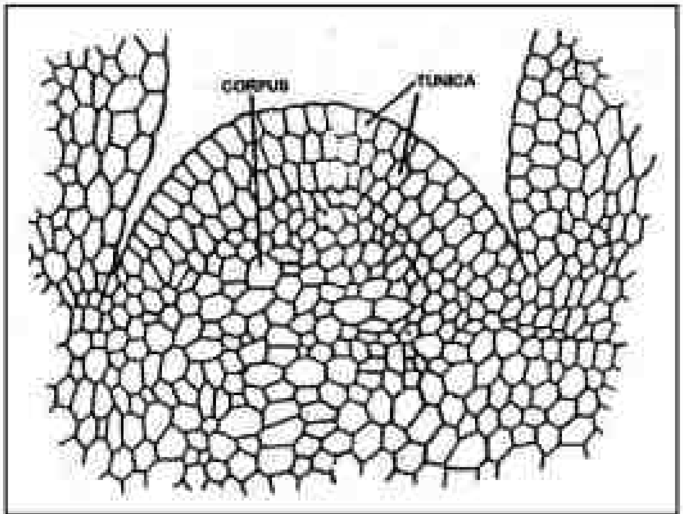


Fig.5.II. Apical meristem : L.S. through shoot apex of Vinca, showing three-layered tunica and corpus beneath it.

The apical meristem exhibits a dome shaped structure with clear demarcation in outer layers (Tunica) and the inner mass (corpus) (Fig. 5.11). The apical meristem is composed of a small mass of cells which are alike and constitute the promeristem. The cells of the promeristem differentiate into three regions viz. dermatogen, periblem and plerome which grow and give rise to primary permanent tissues (Fig. 5.III).

(i) Dermatogen :

This is the single outer-most layer of cells. These divide and give rise to the epidermis of the stem. In roots the cells of the dermatogen form a mas of small tissues called calyptrogen. The calyptrogen is also meristematic and give rise to root cap. In dicot root, dermatogen forms epiblema.

(ii) Periblem :

This is located internal to the dermatogen and forms the cortex of the stem and root.

(ii) Plerome:

This lies internal to the periblem. It is the central region where cells show a tendency to elongate. These elongated cells form proaombium that gives rise to the varcular tissues (xylem and phloem) constituting the central cylinder or stele of the stem.

Intercalary meristem :

It is placed between two permanent tissues. Actually it is a part of the apical meristem which get separated from the apex during growth. Such meristems are found in monocot stems and leaf sheaths. They help in increasing the length of the organ.

Lateral meristem :

These meristems occur laterally on roots and stems. The cells are rectangular and always divide in tangential plane. The cork cambium and fascicular combium are examples of lateral meristems. The new cells formed by division differentiate into secondary tissues. These tissues lead to increase in thickness.

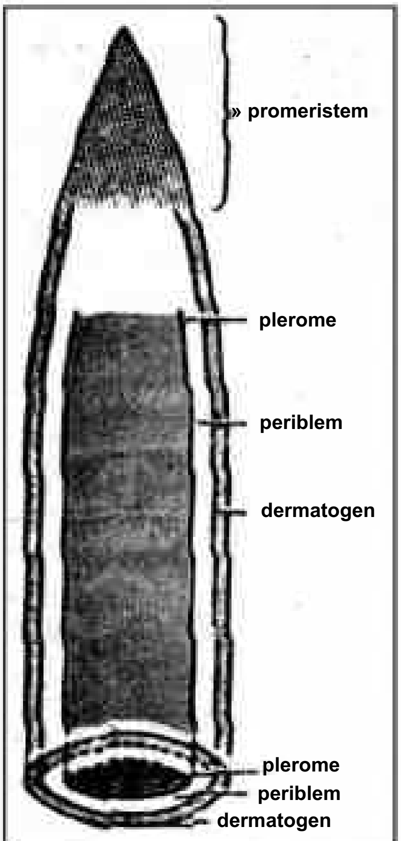


Fig.5.111 .L.S. of main axis showing histogens

IV. Meristem based on function :

Meristem may be of three types on the basis of physiological aspects : protoderm, pro-cambium and fundamental or ground meristem. The primary meristem at the apex of the axis is gradually differentiated into the following zones.

Protoderm :

It is the outermost layer which by radial division gives rise to a single layered epidermis. Sometimes by tangential division, it forms multiple epidermis.

Procambium :

Elongated tapering cells of the growing region constitute the procambium. It produces primary varcular tissues i.e. xylem, phloem and cambium. Procambium strands are scattered or occur in a ring, in monocot stems and dicot stems respectively.

Fundamental or Ground Meristem :

The remainder of the meristematic tissues lying in between protoderm and procambium constitutes fundamental or ground meristem. The cells of this region are large, thin walled and isodiametric. It forms hypodermis, cortex, endodermis, pericycle, pith and medullary rays.

V. Meristems based on plane of division :

There are three types of meristem based on the plane of division.

Mass or block meristem :

The cells of this meristem divide in all planes to form an irregular mass. Hence it leads to formation of structures like endosperm, young pith and cortex etc.

Plate meristem :

The cells divide in two planes (Periclinal followed by several anticlinal divisions) and thus form plate-like structures. Plate meristem results in the formation of uniseriate epidermis and multiseriate leaf blade.

Rib or file meristem :

Cells of this meristem divide anticlinally to form a column of cells. It results in increasing the length of various organs. Cortex and pith in stem are formed from this meristem.

VI. Special type : Wound meristem.

These are the surrounding tissues of wound. They multiply to heal up the wound.

Induced meristem :

They are developed at the cutting regions of plant body due to the application of hormones (Auxin). They help in initiation of root primordia as seen in Rose plants.

Hypertrophy :

This type of meristem occur in diseased tissue which multiply abnormally resulting in formation of gull (enlarged mass of cells).

Peristemoid :

This type of meristem is represented by stomata initial, archegonial initial, hair initial etc.

Cambium :

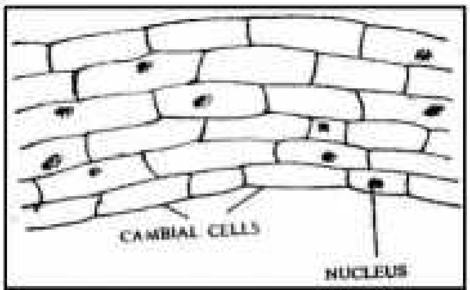


Fig.5.IV. Cambium tissue in T.S.

Cambium is a type of meristematic cells. (Fig. 5.1V) This is a thin strip of primary meristem lying in between xylem and phloem. Cambium originates from pro-combium. It is a meristematic tissue and possesses most of the characteristics of cells constituting a meristem. It usually consists of a few layers of thin-walled and roughly rectangular living cells. The nucleus is comparatively large. Cells of cambium are in a state of active division. Cambium cuts off xylem on one side and phloem on the other side. Cambium restricted to vascular bundles and lying in between xylem and phloem is known as fascicular cambium. A strip of cells adjoining fascicular combium between the vascular bundles when becomes meristematic is known as interfascicular cambium. Cambium developing in the cortex of stem is known as phellogen or cork-cambium. Cambium is responsible for secondary growth in thickness of the plant Body. Summary of the classification of meristematic tissues is given below:

Classification of Plant tissues

Merist ematic | Permanent

Meristematic

- on the basic of development - Promeristem
- on the basic of origin
  - Primary meristem
  - Secondary meristem
- on the basic of position
  - Apical meristem
  - Intercalary meristem
  - Lateral meristem
- on the basic of plane of division
  - Mass or Block meristem
  - Plate meristem
  - Rib or file meristem
- on the basic of function
  - Protoderm
  - Procambium
  - Ground meristem

Permanent

- Simple tissue
  - Parenchyma
  - Collenchymatry
  - Sclerenchymato
- Complex tissue
  - Xylem
  - Phloem
- Special & secretory
  - Laticiferous tissue
  - Glandulartissue

5.7.1.2. Permanent Tissues :

These are composed of fully differentiated mature cells that have lost the power of division. They have attained their definite form and size.

Characteristic features of permanent tissues :

(i) Cells may be living or dead.

(ii) Cell walls may be thin or thick.

(iii) Cells may contain reserve, excretory or secretory substances.

(iv) Intercellular spaces may be present or absent.

(v) Metabolic activities are relatively slow.

(vi) Vacuoles prominent.

Classification of permanent tissues :

On the basis of **origin,** permanent tissues are of two types (a) Primary permanent tissues which develop from primary meristematic tissue, eg. parenchyma, collenchyma etc. (b) Secondary permanent tissues which develop from secondary meristems, eg. secondary xylem, secondary phloem, cork etc.

On the basis of **function,** permanent tissues are of the following types

(i) Photosynthetic or assimilatory tissue.

(ii) Food storing tissue.

(iii) Conducting or vascular tissue.

(iv) Secretory tissue

(v) Mechanical tissue

(vi) Protective tissue

Broadly permanent tissues are of the following three types :

(i) Simple tissues

(ii) Complex tissues

(iii) Special or Secretery tissues.

Simple tissues :

A simple tissue is made up of one type of cells forming a homogenous or uniform mass. These are of following three types (Fig. 5.V) :

(a) Parenchyma:

The cells are more or less isodiametric. Typical parenchymatous cells are oval, spherical or polygonal in shape. Their walls are thin and made up of cellulose. Young cells are loosely packed with intercellular spaces. The cells have active protoplast having power of growth and division. They may contain leucoplasts or sometimes chloroplasts. The cells contain vacuolated cytoplasm with a distinct nucleus. They occur universally in all plants in the softer parts like cortex; pith, mesophyll of leaves, fleshy parts of succulents, pulp of fleshy fruits etc. (Fig.5.5a).

Type of parenchyma :

(i) Normal type : They are isodiametric with intercellular spaces. They form cortex, pith etc.

(ii) Chlorenchyma : These are the parenchyma containing chloroplasts.

(iii) Aerenchyma: Parenchymatous cells with well developed air cavities forming a connected system throughout the entire plant. They provide buoyancy to the floating hydrophytes and also help in gaseous exchange.

(iv) Idioblast : These are the parenchyma which produce and store oil, tannins, calcium oxalate in their vacuoles or cytoplasm.

(v) Prosenchyma : These are thick and elongated cells providing mechanical support to the plants.

(vi) Accessory parenchyma : parenchymatons cells which become meristematic and help in repairing wound.

Function of paranchyma :

Its function is mainly storage of food, water and mucilage. It helps in photosynthesis, provide buoyancy to plants, helps in gaseous exchange and wound healing and regeneration by cell division.

(b) Collenchyma :

The tissue consists of somewhat elongated living cells with inter cellular spaces much thickened due to deposit of cellulose and pectin. The cell wall is unevenly thickened. The cells often contain chloroplasts and thus participate in photosynthesis. Being flexible in nature, cellenchyma gives tensile strength to the stem. Its function is, therefore, both mechanical and vital.

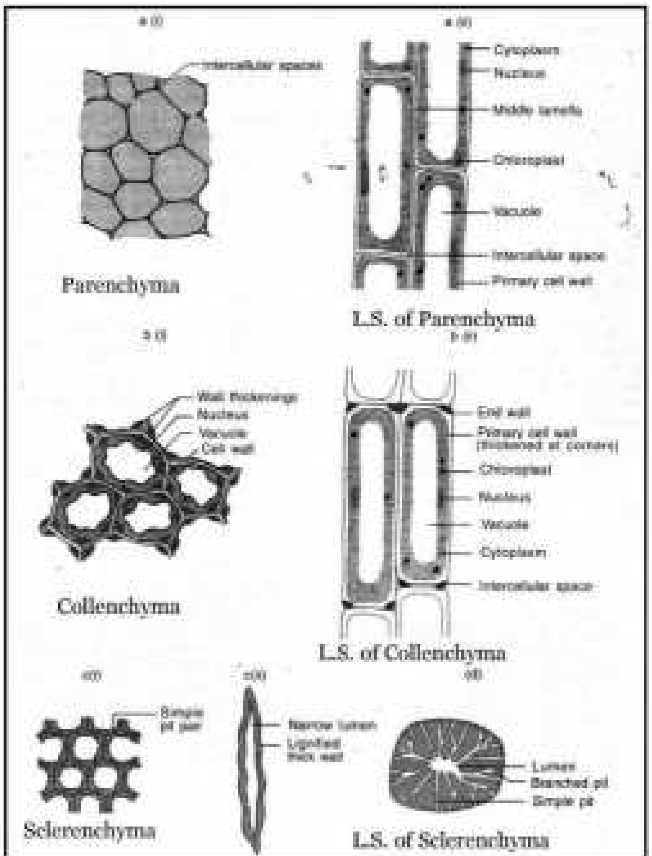


Fig.5.V. Simple permanent Tissues

(c) Sclerenchyma :

It consists of long, narrow or short, thick walled and lignified cells usually pointed at both the ends. Matured cells become dead due to loss of living protoplast. They give rigidity and mechanical strength to the plant body. On the basis of variation in form, structure, origin and development, sclerenchyma may be either fibres or sclereids. The fibres are pointed and needle like. They occur in groups as sheets or cylinders in various parts of the plant body. The sclereids are very thick walled, hard and strongly lignified. They are mostly isodiametric, polyhedral short and cylindrical with narrow cavity.

Special or Secretory tissues :

The tissues which are concerned with special functions like secretion or excretion of different kinds of substances like resins, latex, gums, nectar etc. are called special or secretory tissue. These tissues are of two main types.

(i) Laticiferous tissue :

These are long, thin walled living, multinucleate and profusely branched tube like tissues. They contain milky juices called latex. Latex may contain organic substances like protein, carbohydrates, oils, enzymes, alkaloids and some inorganic salts in emulsion or suspension form. These tissues are irregularly distributed in parenchymatous tissues. They occur either as latex cells or latex vessels (a) Latex cells are single, multinucleate with scanty cytoplasm. They may be branched or unbranched without forming network. They are commonly found in *Calotropis,* Catharanthus, *Ficus, Euphorbia* etc. (b) Latex vessels are formed by longitudinal rows of parallel branched ducts connected with one another by partial or total dissolution of the end walls of their branches. They are commonly found in *Carica, Papaver, Argemone* (Fig. 5.VI).

(ii) Glandular tissues :

These tissues are made up of glands. The glands are well organised and specialised structures which contain some secretary or excretory products. They occur either as single cells or in groups. Glands may be external or internal (a) External glands are superficial in nature and formed on epidermis. They may occur as hydathodes (Fig. 5.VII), glandular hairs, nectaries and digestive glands etc. (b) Internal glands are confined to internal tissues. They are formed by lysis of some of the cells or by splitting of cells at middle lamella. They occur as oil glands, mucilage secreting glands etc.

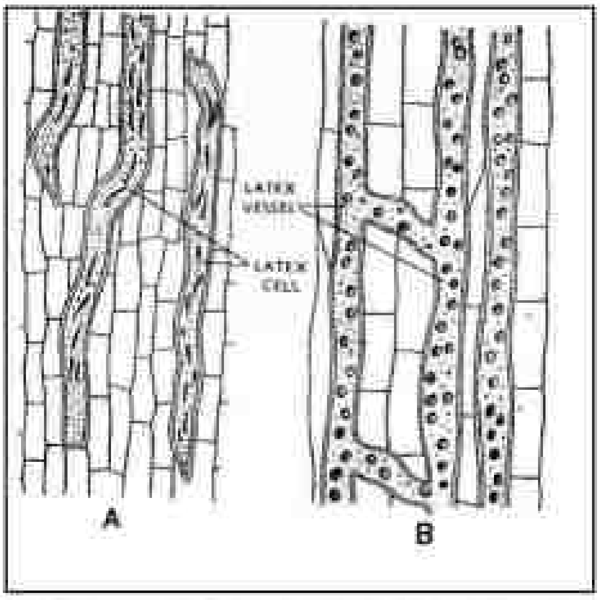


Fig.S.VI. Laticiferous ducts in sectional view
A. *Euphorbia pilulifera,* B. *Carica papaya*

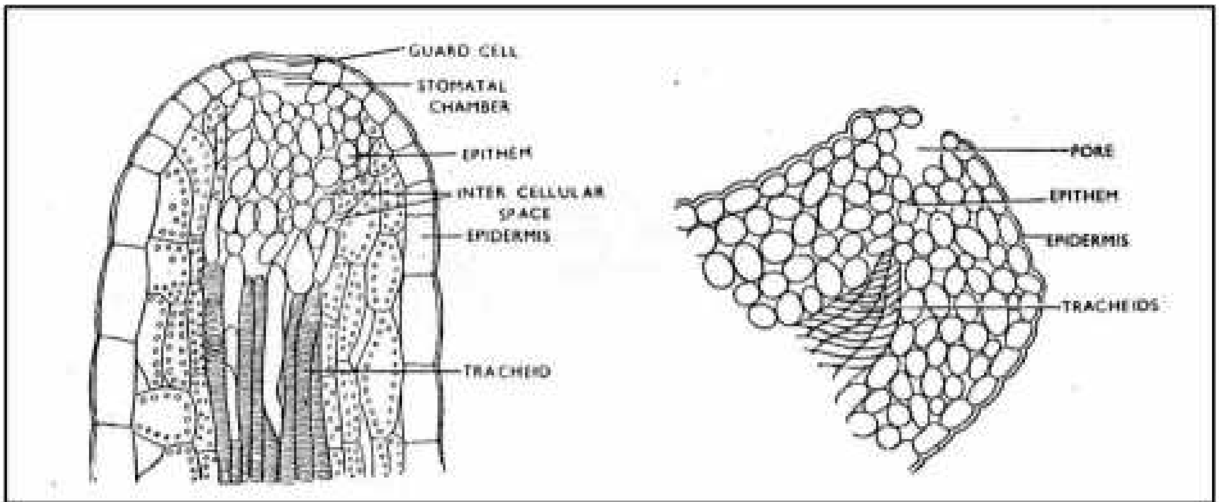


Fig.5.VII. Hydathode : A Primula spp. B. at the margin of tomato leaf

5.7.1.3. Complex Tissues :

Complex tissue is an assemblage of two or more types of cells performing a common function. It is heterogenous in nature. Xylem and phloem constitute complex permanent tissues,

(a) Xylem (Xylos = wood):

Xylem or wood is a complex tissue consisting of both living and dead cells. It forms a part of vascular bundles. It is a conducting tissue and is composed of four elements of different kinds:

(i) Tracheids (ii) Vessels (iii) Wood fibres and (iv) Wood parenchyma. The function of xylem is to conduct water and mineral salts upwards from the root to the leaf. Besides, it gives machanical strength to the plant body.

(i) Tracheids :

A single tracheid is a very elongated or tube-like cell with hard, thick and lignified walls and a large cavity. They are devoid of protoplast and hence dead. The end of the tracheids are tapering, blunt or chisel-like. Their walls are usually provided with one or more rows of bordered pits. Tracheids may also be annular, spiral, scalariform or pitted. In transvevse section they are mostly angular, either polygonal or rectangular (Fig.5.VIII).

In angiosperms they occur associated with vessels. Being lignified and hard, tracheids give strength to the plant body. Their main function is to conduct water and mineral salts from the root to the leaf.

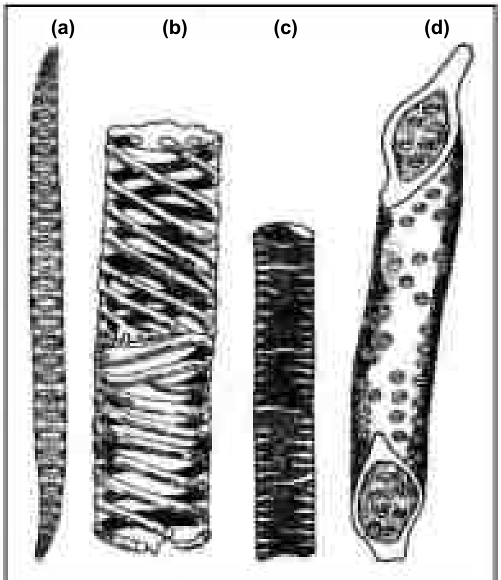


Fig. 5. VI11. ***Different types of tracheids (a) Annular (b) Spiral (c) Scalariform (d) Pitted***

(ii) Vessels or Tracheae :

Vessels are rows of elongated tube-like dead cells, placed one above the other with their transverse or end-walls perforated. A vessel or trachea is thus, like a series of water pipes forming a pipe-line. The cells are dead and without protoplast. They are shorter and broader than tracheids. Their walls are thickened in various ways. Depending on the mode of thickening verseis have received names such as annular, spiral, scalariform, reticulate and pitted (Fig. 5.IX). Vessels have been found in a majority of angiosperms and in some pteridophytes and gymnosperms. They help to conduct water and mineral salts. They also serve the mechanical function of strengthening the plant body.

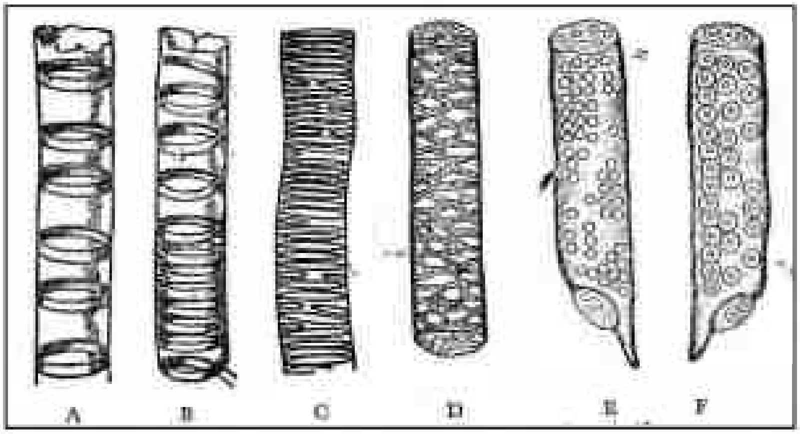


Fig.5.IX. kinds of vessels A. annular; B. spiral; C. scalariform; D. reticulate; E. a vessel with simple pits; F. a vessel with bordered pits.

(iii) Wood fibres or xylem fibres :

Sclerenchymatous cells associated with xylem are known as wood fibres. These are found in both the primary and secondary xylem. They have thickened walls and obliterated central lumen. They add mechanical strength to the xylem and the plant body as a whole.

(iv) Wood parenchyma :

Parenchymatous cells associated with xylem form the wood parenchyma. The cells are living and possess thin cellulosic walls. They assist in the transport of water. They store starch, oil and ergastic substances like tannins.

The first formed xylem elements are described as protoxylem and consists of annular, spiral and scalariform vessels, and lie towards the centre of the stem. The later formed xylem is described as metaxylem and it consists of some tracheids alon gwith reticulate and pitted vessels. In stem, it lies away from the centre and its vessels have much bigger cavities compared to those in the protoxylem.

Phloem

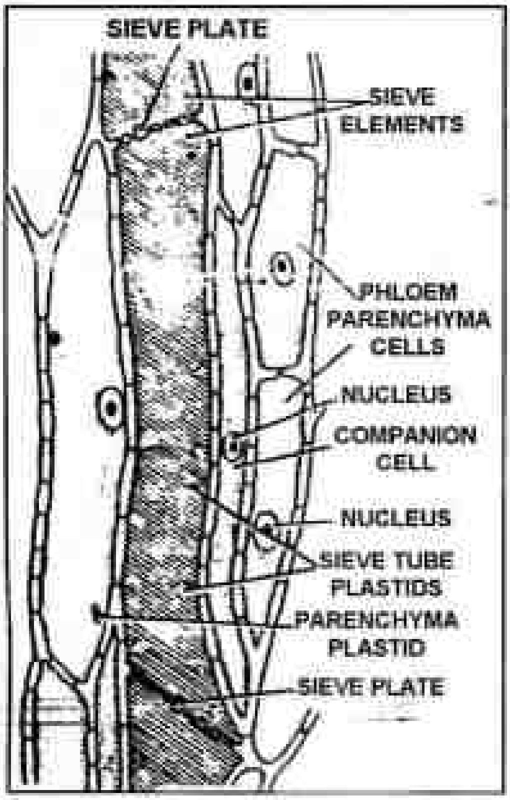


Fig.5.X. Phloem tissue from the stem of *Nicotian a.*

Phloem or bast is another permanent complex tissue. It is also known as bast leptome. It is composed of four elements (Fig. 5.X).

(i) Sieve-tubes (ii) Companion cells (iii) Phloem parenchyma (iv) Phloem fibres.

(i) Sieve-tubes :

Sieve-tubes occur as long, slender tube-like structures composed of elongated cells, placed end to end. Their walls are thin and made of cellulose. Their transverse walls are oblique and are perforated (sieve pores) in a sieve like manner to form the sieve plate. The protoplasmic strands of one sieve tube pass to the adjacent sieve plate. In winter, the sieve-plates get impregnated with callus pads made up of cellulose. On arrival of spring i.e. under the favourable conditions the callus gets dissolved. A young sieve tube contains nucleus, cytoplasm and other organelles. In old sieve tubes the callus forms a permanent deposit. Its nucleus gets disintegrated but a layer of cytoplasm prevails which is continuous through the pores. Sieve tubes conduct food materials like carbohydrates and proteins from leaves to the storage organs and later from the storage organs to the growing regions of the plant body.

(ii) Companion cells :

These are specialised parenchymatons cells which are closely associated with sieve tube elements in their origin, position and function. It is living, containing dense granular cytoplasm and large elongated nucleus. Companion cells are connected with sieve tubes by pits present in their common longitudinal wall. The companion cells play an important role in the maintenance of pressure gradient in the sieve tubes. They occur only in angiosperms.

(iii) Phloem parenchyma :

These are thin walled living parenchymatous cells associated with phloem tissue. They store organic food materials but are absent in monocotyledons.

(iv) Bast fibres or phloem fibres :

Elongated sclerenchymatons cells having pointed, needle like apices occurring in the phloem are knwon as phloem fibres or bast fibres. The walls of these fibres are usually thickened due to the deposit of cellulose or lignin. At maturity the bast fibres lose their protoplasts and become dead. Phloem fibres of many plants like *Corchorus, Cannabis* etc. are the sources of commercial fibres.

5.7.2. THE TISSUE SYSTEM :

In higher plants tissues are arranged into different tissue systems. Sachs, a German scientist for the first time in 1875 classified the plant tissue system into three basic categories basing on their position and morphology. These are : (1) epidermal tissue system, (II) the ground/fundamental tissue system, and (III) the vascular tissue system. Each system may consists of only one or a combination of tissues that may be structurally alike or of different nature, but perform a common function and share a common origin.

1. The Epidermal Tissue System :

The epidermal tissue system conists mainly of epidermis, stomata, the epidermal appendages, root hairs etc. The epidermis (epiupon; dermaskin) is the outermost covering of the primary plant body. It originates from the protoderm. In shoot, apices with distinct tunica and corpus organization, the epidermis develops from the outer layer of tunica. The epidermis is usually single layered but multilayered epidermis also exists as in the leaves of Ficus, Begonia, Nerium etc. In old stems, after secondary growth epidermis is replaced by periderm. The

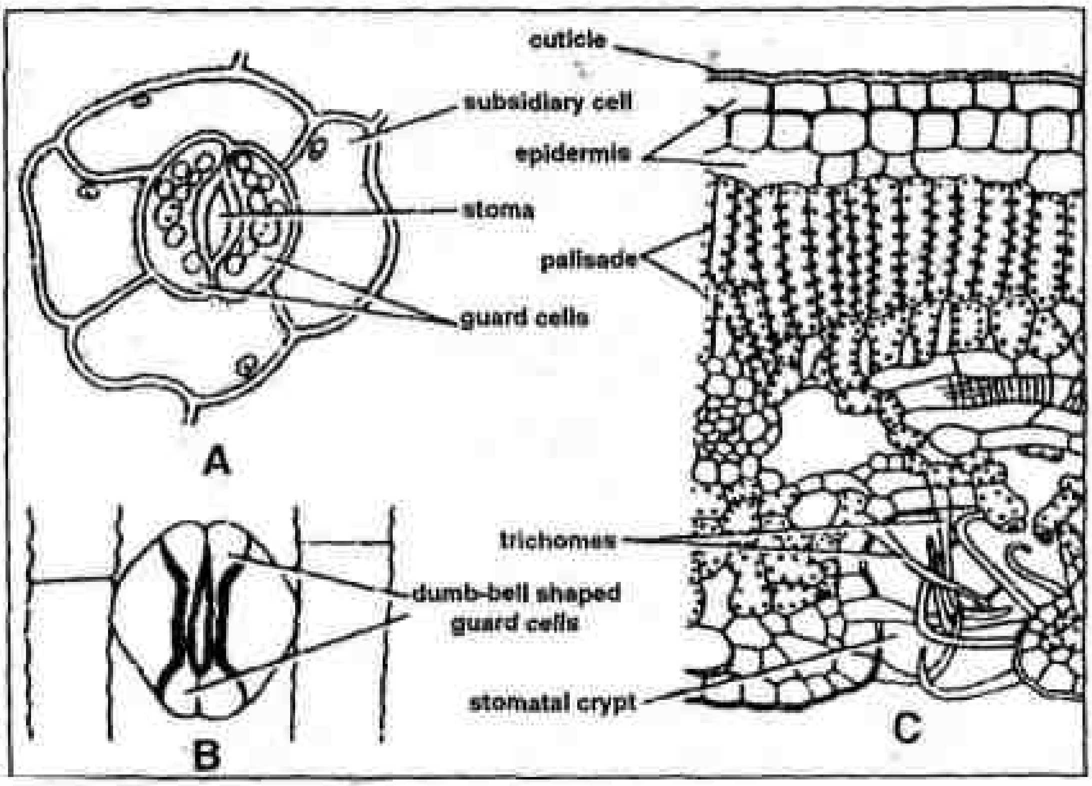


Fig.5.XI. Stomata A. structure of a typical stoma B. stoma of a monocot leaf with dumbell-shaped guard cells C. sunken stoma in *Nerium* leaf.

epidermis is made up of elongated compactly arranged cells forming a continuous layer without intercellular spaces except in petals of plants like *Linum.* The cells appear more or less rectangular in transection. The epidermal cells are parenchymatous in nature with a large central vacuole surrounded by a thin layer of colourless cytoplasm. The outer or exposed walls of epidermal cell are thick and usually covered by a cuticle formed by the deposition of a waxy material secreted by epidermal cells. The outermost layer in root is referred to as epiblema or piliferous layer due to its structure and nature of origin. Epiblema is neither cutinised nor provided with stomata. The epidermis in some monocots like the members of the family Poaceae contain **builliform** or **motor** cells. These are thin walled, larger cells helping in rolling and unrolling of the leaves by changes in their sizes, depending on the inflow and outflow of water.

Several minute openings called stomata (sing, stoma) are found in the epidermis of young, green, aerial parts and leaves. Each opening is surrounded by a pair of guard cells (Fig .5.XI). Guard cells, unlike epidermal cells contain chloroplasts and are responsible for the opening and closing of stoma. Sometimes, a few neighbouring epidermal cells, in the vicinity of guard cells become specialised in their shape, size and contents and are known as **subsidiary cells.** In such case, the stomatai aperture togetherwith the guard cells and the subsidiary cells are called stomatal apparatus.

When the subsidiary cells and guard cells develop from the same mother cells then the stomata are **mesogenous** (Hyplocheilic). If the subsidiary and guard cells have independent origin the stomata are **perigenous** (syndetocheilic). In **mesoperigenous** condition, at least one subsidiary cell has a common origin with the guard cells and the rest do not. The distribution of stomata in leaves vary greatly. In most of the dicot leaves the stomata are confined to the lower surface of the leaf. Such leaves are called **hypostomatic.** In some plants like *Polygonum amphibium,* having floating leaves stomata are confined to upper surface of leaf. Such leaves are called **epistomatic.** In monocots stomata are found on both surfaces such leaves are **amphistomatic.** In plants growing in deserts or dry regions, stomata occur **sunken** in pits to reduce excessive transpiration.

The cells of the epidermis give rise to a number of appendages which vary greatly in their shape, structure and function. These are known as **trichomes** (fig. 12. 13). These appendages may be multicellular or unicellular. The unicellular trichomes are usually simple, unbranched and elongated structures. The multicellular trichomes and glands are made up of several layers of cells. There are four main types of trichomes : (i) Hairs, (ii) collectors, (iii) water vesicles or bladders and (iv) scales. The multicellular haires are associated with stem epidermis while unicellular hairs are found on roots. Hairs can also be branched or unbranched. Collectors are glandular hairs with multicellular stalk and head. They are found in bud scales and stipule. Water vesicles, otherwise known as vesicular hairs are greatly distended epidermal cells storing water. Scales are modified trichomes with discoid sheet or plate of cells mounted on stalk. Besides trichomes epidermal emergences like spines, warts are also found in plants.

Epidermal root hairs are extensions of individual epidermal cells, which occur in a zone just behind the tips of young growing roots. Because a root hair is simply an extension and not a separate cell, there is no cross-wall isolating it from the epidermal cell. The root hair is formed due to elongation of epidermal cell, and is therefore, not a protuberance or appendage. The root hairs are ephemeral (short-lived) structures which play an important role in anchoring the plant body in the soil and absorbing water and minerals from the soil.

I. Function:

(i) Protection of inner tissue.

(ii) Cuticularization of epidermis, checks transpiration. Presence of cuticle also reduces heating by reflecting light to certain extent.

(iii) Stomata are responsible for exchange of gases.

(iv) Bullform cells help in rolling and unrolling of leaves thus control transpiration.

(v) Different appendages carry out specialised functions like scale for protection, water vesicles for retention of water etc. glands for secretion etc.

(vi) Root hairs are responsible for absorption.

(vii) Epidermal hairs on seeds help in dispersal.

II. The Ground Tissue System (Fundamental Tissue System):

The ground tissue system or fundamental tissue system forms the main bulk of the plant body. It extends from below the epidermis upto the central region. This system has various kinds of tissues such as parenchyma, collenchyma and sclerenchyma of which parenchyma is the most abundant. It is differentiated into following zones and sub-zones.

I. Cortex :

This is the zone that lies in between epidermis and pericycle, and is made up of primary tissues. It varies in thickness from a few layers to many layers. In monocot stems, owing to the presence of scattered vascular bundles, the cortex is undifferentiated and the zone is predominantly parenchymatous. In roots the cortex consists of many layers of thin-walled parenchyma and a distinct endodermis. In the leaves the ground tissue, consisting of thin-walled chlorenchyma is called mesophyll. In the dicotyledon stems the cortex is usually differentiated into :

(a) hypodermis : (or outer cortex) (b) **General cortex** (or middle cortex) and (c) **endodermis** (or innermost cortex) Hypodermis lies just below the epidermis (absent in roots), composed of few layers of continuous or discontinuous band of collenchyma (as in dicot stems) or sclerenchyma (as in monocot stems). The general cortex or cortical parenchyma is a few layered thin-walled parenchymatous zone with or without chloroplasts. The cortex is composed of thin-walled, uniform, round and spherical parenchymatous cells. The cells have copious intercellular spaces but the angular parenchymatous cells are without intercellular space. In some cases chlorenchyma or aerenchyma may be differentiated from these cells to help in the adaptation of the plant. The endodermis is the innermost layer, often wavy and is single layered. It often contains numerous starch grains. In a transverse section it appears barrel shaped without intercellular spaces. The cells show deposition of waxy materials- **Suberin.** On their radial walls, these appear in the form of strips or bands which are called **casparian strips** (Fig. 5.XII. a,b,c). In roots, some thin-walled, rounded cells are are seen in endodermis in the proximity of protoxylem which area known as **passage cells.** The passage cells allow flow of water from cortex to xylem but prevent the back flow of water due to the thickening of radial walls and outer walls.

Function : The cortex has several primary and secondary functions. In the stem it basically serves as a protective zone. Besides, the cortex in the stem also stores food. In roots it mainly stores food and also helps in absorption and translocation of water.

2. Pericycle :

It forms a multi-layered zone between the endodermis and the central vascular cylinder. Pericycle is present in both stem and root but is not found in many hydrophytes and monocot stems. In dicot stems, it occurs as a cylinder encircling the vascular bundles and the pith. Pericycle originates from apical meristem. Pericycle may be parenchymatous as in roots or sclerenchymatous as in dicot stems. In dicot stems the sclerenchymatous pericycle may be continuous or discontinuous. The scleremchyma form isolated strands which associate with the phloem or bast of the vascular bundle in the form of a cap known as the **hard bast.** In roots, the pericycle consists of a single layer of small very thin-walled, more or less barrel-shaped cells.

Function : In roots the pericycle is the seat of origin of lateral roots. In dicot roots pericycle give rise to lateral meristem. In stems, pericycle is the seat of origin of adventitious roots. Parenchymatous pericycle serves as storage layer.

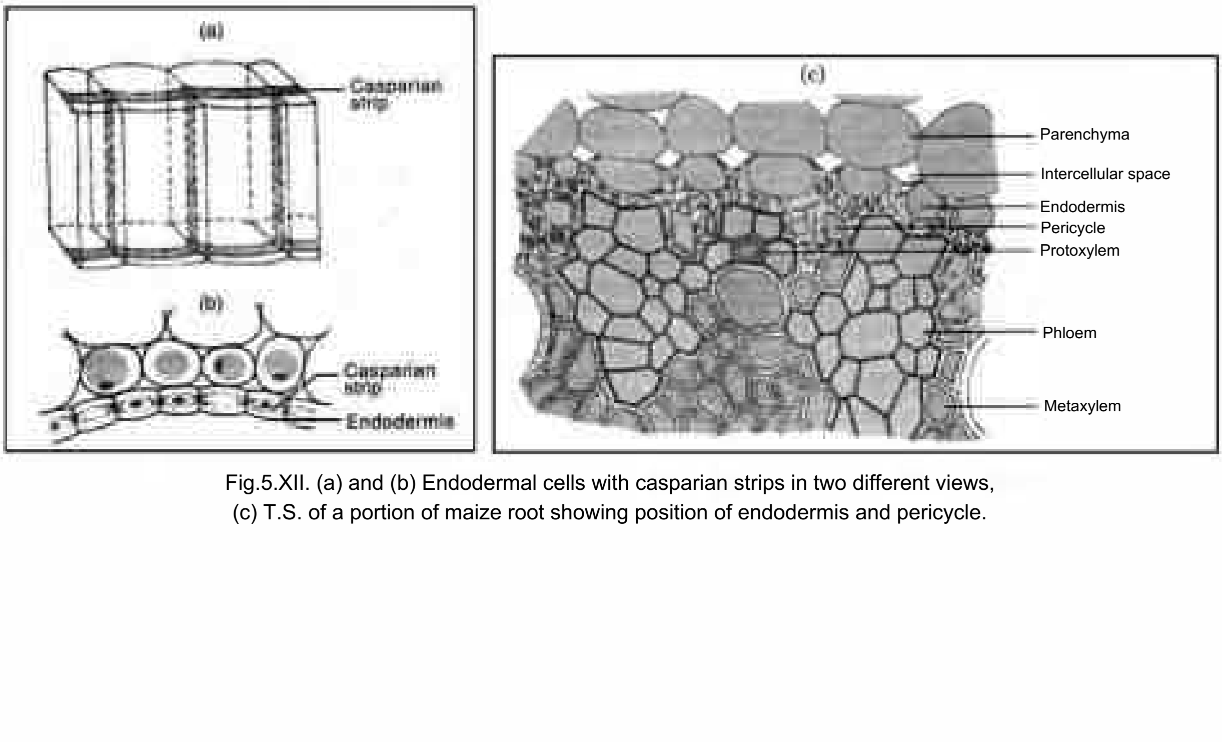


Fig.5.XII. (a) and (b) Endodermal cells with casparian strips in two different views,
(c) T.S. of a portion of maize root showing position of endodermis and pericycle.

3. Pith :

The central core part of the ground tissue is known as pith or medulla. It is usually made up of thin-walled, large-celled parenchyma with or without intercellular spaces. In dicot stems, the pith is often large and well developed. Here, it extends out-wards to the pericycle between the vascular bundles. Each such extension of pith is a strip of parenchyma known as **pith ray** or medullary ray. In dicot root, the pith is either small or absent whereas in monocot root a distinct large pith is present. In dicot root often bigger vessels of xylem meet at the centre.

Function : It chiefly serves as the store house of several excretory substances such as tannins, phenols, calcium oxalate etc. It also provides mechanical strength. The medullary rays, at the time of secondary growth, become partly meristematic and produce secondary meristem.

III. The Vascular Tissue System : (Fascicular Tissue System).

The vascular or fascicular tissue system is derived from procambium and serves as the conducting system of plants. The vascular tissue system consists of varying number of strands or bundles of tissues embedded in the ground tissue known as **vascular bundles.** Each vascular bundle is constituted by xylem and phloem. A strip of meristematic tissue called cambium may or may not be present in between xylem and phloem. When cambium is present the vascular bundle is said to be **open vascular bundle** and when cambium is absent it is said to be **closed.** Open vascular bundles are associated with dicot stem where as closed ones are seen in monocot stem. Further, the vascular bundles are arranged in a ring in the ground tissue of dicot stem, whereas they are scattered in the ground tissue of monocot stem.

Depending upon the organ of plants and their function in the plant body, the arrangement of xylem and phloem differs in vascular bundles. Accordingly vascular bundles are of the following types (Fig. 5.XIII).

(i) Radial : Vascular bundles have xylem and phloem patches arranged separately on alternate radii. This is seen in roots.

(ii) Conjoint: Vascular bundles have xylem and phloem arranged on the same radius situated opposite to each other. This is seen usually in stems and leaves. Conjoint vascular bundles can again be of two types depending upon the number and position of phloem patches.

(a) **Collateral** vascular bundles have one patch of phloem and one patch of xylem. They can be either open or closed type. It is a very common type of vascular bundle seen in stems of most dicot except the members of family cucurbitaceae and some members of family Convolvulaceae.

(b) Bicollateral vascular bundle consists of two patches of phloem on either side of a single patch of xylem. There are also two patches of cambium on both side of xylem. The outer patch of phloem lying towards the periphery is separated from the xylem by outer cambium strip. The inner patch of phloem lying towards the centre is separated from xylem by inner strip of cambium. These vascular bundles are always open. The outer combium is concave and the inner is plano-concave in appearance. These vascular bundles are found in the stems of the members of family Cucurbitaceae and some members of Convolvulaceae.

(iii) Concentric : These vascular bundles have either phloem surrounding the xylem or xylem surrounding the phloem. This is again of two types.

(a) Amphicribral Xylem lies at the centre and is surrounded by a ring of phloem. It is also known as hadrocentric and in common in Pteridophytes like *Lycopidium, Selaginella* etc.

(b) Amphivasal Phloem lies at the centre and is surrounded by xylem. It is also known as leptocentric type. Such bundles are seen in certain monocot stem like *Dracaena.*

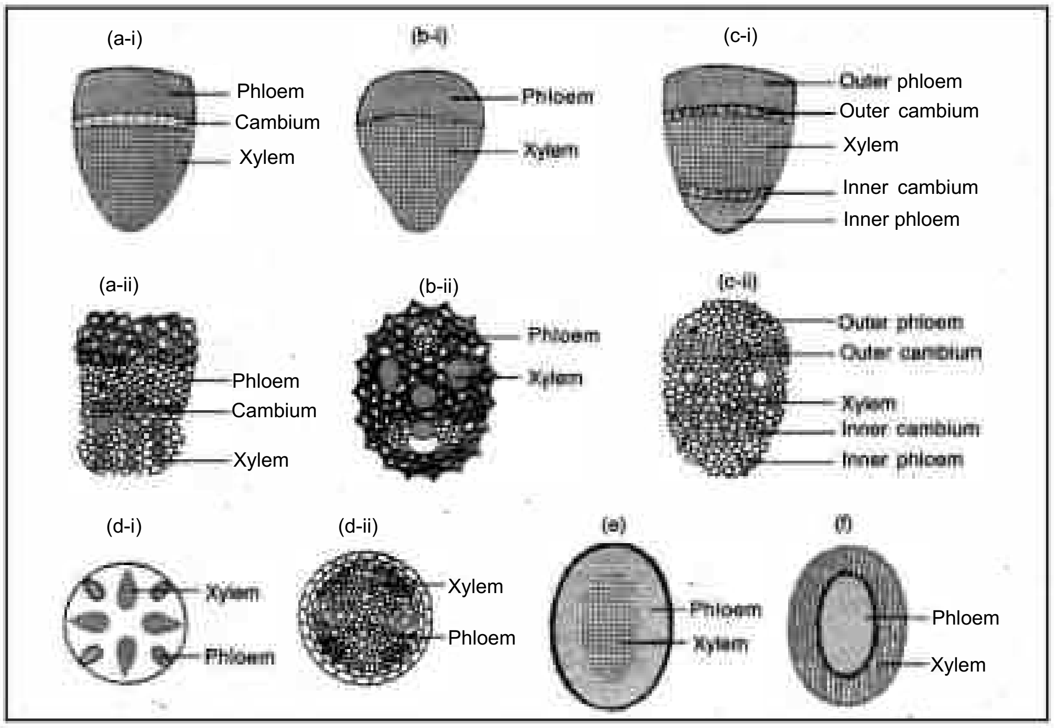


Fig.5.XIII. Various types of vascular bundles : a-i & ii. conjoint collateral open; b.-i, ii. conjoint collateral closed; c-i/ii. Bicollateral; d-i/ii. Radial; e-Amphicribral (f) Amphivasal.

5.7.3. ANATOMY OF STEM, ROOT AND LEAF :

Anatomy of Stem :

Generally stem forms the aerial part of the plant. It has characteristic internal organization. The stem performs various functions and each function is carried out by a different tissue. The detailed anatomy of stem can be studied under two headings such as dicotyledonous stem and monocotyledonous stem.

Common anatomical features of stem :

(i) Epidermal hairs are mostly multicellular.

(ii) Cortex is differentiated into zones.

(iii) Vascular bundles are conjoint, collateral, bicollateral or concentric.

(iv) Xylem is endarch.

Common anatomical features of dicot stem :

(i) Cortex is divisible into different zones.

(ii) Hypodermis is usually collenchymatous.

(iii) Vascular bundles are arranged in a ring.

(iv) Vascular bundles are conjoint, collateral, open endarch.

(v) A distinct pith is present.

(A) Anatomy of some dicotyledonous stems :

The internal structure of dicotyledonous stems varies in different plants. *Helianthus* and *Cucurbita* stems deseribed below.

Internal structure of stem of Helianthas annus (Sun flower) :

A thin transverse section of the stem shows following features. The outline of the cross section of stem is circular (Fig. 5. XIV).

Epidermis :

It is the outermost layer. It consists of a single row of closely packed thin parenchymatous cells. A thin layer of cuticle sometimes remain present on the epidermis. Epidermis bears uniseriate multicellular hairs.

Cortex :

It occurs below the epidermis and extends up to the pericycle. It consists of three regions. The outer hypodermis, the middle general cortex and lowermost endodermis.

(i) Hypodermis :

It occurs just below the epidermis. It consists of a few layers of collenchymatous cells. The cells are thickened at the intercellular spaces. The cells are living and contain chloroplasts.

(ii) General cortex :

It occurs between hypodermis and endodermis. It consists of several layers of thin-walled parenchymatous cells.

(iii) Endodermis :

This is the inner most layer of cortex. It consists of a single layer of compactly arranged barrel shaped cells. The cells of endodermis contain numerous starch grains. Thus endodermis is referred to as **starch sheath.**

Pericycle :

This zone occurs in between the endodermis and the vascular tissue. It consists of semilunar patches of sclerenchyma alternating with parenchyma. Each patch of sclerenchyma is associated with the phloem of vascular bundles. Thus it is known as hard bast or bundle cap.

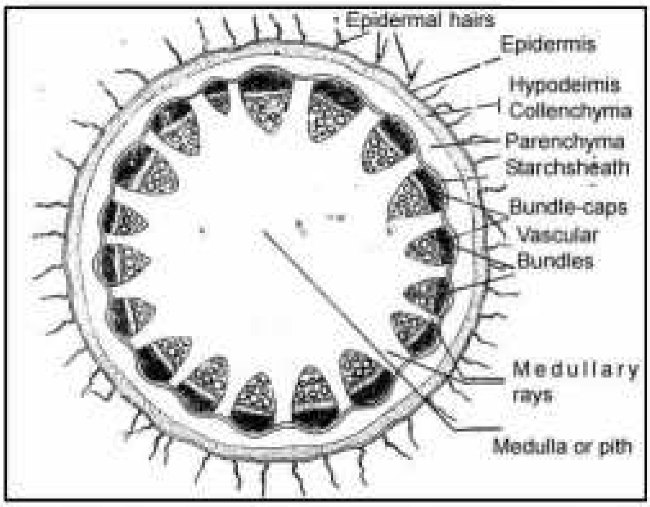
Vescular bundles :

Vascular bundles are arranged in a ring. They are separated from each other by parenchymatous medullary rays. Each vascular bundle is conjoint, collateral and open type. It consists of phloem, combium and xylem.

(i) **Phloem :** It occurs towards the periphery and consists of sievtubes, companion cells, bast fibres and phloem parenchyma.

(ii) **Cambium :** It occurs in between phloem and xylem. It consists of 2-3 layers of thin walled, small sized compact and rectangular cells.

(iii) **Xylem :** It occurs towards the centre and consists of tracheids, vessels, wood parenchyma and wood fibres. Xylem is endarch i.e. protoxylem lies towards the centre, and metaxylem towards the periphery.



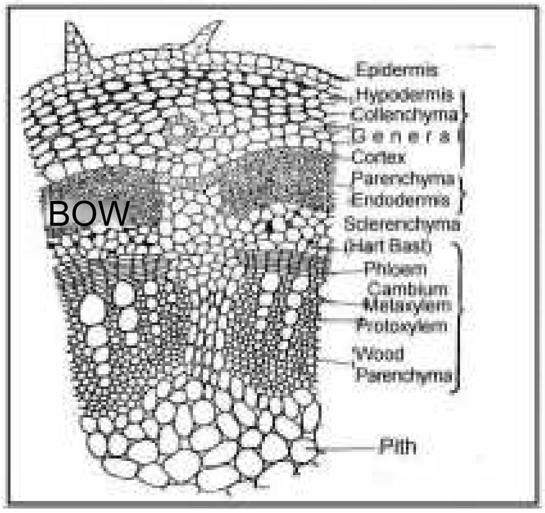


Fig.5.IV. T.S. of stem of **Helianthus annus** : A. Ground plan B. A portion magnified.

Pith :

It occurs at the centre. It consists of round, thin walled parenchymatous cells with distinct intercellular spaces.

Pith rays : (Medullary rays)

These are the regions radiating from pith. They occur in between the vascular bundles. They consist of a few layers of radially elongated parenchymatous cells.

INTERNAL STRUCTURE OF STEM OF CUCURBITA MAXIMA

The outline of a cross section is wavy having ridges and furrows (Fig. 5. XV).

Epidermis : It consists of a single layer of cells. The epidermis is covered by a thin layer of cuticle. Multicellular hairs arise from epidernal cells.

Cortex: It occurs below the epidermis and extends upto the pericycle. It consists of the outer hypodermis, the middle general cortex and the lowermost endodermis.

(i) **Hypodermis :** It occurs below the epidemis, consists of 6-7 layers of collenchymatous cells in the ridges and 2-3 layers in the furrows.

(ii) **General cortex :** It forms a narrow zone consisting of 2-3 layers of chlorenchymatous cells.

(iii) **Endodermis :** It is the innermost layer of the cortex lying immediately outside the pericycle. It consists of barrel shaped cells and is wavy in outline, the cells contain starch grains.

Pericycle: It consists of 3-4 layers of thick-walled, lignified, polygonal, sclerenchymatous cells. The general out-line of this layer is also wavy.

Vascular bundles : The vascular bundles are arranged in two rings. They are conjoint, bicollatral and open type. The outer ring of vascular bundles are comparatively small in size and occur opposite to ridges. The inner ring consists of larger vascular bundles which occur below the furrows. Each vascular bundle consists of

(i) Xylem (ii) Two strips of cambium and (iii) two patches of phloem.

Phloem : Phloem occurs in two patches. The outer phloem is towards the periphery and the inner phloem is towards the pith. The outer phloem is planoconvex and the inner one is semilunar in shape. Phloem consists of sieve tubes, companion cells, phloem fibres and phloem parenchyma.

Cambium : Combium occurs in two strips-the outer and the inner one on each side of the xylem. The cells are rectangular and thin walled.

Xylem : It is located in between the two cambium patches. It consists of vessels, tracheids, wood fibres and wood parenchyma. Xylem is endarch in nature.

Pith : It is a hollow cavity.

B. Internal structure of monocotyledon stems :

Stems of monocotyledon plants exhibit a number of variations in their anatomy from that of dicotyledon stems. The following distinct differences are marked in monocot stem.

(i) The hypodermis is sclerenchymatous and sometimes with sclerenchyma patches or embedded vascular bundles in the hypodermis.

(ii) There is no distinction into general cortex, endodermis, pericycle and stelar region. The whole mass of tissue constitutes the ground tissue.

(iii) The vascular bundles are scattered and lie more towards periphery than the centre.

(iv) Each vascular bundle is closed i.e. devoid of cambium.

(v) The vascular bundle has either a sclerenchymatous bundle sheath or bundle cap.

(vi) Phloem parenchyma is absent.

(vii) Pith is absent.

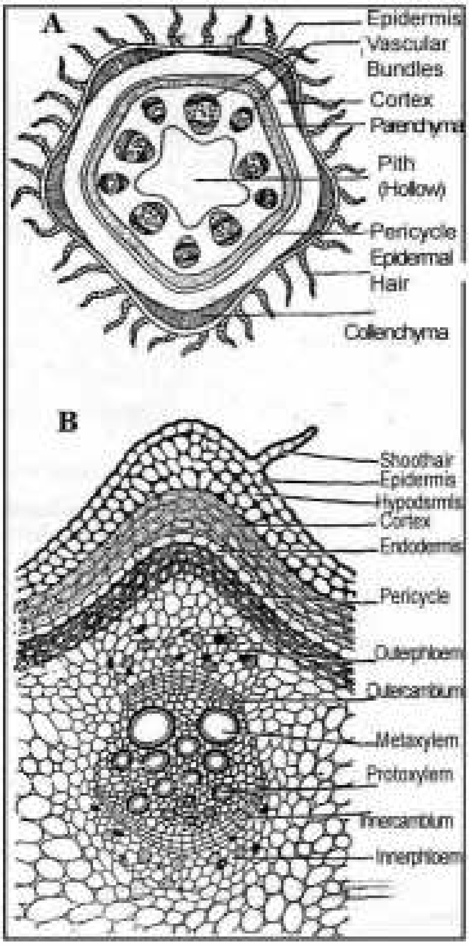


Fig.5.XV. T.S. of cucurbits stem: A.Ground plan B. A portion magnified.

Internal structure of stem of maize *(Zea mays) :*

A thin transverse section of the young maize stem reveals the following internal structure from the periphery to the centre (Fig. 5. XVIA).

(i) The outline of the stem is circular.

(ii) **Epidermis :** This is the outermost layer of cells which is usually single layered. It is covered with a thick cuticle and bears few stomata.

(iii) **Hypodermis :** This forms a narrow zone of sclerenchyma, usually two or three layers thick. It occurs below the epidermis.

(iv) **Ground tissue :** The entire tissue lying inside the epidermis, except for the vascular bundles, is known as the ground tissue. The ground tissue is not differentiated into cortex, endodermis, pericycle and pith. It consists of rounded parenchymatous cells with distinct intercellular spaces.

(v) **Vascular bundles :** The vascular bundles are many in number and are of variable size. They are collateral and closed and lie scattered in the ground tissue. The

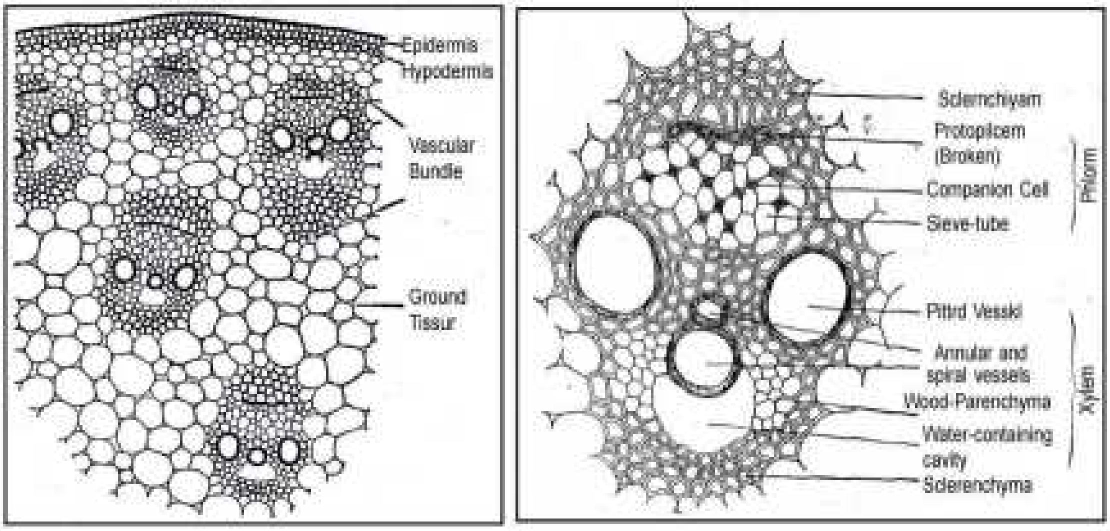


Fig.5.XVI. (A) Maize stem (a scetor) in T.S.
(B) A Vascular bundle in Maize stem (magnified.)

peripheral vascular bundles are smaller in size than the central ones. Each vascular bundle is oval and is more or less completely surrounded by a sheath of sclerenchyma which is specially developed on the two sides - upper and lower. The vascular bundles are conjoint, collateral, endarch and closed. The vascular bundle consists of two parts, xylem and phloem (Fig. 5. XVIB).

(a) **Xylem :** The xylem consists of four distnct vessels arranged in the form of a Y, and a small number of tracheids arranged irregularly. Two smaller vessels lying at the arm base constitute the protoxylem. The two bigger vessels lying laterally constitute the metaxylem, The lowermost protoxylem vessels open into a cavity called water containg cavity. Besides, wood fibres occur associated with tracheids in between the two big pitted vessels. Thin walled wood (or xylem) parenchyma surrounding the water containing cavity occurs in the protoxylem.

(b) **Phloem :** The phloem lies outer to the xylem. It consists of sieve tube elements and companion cells. Phloem parenchyma is absent. The outermost portion of the phloem, which is a broken mass, is the protophloem, and the inner portion is the metaphloem.

Internal structure of stem of *Canna* :

A thin transuerse section of the young *Canna* stem shows the following internal structure from the surface to the centre.

The stem is circular in outline (Fig. 5.XVII).

(i) **Epidermis:**

Epidermis consists of a single layer of tangentially elongted, cutinised and compactly arranged cells.

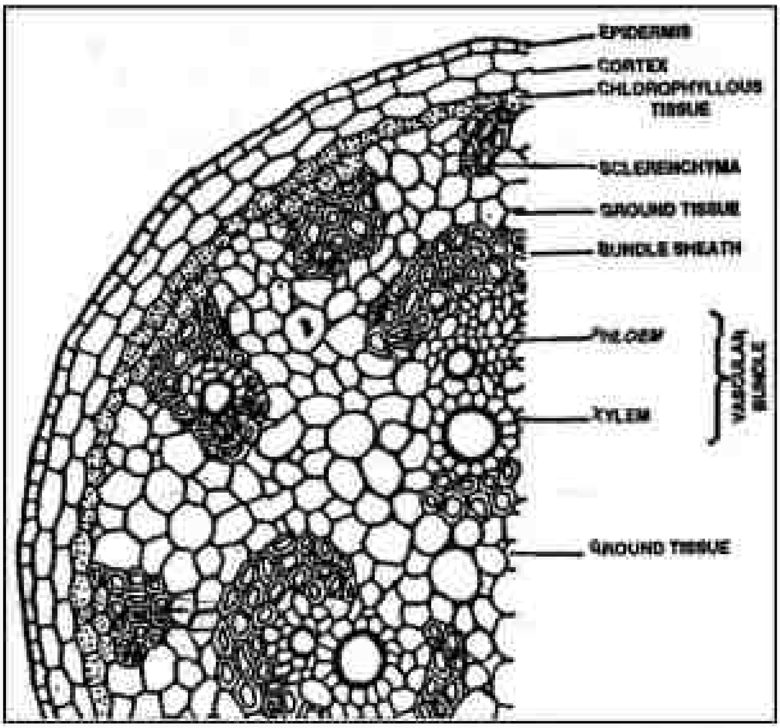


Fig.5.XVII. A Portion in T.S. of flowering scape (stem) of Canna.

(ii) Ground tissue :

It is the whole tissue that extends from the epidermal layer to the centre of the axis and in this tissue vascular bundles are embedded. It is not differentiated into hypodermis, endodermis and pericycle. It consists of the following regions.

Just below the epidermis 2-3 layers of compactly arranged parenchymatous cells are present.

Inner to parenchymatous layer, a few layers of chlorenchyma cells occur.

Isolated patches of sclerenchymatous cells are seen attached to the inner side chlorenchymatous layer. The rest of the ground tissue consists of thin walled parenchymatous cells.

(iii) Vascular bundles :

Vascular bundles varying in shapes are distributed irregularly in the ground tissues. More number of vascular bundles are seen towards periphery. Peripheral bundles are smaller than the central bundles. Each vascular bundle is oval shaped and has a sclerenchymatous bundle sheath. The vascular bundles are conjoint, collateral, endarch and closed. In the xylem there is a large metaxylem element being surrounded by few protoxylem elements. Phloem is present on the outer part of the vascular bundle. It does not possess phloem parenchyma.

Table - 5.1

Differences between Zea *mays* and *Canna* Stem

Stem of ***Zea mays***	**Stem of** ***Canna***
1. Cuticle is thick	1. Cuticle is thin
2. Hypodermis consists of 2-3 layers of sclerenchyma	2. There occurs 2-3 layers of compactly arranged parenchyma below the epidermis
3. Chlorenchyma layer and patches of selerenchyma are absent in ground tissue	3. Chlorophyllous layer and patches of sclerenchyma occur in the ground tissue.
4. Xylem is "Y" shaped with metaxylem consisting of two wide, pitted vessels making the arms of "Y". Protoxylem elements are generally present at the base of "Y".	4. There is a single metaxylem vessel which is surrounded by protoxylem elements.
5. Phloem elements are present between the forked arms of the "Y" shaped xylem.	5. Phloem elements surround the xylem element and found on the outer part of the vascular bundle.

5.7.32. ANATOMY OF ROOTS

The internal structure of root is comparatively simple than that of the stem. It is a simple organ and lacks any lateral appendages and nodes. The primary structure of the root in a transverse section shows certain distinct characters.

(i) The outermost layer of the root is known as epiblema or piliferous layer. It is not covered by cuticle.

(ii) Epidermal hairs or root hairs are unicellular

(iii) Hypodermis is absent.

(iv) Cortex is a broad zone.

(v) Endodermis is with characteristic casparian strips which occur outside the vascular bundles.

(vi) Vascular bundles are radial.

(vii) Xylem is exarch.

The detailed anatomy of dicot and monocot roots are described separately.

(A) Dicot root:

Dicot roots show the following distinct anatomical features.

(i) Number of vascular bundles varies from 2-6.

(ii) The pith is either reduced or absent.

(iii) Old roots exhibit secondary growth.

Internal structure of young root of gram *(Cicer arietinum) :*

A thin transverse section of the root reveals the following internal structure under microscope (Fig. 5. XVIII).

1. **Epiblema :** This is the single outermost layer of thin walled cells.

   Some of these cells give rise to unicellular root hairs from their outer surface.

2. **Cortex:** Inner to epiblema, there occurs multilayered thin walled parenchymatous cortex with conspicuous intercellular spaces.

3. **Endodermis :** The endodermis is the innermost layer of cortex. It surrounds the stele as a cylinder. It consists of closely packed barrel shaped cells. Radial walls and inner walls of this layer are often thickened. This thickening is known as casparian strips.

4. **Pericycle :** Inner to endodermis, there occurs pericycle. It consists of single layered, thin walled small parenchymatous cells.

5. **Vascular Bundles :**

   Xylem and phloem occuring in separate patches arranged in a ring.

   Vascular bundles are four in number arranged on alternate radii.

   Xylem is exarch i.e. protoxylems towards periphery and metaxylems towards centre.

   The xylem consists of vessels.

   The phloem consists of sieve tubes, companion cells and phloem parenchyma.

6. **Conjunctive Tissue :** The parenchymatous cells lying between xylem and phloem bundles is known as conjunctive tissue.

7. **Pith :** Pith is absent but a very narrow zone of parenchyma is present. In old roots, pith is not observable.

B. Monocot root:

The roots of monocotyledons show the following anatomical features

(i) Number of vascular bundles are usually more than six.

(ii) The pith of monocot root is broader than that of dicot root.

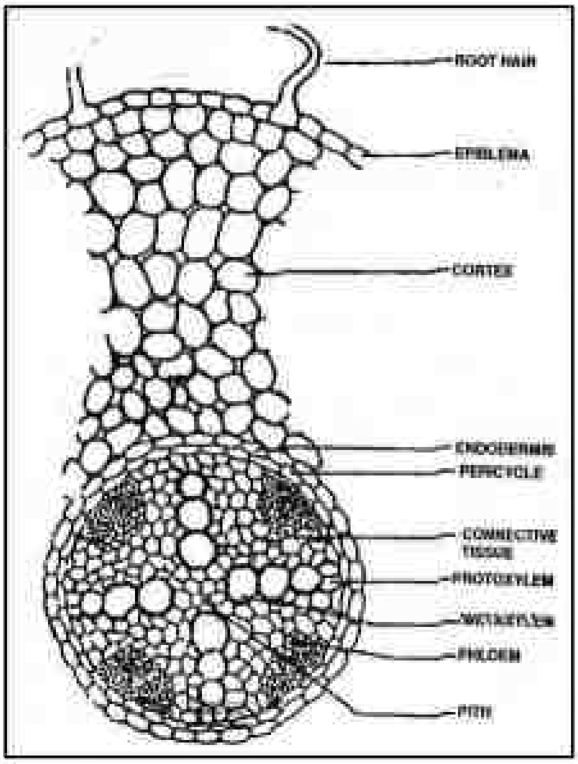


Fig. 5.XVIII. T.S. of a typical dicot root.

Table - 5.11

Anatomical differnces between stem and root.

Stem	Root
1. Mostly epidermis is covered by distinct cuticle.	1. Epiblema lacks cuticle.
2. Stem hairs are either unicellular or multicellular They are separated from epidermal cells by walls.	2. Root hairs are unicellular. They are not separated from cells of epiblema by walls.
3. Stomata may occur in epidermis.	3. Stomata are absent.
4. Cortex is generally differentiated into zones like hypodermis, general cortex and endodermis.	4. Cortex is an undifferentiated mass.
5. Hypodermis is either collenchymatous or selerenchymatous.	5. Hypodermis is absent. Thick walled exodermis is present in some roots in its place.
6. Endodermis lacks casparian strips, cells of endodermis contain starch grains. Pericycle is not present in all stems. Lateral branches are superficial. They do not develop from pericycle.	6. Endodermis is distinct with casparian strips, Pericycle is present. Lateral roots arise from pericycle.
7. Vascular bundles are conjoint, collateral or concentric.	7. Vascular bundles are radial in arrangement.
8. Xylem is endarch.	8. Xylem is exarch.

Table - 5.III

Anatomical differences between dicot and monocot stems.

Dicot stem	Monocot stem
1. Hypodermis is collenchymatous.	1. Hypodermis selerenchymatous.
2. Ground tissue system is clearly differentiated into cortex and pith.	2. Ground tissue system is not clearly differentiateliated into cortex and pith.
3. Vascular bundles are arranged in a ring. This is called stelar region.	3. Vascular bundles are scattered in the ground tissue system.
4. Vascular bundles are fewer in number.	4. Vascular bundles are comparatively more in number.
5. Vascular bundles are wedge shaped.	5. Vascular bundles are ellliptical or rounded
6. Vascular bundles are surrounded by bundle sheath.	6. Vascular bundles are not surrounded by any bundle sheath.
7. Vascular bundles are closed.	7. Vascular bundles are open.
8. Phloem parenchyma is absent.	8. Phloem parenchyma is present.
9. Pith is present.	9. Pith is absent but grand tissue is present.

Table - 5.1V

Anatomical differences between dicot root and monocot root.

Dicot root	Monocot root
1. Cortex is comparatively narrow.	1. Cortex is wide.
2. Pericycle is single layered.	2. Pericycle is oftern multilayered.
3. Pericycle produces lateral roots, cambium and cork cambium.	3. Pericycle produces lateral roots.
4. Vascular bundles ranges from two to six in number.	4. Vascular bundle are more than six in number.
5. Xylem vessels are angular.	5. Xylem vessels are oval or rounded.
6. Pith is not well developed or absent	6. Pith is well developed.
7. Secondary growth takes place.	7. Secondary growth does not take place.

Internal structure of young root of Maize (Zea mays):

A thin transverse section of the root reveals the following internal structure under the microscope (Fig. 5.XIX).

1. **Epiblema or piliferous layer:** This is the single outermost layer composed of row of loosely-set thin walled cells with a number of unicellular root hairs.

2. **Cortex :** It occurs beneath epidermis. This is a many layered zone of parenchymatous cells with conspicuous inter-cellular spaces between them.

3. **Endodermis :** The innermost layer of cortex is differentiated as an endodermis. The endodermis is composed of a row of barrel-shaped closely packed cell. Radial walls and often the inner walls develop secondary thickening, known as casparian strips.

   Certain cells of endodermis remain thin walled, known as passage cells which facilitate the movement of water from cortex to protoxylem.

4. **Pericycle :** This is the ring like layer lying internal to the endodermis. It is made up of both parenchyma and sclerenchyma cells.

5. **Vascular bundles :** Polyarch (many in number) and radial i.e. xylems and phloem form an equal number of separate bundles. They are arranged in a ring. Protoxylem occur towards the periphery and metaxylems lie towards centre, i.e. xylem is exarch. Protoxylems consist of annular and spiral vessels, and metaxylems of reticulate and pitted vessels.

6. **Conjunctive tissues :** The parenchyma in between xylem and phloem bundles is known as conjunctive tissues.

7. **Pith :** Pith is large and central in position. It is composed of loosely arranged parenchymatous cells containing abundant starch grain.

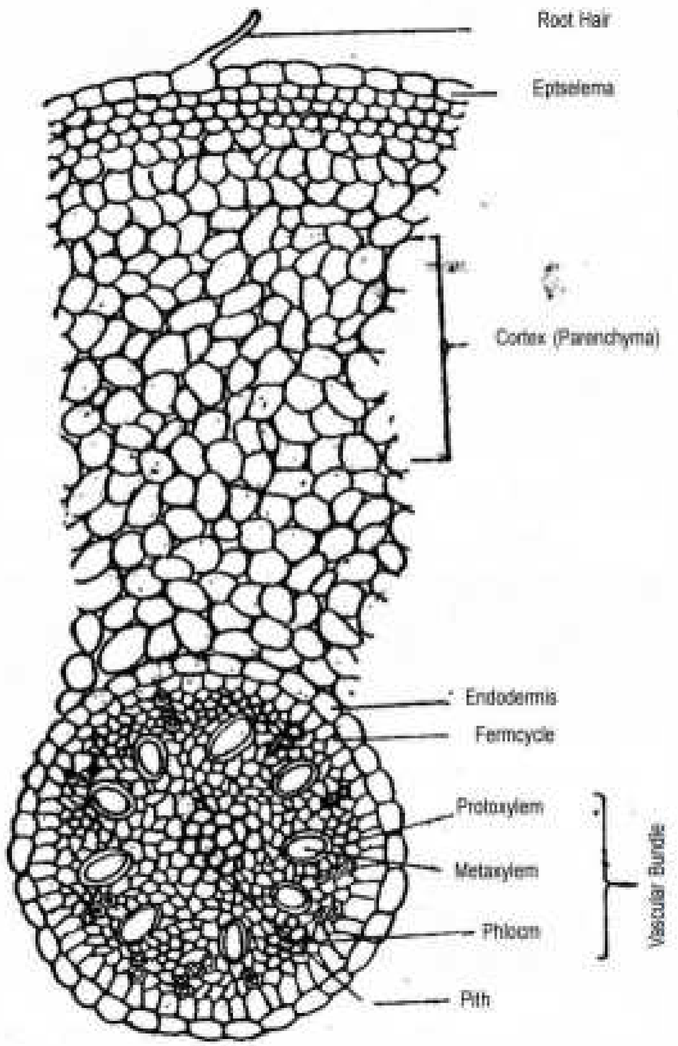


Fig.5.XIX. T.S. of the root of Zea mays.

5.7.3.3. ANATOMY OF LEAVES :

Leaves exhibit tissue system like stem and roots. The tissue system of leaves consists of epidermal tissues, ground tissues, and vascular tissues. All the said tissues show a definite pattern of arrangement with certain differences in the dicotyledons and monocotyledons. The arrangement of leaf lamina both in dicotyledons and monocotyledons exert certain influence on their internal structure and thus, they are being dealt under dorsiventral and isobilateral leaves respectively.

A. Dorsiventral Leaf

Dorsiventral leaves are found in dicot plants. Here a leaf-blade is held horizontally by the petiole. Its upper surface is directly exposed to the sun and the lower surface is less illuminated. Because of the unequal illumination, there occurs difference between the lower and upper sides of leaf. Thus the leaf is said to be dorsiventral.

Ficus bengalensis, Ficus religiosa, Citrus, Healianthus, Mangifera indica etc. are examples of dorsiventral leaves.

Internal structure of leaf of Mango *(Mangifera indica)*

A thin transverse section passing through mid-rib region reveals the following internal structure (Fig. 5. XX).

1) **Upper Epidermis :**

This consists of a single layer of cells covered by a thick cuticle. The cuticle prevents excess loss of water from the leaf surface.

2) **Lower Epidermis :**

This is also a single layer with a thin cuticle. Stomata occur in between the epidermal cells. Each stoma is surrounded by two guard cells. The guard cells contain chlorplasts. Remainder of the epidermal cells lack chloroplast. Internal to each stoma a large cavity called the respiratory cavity is seen. The stoma facilitates exchange of gases (Oxygen and Carbon dioxide) between the atmosphere and the internal tissues, besides loss of water by transpiration.

3) **Mosophyll :**

The ground tissue lying between the upper epidermis and the lower epidermis constitutes the mesophyll. It is differentiated into palisade parenchyma and spongy parenchyma.

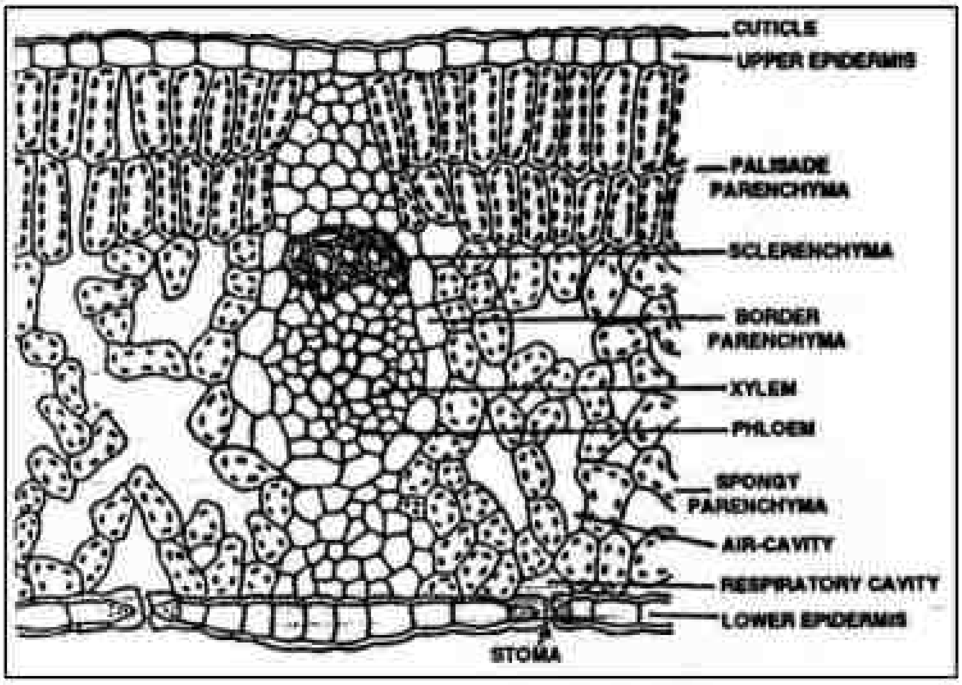


Fig.5.XX. Transverse section of a typical dorsiventral leaf.

a) Palisade Parenchyma :

It consists of 2-3 layers of cells and occurs below the upper epidermis. The cells are elongated and closely packed with their long axis at right angles to the epidermis. The cells contain a large number of chloroplasts. Thus, the function of palisade parenchyma is synthesis of carbohydrate by the pocross of photosynthesis.

b) Spongy Parenchyma

This zone is present below the palisade zone and extends upto the lower epidermis. Its cells are round, oval or irregular and are loosely arranged, enclosing numerous large intercellular spaces and air cavities. The air spaces help in the exchange of gases with external atmosphere. The cells contain a few chloroplasts, which is much less than the palisade tissue. This is why the colour of lower surface is lighter than the upper surface of leaf.

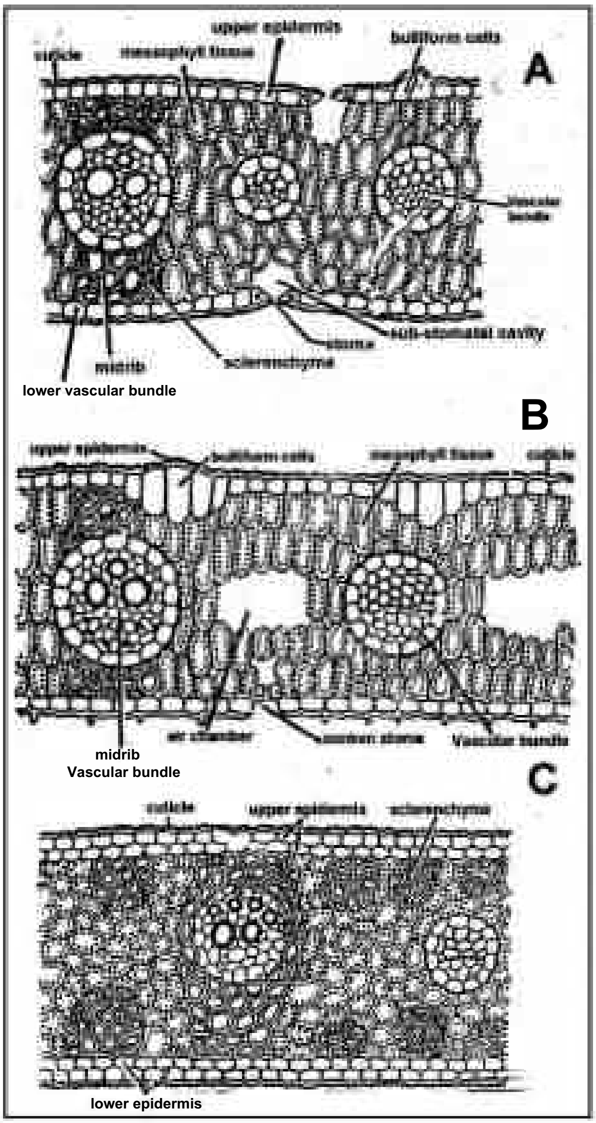


Fig. XXI. A. T.S. of maize leaf. B. T.S. of Bamboo leaf. C. T.S. of Date palm leaf.

Vascular bundles

Vascular bundles are conjoint, collateral and closed.They are embedded in the mesophyll tissue. Some vascular bundles are small and some are large. Each vascular bundle is surrounded by a parenchymatous bundle sheath. In case of large bundles, bundle sheath is connected with the epidermal layers by panels of parenchyma cells. These panels are called **bundle sheath extension.** Larger bundles correspond to midrib. In each bundle, xylem occurs on adaxial (i.e. upper) side of leaf, i.e. towards the upper epidermis. Xylem is mesarch. The phloem occurs on the abaxial (i.e. lower) side, i.e. towards the lower epidermis.

B. Isobilateral leaf

Isobilateral leaves are also called unifacial leaves. These types of leaves are seen in most of the monocotyledons. An isobilateral leaf is more or less equally illuminated on both sides. Maize, bamboo, date palm leaves etc. are the typical examples of isobilateral leaves. A thin section at right angle to one or more veins reveals the following internal structure.

Internal structure of isobilateral leaf:

A typical isobilateral leaf has the following internal structure (Fig. 5.XXI).

Epidermis

The structure of both upper and lower epidermis is more or less similar. Each of the epidermis consists of a single layer of non-chlorophyllous cells. The epidermis on either side bears more or less an equal number of stomata and is also uniformly thickened and cutinized. In grasses a few large, empty and colourless cells are also present at intervals on the upper epidermis. These are called bulliform cells.

Mesophyll

The entire tissue between the upper and lower epidermis is called the mesophyll. The mesophyll is not differentiated into palisade and spongy parenchyma.

Vascular bundles

Many vascular bundles are seen equally spaced in the mesophyll tissue. They are arranged in a parallel manner. The size of the vascular bundles may be equal in some plants and unequal in others. Each vascular bundle is conjoint, collateral, endarch and closed. Vascular bundles are surrounded by a distinct parenchymatous bundles sheath (border parenchyma). Two distinct patches of sclerenchyma are present above and below each of the large vascular bundle and extend upto the upper and lower epidermal layers. The xylem is located towards the upper epidermis and the phloem towards the lower epidermis.

Table - 5.V

Major anatomical differences between dorsiventral and isobilateral leaf.

Features	Dorsiventral leaf	Isobilateral leaf
Cuticle	Thick at upper epidermis and thin at lower epidermis	uniform cuticle
Stomata	More on lower surface	Equal number of stomata on either side.
Upper Epidermis	Continuous, or few stomata no bulliform cells	Discontinuous, presence of many stomata, bulliform cells present.
Mesophyll Tissue	Differentiated into palisade parenchyma and spongy parenchyma	Uniform and not differentiated into spongy and palisade parenchyma.
Vascular Bundles	Irregularly distributed and of different sizes	Regularly distributed and of almost equal size except the central one.

Table - 5VI

Distinction between palisade and spongy parenchyma.

Palisade parenchyma	Spongy parenchyma
1. Present in dorsiventral leaves	Present in both dorsiventral and isobilateral leaves.
2. Columnar cells without intercellular spaces. Closely arranged	Rounded cell with intercellular spaces, loosely arranged.
3. Contain more amount of chloroplasts	contain less amount of chloroplasts.
4. No respiratory cavity through stomata.	Possess respiratory cavity and open to outside
5. Prsent below the upper epidermis	Present below the palisade layer in dorsiventral leaf and between both the epidermis in isobilateral leaf.

5.7.4. SECONDARY GROWTH :

In most dicotyledonous stems and roots, distinct secondary growth is visible, which increases the diameter or thickness of the stems and roots. Secondary tissues are formed due to the activity of the lateral meristems, i.e. cambium in the stelar region and cork-cambium in the extra-stelar region respectively. The increase in thickness due to the addition of secondary tissues cut off by the cambium and the cork cambium in the stelar and extra-stelar regions respectively is spoken of a secondary growth.

In general secondary growth is not marked in monocot stem. However the stems of *Dracaena. Agave Yucca* etc. exhibit secondary growth. Under experimental conditions, some leaves also exhibit secondary growth.

5.7.4.1. SECONDARY GROWHT IN DICOT STEMS :

Formation of Cambium ring The strip of cambium present between xylem and phloem of a vascular bundle is known as fascicular or vascular cambium. At first the parenchymatous cells of the medullary rays in a line with cambium becomes maristematic. This joins to the fascicular cambium on either side and forms a complete ring. The cambium ring is thus partly primary and partly secondary meristem in origin.

(A) Activity of the cambium and formation of secondary tissues

The cambial ring becomes active and begins to cut off new cells, both to-wards the inner and outer sides. The cells cut off to-wards the outer side get differentiated into the secondary phloem. The cells to-wards the inner side get differentiated into the secondary xylem. The secondary phloem consists of sieve-tubes, companion cells, phloem parenchyma and often patches of bast fibres. Many of the textile fibres of commerce such as jute, hemp, flax etc.

are the bast fibres of secondary phloem. The secondary xylem consists of scalariform and pitted vessels, tracheids, wood fibres and wood parenchyma (Fig. 5.XXII).

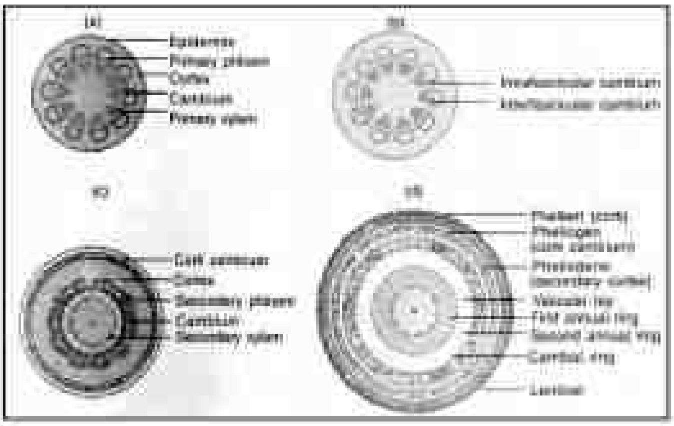


Fig.5.XXII. Different stages in the secondary growth in a dicot stem

The cambium is always more active on the inner side than on the outer. As a result, the xylem increases more rapidly than the phloem and soon forms a hard compact mass. This forms the main bulk of the plant body. Due to the continued formation of secondary xylem, both the primary and secondary phloem of the earlier years get gradually crushed.

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

Fate of primary tissues

The primary xylem and primary phloem tissues are pushed inward into the pith and outwards respectively by the continuous production of secondary tissues cut off by the cambium ring. The primary xylem is gradually pushed inward and is found at the centre of the axis; where as, the primary phloem, being soft in nature, gets completely crushed.

These activities in the stelar region exerts a great pressure outwordly. The cortex cells, the pericycle and the epidermis divide anticlinally to cope up with the production of tissues in the stelar region.

Formation of annual ring or growth ring

The activity of the cambium ring is under the control of series of physiclogical and environmental factors. For example, in spring the cambium becomes more active and forms a greater number of vessels with wider cavities. In winter, the temperature is low due to which the cambium also becomes less active and forms narrow pitted vessels, tracheids and wood fibres. The xylem (wood) formed during the spring is known as spring wood or early wood and which is formed in winter is called autumn wood or late wood. The spring wood is lighter in colour and exhibits low density where as the autumn (or winter) wood is darker and has higher density. These two kinds of wood appear together, in a transverse section of the stem, as a concentric ring known as the annual ring or growth ring. Successive annual rings are formed year after year by the activity of the cambium. Each annual ring corresponds to one years growth. Thus one can estimate the age of plant to some degree of accuracy by counting the total number of annual rings. Annual rings are readily seen with naked eye in the logs of a tree trunk (Fig. 5.XXIII).

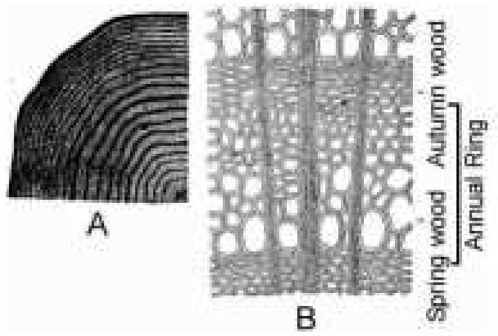


Fig. 5.XXIII. A, cut surface of a stem showing annual rings, B, an annual ring in section (magnified).

Heart-wood and sap-wood : In old trees, the greater part of the secondary wood is filled up with tannins resins, gums, essential oils, etc., which make it hard and durable. It looks dark or brown. This region is known as heart-wood. The heart is dead and conduction water does not take place through it. The heart wood gives mechanical support to the stem. The outer region of the secondary wood is of lighter colour and is known as sap-wood or alburnum. It helps in conduction of water and mineral salts from the root to the leaf.

(B) Secondary growth in extra-stelar region

Secondary growth in the extra stelar region occurs to cope with the addition of tissues in the stelar region. It occurs in the cortex and helps in the formation of periderm. It occurs by the formation and activities of a secondary meristem called cork cambium or phellogen.

Origin and activity of the cork-cambium or phellogen

Due to the addition of secondary phloem and secondary xylem elements, the outermost layer of the cortex becomes highly stretched and may crack open. During this process, a few layers of meristematic tissue arise in the cortex. This is called the cork cambium or phellogen. The nature of cambium is secondary. Commonly it arises in the outer layers of the cortex i.e. hypodermis. It may also arise in the epidermis itself, or in the inner layers of the cortex, or even in the pericycle. The cork combium consists of narrow, thin-walled and roughly rectangular cells. It is of few layers in thickness. The cork cambium cuts off cells on both the sides-cork on the outer side and secondary cortex on its inner side. The cells of the secondary cortex are parenchymatous in nature and often contain chloroplasts.

Cork

The new cells cut off by the cork-cambium on its outerside are roughly rectangular and soon become suberized. They form the cork of the plant. Cork cells are dead, suberized, thick-walled and brown in colour. They are arranged in radial rows. Being suberized, cork is impervious to air and water.

Functions of Cork

(i) It acts as a waterproof covering to the stem (ii) It also protects the plant against the attacks of parasitic fungi, (iii) Cork cells, being dead and empty, containing air only, are bad conductors of heat. This being so, a sudden variation in outside temperature does not affect the internal tissues of the plant, (iv) Cork is also made use of by the plant for the healing of wounds. (The bottle cork is obtained from the cork cells of *Quercus suber.)*

Bark

In restricted sense, all the dead tissues lying outside the active cork cambium constitute the bark of the plant. It, therefore, includes the epidermis, the lenticels and cork, and sometimes also hypodermis and a portion of the cortex depending on the position of the corkcambium. Thus the deeper the origin of the cork-cambium, the thicker would be the bark (Fig. 5.XIV).

The term bark in a wider sense is used to describe all tissues outside the vascular cambium of the stem.

Phellem, phelloderm and phellogen layers are collectively called *periderm.* Thus periderm is a protective multilayered structure of secondary origin.

On the basis of function, two types of barks are distinguished **ring bark** and **scale bark.** When the cork cambium appears in the form of a complete ring, the bark that is formed comes away in a sheet; such a bark is known as the ring bark as in *Betula.* When the cork-combium appears in strips the resulting bark comes away in the form of scales, such a bark is known as the scale bark as in *Psidium* (guava).

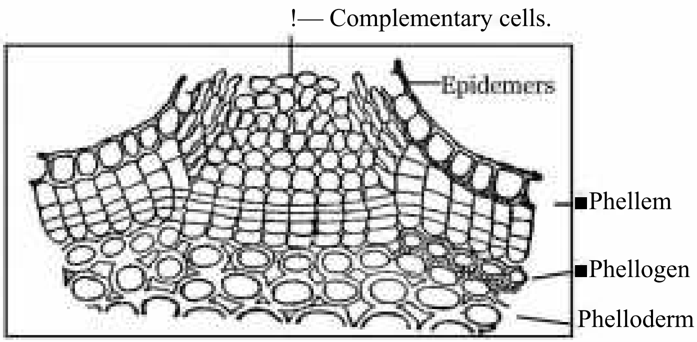


Fig.5.26. Transverse section through lenticel

Function of bark

The bark protects the inner tissues; (i) against the attack of fungi and insects (ii) against loss of water by evaporation and (iii) against variation of external temperature.

Lenticels

These are small aerating pores formed in the bark of stems through which gaseous exchange takes place. Externally they appear as scars or raised portions on the surface of stems. Lenticels are first formed below the stomata. A section through one of the scars shows that the lenticel consists of a loose mass of small thin walled cells called complementary cells or filling tissue.

SAMPLE QUESTIONS

A. VERY SHORT ANSWER TYPE QUESTIONS :

I. Fill in the blanks :

1. Prop root is a modified------------ .
2. In----------the adventitious root is modified for floating purpose.
3. The modified adventitious root in *Tinospora* is----------------.
4. The thorn of *Aegle* is a modified--------------.
5. Zingiber is a modified------------ .
6. Stem is negatively gootropic whereas root is--------------- phototropic.
7. Root is positively geotropic whereas stem is positively---------------- .
8. In *Allium cepa* the type of modified stem is a----------------.
9. The appendage present at the base of the pedicel of a flower is known as-------------.
10. The appendage present in between the base of the pedicel and thalamus is called---------------.
11. The swollen upper portion of the pedicel in a flowers is known as----------------.
12. A plant is said to be---------- when both male and female flower are present in the same plant.
13. A plant is said to be----------- when both androecium and gynoecium are absent.
14. When staminate, pistillate and bisexual flowers develop on the same plant, it is- said to be----------.
15. A flower is said to be----------- when it is divided into exactly two equal halves passing through the centre in one position only.
16. In epigynous flower the ovary is------------ .
17. In--------- flower the thalamus is a inverted cone with spongy flat top.
18. In rose flower the development of thalamus is called-------------- .
19. Foliar nature of sepals is seen in------------ flower.
20. In banana, the bract is----------- shaped.
21. Small, dry, scaly bracts found in grass family are called-------------- .
22. When sepals are coloured like petals the calyx of the flower is said to be-----------------.
23. The calyx is known as------------when the sepals remain attached in fruit.
24. In mustard the form of corolla is------------ .
25. In *Vinca* the form of corolla is------------ .
26. Quincuncial type of aestivation is found in------------- plant.
27. The flower is said to be------------in which the carpels are united.
28. The placentation, in the members of family cruciferae is of----------------type.
29. The placentation,------------- type is found in the family Compositae.
30. In *Brassica,* the type of infloréscnce is-------------.
31. In *Oryza,* the type of inflorescence is-------------.
32. In Banana, the type of inflorescence is--------------- .
33. In *Coriandrum* the type of inflorescence is------------- .
34. Hypanthodium type of inflorescence is found in--------------.
35. Cyathium type of inflorescence is found in------------- .

36. In family Labiatae, the type of inflorescence is--------------.
37. In *Calotropis,* the type of inflorescence is------------- .
38. In cotton the fruit is------------type.
(legume, follicle, siliqua, capsule)
39. The fruit of pomegranate is a--------------.
(berry, amphisarca, balausta, nut)
40. Coconut is a fruit which is classified as---------------.
(drupe, berry, nut, capsule)
41. A polycarpellary apocarpous pistil gives rise to----------------. kind of fruit.
(simple, aggregate, multiple pome)
42. The fruit of pineapple is known as--------------.

(syconus, hesperidium, sorosis, balausta)
43. Caryopsis type of fruit is found in--------------.
(legume, mustard, rice, cotton)
44. Tomato is a fruit classified as-------------.
(drupe, berry, capsule, pepo)
45. Mango is a fruit which is classified as-------------- .
(drupe, berry, nut, pome)
46. Mustard is a fruit classified as------------- .
(legume, follicle, siliqua, capsule)
47. The receptacle grows, becomes fleshy and edible in---------------- .
(pome, berry, drupe, pepo)
48. Parthenocarpic fruit results when --------------.
(ovules do not develop in the ovary, more than one embryo develop in the ovule, fruits develop without fertilisation, gametes formed without reduction division)
49. In *Mimosa* the fruit is------------ type.
(cremocarp, regma, carcerule, lomentum)
50. ---------type of fruit is found in sunflower.
(Caryopsis, achene, cypsela, nut)
51. The fruit of fig is known as------------- .
(syconous, hesperidium, sorosis. balausta)
52. *Hiptage* fruit is classified as-------------.
(caryopsis, samara, achene, cypsela)
53. The fruit of castor is known as--------------.
(Lomentum. cremocarp, regma, carcerulus)
54. The fruit of orange is known as--------------.
(drupe, berry, pepo, hesperidium)
56. The fruit develops from a hollow, pear-shaped fleshy receptacle enclosing a number of minute seeds is known as------------- .
(drupe, berry, sorosis, syconus)
57. The edible part of apple (pome) is--------------.
(fleshy calyx, fleshy thalamus, fleshy peduncle, fleshy ovary)

58. In Rice the edible part of fruit is------------- .
(thalamus, endocarp, placentae, starchy endosperm)
59. Companion cells are associated with
60. Numerous uascular bundles are scattered in the ground tissue ofstem.
61. Vascular bundles in which phloem is found on both sides of xylem are called

62. The inner, darker and harder portion of secondary xylem that cannot conduct water in an older stem is calledwood.

II. Express the followings in one word :

1. The roots that develop from the base of the radicle in rice plant.
2. The root system that develops from the portions other than the radicle.
3. The modified tap root that looks like a spindle.
4. The organ of the plant that arises from the plumule.
5. A compact young shoot in which the young rudimentary leaves are covered.
6. Openings present on the leaves for gaseous exchange.
7. The membranous stipules that occur in *Polygonum.*
8. The type of compound leaves found in *Coriandum.*
9. The type of compound leaves found in *Bombax.*
10. The type of modification of leaf in which petiole forms a sickle shaped structure.
11. A flower in which gynoecium is present, but androecium is absent.
12. A flower which is divided into equal halves passing through the centre in any plane.
13. Male and female flowers borne on two different plants.
14. Staminate, pistillate and bisexual flowers develop on the same plant.
15. Flowers without sepals and petals.
16. The thalamus projecting into the ovary and carpels remaining attached to it and separating at maturity.
17. Bracts form one or more whorls around a flower or a group of flowers.
18. Sepals falling off along with the petals just after fertilization.
19. Growth of calyx along with the fruit.
20. The funnel shaped corolla looking like an inverted cone.
21. Form of corolla in which the corolla tube is swollen in the middle but tapers towards both base and apex.
22. The condition where calyx and corolla are not differentiated.
23. Stamen without fertile anthers.
24. Attachment of the anther to the filament where anthers seem to swing freely.
25. Condition where out of six stamens, four inner long and two outer short.
26. Anthers remaining free and filaments united to form one bundle.
27. Condition where stamen attached with the corolla lobes.
28. Stamens are united by their anthers while filaments are free.
29. Both filaments and anthers are untied throughout their length.
30. Condition of stamens in which the first whorl is alternating with sepals and the second whorl is alternating with petals.

31. Syncarpous ovary, two or more chambers, centrally placed placenta bearing ovules (Name the type of placentation).
32. In a flower out of four stamens two are outer and shorter and two are inner and longer. What is the condition known as?
33. Monocarpellary gynoecium in which the placenta develops along the fused margin of the carpel. (Name the type of placentation).
34. Type of racemose inflorescence found in *Tridax.*
55. Type of cymose inflorescence found in *Ixora.*
56. (a) Which is the edible part of Orange ?
    (b) Which is the edible part of Cashew nut ?
    (c) Which part of the Jackfruit is edible ?
    (d) Which is the edible part in Coconut ?
    (e) In which fruit fleshy aril is edible ?
    (f) Which is the edible part in Mango ?
    (g) Which is the edible part of Banana ?
    (h) In Date-palm which is the edible part ?
    (i) Which is the edible part in Grape ?
    (j) Which mechanism helps the seeds of *Amaranthus* to disperse by wind ?

III. Indicate whether the following sentences are true or false.

1. Roots are negatively geotropic.
2. Tap root develops from radicle.
3. Root hairs are multicellular.
4. The root of *Tinospora* can manufacture its own food by photosynthesis.
5. Usually the root bears the buds.
6. *Cuscuta* is an example of epiphytic root.
7. Carrot is an adventitious root modification.
8. Pneumatophores provide support to the plant.
9. The stem ends in an axillary bud.
10. Stem hairs are multicellular.
11. Branches are endogenous in origin.
12. Offset is an underground stem modification.
13. Floral bud is modified into tendril in *Passiflora.*
14. Tendrilar stipules are seen in *Smilax.*
15. Leaf tendril is modified to provide protection.
16. Phyllode is a modified leaflet.

IV. Write true or false. Then correct the sentences without Changing the underlined words.

1. <u>Conjoint</u> vascular bundles are those in which xylem and phloem occur in one strand.
2. In maize stem <u>bicollateral</u> vascular bundles are seen.
3. <u>Vascular tissue</u> system develops from ground meristem.
4. <u>Epidermal tissue</u> system originates from protoderm.

5. Endodermis is the outer layer of stele.
6. Outer layer of tunica always gives rise to epidermis.
7. Bulliform cells belong to epidermal tissue system.
8. Epistomatic leaves are generally found in hydrophytes.
9. Casparian strips are seen in pericycle layer.
10. Starch sheath refers to cells of pericycle with starch.

B. SHORT ANSWER TYPE QUESTIONS :

I. Differentiate between :

1. Thorn and spine.
2. Stem tuber and root tuber.
3. Phylloclade and phyllode.
4. Bulb and Bulbil.
5. Sucker and sucking root.
6. Stem tendril and leaf tendril.
7. Compound leaf and branch.
8. Monoecious and dioecious
9. Zygomorphy and actinomorphy
10. Monochlamydous and dichlamydous
11. Isomerous and heteromerous
12. Hypogynous end epigynous
13. Marcescent and accrescent calyx
14. Bilabiate and personate corolla
15. Twisted and imbricate aestivation
16. Tetradynamous and didynamous stamens
17. Syngenesious & synandrous stamens
18. Drupe and Berry.
19. Siliqua and Silicula
20. Dry and fleshy fruits
21. Caryopsis and cypsela
22. Cremocarp and regma
23. Pepo and pome .
24. Sorosis and syconus
25. Spongy parenchyma and palisade parenchyma.
26. Vascular bundles of Maize and *Tridax.*
27. Heart wood and sap wood.
28. Permanent tissues and meristematic tissues.
29. Spring wood and autumn wood.
30. Cork nand bark.

II. Write notes on :

Ephiphyte;	Pneumatophore;
Prop root;	Fasciculated root;
Offest;	Sucker;
Bulbil;	Phyllotaxy;
Corm;	Stolon;
Phylloclade;	Pitcher;
Bladder;	Genetic spiral;
Gynandrophore;	Carpophore;
Glumes;	Vexillary aestivation;
Pollinia;	Versatile stamen;
Distractile anthers;	Gynostegium;
Free central placentation;	Gynobasic style;
Capitulum;	Spikelet;
Spadix;	Verticillaster;
Hypanthodium;	Cyathium;
Sorosis;	Lomentum;
Cremocarp;	Achene;
Pome;	Syconus;
Nut;	Cypsela;
Regma;	Berry;
Cambium;	Promeristem;
Lateral meristem;	Glandular tissues;
Bark	Annual ring;
Lenticels	Different types of stomata;
Hydathode	Trichomes;

C. LONG ANSWER TYPE QUESTIONS :

1. How many kinds of roots are there? Describe with examples.
2. What modification? Give an account of tap root modifications.
3. Discuss the different types of modified adventitious roots which perform vital functions.
4. Define bud and describe different types of buds with examples.
5. Describe diferent types of underground modified stem.
6. Give a brief account of phyllotaxy.
7. Give an account of different types of venations.
8. What are stipules? Describe with examples different types of stipules.
9. Give an account of various leaf modifications with diagrams and examples.

10. It is commonly believed that only roots develop below the ground. How would you prove that potato tuber is a stem and not a root ?

11. Describe the different parts of a typical flower.

12. Flower is a modified shoot- Justify the statement.

13. What is placentation ? Describe various types of placentation with examples.

14. What is inflorescence ? Describe the different types of racemose inflorescence.

15. Differentiate between racemose and cymose inflorescence. Give an account of cymose inflorescence.

16. Give a brief account of different types of simple fruits.

17. Wnat are aggregate fruits? How is it different from composite fruits ? Describe different types of aggregate fruits.

18. Compare the internal structure of a dicot stem with that of a dicot root.

19. Decsribe the anatomy of a typical monocot stem with labelled diagram. Point out the differences in the structure of vascular bundles in monocot stem and dicot stem.

20. Describe the internal structure of typical dorsiventral leaf.

21. Describe the internal structure of a monocot root.

22. What is secondary growth ? Describe the successive stages of normal secondary growth seen in dicot stems leading to the formation of annual rings. Point out the importance of such rings.

❑ ❑ ❑

ANIMAL TISSUES AND GROSS ANATOMICAL ORGANIZATION OF COCKROACH

CHAPTER 6

A tissue is defined as an organized layers or masses of structurally similar cells of common embryonic origin and performing a particular function. The word tissue (L. tesere= to weave) was introduced by a French surgeon Xavier Bichat (1771-1802) who was is presently known as the father of **Histology.** The branch of Biology that deals with the study of tissues is called Histology. This word was coined by Mayer (1819). Two or more different types of tissues unite to form larger functional units called organs.

Based on structure and functions, the animal tissues are classified into four major types: Epithelial tissue, Connective tissue, Muscular tissue and Nervous tissue.

6.1. EPITHELIAL TISSUE (EPITHELIUM) :

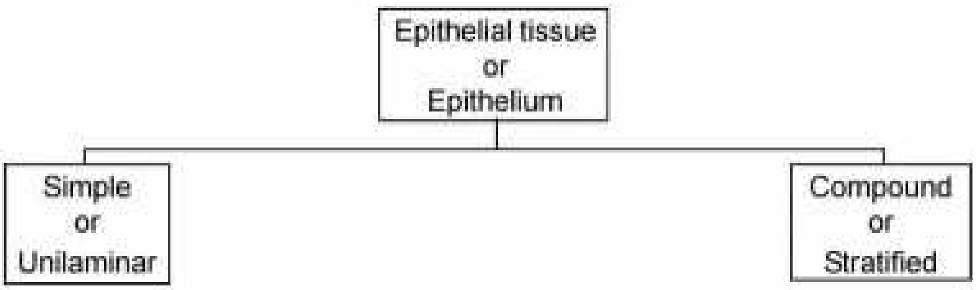
The term epithelium (Gr. Epi = upon, thelio =grows) was proposed by **Dutch scientist Raysch in 18th century.** It has the following features and functions.

1. The calls are many, closely placed without inter-cellular space and matrix.
2. The cells are placed upon a non-cellular gelatinous **basement membrane.**
3. It forms a protective covering over the body and body organs and also lines the internal cavities.
4. Epithelium is highly regenerative, thus facilitates rapid healing of wounds.
5. It helps in secretion of various substances, absorption, excretion, respiration, perception, transportation etc.

Types of Epithelial tissue

Based on functions, epithelial tissue is of two major categories such as covering epithelia and glandular epithelia.

But based on the number of layers, the epithelial tissue is of the following types:



6.1.1. Simple Epithelium :

Simple epithelium is formed of a single layer of cells. It is further classified into the following types based on their shape size, presence or absence of cilia, secretion etc. These are

(a) Squamous epithelium

(b) Cuboidal epithelium

(c) Columnar epithelium

(d) Ciliated epithelium

(e) Glandular epithelium

(f) Germinal epithelium

(g) Pigmented epithelium

(h) Sensory epithelium

(i) Pseudostratified epithelium

6.1.1.1. Simple squamous epithelium (Fig. 6.1 and 6.2) :

It is formed by a single layer of flat or spindle-shaped cells. The cells are closely fitted like the tiles on a floor with serrated edges. Therefore, this epithelium is often known as **pavement epithelium.** Each cell contains a centrally placed spherical nucleus.

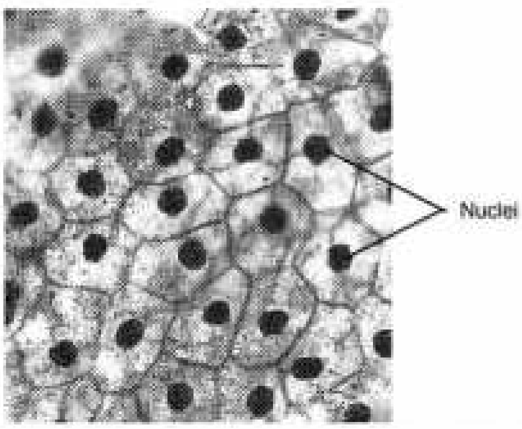


Fig. 6.1 : Surface view of simple squamous epithelium

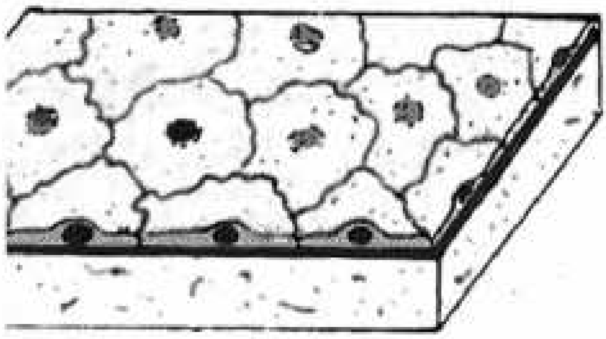


Fig. 6.2 : Simple squamous epithelial cells in three dimension (diagrammatic).

Occurrence: It forms the lining of various coelomic cavities **(peritoneum);** lining of blood vessels **(endothelium);** internal lining of the heart **(endocardium);** and outer lining of several organs present in **peritoneal** and **pleural cavities;** such as oesophagus, stomach, intestine and lung **(mesothelium).** It also lines the Bowman's capsule of the nephron, alveoli of the lung, membranous labyrinth, lens of the eye and taste buds. Outermost layer of frog's skin is also formed of simple squamous epithelium.

Functions : It helps in protection, ultra-filtration and gaseous exchange.

6.1.1.2. Simple cuboidal epithelium (Fig. 6.3 and 6.4) :

It consists of a single layer of cubical cells, all resting on a basement membrane. The cells are polygonal in surface view and almost of equal height and width. The nuclei are spherical.

Occurrence: Follicles of the thyroid gland and salivary gland, lining of the ducts of many glands, convoluted tubule of the nephron, acini of the pancreas, liver, thymus, sweat glands, germinal epithelium of the gonads, choroid plexuses, inner part of the lens and pigment layer of the retina.

Functions : It forms a protective layer. It is also involved in secretion, storage, excretion and formation of gametes.

6.1.1.3. Simple columnar epithelium (Fig. 6.5 and Fig. 6.6) :

It is a layer of closely packed tall or rectangular cell. The cells are polygonal in a surface view. The nuclei are frequently elongated in conformity with the shape of the cells.

Occurrence: These are found in the mucosal lining of stomach, large intestine and rectum.; lining of the gall bladder and bile duct; gastric gland and vas deferens.

Functions : Secretion of digestive juice and absorption of digested food.

6.1.1.4. Ciliated epithelium :

When cuboidal and columnar epithelia bear cilia at their free ends, they are known as ciliated epithelia. Each cilium arises from a **basal granule** situated in the cytoplasm of the cell.

Occurrence: Cuboidal ciliated epithelium occurs in the neck region (junction of the renal corpuscle and renal tubule) of the nephron. Ciliated columnar epithelium lines most of

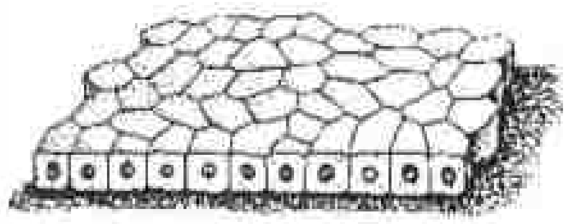


Fig. 6.3 : Simple cuboidal epithelium in three dimension (diagrammatic).

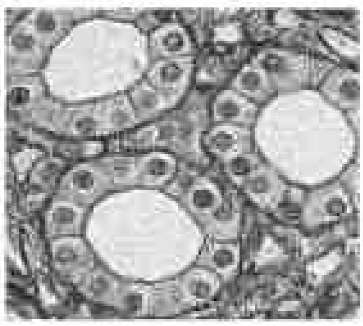


Fig. 6.4 : Photomicrograph of simple cuboidal epithelium lining the collecting tubule.

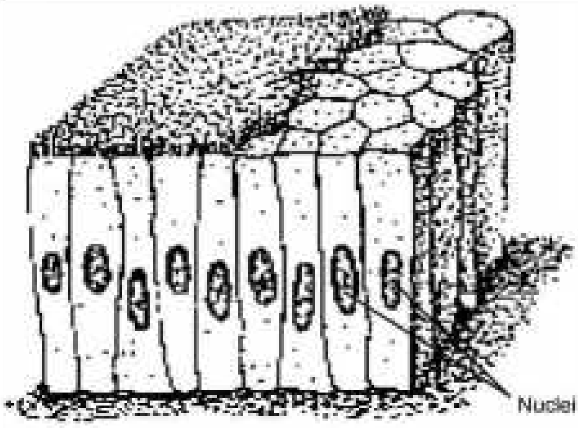


Fig. 6.5 : Simple columnar epithelium in three dimensions (diagrammatic).

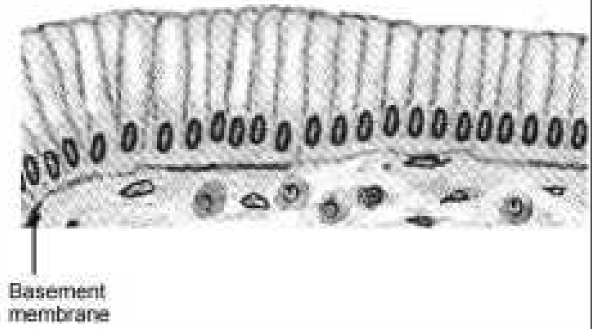


Fig. 6.6 : Photomicrograph of simple columnar epithelium

the respiratory tract, uterus and oviduct. It is also present in parts of the middle ear and auditory tube. It is present in the ependymal lining (ependymal epithelium) of the central canal of the spinal cord and the ventricles of the brain.

Functions : Drainage of fluid in the desired direction.

6.1.1.5. Glandular epithelium :

Some cuboidal and columnar epithelial cells are modified as gland cells engaged in the synthesis and release of secretory products into an extra-cellular space. All glands, whether exocrine or endocrine, are made up of glandular epithelial cells. Glands are primarily of two types : **unicellular** and **multicellular.**

(i) Unicellular glands : Unicellular glands are modified columnar epithelial cells, which secrete mucous. These cells are known as **goblet cells.** Goblet cells are found in the mucosal lining of the gastro-intestinal tract of vertebrates. The mucous secreted by these cells serves as a lubricant and thus protects the delicate tissues from wear and tear due to friction.

(ii) Multi-cellular glands (Fig. 6.7): These are formed by many secretory cells. Several of these secretory cells together constitute secretory units known as **acini (singular: acinus).** The acini sink below the surface and form large multi-cellular glands. These are classified on two counts. On the basis of the number of secretory units, they are of two types : **simple** (one secretory unit) and **compound** (multiple secretory units) and on the basis of the structure of acini, they are classified as **tubular, alveolar** and **tubulo-alveolar** glands. A tubular gland has tube-like secretory unit, while in an alveolar gland, the secretory unit is a sac- or flask-like structure, known as an **alveolus.** In tubulo-alveolar, both structures are present.

- **(a) Simple tubular:** The secretory unit is a single tube-like structure, [e.g.; intestinal gland (Crypt of Lieberkuhn)]
- **(b) Simple coiled tubular:** The tubular part is coiled, (e.g.; sweat gland)
- **(c) Simple branched tubular:** The tube is branched, (e.g.; gastric gland)
- **(d) Simple alveolar:** The glandular part is a single alveolus, (e.g.; mucous glands in the skin of frog).
- **(e) Simple branched alveolar:** The glandular alveolus is branched, (e.g.; sebaceous gland)
- **(f) Compound tubular:** Each tubular secretory unit is divided into several units, [e.g.; intestinal mucous glands (Brunner's gland)].
- **(g) Compound alveolar:** Each alveolar secretory unit is divided into several units, (e.g.; Mammary gland)
- **(h) Compound tubulo-alveolar:** Each secretory unit consists of both tubular and alveolar structures, (e.g.; Exocrine pancreas and salivary gland).

Glands are classified on three more counts :

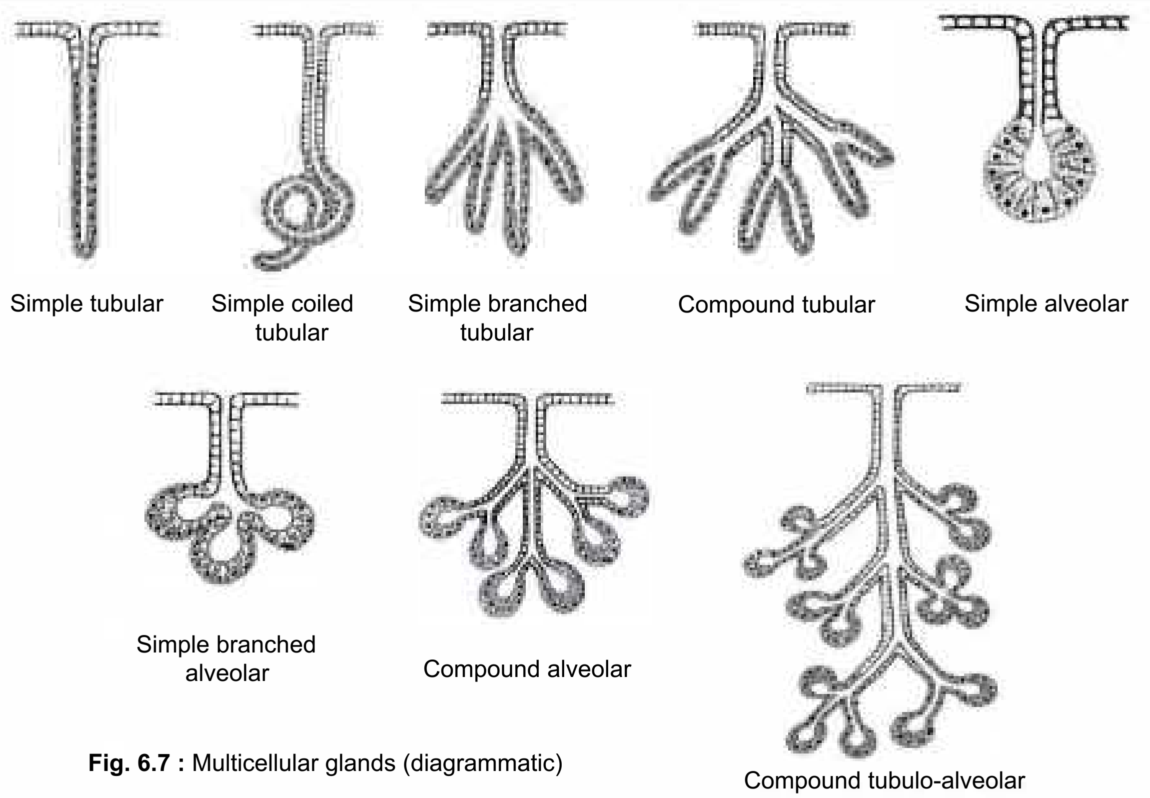


Fig. 6.7 : Multicellular glands (diagrammatic)

1. Nature of secretion

The glands are classified as **serous, mucous** and **mixed,** based on the nature of secretion. A serous gland secretes a clear watery fluid, often containing enzymes, [e.g.; sweat gland, intestinal gland and salivary gland (parotid gland)]. A mucous gland secretes a viscous fluid containing a muccopolysacharide (e.g.; cardiac and pyloric glands of the stomach). A mixed gland secretes both of the above (e.g.; gastric glands).

2. Mode of secretion

Glands are divided into three types based on the mode of secretion. In **merocrine glands** (sometimes called **ecrine** or **epicrine),** the secretion is released by exocytosis without causing a damage to the secretory cell (e.g.; exocrine pancreas, gastric gland and sweat gland). In some glands, the apical parts of the secretory cells are shed off to discharge the secretion. It causes a partial damage to the cells. This type of gland is described as **apocrine** (e.g.; mammary gland). In some glands, the entire secretory cell disintegrates, while discharging its secretion (e.g.; sebaceous gland). This type of gland is known as **holocrine.**

3. Presence or absence of ducts

Glands are of two types : **exocrine** and **endocrine.** An exocrine gland possesses well defined ducts, thus discharging its secretion to a lumen or cavity (e.g.; exocrine pancreas, liver and salivary gland). An endocrine gland is a ductless gland. It discharges its secretion directly into the blood, [e.g.; pituitary, thyroid, adrenal and endocrine pancreas (islet of Langerhans)].

6.1.1.6. Germinal epithelium:

It is a modified cuboidal epithelium (e.g.; seminiferous tubules of the testis and ovarian follicles). These epithelial cells produce gametes through gametogenesis.

6.1.1.7. Pigmented epithelium:

It consists of columnar epithelial cells containing visual pigment (e.g.; retina of the eye). It absorbs excess of sun light that enters into the eye.

6.1.1.8. Sensory epithelium :

It is a modified columnar epithelium. The cells bear sensory hairs at their outer surfaces for receiving stimuli. The basal part is innervated by a nerve fibre for conveying the impulse (e.g.; utricle, saccule and organ of corti).

6.1.1.9. Pseudo-stratified epithelium :

In this epithelium, columnar epithelial cells are present in a single layer. All cells rest on a basement membrane, but not all of them extend to the free surface. The nuclei lie at different heights, giving it a false stratified appearance. These cells are mostly ciliated (e.g.; nasopharynx).

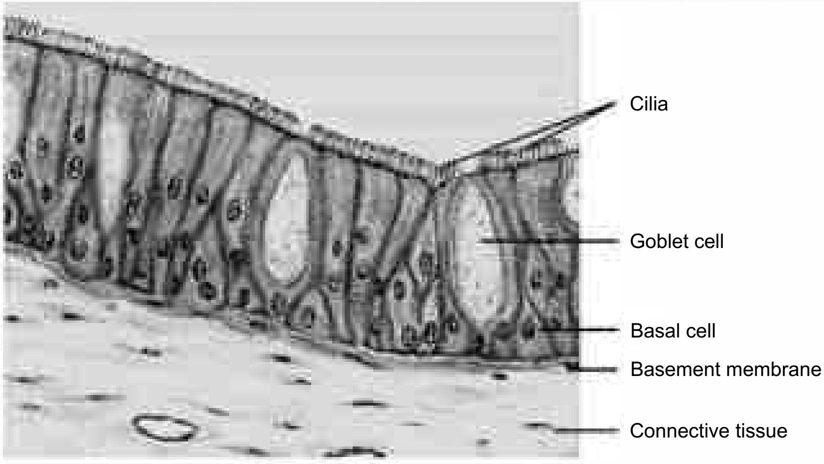


Fig. 6.8 : Photomicrograph of pseudostratified ciliated columnar epithelium with unicellular gland cells (goblet cells).

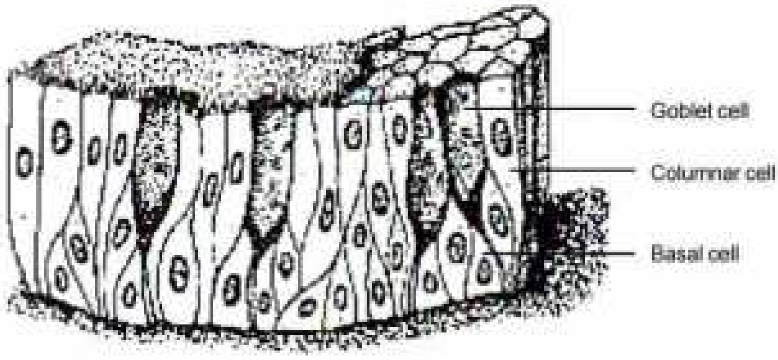


Fig. 6.9 : Pseudostratified columnar epithelium in three dimensions (diagrammatic)

6.1.2. Compound or stratified epithelium :

Compound epithelium has two or more layers of epithelial cells, lying one above the other. The epithelium has a stratified or multi-layered appearance and hence, the name stratified epithelium. It is characterized by the morphology or shape of cells of the outermost layer. The cells of the innermost layer rest upon a basement membrane. Like the simple epithelium, the cells are tightly packed so that there is hardly any inter-cellular space. Cells of all layers may not have a uniform shape. For example, the inner layer of cells may be cuboidal and columnar, while those of the outermost layer may be squamous. It is classified as squamous, cuboidal, columnar, columnar ciliated and transitional according to the shape of cells of the surface layer.

6.1.2.1. Stratified squamous epithelium :

Cells of the basal layer are columnar and are arranged in a single layer. The intermediate layers have polyhedral cells, but on reaching the surface, they become squamous.

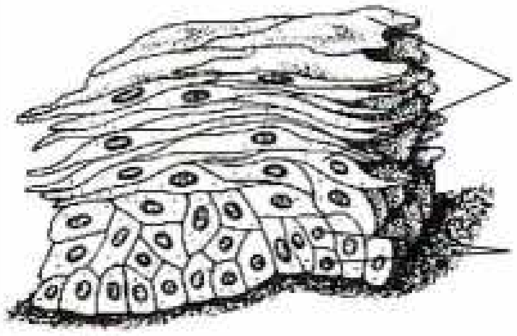


Fig. 6.10 : Non-keratinized stratified squamous epithelium in three dimensions (diagrammatic)

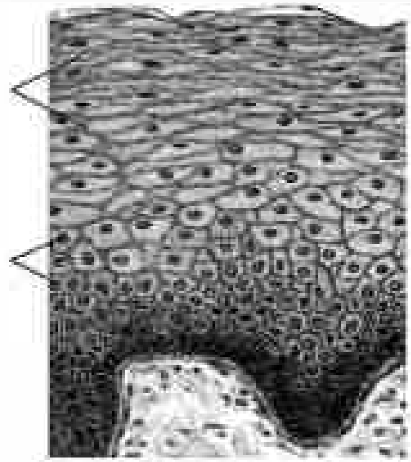


Fig. 6.11 : Photomicrograph of non-keratinized stratified squamous epithelium

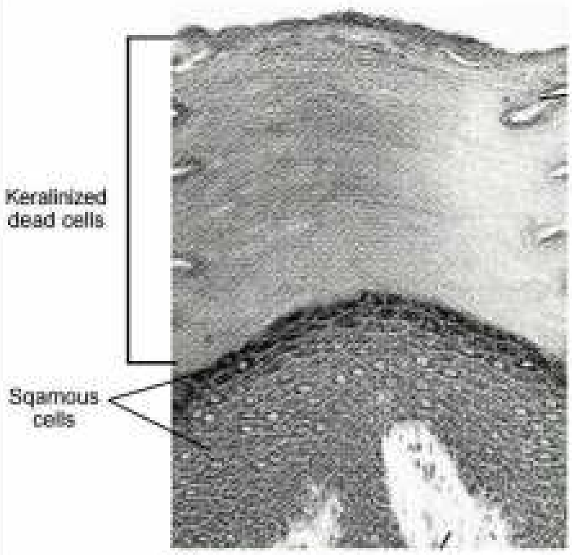


Fig. 6.12 : Photomicrograph of keratinized stratified squamous epithelium

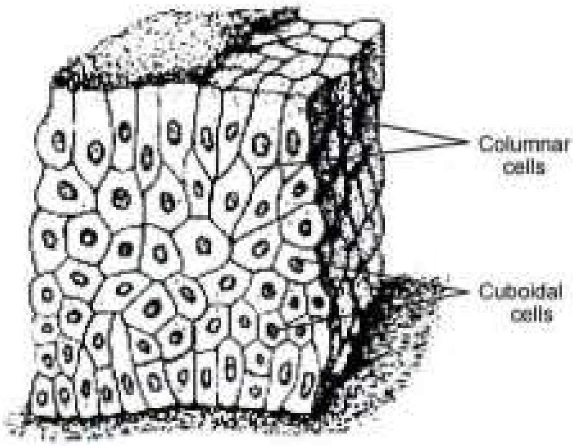


Fig. 6.13 : Stratified columnar epithelium in three dimensions (diagrammatic)

This is again of two types : **non-keratinized** and **keratinized.** In non-keratinized epithelium (Figs. 6.10 & 6.11), all cells are living and therefore, the surface cells are nucleated (e.g.; lining of the oral cavity, vagina and anal canal). Conversely, in keratinized epithelium (Fig. 6.12 and 6.13), the surface cells are dead, constituting **stratum corneum.** This layer is periodically cast off (e.g.; palm and sole).

6.1.2.2. Stratified cuboidal epithelium:

Out of a few layers of cells, the most superficial layer consists of cuboidal cells. This epithelium has a limited distribution and is seen only in a few organs (e.g.; lining of ducts of salivary gland and pancreas).

6.1.2.3. Stratiified columnar epithelium :

The cells of the outermost layer are columnar. The cells of the lower layers are cuboidal or polyhedral (e.g.; lining of the larynx, pharynx, epiglottis and conjunctiva of the eye).

6.1.2.4. Stratified columnar (ciliated):

Cilia are present on the free outer surface of the outermost layer of cells (e.g.; lining of the soft palate on the nasal side).

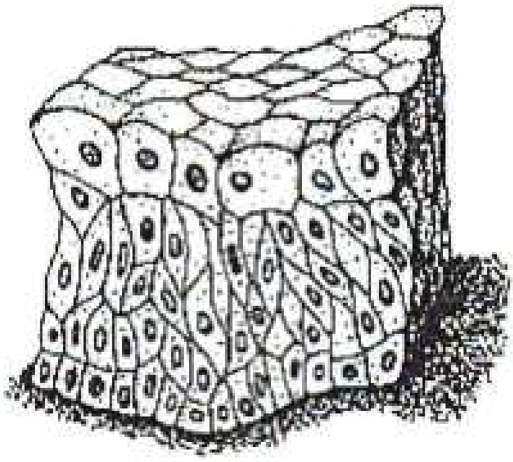


Fig. 6.14 : Transitional epithelium in three dimensions (diagrammatic).

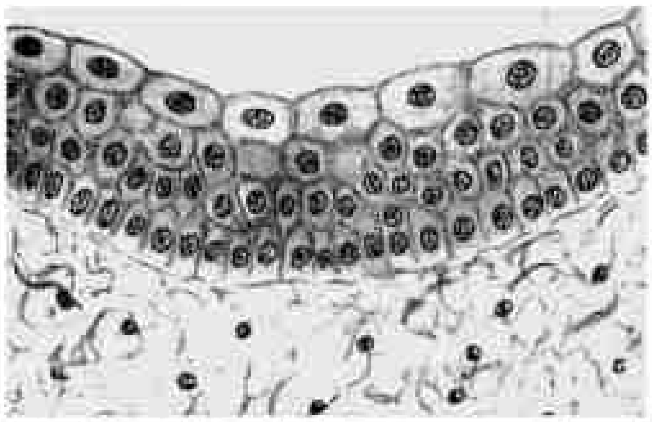


Fig. 6.15 : Photomicrograph of transitional epithelium in the wall of urinary bladder.

6.1.2.5. Transitional epithelium (Fig. 6.14 and 6.15) :

This occupies an intermediate position between simple epithelium and stratified epithelium. The number of layers of cells changes with time. For example, the wall of the distended urinary bladder has 2-3 layers of cells. However, when the bladder contracts, this number increases to 5-6. An important feature of this epithelium is the presence of a thin basement membrane compared to other epithelia (e.g.; wall of the urinary bladder and ureter).

6.2. CONNECTIVE TISSUE :

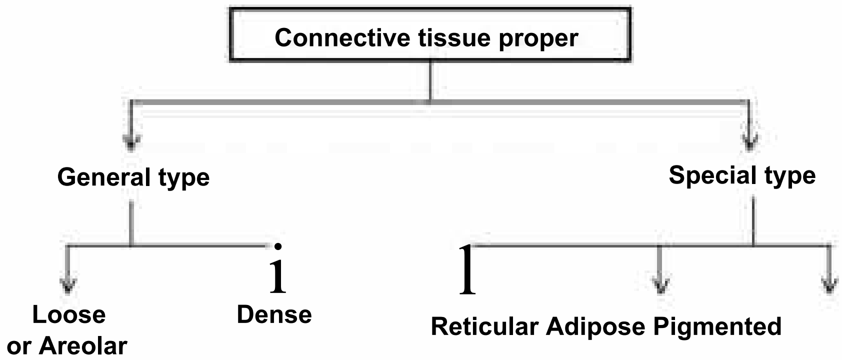
Connective tissue binds, anchors, and supports various types of cells, tissues, and organs in the body. It also forms packing around organs. In a nutshell, the connective tissue, along with the skeletal elements, binds all parts of the body into an integrated structure. It develops from the embryonic mesoderm. Structurally, it consists of different kinds of cells and a considerable amount of **inter-cellular material** or **matrix.** The matrix, in turn, consists of non-living matter such as, **connective tissue fibers, ground substance** and **tissue fluid.**

Structurally, the cells and the matrix differ in form and structure. Connective tissue is of three basic types :

1. **Connective tissue proper**
2. **Skeletal connective tissue**
3. **Fluid connective tissue.**

6.2.1. Connective tissue proper:

This connective tissue connects all parts of the body together and primarily is of two types : **general type** and **special type.** General type is further divided into **loose (areolar)** and **dense connective tissues.** Special type is divided into **reticular, adipose** and **pigmented** connective tissues. An outline classification is presented hereunder.



6.2.1.1. Loose or areolar connective tissue (Fig. 6.16) :

It is more prevalent than dense connective tissue. It is characterized by a loose and irregular arrangement of connective tissue fibers and the presence of abundant ground substance. Several types of connective tissue cells are found in the matrix.

(a) Cells : Fibroblasts; fibrocytes; macrophages (histiocytes); adipose (fat) cells; mast cells; plasma cells and **leucocytes,** such as **neutrophils** and **eosinophils** are the main constituent cells of loose connective tissue. Fibroblasts and adipose cells are the major constituent cells, while other cells migrate into the tissue from the blood circulation.

(i) **Fibroblasts :** This is the most common cell type. As the name indicates the cell synthesizes connective tissue fibers and ground substance. Fibrocytes are inactive or resting fibroblasts.

(ii) **Macrophages (Histiocytes):** These are phagocytic cells and most numerous in the loose connective tissue. These cells engulf bacteria, which infilter into the tissue. They also patrol the matrix and check infiltration by foreign elements.

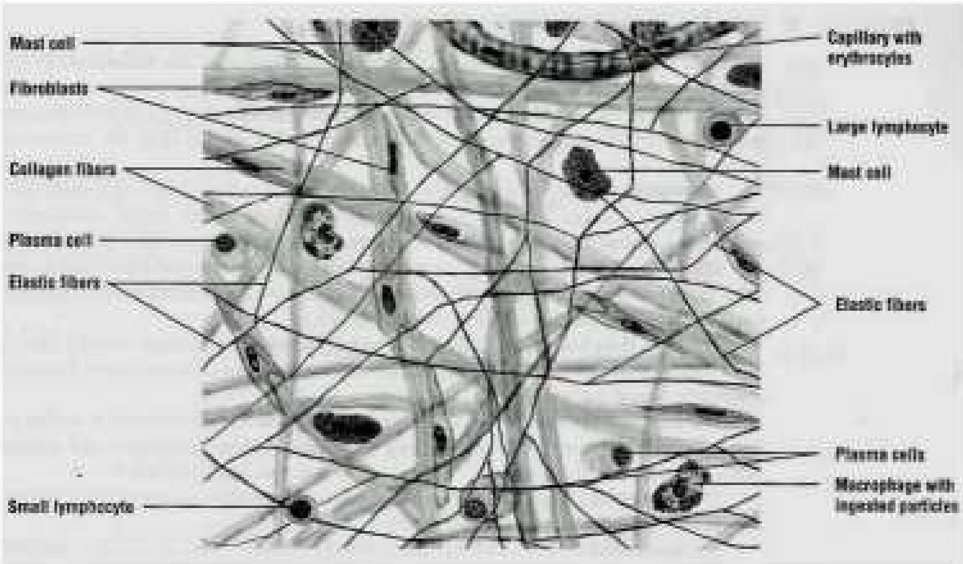


Fig. 6.16 : Spread loose connective tissue (with cells and fibers).

(iii) **Mast cells:** These are small round or oval cells with small centrally placed nuclei. The cytoplasm is filled with **histamine.** When released, **histamine causes allergic reactions**

(iv) **Plasma cells :** These cells arise from lymphocytes and are potential antibody forming cells.

(v) **Adipose cells** : Adipose (fat) cells are fat storing cells, found in varying number in loose connective tissue. When the adipose cells predominate, the connective tissue is known as adipose tissue.

(b) Fibers: Three types of fibers, such as **collagen, elastic** and **reticular fibers** are found in the loose connective tissue. Collagen fibers, also known as **white fibers,** are tough, fibrous proteins, present in unbranched bundles. These are most abundant and present in almost all connective tissues. Elastic fibers, also known as **yellow fibers** are thin, small and branching fibers having less tensile strength. **Reticular fibers** are thin and form a delicate net-like framework.

Distribution : Loose connective tissue is distributed in varying amount throughout the body.

Functions

1. It serves as a supporting and packing tissue.
2. It binds all tissues and organs of the body.
3. It fights and destroys invading bacteria.

6.2.1.2. Dense connective tissue:

Dense connective tissue contains more densely packed collagen fibers than loose connective tissue. The cells are few and the ground substance is less. It is of two types: irregular and regular. In **irregular dense connective tissue,** the collagen fibers are present irregularly [e.g.; dermis and capsule (connective tissue sheaths) of organs]. **Regular dense connective tissue** (Fig.6.17) has densely packed parallel bundles of collagen fibers (e.g.; tendon and ligament). A tendon is a regular dense connective tissue connection between a bone and skeletal muscle, while a ligament between two bones. In both irregular and regular dense connective tissues, fibroblasts are the most abundant cells and are placed between collagen fiber bundles.

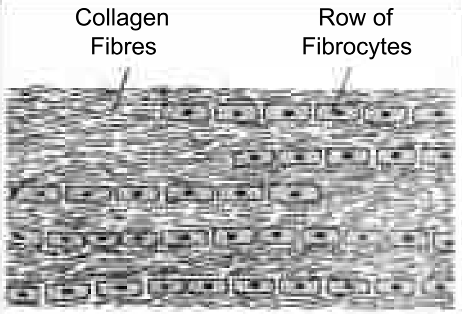


Fig. 6.17 : Regular dense with birous connective tissue

6.2.1.3. Reticular connective tissue (Fig. 6.18):

It is characterized by the presence of **reticular or stellate cells** and **reticular fibers.** The cells have reticular processes, which are interwoven forming a reticulum or network (e.g.; lymphoid tissue and bone marrow).

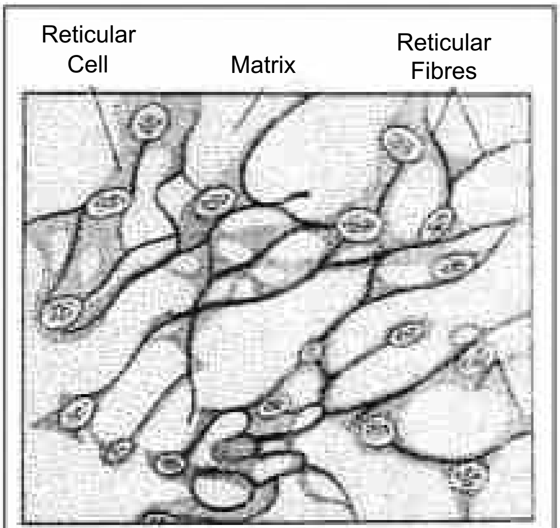


Fig. 6.18: Reticular connective tissue

6.2.1.4. Adipose tissue :

Adipose tissue is an aggregate of **fat cells** or **adipocytes.** The adipocytes have lost their fiber-forming function and have assumed the function of fat storage. Each fat cell contains a large fat droplet and as a result, a fat cell becomes swollen and spherical. Consequently the nucleus is flattened and is disblaced to the peripheral part of the cell (Fig. 6.19). Fat cells may be scattered singly or may associate with reticular fibers to form an adipose tissue, (e.g.; sub-cutaneous tissue). It stores excess of fat and metabolizes it, as and when necessary. It also helps maintain the body temperature. Adipose tissue is primarily of two types : **white** and **brown.**

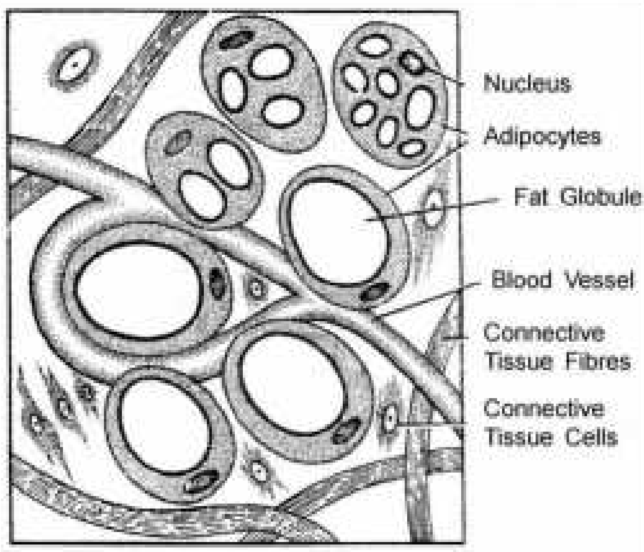


Fig. 6.19 : Adipose connective tissue

6.2.1.5. Pigmented connective tissue:

In pigmented connective tissue, the cells are filled with black or brown pigment, usually **melanin** (e.g.; choroid of the brain and iris of the eye).

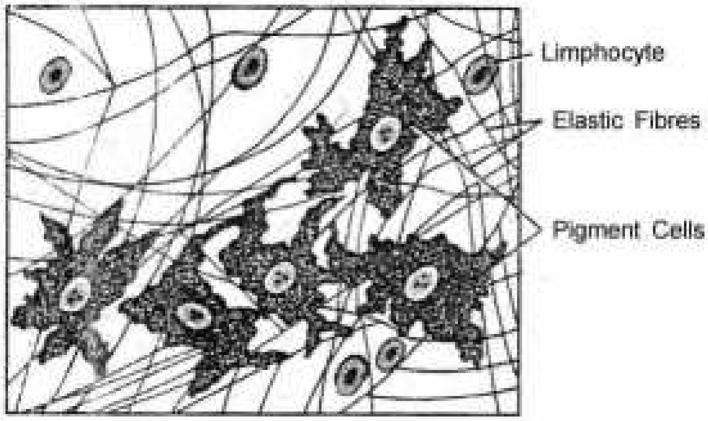


Fig. 6.20 : Pigmented connective tissue

6.2.2. Skeletal connective tissue :

The structural integrity and shape of animals, especially those of vertebrates is maintained by connective tissue. In the preceding section, we discussed about an element that connects the cells, tissues, organs and organ systems. In this section, we shall discuss about another element that provides a physical support and gives a definite shape to the body of vertebrates. This element is another type of connective tissue i.e. **skeletal (hard** or **solid) connective tissue.** It is primarily divided into **cartilage** and **bone.** These two elements together constitute the skeletal system, which forms a solid frame of the body of all vertebrates.

6.2.2.1. Cartilage :

Cartilage is a special connective tissue. It is a comparatively softer and more pliable element of the skeletal connective tissue than bone. It is the first level of endoskeleton formation. In some vertebrates, especially in cartilaginous fishes, it persists as such, while in a majority, it undergoes ossification and changes into bone. However, in the endoskeleton of vertebrates other than cartilaginous fishes, a few cartilages persist and others ossify into bones. Therefore, it is logical to say that the endoskeleton of vertebrates consists either exclusively of cartilages or both cartilages and bones. A cartilage, like other connective tissues, consists of **cartilage cells (chondroblasts** and **chondrocytes)** and an **inter-cellular substance** or **matrix.** The matrix consists of **connective tissue fibers** and a **ground substance.** There are three types of cartilages in the body: **hyaline, elastic** and **fibrocartilage.** This classification is based on the amount and type of fibers present in the matrix.

CARTILAGE

Hyaline cartilage Elastic cartilage Fibrocartilage

(a) Hyaline cartilage

It is the most common type of cartilage. As an embryo develops, most of the hyaline cartilages undergo ossification or calcification by **endochondral ossification** and change into bones.

Structure (Fig. 6.21): Hyaline cartilage looks **bluish-white** and **translucent** in a fresh preparation.It is surrounded by a peripheral layer of vascularized, dense irregular connective tissue sheath, called **perichondrium.** However, the hyaline cartilage at the articular surfaces of long bones does not possess a perichondrium. The inner layer of the perichondrium is **chondrogenic** i.e. it gives rise to new chondroblasts, which secrete the matrix. As the cartilage grows and the volume of the matrix increases, the individual chondroblasts are trapped in fluid-filled compartments called **lacunae** (singular; lacuna). Inside the lacuna, a chondroblast is known as a **mature cartilage cell** or **chondrocyte.** Some lacunae contain more than one chondrocytes forming **isogenous groups.**

The cartilage matrix is produced and maintained by chondroblasts and chondrocytes. The matrix is hydrated with high water content. It consists of small collagen and elastic fibers in varying amounts. The ground substance consists of **glycosaminoglycan-protein aggregates,** known as **proteoglycans. Chondroitin sulfate** and **hyaluronic acid** are the more prevalent sulfated and non-sulfated glycosaminoglycan constituents of the matrix, respectively. An adhesive glycoprotein, **chondronectin** binds chondroblasts and chondrocytes and collagen fibers to proteoglycans, [e.g.; articular surface of long bones, costal cartilage (end of rib), nose, larynx, trachea and bronchi].

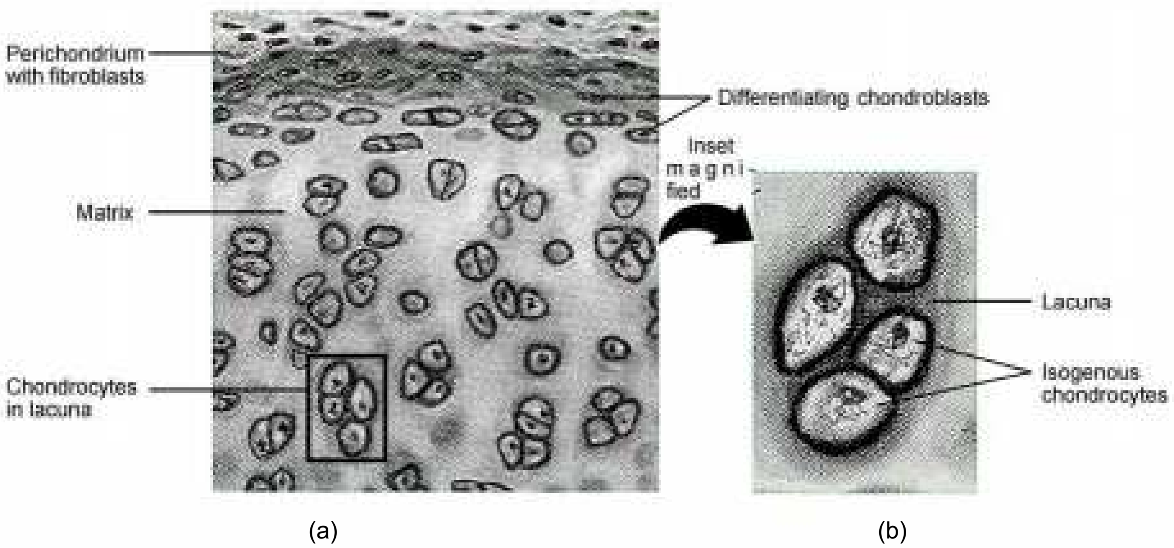


Fig. 6.21 : (a) Photomicrograph of the structure of hyaline cartilage and (b) Magnified view of the inset with a lacuna containing four chondrocytes.

(b) Elastic cartilage (Fig. 6.22):

Elastic cartilage appears **yellowish** and **opaque** in fresh preparation. It is similar in structure to hyaline cartilage, except for the presence of **numerous branching elastic fibers** in its matrix. Elastic cartilage is highly flexible, (e.g.; external ear, wall of the auditory tube and epiglottis).

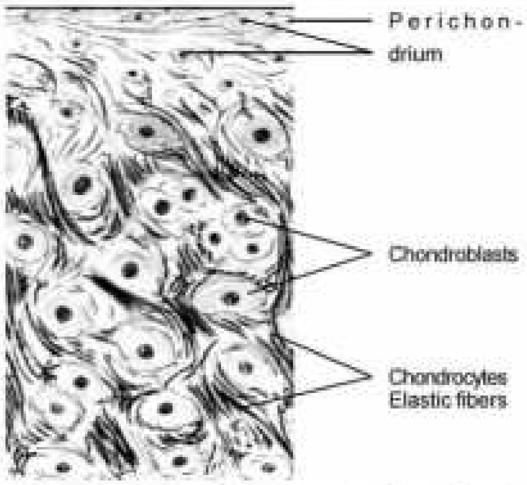


Fig. 6.22 : Photomicrograph of the structure of an elastic cartilage.

(c) Fibrocartilage (Fig. 6.23):

Fibrocartilage is characterized by the presence of a large amount of irregular and dense bundles of collagen fibers in its matrix. In contrast to hyaline and elastic cartilages, it consists of alternating layers of cartilage matrix and thick and dense layers of collagen fibers. The chondrocytes, present in lacunae are also disposed in parallel rows, (e.g.; interverebral disc, pubic symphysis and some joints)

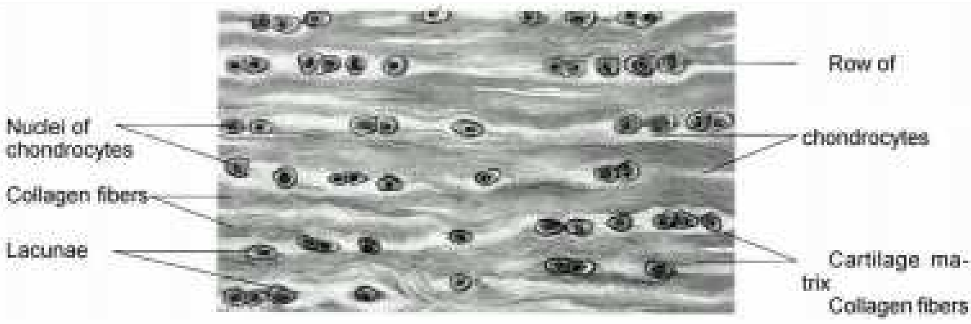


Fig. 6.23 : Photomicrograph of the structure of a fibrocartilage.

Bone :

Bone is a special connective tissue like that of the cartilage and consists of bone forming cells, present in an inter-cellular matrix. The matrix is made up of collagen and elastic fibers and an amorphous ground substance. Two types of bones have been recognized : **cancellous** or **spongy** and **compact** or **woven.**

(a) Cancellous (spongy) bone [Figs. 6.24 (a) and (b)J:

Cancellous bone is relatively softer and spongy and consists of bony plates called **trabecullae** (singular; trabeculus). Each trabeculus consists of a number of **lamellae** (singular: lamella), between which there are lacunae containing **osteocytes.** A lamella is a layer of bony material. The trabecullae enclose wide spaces that are filled with bone marrow. The bone receives nutrition from blood vessels vascularizing the bone marrow. Thus, this bone marrow is known as **red bone marrow.**

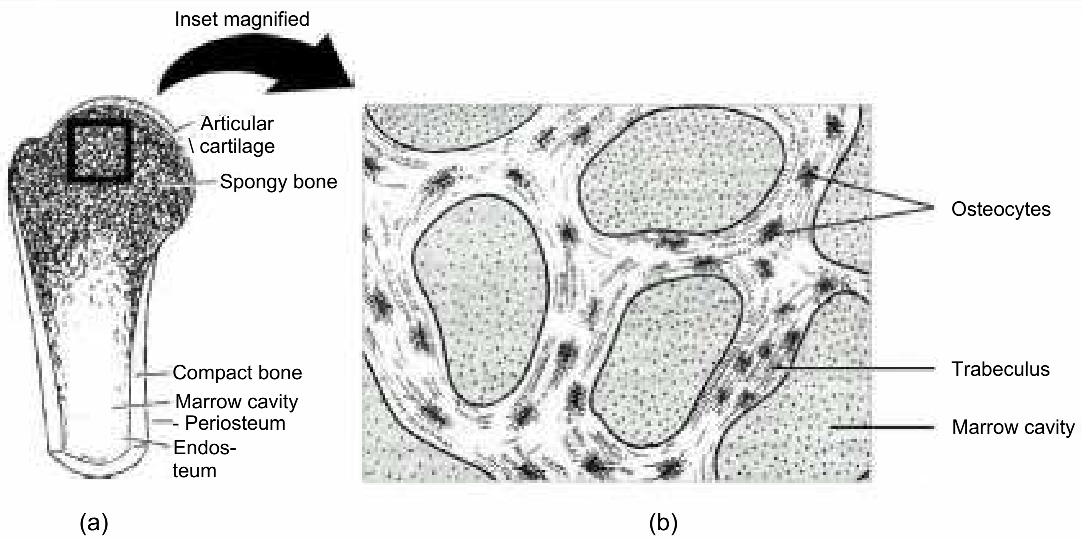


Fig. 6.24 : Structure of cancellous (spongy) bone, (a) Spongy bone at the end of a long bone and (b) microscopic structure of spongy bone

(b) Compact (woven) bone (Fig. 6.25):

In this type of bone, the lamellae (layers of bony material) are compactly present, so that there is no marrow cavity. Hence, the name is compact bone. The thick bony material surrounds a cylindrical cavity, known as **marrow cavity.** The marrow cavity is filled with **yellow bone marrow** containing **adipose cells.** The bone is surrounded by a layer of fibrous connective tissue, known as **periosteum.** Similarly, the marrow cavity is lined by another layer of fibrous connective tissue sheath, the **endosteum.**

Inner to the periosteum and outer to the endosteum, **bone forming stem cells,** known as **osteoprogenitor cells** are present. These cells divide and give rise to **osteoblasts.** Osteoblasts are the actual bone forming cells. On forming and depositing bony material, the osteoblasts are exhausted and turn into **mature osteocytes,** which are locked in **lacunae** in the interior. **Osteoclasts are bone resorbing macrophage-like cells.** These are superficially present in shallow concavities, known as **Howship lacunae.** Inner and outer to the periosteum and endosteum, respectively, the lamellae are organized in circumferential manner. These lamellae are known as outer and inner **circumferential lamellae,** respectively. Between the two circuferential lamellae, the lamellae are organized into **Haversian systems** or **osteons.** Between two adjoining osteons, the angular interstitial cavities are occupied by **interstitial lamellae.**

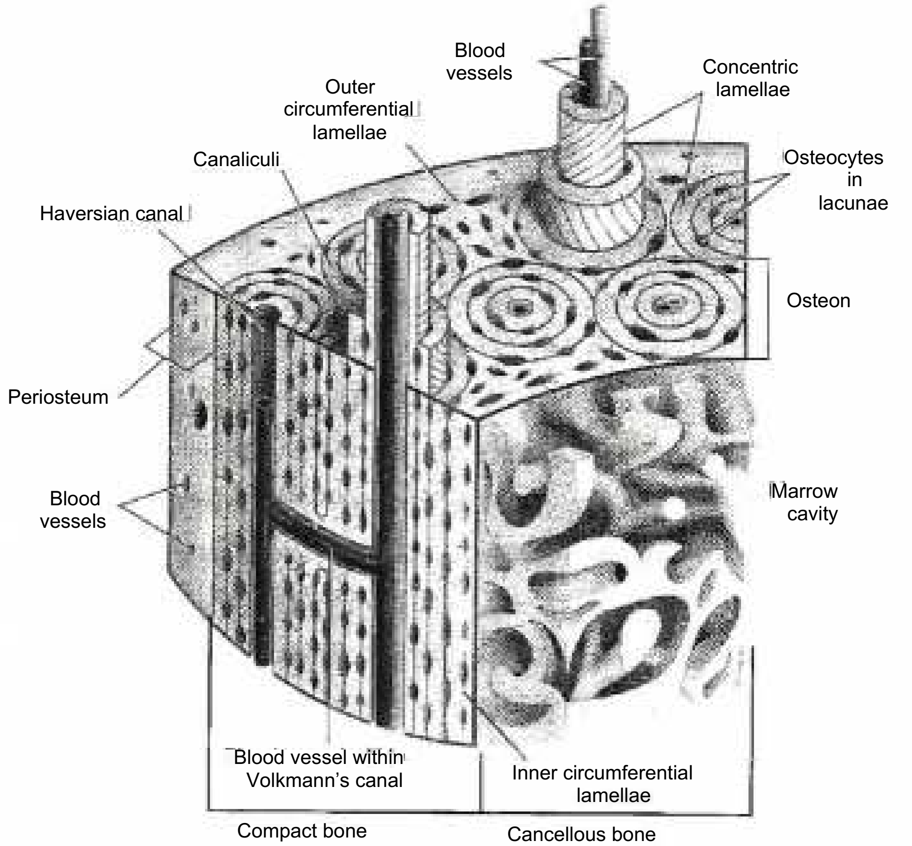


Fig. 6.25 : Gross organization of a compact bone.

(i) Haversian sysem (Osteon) [Figs. 6.26 (a) and (b)J:

A Haversian system consists of concentric layers or rings of lamellae. Each lamella contains **singular osteocytes, trapped in lacunae.** Slender processes, known as **canaliculli,** radiate from each lacuna, which are occupied by slender processes of the trapped osteocyte. The ends of the processes of neighbouring osteocytes meet within the canaliculi and have gap junctions at the site of contact. The lamellae surround a canal called **Haversian canal.** Haversian canals run predominantly along the length of the bone. However, they also anastomoise with each other and communicate with the marrow cavity by canals called **Volkmann's canals.** (Fig.6.25).

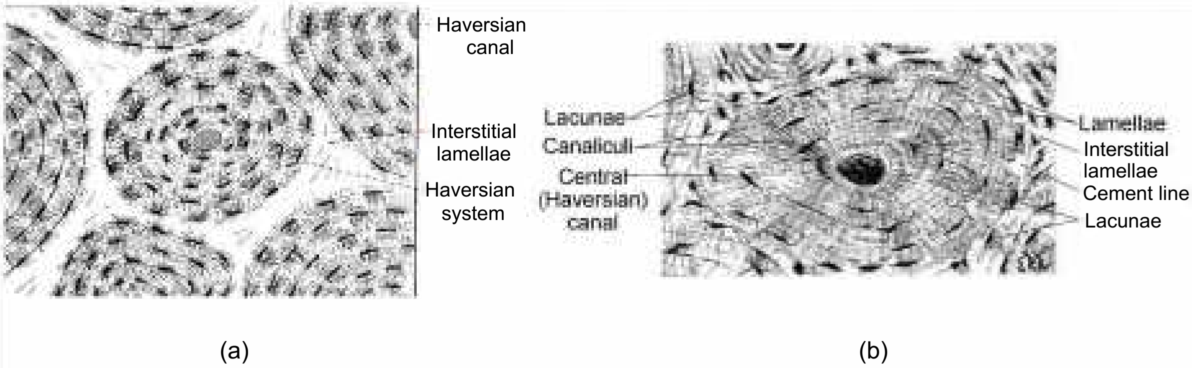


Fig. 6.26 : Organization of compact bone, (a) A few Haversian systems and (b) magnified view of a single Haversian system.

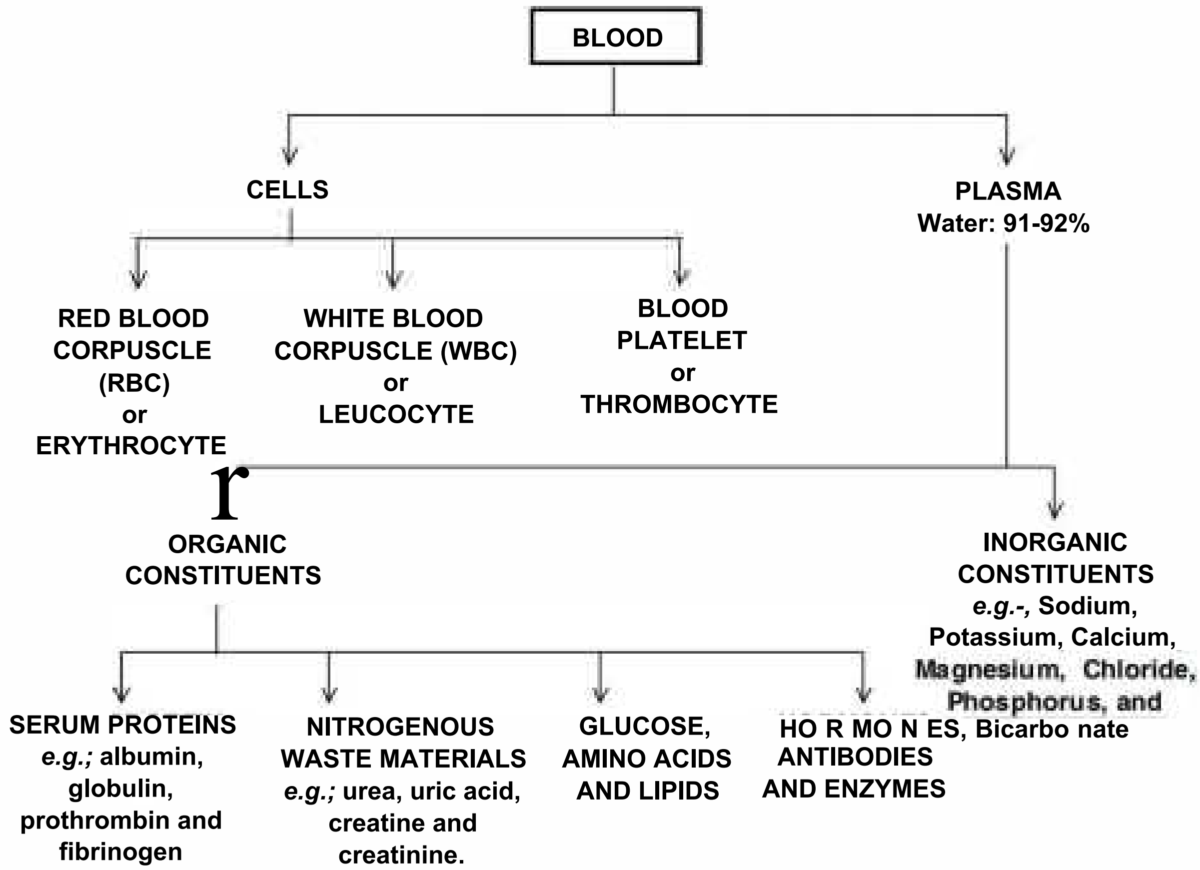
(ii) Bone matrix : The matrix consists of **collagen fibers** and **organic** and **inorganic compounds. Sulfated glycosaminoglycans** and **hyaluronic acid** constitute the organic matter of the bone. These form large **proteoglycan aggregates.** Glycoproteins are also present in a considerable amount. Some bone specific glycoproteins are **osteocalcin, osteopontin** and **osteonectin.** The inorganic constituent of the bone is **calcium phosphate** [$Ca_3(PO_4)_2$]. It is organized into **hydroxyapatite crystals** [$Ca_{10}(PO_4)_6(OH)_2$], a complex salt of calcium. Hydroxyapatite crystals lie parallel to the collagen fibers and contribute to the lamellar appearance of the bone.

6.2.3. Fluid connective tissue :

Fluid connective tissue is a special type of connective tissue, which includes blood and lymph. In both, different types of **corpuscles (cells)** are suspended in a fluid matrix, known as the **plasma.** Fibers are absent.

6.2.3.1. Blood :

(a) Plasma: Plasma is the inter-cellular substance or the matrix, which does not contain any fiber that is common to all other types of connective tissues. Its main constituent is water with dissolved **colloids** and **crystalloids.** The water makes up around 91-92% of the plasma. The colloids are **proteins such as prothrombin** and **fibrinogen (blood coagulation protein); serum albumins; serum globulins (immunoglobulins or antibodies);** and **hormones.** The crystalloids are the **ions of sodium, potassium, calcium, magnesium, chloride, phosphate** and **bicarbonate.** Several other substances like glucose; amino acids; lipids and nitrogenous waste materials, such as urea, uric acid, xanthine, creatine and creatinine are also present in dissolved state. The yellow colour of the plasma is due to the presence of colouring matter such as, **bilirubin** and **carotene.**



Outline classification of blood into its constituents

(b) Cells : The cells, which are also known as the **formed elements** are suspended in the plasma and are of three types : **red blood corpuscles (RBC)** or **erythrocytes, white blood corpuscles (WBC)** or **leucocytes** and **blood platelets** or **thrombocytes.**

(i) Red blood corpuscles (Erythrocytes): Human RBCs are biconcave disc-like red cells [Fig. 6.20 (a)]. The central part of the cell is depressed or biconcave due to the absence of a nucleus. All mammals, but camels; and llamas; have **anucleate RBCs** i.e., the RBCs are without nuclei. The red colour is due to the presence of a **red-coloured respiratory pigment, haemoglobin.** Haemoglobin is a **conjugate protein (metalloprotein)** containing iron as its metallic part. It is the iron that imparts red colour to the RBC. These are most numerous in human blood. In a healthy human, it ranges from 4.5 million to 5.5 million per mm^3 of blood. It is approximately 600 times the number of WBCs present in the blood. When suspended in a suitable medium, the RBCs pile up one above the other forming a **rouleaux** [Fig. 6.28 (c)]. RBCs maintain their normal shape only if suspended in an isotonic medium. If the medium becomes hypotonic, the cells absorb water by **endo-osmosis** and swell up and ultimately burst releasing the haemoglobin into the medium. This phenomenon is known as **haemolysis.** Haemolysis results in the formation of a ruptured plasma membrane, known

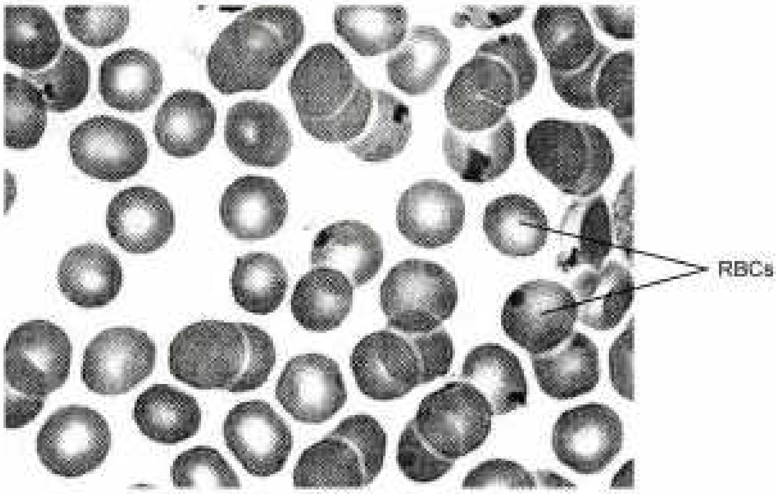
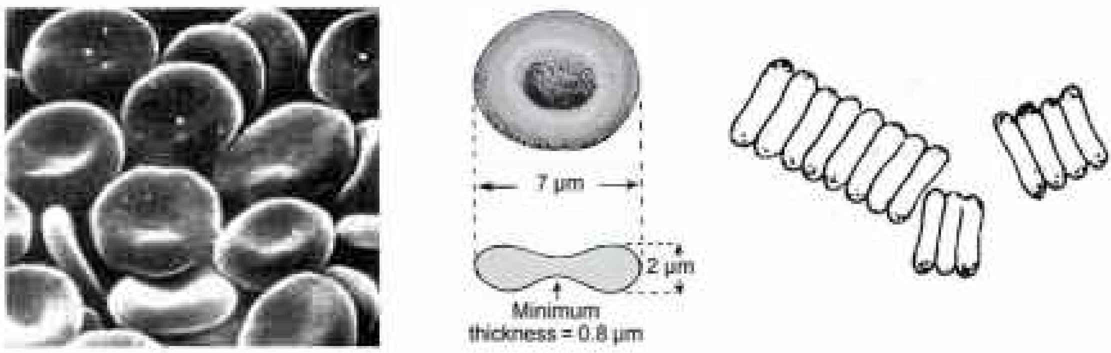


Fig. 6.27 : RBCs in a human blood smear.

as a **red cell ghost.** Alternately, if the RBCs are placed in a hypertonic medium, there is a loss of water from the cells due to **exo-osmosis** and consequently, the cells shrink. Their surfaces develop irregularities. This phenomenon is known as **crenation** and the shrunken RBCs are often called **echinocytes.**



(a) (b) (c)

Fig. 6.28 : Human RBC. (a) scanning electron micrograph of human RBC; (b) dimensions of RBC; and (c) rouleaux formation.

RBCs differentiate from the **myeloid stem cells** of the red bone marrow. The process of formation of RBC is known as **haemopoiesis** or **haematopoiesis.** They have a limited life span i.e. they are renewed every 120 days. They are destroyed in the spleen and the haemoglobin is metabolized in the liver into bile pigment, bilirubin. Therefore, spleen is referred to as the **graveyard of RBCs.**

Functions : RBCs transport molecular oxygen from the lungs to the tissues. As such, haemoglobin is known as **deoxyhaemoglobin** and in combination with oxygen, it is known as **oxyhaemoglobin.** One molecule of haemoglobin combines with four molecules of oxygen in a **cooperative (allosteric) manner** and gets saturated. On delivering oxygen to the tissues, it changes to **deoxyhaemoglobin.** Carbondioxide that is released from the tissues gets dissolved in the blood and is carried to the lungs in different chemical combinations. A part of the carbon dioxide is also carried by the haemoglobin as **carbaminohaemoglobin.**

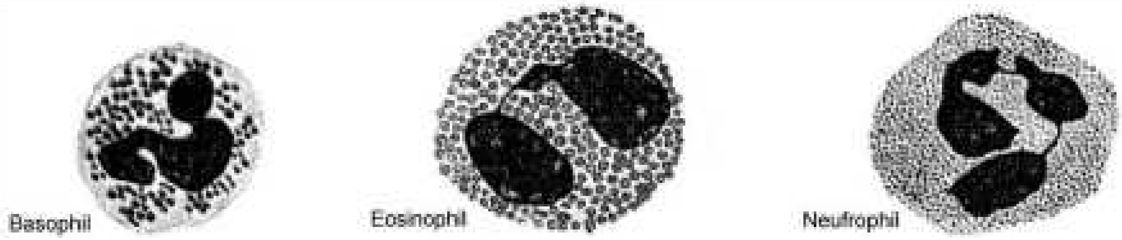
Deficiency of haemoglobin in the blood is called **anaemia.** It is generally produced due to a deficiency of iron in the diet. In this type of anaemia, the RBCs are relatively smaller in size **(microcytic). Haemolytic anaemia** is caused due to an excessive destruction of RBCs. This occurs, when the RBCs are abnormal. One such abnormality is the absence of **ankyrin, a protein of the cytoskeleton,** so that the RBCs become spherical, rather than biconcave. This abnormality is known as **spherocytosis. Sickle cell anaemia** is another form, where the haemoglobin is abnormal due to an **amino acid substitution in the beta globin polypeptide.** It is a **single gene recessive disorder.** In an exactly opposite pathological condition to anaemia, more RBCs than normal are formed. This condition is known as **polycythemia.**

(c) White blood corpuscles (Leucocytes): White blood corpuscles (WBCs) or leucocytes are named so because they lack haemoglobin. These are nucleated blood cells having variable shapes and sizes. Their number in human blood is much less than the number of RBCs. In a healthy human, the number of WBC ranges from 8000 to 10000 per mm^3 of blood. Under special pathological conditions, the normal number varies considerably.

WBCs are primarily classified as granulocytes and agranulocytes based on the presence or absence of characteristic stained granules in their cytoplasm. Depending upon the staining characters of the granules, the granulocytes are of three types : **neutrophils, eosinophils** or **acidophils** and **basophils.** Agranulocytes do not contain characteristic granules in their cytoplasm. They are of two types : **lymphocytes** and **monocytes.** Each class of WBC has a specific relative number or percentage as given below:

Leucocyte class	**Percentage**
Neutrophil	60-70
Eosinophil	2-4
Basophil	>1
Lymphocyte	20-30
Monocyte	3-8

(i) Neutrophils [Fig. 6.29 (c)J: The name is derived from neutral staining character of the cytoplasmic granules. A neutrophil is further characterized by a multi-lobed nucleus.



(a) (b) (c)

Fig. 6.29 : Three different types of granulocytes, (a) basophil; (2) eosinophil; and (c) neutrophil.

The shape of the nucleus varies from neutrophil to neutrophil. Therefore, this WBC is alternately known as **polymorphonuclear granulocyte.** In human female, the nucleus is seen to possess an additional smaller lobe at one end. This lobe is known as **drum stick.** Neutrophils have a very short life span. They circulate in the blood for approximately 10 hr and then enter the connective tissue, where they live for another 2-3 days. As indicated in the table above, the neutrophils are the most abundant WBC. These are attracted by chemotactic factors secreted by bacteria at the site of infection, act as phagocytes and engulf and digest them.

(ii) Eosinophil (acidophil) [Fig. 6.29 (b)J: The name of the WBC is derived from the **acidic staining character** of the cytoplasmic granules. The cytoplasmic granules stain specifically with **eosin,** an **acidic dye. The nucleus is bilobed.** They have a short life span. They circulate in the blood for around 10 hr and then migrate to the connective tissue and remain there for upto 10 days. Eosinophils are phagocytic cells with an affinity for **antigen-antibody complexes** formed at the site of **inflammation** and **allergic reaction.** They also migrate to the site of parasitic infection and specifically kill helminth larvae.

(iii) Basophil [Fig. 6.29 (a)]: This granulocyte has cytoplasmic granules having **basic staining character. The nucleus is bilobed.** They have a short life span and a negligible percentage in the blood. Their function is similar to that of **mast cells.** Basophils store **histamine** and **heparin.** Release of histamine causes allergic reactions and vascular changes, which leads to fluid leakage from blood vessels. This causes severe **hypersensitivity responses** and **anaphylaxis.**

(iv) Lymphocytes : Lymphocytes have variable life span ranging from several days to months. They are of two types : **small** and **large lymphocytes** [Figs. 6.20 (a) & (b)]. They play a key role in the immune response of the body. Lymphocytes mature and become immunologically competent in **thymus** and **bursa of Fabricius** or its analogous structure. Thymus maturing lymphocytes are called **T-lymphocytes,** while lymphocytes, which mature in bursa of Fabricius or its analogous structure, are called **B-lymphocytes.** T-lymphocytes act as **killer cells.** B-lymphocytes are stimulated to differentiate into potential **antibody secreting cells,** the **plasma cells.**

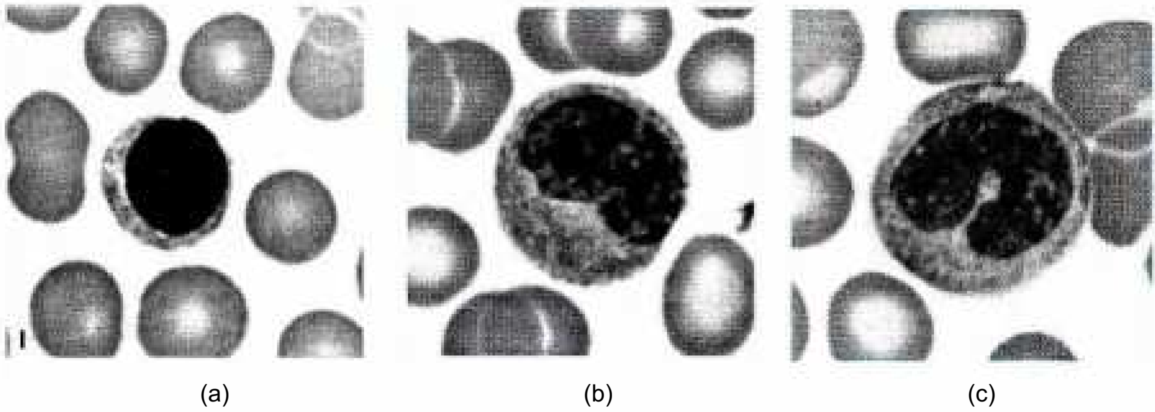


Fig. 6.29 : Different types of agranulocytes. (a) small lymphocyte; (b) large lymphocyte; and (c) monocyte.

(v) Monocyte [Fig. (c)J: There is no cytoplasmic granule. **The nucleus is horse shoe shaped.** They live in the blood circulation for 2-3 days. Then they move into the connective tissue, where they live for a few months. In the connective tissue, monocytes become **phagocytes.** At the site of infection, monocytes differentiate as **tissue macrophages,** which then destroy bacteria, foreign particles and cellular debris.

All WBCs differentiate from **lymphoid stem cells** of the bone marrow in a process known as **haemopoiesis.** Under certain pathological conditions, WBCs increase or decrease in number. The increase in number beyond normal is known as **leucocytosis,** while a decrease in the number is known as **leucopenia.** In an acute condition, known as **eukaemia,** there is an uncontrolled production of all classes of WBC in the bone marrow. Immature WBC (WBC precursors) are seen in large number in the peripheral blood. It is a malignant, life threatening condition.

(d) Blood platelets : Also known as **thrombocytes,** blood platelets are small, round, oval or irregular disc shaped anucleate (without nucleus) cells. In an ordinary blood film, each platelet appears to have a **clear outer zone** called **hyalomere** and a **granular central zone** called **granulomere.** The life span is around 10 days and the normal number varies from2, 50, 000 to 5, 00, 000 per mm^3 of blood. Platelets play a very important role in **blood coagulation.** Platelets contain an essential enzyme, **thromboplastin** that is essential in initiating the blood coagulation cascade ending in the formation of **fibrin mesh.** The enzyme is released from the platelets following an injury. More than normal number of platelets (thrombocytes) causes a pathological condition, known as **thrombocytosis.** Deficiency of platelets is known as **thrombocytopenia,** which leads to a prolonged bleeding following a minor injury.

6.2.3.2. Lymph :

Lymph is a colourles fluid filtrate of the blood capillaries, containing the same proteins and salts as that of the plasma, but in smaller amount. It circulates in a system of lymphatic vessels, which are finally drained to the venous blood via the **thoracic duct** and **right lymphatic duct.** Both T- and B-lymphocytes and other WBCs are the predominant cells of the lymph. However, occasionally, a very insignificant proportion of RBCs are present. Following a lipid-rich meal, the lymph is seen to contain **dissolved fat globules (chylomicrons).** Lymph in the lacteal (the lymphatic channel in the intestinal wall) looks milky due to the absorption of digested lipids into it. Such a milky fluid is known as **chyle.**

Lymph returns the blood proteins and other essential solutes, back to the blood, which are filtered through the capillaries into the tissue space. Thus, it helps maintain the osmolarity of the blood plasma. It carries the differentiated T- and B-lymphocytes to the tissues and thus, it helps to guard each and every part of the body against microbial invasion.

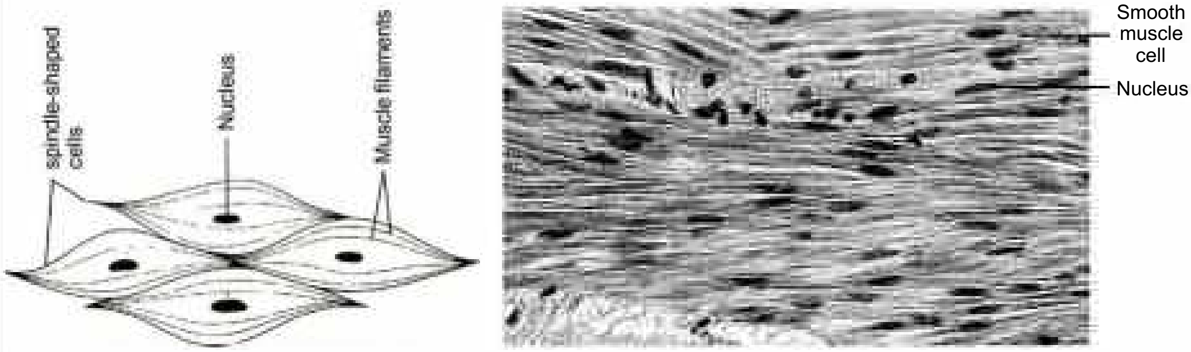
6.3. MUSCULAR TISSUE :

Muscular tissue is composed predominantly of muscle cells or myocytes, which possess two fundamental properties :

1. High degree of contraction and relaxation.
2. Conversion of chemical energy to mechanical energy, during contraction.

All cells possess some degree of contraction and relaxation. However, the muscle cells are specially equipped to undertake the highest degree of contraction and relaxation ever. This is due to the presence of **contractile protein myofilaments : actin** and **myosin.**

A muscle is made up of unitary structures, the **muscle cells** or **myocytes.** The cytoplasm of a muscle cell is called **sarcoplasm** and the surrounding plasma membrane is called **sarcolemma.** Such an elongated muscle cell is known as a **muscle fiber.** There are three types of muscle : **smooth, skeletal** and **cardiac.** All, but smooth muscle cell, are elongated. Muscles may be **voluntary** or **involuntary** from contraction and relaxation at will point of view. For example, smooth and cardiac muscle contract and relax all throughout the life. Their contraction and relaxation is not under the control of their will. Therefore, these muscles come under the category of involuntary muscle. On the other hand, skeletal muscle contracts and relaxes at will or as and when necessary. It is a voluntary muscle. Another classification is based on the organization of the contractile protein myofilaments. In skeletal and cardiac muscles, the protein filaments are organized in parallel bundles, thus giving a striated appearance in stained microscopic preparation. These are therefore, called **striated muscle.** The protein filaments are present in a stray manner in smooth muscle cells i.e., they are not organized into bundles and hence, smooth muscle is classed as **non-striated muscle.** Further, the bundles of protein filaments in skeletal and cardiac muscle give cross striated or striped appearance and hence, these muscles are often referred to as **striped muscle** and smooth muscle as **unstriped muscle.**



(a) (b)

Fig. 6.30 : Smooth muscle cells (myocytes), (a) Four smooth muscle cells (diagrammatic), and (b) photomicrograph of smooth muscle cells in a section.

Thus, muscle is of three types, as noted hereunder with their gross features.

1. **Smooth muscle:** Involuntary, nonstriated and unstriped
2. **Skeletal muscle :** Voluntary, striated and striped
3. **Cardiac muscle:** Involuntary, striated and striped

6.3.1. Smooth muscle [Figs. 6.30(a) & (b)J:

Smooth muscle is made up of long spindle shaped muscle cells or **myocytes,** each with a broad central part with tapering ends. The nucleus is oval or elongated, lies in the broad central part.Smooth muscle cells form aggregates or bundles, known as **fasciculi** (Singular fasciculus). The fasciculi are further aggregated to form layers of variable thickness. Each fasciculus is surrounded by delicate collagen, elastic and reticular fibers, which hold all the myocytes of the fasciculus together. The sarcoplasm contains myofibrils of protein filaments; actin and myosin, which are disposed in a random manner. Thus, the smooth muscle cells do not exhibit striated and striped appearance, (e.g.; wall of the alimentary canal; urinary bladder; uterus; arteries; veins; bronchi; and ureters).

6.3.2. Skeletal muscle :

6.3.2.1. Structure : Skeletal muscle, as the name indicates, is attached to the elements of the skeletal system, such as bones and cartilages. A skeletal muscle is surrounded by a connective tissue sheath, the **epimysium.** The muscle is made up of bundles of elongated and cylindrical muscle fibers, known as **fasciculi.** Each fasciculus is surrounded by a sheath, known as **perimysium** and each muscle fiber is surrounded by an **endomysium** (Fig.6.31). **A muscle fiber consists of many myofibrils and each myofibril consists of two types of protein myofilaments: actin** and **myosin** (Fig.6.33). A skeletal muscle fiber is a multinucleate elongated cell **(syncytium)** with a surrounding **sarcolemma.** The bulk of the fiber is occupied by **myofibrils.** This results in the displacement of the active sarcoplasm with the nuclei to the peripheral part. Each myofibril is surrounded by an extensive network of endoplasmic reticulum, known as **sarcoplasmic reticulum** and **mitochondria.** The sarcoplasmic reticulum is in the form of tubules, which join to form terminal cisternae, present between each anisotropic (A) and isotropic (I) bands. The sarcolemma invaginates between each A and I bands to form a transverse tubule. The sarcoplasmic reticulum in the form of tubules and terminal cisternae and transverse tubules constitute a **sarco-tubular system** (Fig. 6.32).

6.3.2.2. Structure of myofibril (Fig. 6.33): In a stained microscopic preparation, the myofibrils are seen to exhibit alternating dark and light bands. The dark staining bands are known as **anisotropic bands (A bands),** while the light staining bands are known as **isotropic bands (I bands).** A myofibril contains two types of protein myofilaments : **thick filaments (myosin)** and **thin filaments (actin).** These filaments contribute towards the bulk structure of the myofibril. The filaments are arranged in a periodic manner. This arrangement gives rise to the alternating **A** and **I** bands at regular intervals which imparts a **striated appearance** to the skeletal muscle. The same periodicity is found in all the muscle fibers of a fasciculus, thus giving the muscle a **cross-striated** or **striped appearance** [Figs. 6.34 (a) & (b)].

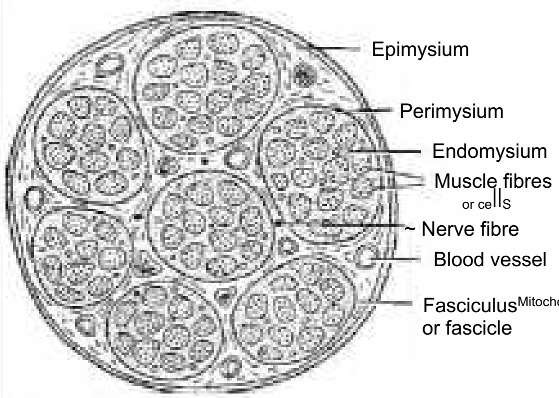


Fig. 6.31 : Three levels of organization (muscle → muscle fiber -> myofibril → myofilament) of skeletal muscle with respective connective tissue sheaths.

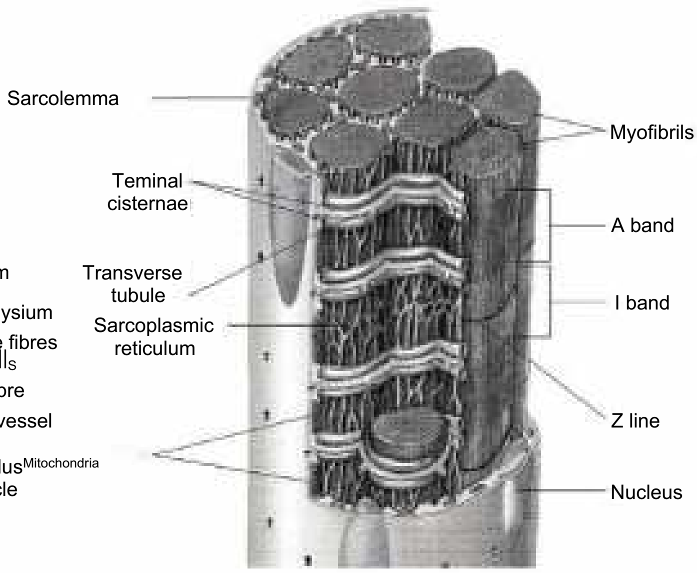


Fig. 6.32 : Organization of myofibrils in a muscle fiber with sarcoplasmic reticulum, terminal cisternae and transverse tubules.

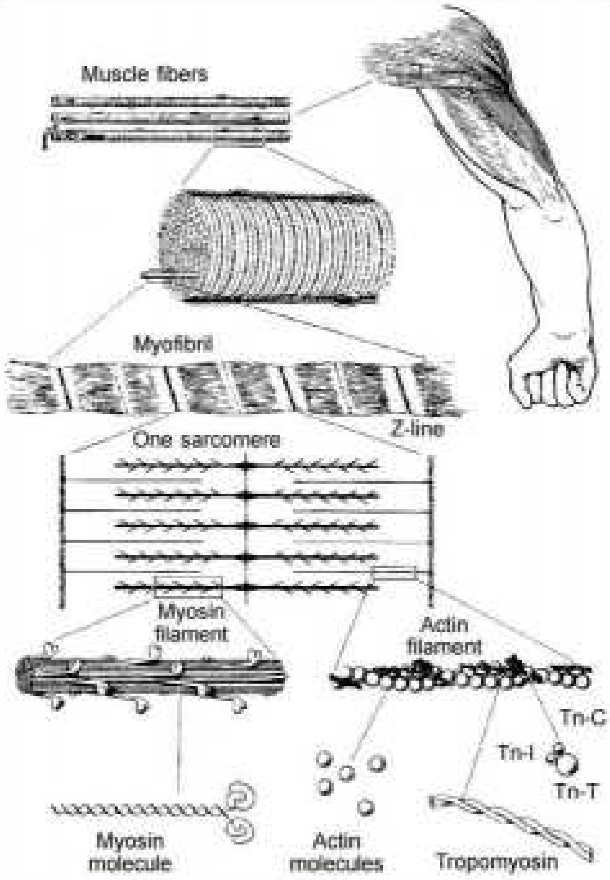
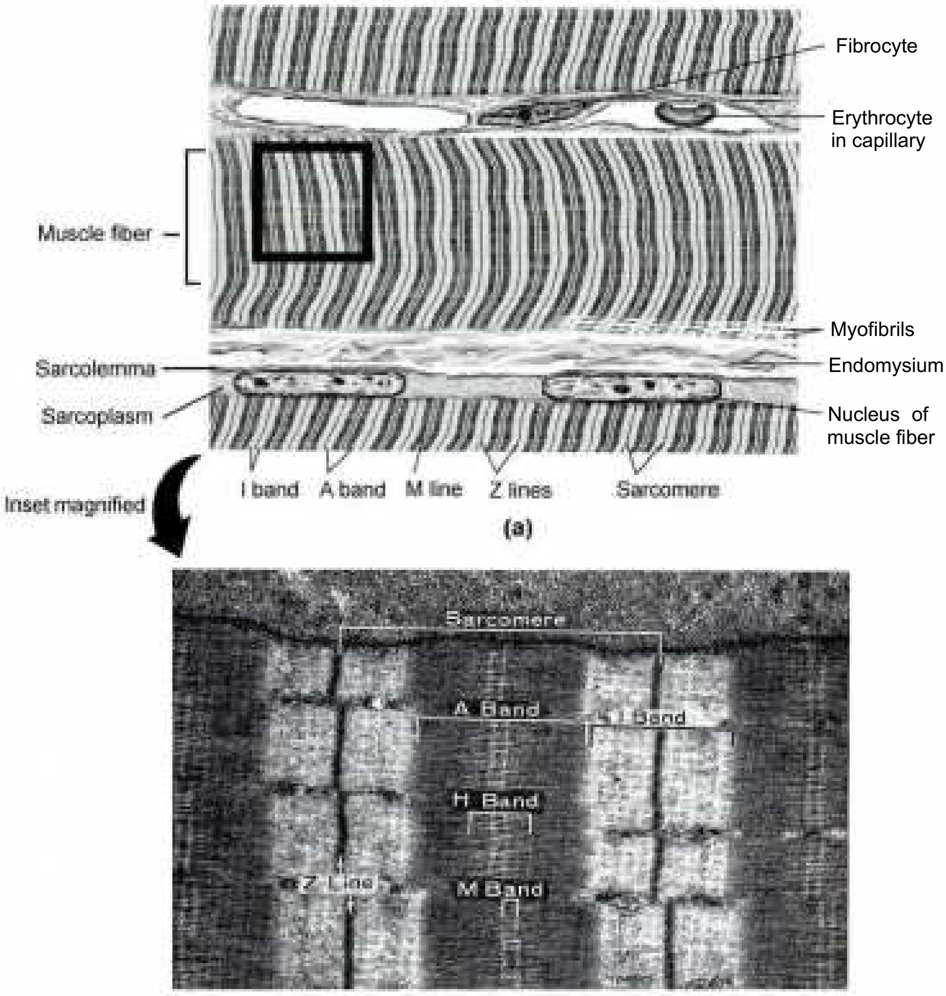


Fig. 6.33 : Sub-microscopic structure of skeletal muscle. (Tn, troponin; C, Calcium binding, I, inhibitory; and T, tropomyosin binding)

A thick line called **Z-line** runs across the middle of each **I** band. The middle of each A band is traversed by a lighter band called the **H-band.** Running through the centre of the H-band, there is a thin **M-band.** The stretch of the muscle fiber between two Z-lines is called a **sarcomere.** The sarcomere is considered as the **contracting unit** of the muscle fiber. The nerve innervating a muscle enters into it at a place called the **neuro-mascular hilus.**

6.3.2.3. Structure of myofilaments (Fig. 6.35): Two main types of myofilaments, such as myosin and actin are present in the myofibril.

(a) Myosin [Fig. 6.35 (c)]: A thick or myosin filament consists of several myosin molecules organized into a bundle that gives it a thick filamentous appearance. Each myosin molecule has two **heavy polypeptide chains,** associated with two pairs of **light polypeptide chains.** The heavy chains are helically coiled around each other. At the N-terminus of each heavy chain, the polypeptide is globular forming a **head** [Fig. 6.35 (c)]. The head has an ATPase activity, which binds to and hydrolyzes ATP to generate mechanical energy during muscle contraction. The myosin molecules are oriented in opposite directions in two halves of the thick filament so that in the middle of the thick filament, there is no head and thus,

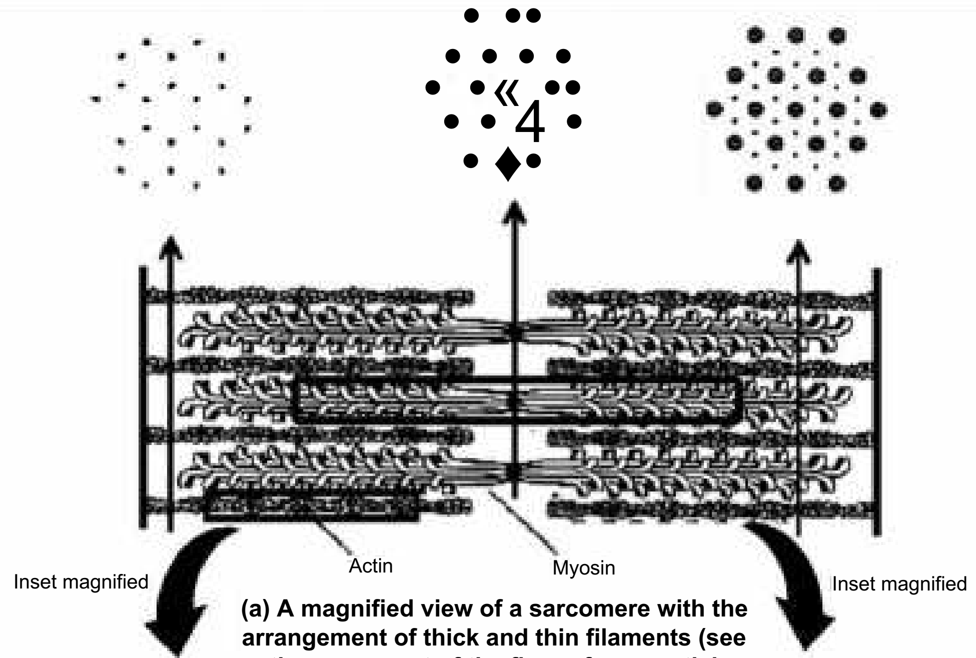


(b)

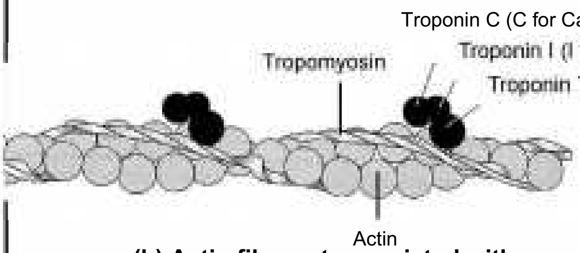
Fig. 6.34 : Structure of a stained muscle fiber, (a) gross structure with alternating A and I bands giving the muscle fiber a striated and striped appearance and (b) magnified view of the inset in (a) revealing the detail structure.

this part has a lighter band-like appearance, which runs across a muscle fiber. This band has been referred to as the **H-band.** Running through the middle of each H band, there is a relatively thicker M-band or line.

(b) Actin [Fig. 6.35 (b)]: A thin or actin filament consists of two actin chains, helically coiled around each other. Each actin chain consists of a linear array of many actin molecules. An actin molecule is a **globular protein** and thus, is known as **globular actin** or **G-actin.** A G-actin molecule has an ATPase ativity and a myosin head binding site. Several G-actins join linearly forming a **fibrous actin** or **F-actin.** Two F-actins helically coil forming an actin filament. During muscle contraction, the myosin heads bind to the G-actin's myosin head binding sites. ATP, bound to the myosin heads are hydrolyzed by the ATPase activity.



(a) A magnified view of a sarcomere with the arrangement of thick and thin filaments (see the upper part of the figure for a spatial arrangement of thick and thin filaments in relation to each other.



(b) Actin filament associated with tropomyosin and tropenin.

(c) Structural organization of a myosin (thick) filament.

Fig. 6.35 : Alignment of thick and thin filaments in a sarcomere. (Note that two Z-lines demarcate a sarcomere)

Mechanical energy is generated, which slides the F-actin and Myosin over each other. Thus the muscle contraction is effected.

There is a regularity in the arrangement of myosin and actin filaments. A myosin filament is surrounded by six actin filaments [Upper part of Fig. 6.35 (a)]

The actin and myosin filaments are not free floating. The thin filaments are anchored to the Z-line by a protein, called **actinin.** The thick filaments are anchored to the Z-lines and M-line by a protein, called **titin** (Fig 6.36). Two other proteins, known as **troponin** and **tropomyosin** also play an important role in muscle contraction. Troponin is a globular protein consisting of three subunits : TnC (Ca^{2+} binding subunit), TnI (inhibitory subunit) and TnT

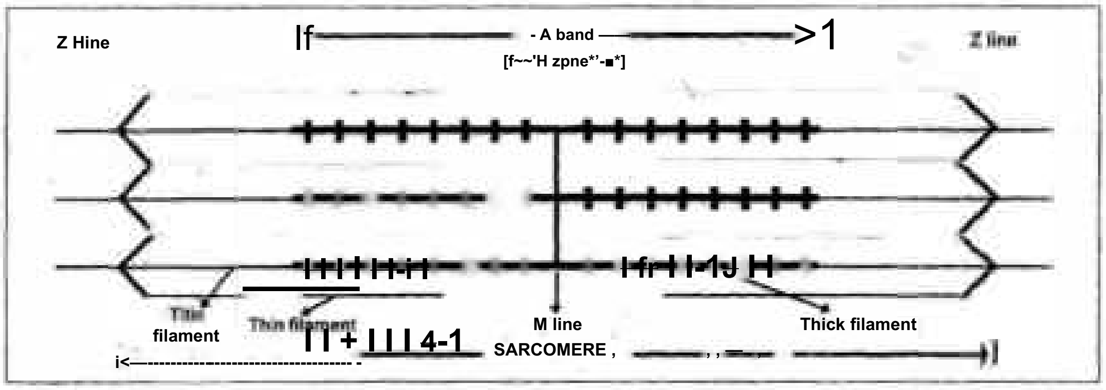


Fig. 6.36 : Organization of a sarcomere with titin filaments anchoring thick (myosin) filaments to Z-lines

(tropomyosin binding subunit). Tropomyosin is a fibrous protein which covers the myosin head binding sites in the actin in a resting muscle fiber. The role of these proteins in muscle contraction is discussed in the Chapter-19 on locomotion and movement, (see the Section 19.3 on muscle contraction).

6.3.3. Cardiac muscle (Fig. 6.37):

6.3.3.1. Structure: Cardiac muscle is present in the wall of the heart, myocardium and large blood vessels that are attached to the heart. It is similar to the skeletal muscle in most of its structural organization. It consists of elongated and cylindrical muscle fibers consisting of uni or occasionally binucleate muscle cells or myocytes. The fibers do not run parallel to each other. They are branched and the branches anastomoise with each other [Figs. 6.37 (a) and (b)]. Each anastomoising point is marked by the presence of a deep staining disc-like structure called **intercalated disc** [Fig. 6.37 (c)]. This is a unique feature of cardiac muscle. Each myocyte is surrounded by a sarcolemma. The nucleus is surrounded by a perinuclear sarcoplasm. However, bulk of the sarcoplasm is peripheral and in this

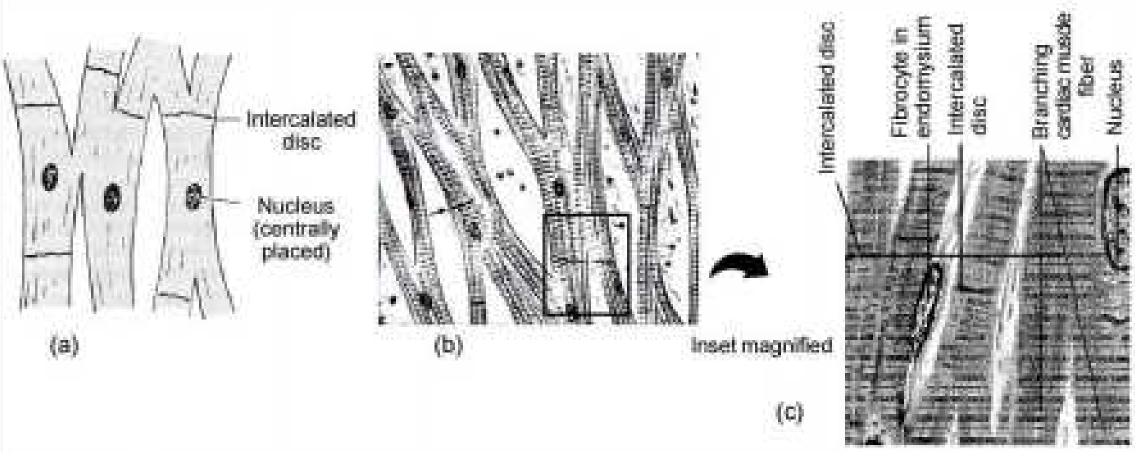


Fig. 6.37 : Cardiac muscle fibers, (a) diagrammatic, (b) photomicrograph of longitudinal section (low magnification) and (c) a part in the inset under higher magnification.

peripheral sarcoplasm, the sarcoplasmic reticulum, mitochondria and other cell organelles are present. The interior of the cell is filled with myofilaments, such as the thick myosin and thin actin filaments, like that in a skeletal muscle fiber.

6.4. NERVOUS TISSUE :

The nervous system is made up of a tissue that is specialized for conducting impulses rapidly from one part of the body to the other. Specialized cells that carry out this work are known as **nerve cells** or **neurons.** The neurons are, thus, the structural and functional units of the nervous system. The neurons within the brain and spinal cord are supported by a host of non-excitable cells. These cells constitute the **neuroglia.**

6.4.1. Structure of a neuron :

Neurons vary considerably in shape, size and other features. However, most of them are built on a common plan. A neuron consists of a **cell body** that gives off a variable number of processes called **neurites.**

6.4.1.1. Cell body :

The cell body is also known as the **soma** or **perikaryon** [Figs. 6.38 (a) and (b)]. It contains a mass of cytoplasm surrounded by a plasma membrane. The cytoplasm contains cytoplasmic organelles and a large spherical or oval nucleus at the centre with a prominent

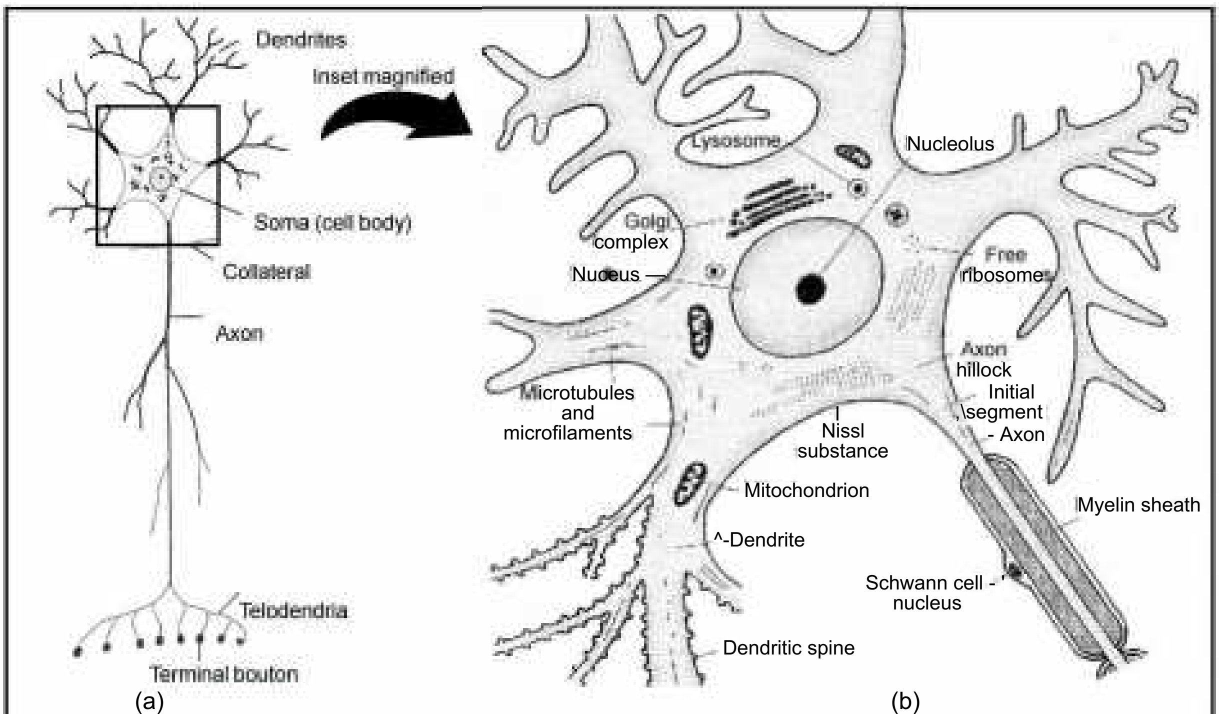


Fig. 6.38 : Structure of a typical neuron, (a) a neuron in the CNS and peripheral ganglion and (b) cell body (magnified)

nucleolus typical to a cell. The presence of centrioles was debated in the past. However, electron microscopic study has confirmed the presence of a pair of centrioles. The cytoplasm contains **basophilic** (stained with basic dye) granular materials called **Nissl body** or **substance** or **granule.** Electron microscopic study reveals that the Nissl body contains **parallel stacks of rough endoplasmic reticulum.** The dendrites also contain rough endoplasmic reticulum, while the axon doesn't. However, smooth endoplasmic reticulum is present in all parts of the neuron (cell body, axon and dendrites). Lysosomes are present only in the cell body. Many slender mitochondria are present in the cell body and dendrites. Mitochondria also occur along the axon and are especially numerous in the axon terminals. The cytoplasm is traversed by a network of fibrils called **neurofibrils.** These fibrils are the **microfilaments** and **microtubules.** The centrioles may be involved in the formation and maintenance of these neurofibrils.

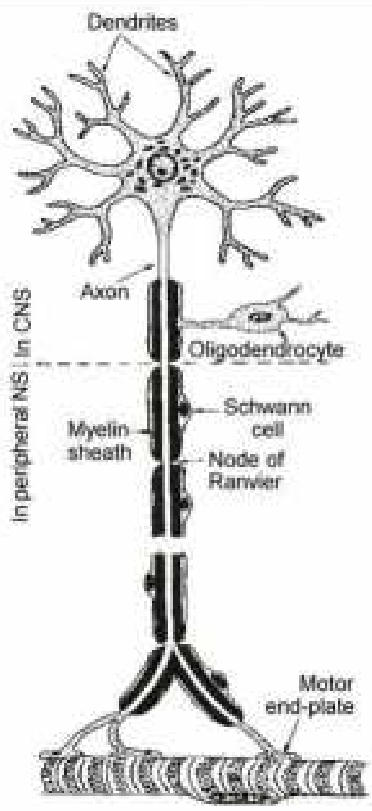


Fig. 6.39 : A neuron exhibiting the structures both of the CNS (see above the broken line) and PNS (see below the broken line).

6.4.1.2. Neurites :

The neurites are of two types: **axon** and **dendrites.**

(a) Axon : The axon is a singular long process, which arises from the cell body and conducts the impulse away from it. It arises from a conical extension of the cell body called **axon hillock.** An axon is of uniform diameter and is devoid of Nissl bodies. The axons, with the exception of those of the central nervous system (CNS), associate with non-conducting cells called **Schwann cells.** Schwann cells form and deposit an insulating lipid, known as **myelin** around these axons. Myelin forms an insulating sheath around many peripheral nerves and thus protects the adjoining tissues from developing a potential difference during the conduction of nerve impulse. A thin layer of Schwann cell cytoplasm persists on the outer side of the myelin sheath forming a secondary layer called **neurilemma** (Fig. 6.40). The myelin is deposited in a discontinuous manner around most peripheral nerves. This results in the formation of **distinct nodes** and **internodes** along the length of the axon. The myelin insulated part is the internode, while the myelin free part is the node called **node of Ranvier** **(Fig. 6.39).** These myelin-sheathed nerve fibers are known as a **myelinated or medullated**

nerve fibers (Fig. 6.39), while those without myelin sheaths are **non-** or **un-myelinated or non-medullated fibers.** The white matter of the brain and spinal code is made up of myelinated or medullated nerve fibers. The axons lying in the CNS are associated with a similar covering formed by **oligodendrocytes** [Fig. 6.39]. Thus oligodendrocytes are the myelin secreting cells in the CNS.

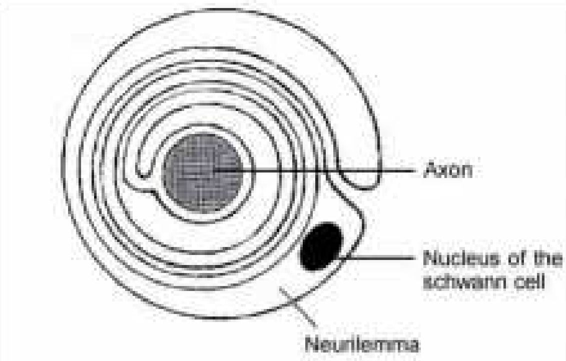


Fig. 6.40 : Mature myelin sheath and neurilemma surrounding a myelinated nerve fiber (axon).

An axon may give off variable number of branches. Branches that arise near the cell body and are perpendicular to the axon are called **collaterals.** At its termination, the axon breaks up into many fine branches called **telodendria** that may end in small swellings, known as **terminal boutons** [Fig.6.38 (a)]. An axon terminates in either of the two ways. In the CNS, its terminal part forms a junction with the dendrite of another neuron. This junction is known as a **synapse.** Outside the CNS, an axon ends in an effector organ (muscle or gland) or forms a synapse with the dendrite of another neuron in the peripheral ganglion.

(b) Dendrites : The many nerve processes, which terminate near the cell body are known as dendrites. Dendrites are short and more numerous processes containing Nissl bodies. These are of uneven thickness bearing small spines of variable shapes. Dendrites carry impulses towards the cell body.

6.4.1.3 Types of neurons (Fig. 6.40):

Neurons are classified on the basis of the number of neurites as: unipolar, pseudounipolar, bipolar, and multipolar.

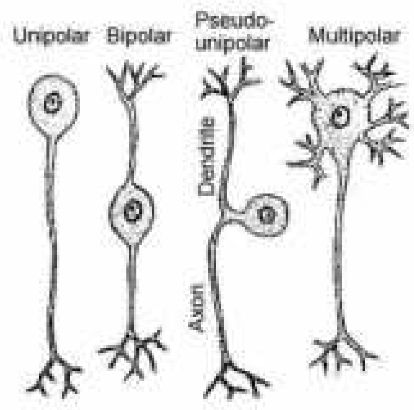


Fig. 6.41 : Types of neurons based on the number of neurites.

(a) Unipolar: The neuron has a cell body followed by an axon. Dendrites are absent.

(b) Pseudounipolar: At one pole of the cell body, there is a T-shaped branching with an axon and a dendrite running in opposite directions, one to the CNS and the other to the peripheral tissue.

(c) Bipolar: The neuron has a cell body and one each of an axon and a dendrite in opposite directions.

(d) Multipolar: The cell body has many neurites, one long axon at one pole and several short dendrites at the other pole.

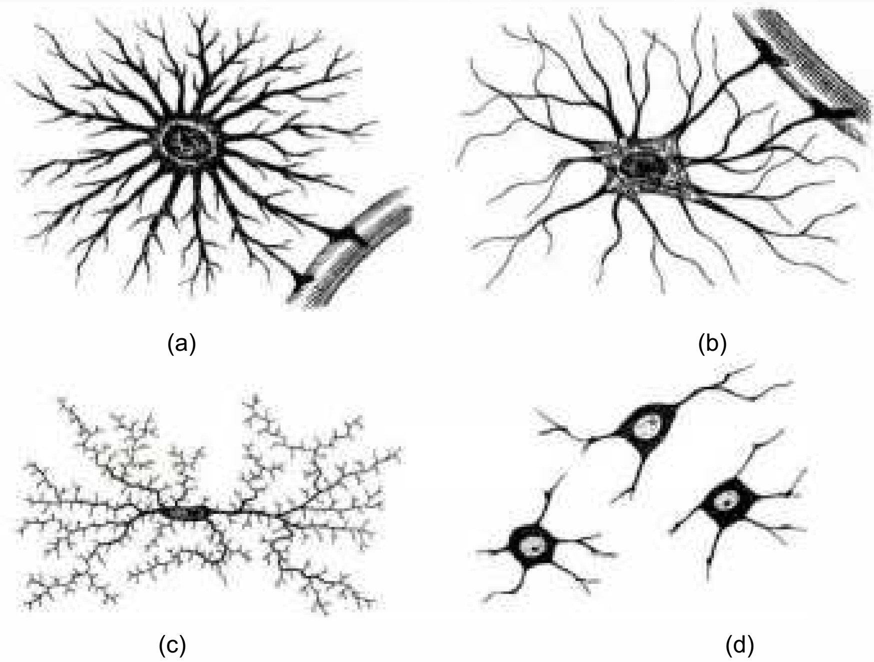


Fig. 6.42 : Morphology of microglial cells, (a) protoplasmic astrocyte; (b) fibrous astrocyte; (c) microglial cells; and (d) oligodendrocytes.

Neurons are also classified on the basis of their functions as: **sensory** or **afferent neurons, motor** or **efferent neurons,** and **interneurons. Sensory neurons** carry impulses from the peripheral receptors (sense organs) to the CNS and **motor neurons** carry impulses from the CNS to the effectors (muscle and glands). **Interneurons** maintain connections between the neurons of the CNS.

6.4.2. Neuroglia :

Neuroglia (nerve glue) are the non-conducting supporting cells of the CNS. In addition to a mechanical support, they also provide a suitable environment for an optimal functioning of the neurons. These are of four types : **astrocytes, oligodendrocytes, microglia** and **ependymal cells.**

6.4.2.1. Astrocytes [Figs. 6.42 (a) and (b)J: Astrocytes are small star-shaped or stellate cells, which give off a number of fine protoplasmic processes. These are of two types : **protoplasmic astrocytes** and **fibrous astrocytes.** Protoplasmic astrocytes are found mainly in the grey matter of the brain. Fibrous astrocytes occur in the white matter. The protoplasmic processes are relatively thinner and longer. Some of the protoplasmic processes, known as **vascular feet** or **pedicels** are intimately associated with the wall of blood capillaries and some others with the neurons. This indicates that they nourish neurons.

6.4.2.2. Oligodendrocytes : These are smaller astrocytes and have fewer processes than astrocytes [Fig. 6.42 (d)]. Oligodendrocytes form myelin sheath around the axons in the CNS.

6.4.2.3. Microglia : These are smallest among all the neuroglial cells [Fig. 6.42 (c)]. Their function is like that of macrophages of the connective tissue. When nervous tissue is damaged or injured, the microglial cells migrate to the site, proliferate and remove the debris by phagocytosis.

6.4.2.4. Ependymal cells : These are simple cuboidal or low columnar cells lining the ventricles of the brain and the central canal of the spinal cord. The apical parts of these cells bear microvilli and cilia. The cilia facilitate the streaming of the cerebrospinal fluid in the central canal and ventricles. The microvilli may also have some absorptive role. Ependymal cells are, recently, established to regenerate neurons and thus are considered are stem cells in nervous system.

DIFFERENCES :

I. Simple epithelium	**Compound / Stratified epithelium**
1. It consists of a **single layer** of epithelial cells, all resting on a **basement membrane.**	1. It consists of **multiple layers** of cells. The lowest layer of cells rests on the basement membrane.
2. Simple epithelium is classified as squamous, cuboidal, columnar and pseudostatified, based on the shape of the cells.	2. The classification into compound squamous, cuboidal and columnar is based on the shape of the uppermost or surface layer of cells.

II Epithelial tissue	**Connective tissue**
1. Epithelial tissue consists of homogeneous types of cells.	1. Connective tissue consists of heterogeneous types of cells.
2. The cells are tightly packed so that there is practically no intercellular space and substance or matrix.	2. The connective tissue cells are scattered leaving a considerable intercellular space, filled with a large quantity of intercellular substance or matrix.
3. Epithelial cells rest upon a **basement membrane** made up of a **glycoprotein substance.**	3. There no basement membrane.
4. Covers the general body surface; lines internal cavities, blood vessels and ducts opening to the external surface and internal cavities and lumens leading to the external surface.	4. Connects other types of tissues and internal organs; forms packing around internal organs; and constitutes the structure of bones, cartilages, blood and lymph.

III. Loose / Areolar connective tissue	Dense connective tissue
1. There is a loose or stray disposition of connective tissue cells and fibers.	1. The cells and fibers are densely or tightly packed.
2. Ground substance is abundant.	2. Ground substance is scanty.
3. Connective tissue cells are more diverse consisting of fibroblasts, macrophages (histiocytes), mast cells, adipose cells, plasma cells etc.	3. Connective tissue cells are less diverse consisting of fibroblasts, macrophages and lymphocytes.
4. It is distributed in varying amounts in different parts of the body. It is present as the sub-cutaneous tissue and connects the visceral organs of the body.	4. It forms the packing tissue (capsule) of the visceral organs. It also connects **bone to muscle (tendon) and bone to bone (ligament).**

IV. Tendon	Ligament
1. It is made up of **white collagen fibers.**	1. It is made up of **yellow elastic fibers.**
2. It is inelastic and tough.	2. It is elastic and strong.
3. Fibroblasts are present in rows.	3. Fibroblasts are scattered.
4. Tendon connects muscle to bone.	4. Ligament connects bone to bone.
5. Tendons have more strength with limited flexibility.	5. Ligaments have strength with remarkable flexibility.

V. Bone	Cartilage
1. Bone is hard and inelastic	1. Cartilage is soft and elastic
2. The bone matrix is formed of the protein, called **ossein.**	2. Cartilage matrix is formed of the protein, called **chondrin.**
3. Inorganic mineral salts are present in the matrix.	3. Inorganic mineal salts are absent.
4. Osteoblasts and osteocytes are bone cells.	4. Chondroblasts and chondrocytes are the cartilage cells.
5. Osteocytes are enclosed within laculnae singularly, which give off fine processes, called canaliculi.	5. Chondrocytes are enclosed within lacunae in groups of two, three or four. No canaliculae are present.
6. Osteocytes give off protoplasmic processes.	6. Protoplasmic processes are absent.
7. Bones are vascular.	7. Cartilages are nonvascular.
8. Haversian and Volkmann's canals are present.	8. Canals are absent.
9. Bone marrow is present.	9. Marrow is absent.
10. Haemopoiesis occurs in the bone marrow.	10. There is no marrow and hence, no haemopoiesis.

VI. Hyaline cartilage

1. Most common type of cartilage present in the body.
2. Bluish-white in colour.
3. Matrix consists mostly of fine collagen fibers and very few elastic fibers.
4. Present at the ends of limb bone as articular cartilages, sternum, larynx, tracheal rings and nasal cartilage.

Elastic cartilage

1. Cartilage present in specific parts of the body.
2. Yellow in colour.
3. Matrix consists mostly of yellow elastic fibers and few fine collagen fibers.
4. Present in the epiglottis, pinna and tip of the nose.

VII. Blood

1. Blood is red in colour due to the presence of a respiratory pigment, haemoglobin.
2. It is composed of plasma, RBC (erythrocytes), WBC (leucocytes) and platelets (thrombocytes).
3. It carries all essential materials and O_2 to the tissues and removes excretory wastes, other harmful materials and CO_2 from the tissues.
4. Neutrophils are most abundant.
5. Contains thrombocytes and the coagulation protein, fibrinogen and hence, helps in clotting or coagulation.

Lymph

1. Lymph is colourless. No respiratory pigment is present.
2. It is composed of plasma and WBC (leucocytes) only.
3. It transports only fatty acid and glycerol to the liver.
4. Lymphocytes are most abundant.
5. Does not have clotting or coagulation function.

VII. RBC (Erythrocytes)

1. RBCs are small, circular, biconcave and non-nucleate cells.
2. Red due to the presence of haemoglobin.
3. More numerous than WBCs i.e. vary from 4.5 to 5.5 millions / mm^3.
4. Life span is approximately 120 days.
5. Carry molecular oxygen from the lungs to the tissues.

WBC (Leucocytes)

1. Larger than RBC, amoeboid and nucleated cells.
2. Colouless due to the absence of haemoglobin.
3. Less numerous than RBC i.e. vary from 8,000 to 10,000 / mm^3.
4. Life span is only a few days.
5. Mostly defend the body from external aggression.

IX. Smooth muscle	Striated muscle
1. These are involuntary, nonstriated and unstriped muscles.	1. These are voluntary, striated and striped muscles.
2. Muscle cells are spindle shaped, containing centrally placed nucleus.	2. Muscle cells are long and cylindrical, called muscle fibers.
3. Myofilaments (actin and myosin) are present in the sarcoplasm. However, these are not organized into regular bundles to impart a striated appearance.	3. Myofilaments such as actin and myosin are organized into regular bundles to impart a striated appearance. The organization is similar in the adjacent muscle fibers so as to impart a striped appearance as well.
4. The nucleus is centrally placed.	4. The nuclei are shifted to the peripheral part of the sarcoplasm due to the presence of myofilaments in bulk.

X. Skeletal muscle	Cardiac muscle
1. Attached to bones and cartilages.	1. Present in the wall of heart and the wall of large blood vessels in the vicinity of their entering or leaving the heart.
2. Voluntary and undergo fatigue.	2. Involuntary and never undergo fatigue.
3. Muscle fibers are long and cylindrical and never branch.	3. The fibers are branched. The branches anastomoise with each other.
4. The fibers are multinucleated (syncytial)	4. The fibers are uninucleate, occasionally binucleated.
5. Intercalated discs are absent.	5. Intercalated discs are present at the anastomoising points.

XI. Actin	Myosin
1. Known as thin filament.	1. Known as thick filament.
2. Made up of two fibrous actins (F-actins), spirally coiled round each other. Each fibrous actin is made by a linear chain of globular actins or G-actins.	2. Made up of many myosin molecules, each with an ATP and actin binding head and a tail.
3. Each G-actin has an ATP binding site and ATPase activity. This activity is used to assemble F-actin from G-actins.	3. Myosin head has an ATPase activity, which hydrolyzes ATP. The energy that is generated is used to from cross bridges and slide acitn and myosin past each other.

6.5. GENERAL ANATOMICAL ORGANISATION OF COCKROACH :

6.5.1. Digestive System of Cockroach (Fig. 6.43):

The digestive system of cockroach ***(Periplaneta americana)*** includes the alimentary canal and digestive glands. Cockroach is **omnivorous.** The mouth parts are of **biting and chewing** type.

6.5.1.1. Alimentary Canal (Fig. 6.43) : It is divided into three sections : (i) **fore gut** or **stomodaeum,** (ii) **mid gut** or **mesenteron** and (iii) **hind gut** or **proctodaeum.** The fore gut is comprised of the **mouth, pharynx, oesophagus, crop** and **gizzard.** The mouth opens into a short tubular pharynx leading to a narrow tubular passage called oesophagus. This in turn opens into a sac like structure called crop used for storing food. Below the crop the gizzard or **proventriculus** is present. It has an outer layer of thick circular muscle and the inner lining is raised into six prominent longitudinal folds. These folds bear chitinous teeth (Fig. 6.44). Gizzard helps in grinding the food particles. The mid gut is a short narrow tube of uniform diameter. The hind gut is comprised of ileum, colon and rectum. The rectum opens to the exterior through the anus.

6.5.1.2. Digestive Glands : The digestive glands, associated with the alimentary canal, secrete enzymes for digestion of food. These are salivary glands, hepatic caecae and mid gut lining. There is a pair of salivary glands. Each gland has a **glandular part** and a sac like storing part called **reservoir.** The reservoirs and the glandular parts drain through a common efferent salivary duct which open into the pre-oral cavity at the base of hypopharynx. The gland secretes saliva which contains enzymes like zymase and mucoid substance.

The hepatic caeca consists of 7-8 small narrow tubular structures ending blindly that open into the anterior end of mid gut. The digestive juice secreted by the hepatic caecae contains trypsin, proteases, peptidases, amylase, lipase etc. The inner lining of mid gut also secretes amylase, proteolytic and lipolytic enzymes.

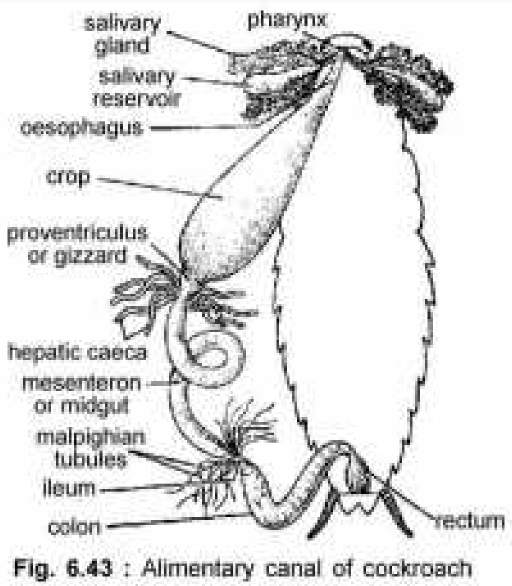


Fig. 6.43 : Alimentary canal of cockroach

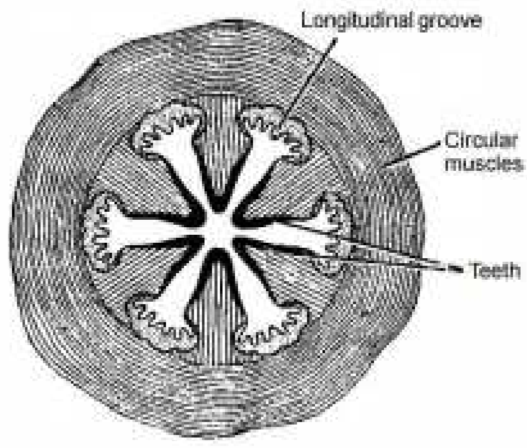


Fig.6.44 : Transverse section of gizzard of cockroach showing chitinous teeth

Respiratory System of Cockroach

The respiratory system consists of **ectodermal tubes** or **tracheae** (singulartrachea), that open through 10 pairs of openings called **spiracles** present on the ventro-lateral sides of the body. The trachea divide and redivide inside the body to form finer branches called **tracheoles.** The opening and closing of spiracles is regulated by the sphincters. Exchange of gases takes place at the tracheoles by diffusion. (For more description and figures refer to Section 16.2.2 of Chapter-16 on Breathing and Respiration.)

6.5.3. Cardio-vascular System :

Open circulation in cockroach : All insects, including cockroach possess open circulatory systems. In an open system, the body fluid (blood) does not circulate in closed blood vessels. It circulates in a large spacious cavity, known as **haemocoel.** The body fluid, known as hemolymph is colourless containing a few amoeboid cells or corpuscles. The haemocoel, indeed, results from an enlargement of blood vessels, whose walls are represented by perforated membranous partitions or **diaphragms,** dividing the haemocoel into three large haemolymph-filled spaces or sinuses such as a **dorsal pericardial sinus,** enclosing the heart; a **middle perivisceral sinus,** enclosing all visceral organs; and a **ventral perineural sinus,** enclosing the ventral nerve cord (Fig. 6.46). Delicate processes of the pericardial sinus extend into the wings, while similar processes from the perineural sinus extend into the walking legs.

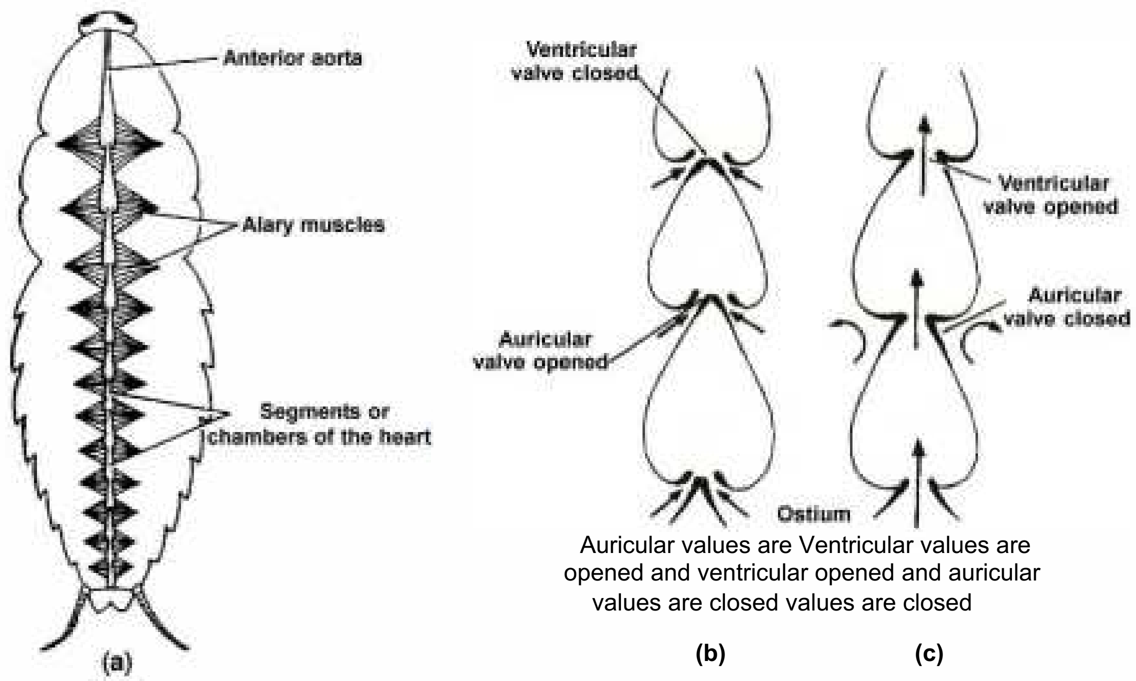


Fig. 6.45: Structure of heart of cockroach, (a) Complete heart with thirteen chambers; (b) Two chambers showing auricular valves open and ventricular valves closed and (c) ventricular valves open and auricular valves closed.

6.5.3.1. Structure of the heart: The heart is a long and tubular structure situated in the pericardial sinus. It consists of **thirteen contractile chambers,** three in the thorax and ten in the abdomen [Fig. 6.45 (a)]. Each contractile chamber is pear-shaped, which is narrow in front and broad behind [Figs.6.45 (b) and (c)]. The narrow anterior end of one projects into the broad posterior end of its preceding chamber. The narrow anterior end is guarded by **ventricular valves.** The heart receives blood from the surrounding pericardial sinus by paired ostia, present at the broad posterior end. The ostia are guarded by **auricular valves.** Segmental paired **alary muscles** are attach each tergum with the dorsal diaphragm. The heart extends anteriorly as a narrow **dorsal aorta.** The blood flows from behind forward through the heart, while in a reverse direction in the perivisceral sinus.

6.5.3.2. Circulation : When the alary muscles contract, the auricular valves open and the ventricular valves remain closed. The haemolymph from the pericardial sinus is pumped into the heart through the ostia. When the alary muscles relax, the auricular valves are closed and the ventricular valves open.

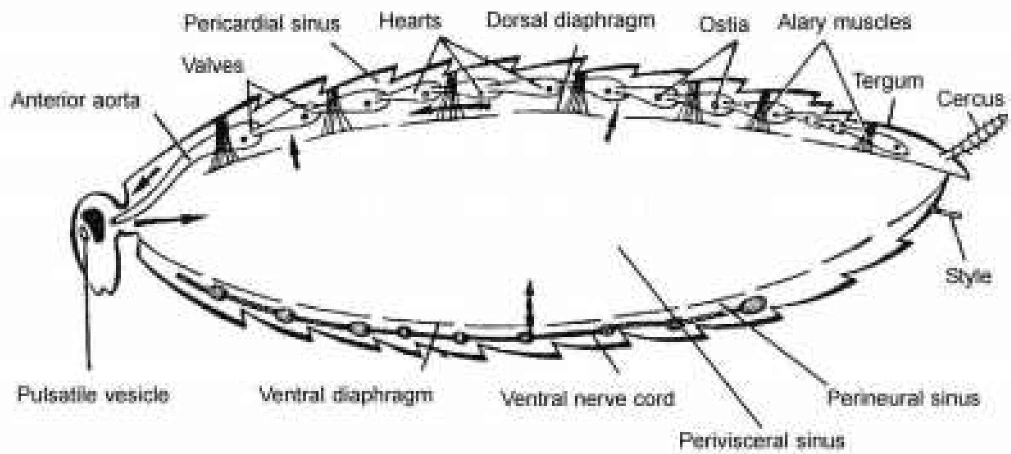


Fig.6.46 : Lateral view of the haemocoel exhibiting three sinuses divided by two horizontal perforated partions

The pericardial sinus receives haemolymph from the perivisceral sinus through the perforated dorsal diaphragm. The haemolymph is forced to flow forward through the heart and then through the dorsal aorta, it is released into the perivisceral and perineural sinuses. The haemolymph from these two sinuses passes into the pericardial sinus through the perforated diaphragms and thus, the circulation is complete.

6.5.4. Excretory System :

The great majority of insects are adapted for life on land. One of the major problems of life on land is conservation of water. This problem is solved by excreting water-insoluble uric acid.

The malpighian tubules are the chief excretory organs where as fat body, cuticle and probably the mushroom gland of males are considered as accessory excretory organs.

6.5.4.1. Malpighian tubule (Fig. 6.47) : There are about 60-150 long, slender and yellow blind tubules extending freely into the peri-visceral sinus from the junction of mid-gut and the hind gut. Each tubule is about 26mm long and 0.5 mm thick. Its wall consists of an outer covering or sheath of connective tissue and muscle fibres and an inner epithelium of large cuboidal cells provided with a brush border surrounding a central lumen.

The nitrogenous waste products are discharged by body cells and tissues into the haemolymph contained in the perivisceral sinus. The malpighian tubules absorb these product from the haemolymph along with water, salts and CO_2.

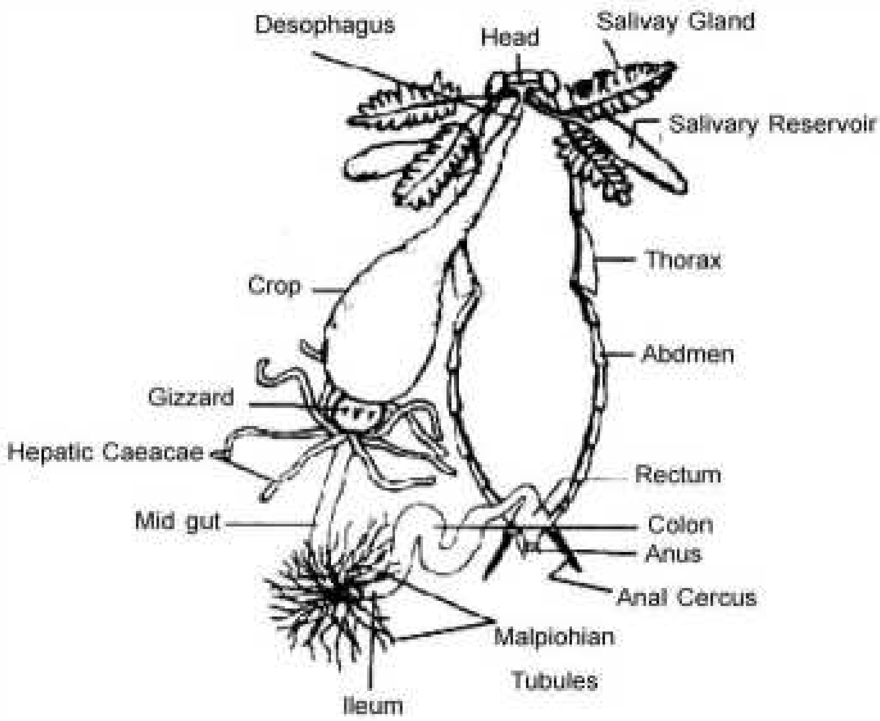


Fig. 6.47 : Malpighian tubules of cockroach attached to the alimentary canal

Water and bicarbonates are reabsorbed and nitrogenous waste product turn into unic acid which is discharged into the gut and then to outside through the anus.

6.5.4.2. Fat body : A large number of fat bodies remain suspended in the haemolymph of the perivisceral sinus. These fat bodies contain specialised cells called **urate cells,** which absorb the nitrogenous wastes from the haemolymph mainly as urates from which uric acid is formed. The uric acid, thus formed, is permanently stored in these urate cells without being discharged out. This kind of excretion is called **storage excretion.**

6.5.4.3. Cuticle of exoskeleton : Cockroach undergoes moulting or ecdysis 10 to 12 times from the nymph to the adult stage, each time increasing in size. Along with the moulted chitinous exoskeleton a small amount of nitrogenous waste is also discharged out.

6.5.4.4. Mushroom gland : This is an accessory reproductive gland in male cockroach. Some cells of this gland are known to absorb nitrogenous waste from the haemolymph and synthesize uric acid from it, which is discharged out along with the spermatophores.

6.5.5. Nervous System (Fig. 6.48):

Head contains a pair of **supra-oesophageal ganglia,** which represent the brain. From the brain arise two cirum oesophageal connectives which pass around the oesophagus and join with the **sub-oesophageal ganglion** below the oesophagus.

A double ventral nerve cord arises from the sub-oesophageal ganglion and travels posteriorward along the midventral line in the perineural sinus. The nerve cord has 3 large thoracic ganglia, one each in the thoracic segments. There are 5 small ganglia one each in the first 5 abdominal segments. The 6th ganglion is largest, located a little behind the 7th abdominal segment. Each of the thoracic ganglia and first 5 abdominal ganglia consist of fusion of 2 ganglia, whereas the 6th abdominal ganglion is formed by fusion of 3 pairs of ganglia.

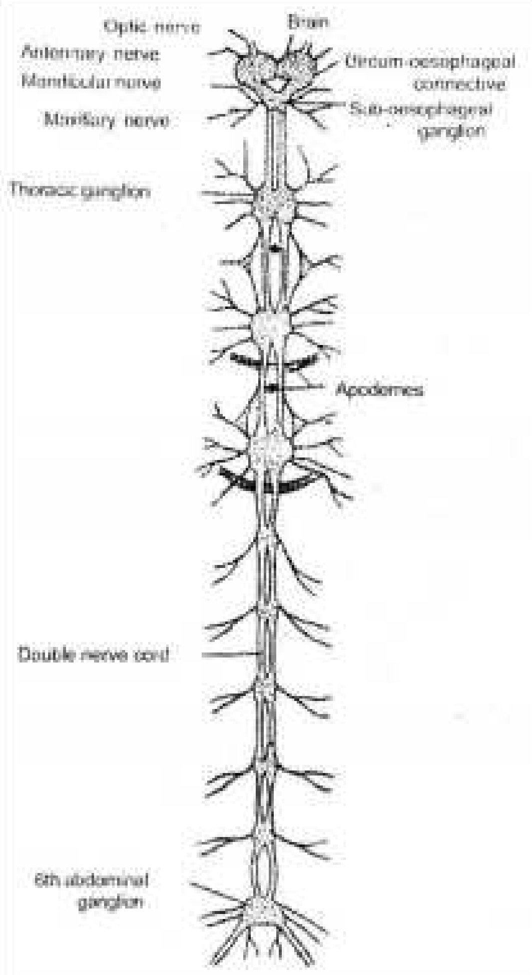


Fig. 6.48 : Nervous system of cockroach

The **brain, suboesophageal ganglion,** the **double nerve cords** and their ganglia constitute the **central nervous system** (CNS) of cockroach.

Three pairs of nerves from the brain innervate **eyes, antenae** and **labrum.** Three pairs of nerves arising from **sub-oesophageal ganglion** innervate **mandibles, maxillae** and **labium.** Nerves from **thoracic** and **abdominal** ganglia innervate different parts of thoracic and abdominal regions.

In addition to this, there is a frontal **ganglion** in front of brain, a pair of **oesophageal ganglia** and a **visceral ganglion** on the crop. All of them are connected to brain through connectives and there is a **sympathetic nervous system** constituted by many visceral ganglia, which innervate the visceral organs.

Cockroach can respond to different types of stimuli due to the presence of receptors in the body. It has a pair of compound eyes which work as **photoreceptor.** Tactile **receptors** are present on antennae, palpi, legs, body and anal cerci. **Olfactory receptors** are present on antennae. **Gustatory receptors** are located on maxillae. The anal cerci contain **auditory** receptors.

6.5.6. Reproductive System :

Cockroaches are **dioecious** i.e. both **sexes are separate.** There is a well defined sexually dimophic feature. The male cockroach bears a pair of anal styles which are absent in the female and both sexes have well developed reproductive organs.

Male reproductive organs (Fig. 6.49) consist of a pair of testes lying one on each lateral side in the 4^{th}-6^{th} abdominal segments. From each testis arises a thin **vas deferens,** which opens into an **ejaculatory duct** through **seminal vesicle.** Both the vasa differentia pass backward upto to the posterior end of abdomen and then bend forward to meet in the middle and open into the ejaculatory duct. The ejaculatory duct is elongated wide median duct which runs backward and opens out through a male gonopore situated ventral to the anus. The junction of the vasa differentia and ejaculatory duct is surrounded by an elaborate **mushroom gland** made up of numerous, compact, finger-like blind tubules, arranged in two distinct groups. Short tubules, the utriculibreviores, forming the bulk of the gland, secrete a nourishing fluid for the sperms.

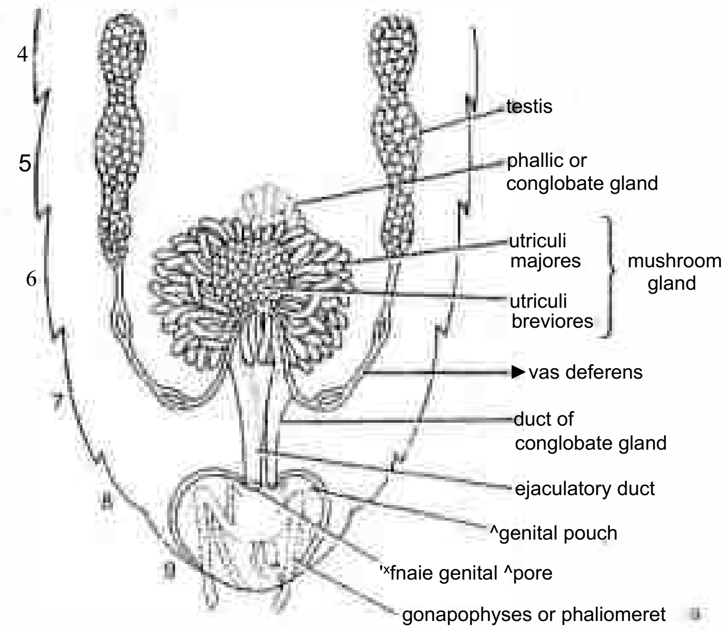


Fig. 6.49 : Male reproductive organs of cockroach in dorsal view.

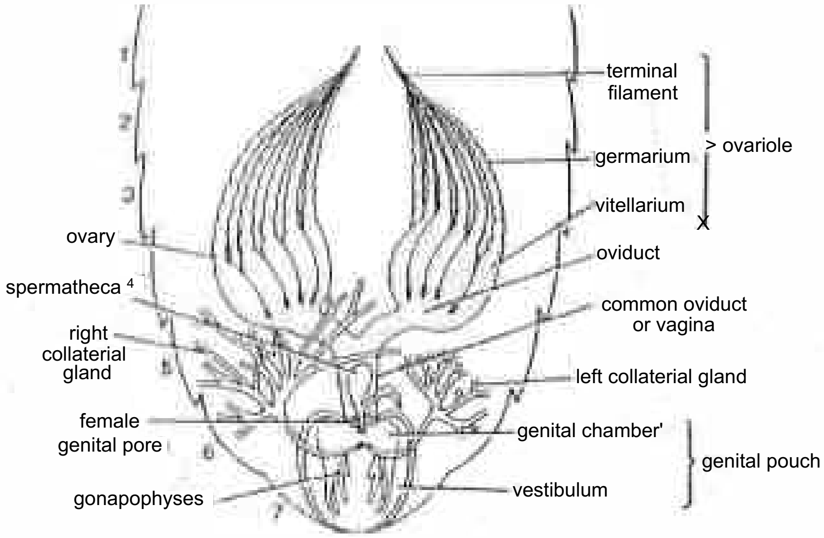


Fig. 6.50 : Female reproductive organs of cockroach in dorsal view.

The female reproductive system (Fig. 6.50) consists of a pair of large bilateral ovaries, lying laterally in the 2^{nd} - 6^{th} abdominal segments. Each ovary is formed of a group of eight ovarian tubules or ovarioles. Each ovariole consists of (i) terminal filaments for suspension of ovariole to the body wall, (ii) germarium which contains oogonia and (iii) vitellarium, the zone which receives the oocytes. The ovarioles contain a chain of developing ova. Oviducts of each ovary unite into a single median oviduct (also called vagina), which opens into the genital chamber. A pair of spermatheca is also present in the 6th segment which also opens into the genital chamber.

SAMPLES QUESTIONS

GROUP - A
(Objective-type Questions)

1. Chose the correct answer :

(i) Ligaments and tendons are formed of

(a) Muscular tissue (b) Epithelial tissue

(c) Connective tissue (d) Nervous tissue

(ii) Segment of the skeletal muscle fiber between two Z-lines is called

(a) A-band (b) H-band

(c) Sarcomere (d) Sarcoplasm

(iii) Schwann cells and nodes of Ranvier are present in

(a) Bone cells (b) Neurons

(c) Muscle cells (d) Chondrocytes

(iv) Notochord originates from

(a) Ectoderm (b) Meroderm

(c) Endoderm (d) None

(v) Which muscle of body works nonstop till death

(a) Unstriped (b) Skeletal

(c) Cardiac (d) Smooth

(vi) In an animal, the tissue is bathed in

(a) Calcium chloride (b) Body fluid

(c) Water (d) Sodium chloride

(vii) Voluntary muscle is present in

(a) Lung (b) Liver

(c) Heart (d) Hind limb

(viii) Non-cellular basement membrane is a feature of

(a) Epithelial tissue (b) Vascular tissue

(c) Nervous tissue (d) Connective tissue

(ix) A tissue is a group of cells having

(a) Similar cells with dissimilar function

(b) Similar cells with similar function

(c) Dissimilar cells with dissimilar function

(d) Dissimilar cells with similar function

(x) Intercellular matrix is minimum in

(a) Bone (b) Vascular tissue

(c) Muscular tissue (d) Cartilage

(xi) Blood vessels are lined internally by

(a) Ciliated epithelium (c) Squamous epithelium

(b) Columnar epithelium (d) Striated epithelium

(xii) Transitional epihelium is found in

(a) Kidney (b) Urinary bladder

(c) Trachea (d) Blood vessel

(xiii) Tendon connects

(a) Muscle to Muscle (c) Bone to Muscle

(b) Bone to Bone (d) Nerve to Muscle

(xiv) Cardiac muscle is

(a) Voluntary and striated (c) Involuntary and smooth

(b) Involuntary and striated (d) Voluntary and smooth

(xv) Epithelium forming the peritoneal lining of the coelom is

(a) Squamous epithelium (c) Columnar epithelium

(b) Cuboidal epithelium (d) Glandular epithelium

(xvi) Myelin sheath is a covering of

(a) Vertebrate nerve fibre (c) Insect nerve fibre

(b) Vertebrate muscle fibre (d) Venticles of heart

(xvii) Nature of dendrite is

(a) Efferent (b) Afferent

(c) Both a and b (d) None of these

(xviii) Which type of connective tissue is a tendon ?

(a) Dense (b)Loose

(c) Fluid (d)Skeletal

(xix) Intercalated disc is found in

(a) Neuron (c) Skeletal muscle

(b) Junction of muscle and nerve (d) Cardiacmuscle

(xx) Larynx and Trachea contain

(a) Hyaline cartilage (b) Elastic cartilage

(c) Bone (d) Fibrocartilage

(xxi) Myoglobin is found in

(a) White muscle fibre (c) Yellow fibre

(b) Red muscle fibre (d) All of these

(xxii) Oil glands in mammal (rabbit) are found in

(a) Epidermis of skin (c) Demis of skin

(b) Mucous epithelium of skin (d) Mucous epithelium of stomach

(xxiii) Erythrocytes of frog are

(a) Non nucleated and biconcave (c) Nucleated biconcave

(b) Nucleated biconvex (d) Non nucleated biconvex

(xxiv) Nerve cells develop from

(a) Ectoderm (c) Endoderm

(b) Mesoderm (d) Ectoderm and Mesoderm

(xxv) Mammary glands are

(a) Apocrine (b) Holocrine

(c) Merocrine (d) None of these

(xxvi) Cardiac muscle contracts

(a) Quickly and is fatigued (c) Slowly and is not fatigued

(b) Quickly and is not fatigued (d) Slowly and is fatigued

(xxvii) Largest erythrocytes are found ir1

(a) Man and Monkey (c) Fish and frog

(b) Amphiuma and Proteus (d) Lizard and Snake.

(xxviii) Which vitamin is essential for blood clotting

(a) Vitamin A (b) Vitamin C

(c) Vitamin K (d) Vitamin E

(xxix) Blood transports

(a) Oxygen only

(b) Respiratory gases and excretory product only

(c) Respiratory gases nutrients and excretory products

(d) Respiratory gases and nutritive substances only

(xxx) Lymph differs from blood in the

(a) Absence of RBC (b) Absence of WBC

(c) Excess of water (d) Absence of protein

(xxxi) Blood is composed of

(a) Plasma and corpuscles (c) Plasma and WBC

(b) Plasma and RBC (d) Colloid particles

(xxxii) If RBCs are kept in distilled water they will

(a) Contract (c) Remain unaffected

(b) Just swell up (d) Swell up and Burst

(xxxiii) RBCs are kept in 8% saline solution it will

(a) Burst (c) Contract

(b) Remain unaffected (d) None of them

(xxxiv) RBC will contract if kept in

(a) Isotonic soln. (c) Hypertonic solution

(b) Distilled water (d) Hypotonic solution

(xxxv) In 100 ml. of blood of adult man amount of haemoglobin is

(a) 11 gm. (b) 12.5 gm.

(c) 14 gm. (d) 20 gm.

(xxxvi) Red bone marrow occurs in

(a) Ribs (c) Ribs and cranium

(b) Ribs, sternum (d) Ribs, sternum, cranium

(xxxvii) Secretion of sebaceous gland is

(a) Holocrine (b) Apocrine

(c) Epicrine (d) Merocrine

(xxxviii) Which is a simple coiled tubular gland

(a) Salivary gland (b) Sweat gland

(c) Sebaceons gland (d) Testes

(xxxix) Haemopoietic tissue is

(a) Dense connective tissue (c) Adipose tissue

(b) Reticular tissue (d) Epithelial tissue

(xl) Harmful bacteria and other foreign bodies are destroyed by

(a) Plasma protein (c) Phagocytosis by RBC

(b) Platelets (d) Phagocytosis by WBC

(xli) Phagocytic cells in Liver are

(a) Kupffer cell (b) Chromaffin cell

(c) Mast cell (d) None of these

(xlii) Which is irregular in shape

(a) RBC (b) WBC

(c) Muscle fibre (d) Epithelial cell

(xliii) An erythrocyte in mammal is without nucleus because

(a) Erythrocyte is not a cell

(b) Nucleus is not required

(c) Nucleus disappears during its formation

(d) Nucleus is absent from the begining

(xliv) Source of energy for muscle contraction is

(a) Actin (b) Myosin

(c) Actomyosin (d) ATP

(xlv) Smooth muscles are

(a) Involuntary, spindle shaped uninucleate and tapering

(b) Voluntary multinucleate and cylindrical

(c) Involuntary cylindrical and multinucleate

(d) Voluntary, branched and uninucleate

(xlvi) The fibrous connective tissue sheath of bones is known as

(a) Pericardium (b) Perichondrium

(c) Perineurium (d) Periosteum

(xlvii) Sarcolemma is a membrane present on the outer side of

(a) Nerve fibre (b) Bone

(c) Muscle fibre (d) RBC

(xlviii)Tissue covering of the body surface is

(a) Epithelial (b) Connective

(c) Muscle (d) Adipose

(xlix) White matter of the spinal cord is made up of

(a) Nerve cells (c) Myelinated nerve fibers

(b) Non myelinated nerve fibers (d) Connective tissue cells

(l) Haemopoiesis in adult human occurs in

(a) Liver and spleen (b) Liver

(c) Spleen (d) Red bone marrow

(li) In human, haemoglobin is present

(a) In the liver (c) In erythrocytes

(b) Dissolved in the blood plasma (d) In spleen

(lii) Maximum number of cell bodies (cytons) are present in

(a) Spinal cord (b) Retina

(c) Brain (d) Ganglia

(liii) If bone is kept in 5% KOH solution for some days.

(a) Be unaffected (b) Dissolve

(c) Becomes Soft and elastic (d) Break

(liv) Which salt is found in maximum quantity in bones

(a) Calcium carbonate (c) Sodium chloride

(b) Calcium phosphate (d) Magnesium chloride

(lv) If a bone is suspended in dilute hydrochloric acid, for a few days, it

(a) becomes harder (c) becomes softer and malleable

(b) remains unaffected (d) dissolves.

(lvi) Mast cells occur in

(a) Nervous tissue (b) Connective tissue

(c) Epithelial tissue (d) Skeletal tissue

(lvii) Afferent nerve fibre carries nerve impulse

(a) From central nervous system to a receptor

(b) From receptor to the central nervous system

(c) From central nervous system to the effector organ

(d) From effector organs to the central nervous system.

(lviii) Increase in the number of erythrocytes is called

(a) Polycythemia (b) Glycosuria

(c) Hyperglycemia (d) Hypoglycemia

(lix) Epithelial tissue performs the following functions

(a) Protection, secretion, absorption and respiration

(b) Protection, secretion, sensation and absorption

(c) Absorption respiration secretion and sensation

(d) All of these

(lx) The cells responsible for dissolving the bone matrix are called

(a) Osteoblasts (b) Osteoclasts

(c) Osteocytes (d) Chondrocytes

(lxi) Colourless plasma without corpuscles and fibrinogen is also known as

(a) Chyle (b) Lymph

(c) Serum (d) Thrombus

(lxii) Mammary glands are modified

(a) Holocrine glands (b) Endocrine glands

(c) Sebaceous glands (d) Sweat glands

(lxiii) Horns of arhinoceros are composed of

(a) Bone (b) Cartilage

(c) Chitin (d) Keratin

(lxiv) A nerve is nothing but a bundle of

(a) Axons (b) Dendrites

(c) Ganglia (d) Cell bodies

(lxv) Possible functions of Nissl body is

(a) Protein synthesis (b) RNA synthesis

(c) RNA storage (d) Impulse conduction

(lxvi) The Male cockroach is identified by the presence of

a) Anal cerci b) Long antennae

c) Anal styles d) Wingless body

(lxvii) In cockroach or insects the excretory organs are

a) Malpighian tubules b) Nephridia

c) Malpighian corpuscles d) Flame cells

(lxviii)Cockroach is

a) Omnivorous b) Sanguivorous

c) Insectivorous d) Carnivorous

(lxix) The juvenile stage of cockroach is known as

a) Larva b) Pupa

c) Maggot d) Nymph

(lxx) In cockroach, the number of spiracles is:

a) 8 pairs b) 10 pairs

c) 12 pairs d) 14 pairs

(lxxi) The blood-filled cavity of cockroach is known as

a) Coelem b) Haemocoel

c) Enteron d) Pseudocoel

(lxxii) Cockroach respires by:

a) Cuticle b) Lungs

c) Trachea d) Book lung

(lxxiii)In cockroach, the main excretory product is

a) Ammonia b) urea

c) Uric acid d) Hippuric acid

(lxxiv) Mouth parts of cockroach are of

a) Sponging type b) Piercing type

c) Sucking type d) Biting and chewing type

(lxxv) Muscles associated with heart of cockroach are:

a) Pericardial muscles b) Striped muscles

c) Tergo-sternal muscles d) Alary muscles (lxxvi) The tubular heart of cockroach is composed of:

a) 6 chambers b) 9 chambers

c) 10 chambers d) 13 chambers

(lxxvii) In cockroach nerve cord is:

a) Single, ventral, solid b) Double, ventral, solid

c) Single, ventral, hollow d) Double,ventral, hollow

(lxxviii) Characters common in cockroach, spider and prawn is

a) Book lungs b) Jointed legs

c) Green glands d) Compound eye

(lxxix) In cockroach, the food is crushed and strained in

a) Crop b) Gizzard

c) Mesenteron d) Hepatic caecae

(lxxx) Blood does not transport oxygen in:

a) Bird b) Earthworm

c) Rabbit d) Cockroach

(lxxxi) How many clitinous teeth does the gizzard of cockroach have?

a) 2 b) 4

c) 6 d) 8

(lxxxii) In female cockroach, the 7th sternum forms a boat shaped structure called:

a) Hypogynium b) Gonopoptysis

c) Phallomere d) Podial plate

(lxxxiii) Each ovary of cockroach is composed of:

a) 4 ovarioles b) 6 ovarioles

c) 8 ovarioles d) 16 ovarioles

(lxxxiv) Which of the following serves as the tongue of cockroach:

a) Labium b) Maxillae

c) Mandible d) Hypopharynx

(lxxxv) Hepatic caeca in cockroach from

a) Junction of midgut and hindgut b) Gizzard

c) Midgut d) Junction of gizzard and midgut

2. Fill in the blanks with appropriate words

(i) Life span of erythrocytes isdays.

(ii) Junction of two neurons is called

(iii) is the structural and functional unit of a muscle fiber.

(iv) are the longitudinal canals found in bone.

(v) Nissl granules are found in

(vi) Outer most layer of a cartilage is known as

(vii) Bone forming cells are called

(viii) Cell bodies of most neurons in peripherial nervous system are grouped together as

(ix) Cartilage is formed by cells, called

(x) are periodic constrictions in the axon of a myelinated nerve fiber.

(xi) Branch of the science dealing with the study of tissues is known as

(xii) Brush border cuboidal epithelial cell possessat their free ends,

(xiii) Plasma without fibrinogen is known as

(xiv) A neuron receives the nerve impulse throughand transmit it through

(xv) Heart containsmuscle.

(xvi) Transportation ofis the main function of blood which is carried by a conjugate protein called

(xvii) Epithelial tissue lining the blood vessel is known as

(xviii)is the group of cells specialized to perform a specific function.

(xix) Haversian canal is found in

3. Answer each of the following in single word :

(i) Name a mammal having nucleated RBC.

(ii) What type of cartilage is found in the intervertebral disc ?

(iii) Name the longest cell in the body.

(iv) Which animal possesses pneumatic bone ?

(v) Who coined the term epithelium ?

(vi) Which muscle doesn't get fatigued throughout life ?

(vii) In which cell, Nissl granules are present ?

(viii) Volkman's canal is present in which tissue ?

(ix) Who is known as father of histology ?

(x) Name the structural and functional unit of nervous tissue.

(xi) Name the tissue connecting muscle to a bone.

(xii) What is the expanded form of RBC ?

(xiii) Name the protein which constitutes the collagen fibre.

(xiv) What type of cartilage is found in ear pinna ?

(xv) Which type of tissue does blood come under ?

(xvvi) Where are Schwann cells found ?

(xvii) Which muscle is self excitatory ?

GROUP - B
(Short Answer-type Questions)

1. Answer each of the following within 50 words :

(i) What is a ligament ?

(ii) How would you obtain pavement epithelium.

(iii) Why blood does not clot in blood vessel ?

(iv) What is the advantage of having transitional epithelium in the wall of the urinary bladder ?

(v) What do you understand by pseudostratified epithelium ?

(vi) What is the fundamental difference between spongy bone and compact bone ?

(vii) Name different types of leucocytes and ennumerate their functions,

(viii) Why have tendons and ligaments more tensile strength ?

(ix) What do you mean by involuntary muscle ?

(x) What is the difference between G-actin and F-actin ?

(xi) Describe the role of troponin and tropomyosin in skeletal muscle contraction.

(xii) How does cardiac muscle differ from skeletal muscle ?

(xiii) Name the cells, which form myelin sheaths in axons of central nervous system and peripheral nervous systems.

(xiv) Name the macrophage associated with the nervous tissue. What is its function ?

2. Write short notes on the following :

(i) Cartilage

(ii) Bone of mammal

(iii) Neuron

(iv) Cardiac muscle

(v) Myofibril

(vi) Adipose tissue

(vii) Stratified epithelium

(viii) Neuroglia

(ix) Haversian system

(x) Leucocytes

(xi) Sarcomere

3. Differentiate between the following :

(i) Axon and Dendron

(ii) Epithelial tissue and Connective tissue

(iii) Cartilage and Bone

(iv) Striated muscle and Non-striated muscle

(v) Tendon and Ligament

(vi) Muscle cell and Nerve cell

(vii) Blood and Lymph

(viii) Cardiae muscle and Skeletal muscle

(ix) Myelinated and Unmyelinated nerve fibre

(x) RBC and WBC

(xi) Areolar tissue and Adipose tissue

UNIT-III : CELL STRUCTURE AND FUNCTION

CELL STRUCTURE AND FUNCTION

CHAPTER 7

7.1. CELL THEORY AND CELL AS BASIC UNIT OF LIFE :

The diverse forms of living organisms starting from microscopic unicellular organisms to giant multicellular ones have a common basic organization. Even early philosophers and naturalist like **Aristotle** and **Paracelsus** could recognize this fact and concluded that all animals and plants are composed of few **'elements'** which are repeated in them. **Lamarck** observed, "no body can have life, if its constituent parts are not formed of cell". However, due to lack of proper optical devices no body could actually go further to establish the cellular organization of the body.

7.1.1. Discovery of Cell :

Discovery of cell was delayed till the development of microscopes with good resolving powers and magnification. Unaided human eye cannot resolve objects less than 100 micrometers apart. Most cells are too small to be visualized with unaided eye. The first microscope was built by **Zacharias Janssen** and **H. Janssen** in 1590. It was further modified with greater magnifying power by **Galileo** in 1610. However, it was a British mathematician and physicist **Robert Hooke** who in 1665 explored the microscopic world under a microscope developed by him. He, for the first time, observed perforated and porous honey comb like structures in the remains of dead cells of a piece of cork (cork of Oak - ***Quercus suber).*** He coined the term **cell** for each empty honey comb like compartment (L. Celia - hollow space). His findings were published in a book **"Micrographia"** written by him. However, the term 'cell' is actually a misnomer as the living cell is neither hollow nor all the cells are covered by a wall. Further studies of cells continued with the development of sophisticated microscope. In 1673 **Leeuwen-hoek** for the first time observed and described free living cells like some bacteria, protozoa, spermatozoa, RBC etc. **Malpighi** (1675) and **Grew** (1682) observed some plant cells. Further detailed studies of cells were interrupted till the invention of good compound microscopes, and better fixation techniques. In 1839 Czech Physiologist **Johannes Purkinje** observed dense complex fluid inside the cell called protoplasm. **Hugo Von Mohl** (1846) confirmed this. **Robert Brown** (1831) found the presence of small spherical bodies within the epidermal cells of orchid root which were later known as nucleus. In 1838 **Schwann** for the first time observed the cell membrane which was so named by **Nageli** and **Cramer** in 1855. It became clear that ***structurally a cell is a mass of protoplasm bounded by a cell membrane and having at its centre a spherical body, the nucleus.***

7.1.2. Cell Theory and Cell as basic unit of life :

The credit of formulation of cell theory, goes to the German Botanist **Mathias Jacob Schleiden** and **Theodore Schwann,** a German Zoologist. This theory established that the cell is the basic unit of life and can be considered as the cell doctrine as it is essentially a fact-based statement. Schleiden in 1838 stated that all plants "are aggregates of fully individualized, independent, separate beings, namely the cells themselves". In 1839, **Theodor Schwann** reported that all animal tissues also consist of individual cells but animal cells lack a cell wall. Both of them compared their findings and jointly proposed the cell theory in 1839 in a paper titled ***"Microscopic investigations on the similarity of structure and growth in animals and plants".*** However, they did not know the mode of origin of new cells and believed that new cells developed spontaneously. **Rudolf Virchow** (1858) observed that new cells develop from pre-existing cells - ***Omnis cellula e cellula.*** Cell theory was modified accordingly.

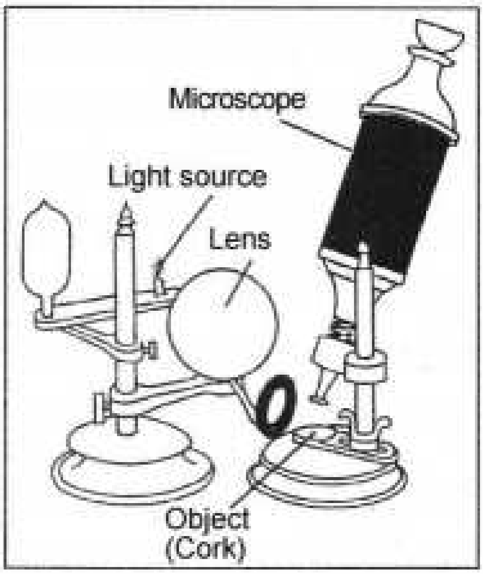


Fig.7.1 : A primitive Microscope developed by Robert Hooke

Fig.7.2 : 'Cells' as seen by Hooke

Fundamental features of Cell Theory

1. All organisms, plants and animals, are composed of one or more cells and their products.
2. Each cell is made up of a mass of viscous substance called protoplasm containing a nucleus.
3. New cells arise from pre-existing ones.
4. All cells are basically similar in their physiology and chemistry.
5. Activities of an organism is the sum total of the activities of its constituent cells.

Exceptions to Cell Theory

Cell theory as proposed above is not universal and exceptions do exist:

1. Viruses are nucleoproteins, lacking internal organization and outside the host, they are as good as dead.

2. Protozoa like ***Paramaecium*** has unicellular, differentiated body with a mouth/gullet, contractile vacuole and many cilia. Similarly thallophytes like ***Acetabularia*** have a unicellular but differentiated structure like foot, stalk and cap. Cell theory does not apply here as they seem to have abandoned cell as a mechanical and structural unit and are regarded as acellular.
3. In some organisms like ***Vaucheria*** and ***Rhizopus*** the body is not differentiated into cells rather they are multinucleate (coenocytes). It has been regarded that in such coenocytic organisms, each nucleus along with protoplasm surrounding it is a wall-less cell and the organism itself is a group of protoplasmic unit. This laid ***Andre Lwoff*** in 1962 to propose another theory. According to this theory the entire organism is regarded as the aggregation of unity of plan, unity of function and unity of composition.
4. Bacteria and blue green algae (cyanobacteria) have no true nucleus, instead they have incipient nuclei.
5. In the surface cells of animal skins and cork of plants, protoplasm is replaced by non living materials.
6. RBC of animal blood and sieve tubes of plants continue to live without nucleus.

Modern Concept of Cell Theory

1. All living organisms, plants or animals, are composed of one or more cells or their products.
2. Cells are structural and functional units of life.
3. New cells arise from pre-existing ones.
4. All cells are basically similar in their chemistry and physiology.
5. Growth of an organism depends on the growth and multiplication of its constituent cells.
6. The function of an organism is the sum total of the function and interaction of its cells.
7. Cell is a self-contained unit.
8. In an organism the hereditary or genetic informations are stored in its cells.

Structurally a cell is defined as "a ***mass of protoplasm bounded by a membrane and having at its centre a spherical body, the nucleus."*** But the existence of coenocytes and living cells without nucleus has given rise to a physiological definition of cell. **A. G Loewy** and **P. Siekevietz** in 1969 defined cell as ***"the smallest organized unit of any living form which is capable of prolonged independent existence and replacement of its own substance in a suitable environment."*** Besides the cell theory, there are other theories too. The protoplasmic theory by **Schultz,** (1861) states that the basic unit of organism is protoplasm, not cell. Organismal theory by **Sachs** (1874) states that the body of an organism is made up of continuous mass of living matters incompletely divided into compartments called cells.

Cell size: Generally cell size ranges from 0.1 to 20 micrometer. The smallest cell so far found is of PPLO (pleuropneumonia like organism) or ***Mycoplasma gallisepticum*** where the cell is 0.1 micrometer in diameter. The largest cell is the egg of Ostrich which is six inches in diameter with shell and three inches in diameter without shell. ***Acetabularia,*** the unicellular green alga, is about ten centimeter in length. In alga like ***Caulerpa*** the length of a cell can be up to one meter. In animals, nerve fibers can be as long as 90cm to one meter. In general, metabolically active cells are smaller and the cells of a particular tissue have almost the same volume.

Cell number: Number of cell varies greatly among the organisms- a single cell in unicellular organism to infinite number of cells in multicellular organisms. A man of 80 Kg can have about 60 thousand billion cells. In colonial forms each type has a fixed number of cells. For example, in green alga ***Pandorina*** each colony has 8, 16 or 32 cells.

Cell shape: The cell may be spherical, polygonal, discoid, cuboidal, columnar or spindle like. Generally individual cells are spherical, but depending on function and organization the shape of the cells vary. Sometimes a particular cell may undergo shape change as is seen in the case of ***Amoeba*** and also in Leucocytes.

Cell Basic Unit

The cell acts as an autonomous, self-contained unit and is capable of performing all the processes of life like metabolism, growth, reproduction and damage repair. The entire set of information for fundamental processes of life is stored inside the cell so that the cell can itself control its own activities. The cell acts as an open system exchanging matters with its environment. The cell exchanges gases with, and absorbs nutrients from its environment. The cell derives energy from respiration, builds up macromolecules from simpler molecules, replaces its worn-out structures with new ones and form new cells with similar hereditary properties. The cell controls its own physico-chemical environment by enzymes produced by it. Each cell is capable of independent existence and has a definite life span. In multi cellular organisms the cell may not have complete independence as there exists a division of labour among different cells of the organism. In such organisms, cells are differentiated into specialized cells to carry out different functions.

Totipotency

All multicellular and sexually reproducing organisms begin their lives as single cells called zygotes formed by the union of sperms and eggs. This zygote contains all the informations necessary for divisions and differentiation at the right time and right place so that a multicellular organism is formed from this single cell. Based on this knowledge German botanist **Gottleb Haberlandt** in 1902 gave the concept of totipotency in plants. ***Totipotency is the potential of any plant cell to regenerate the entire plant.*** This concept of totipotency cannot be applied to all kinds of animal cells. The somatic cell lines in animals after their differentiation to specialized cells lose the power of division. These cells cannot be dedifferentiated to start dividing again. But in contrast, the plant cells can exhibit totipotency when grown in artificial medium. Though the concept of totipotency was advocated by Haberlandt, he himself could not demonstrate it. He cultured isolated palisade tissues of leaf in Knop's solution. The cells grew in size and lived up to a month but failed to divide. **F. C. Steward** at Cornell University in 1958 placed phloem tissue of Carrot ***(Daucus carota)*** in a liquid growth medium and observed that individual cells broke away from tissue fragments. They often divided and developed into multicellular roots. When he placed these roots in solid growth medium they developed into entire plants. Since then totipotency has been demonstrated by several workers in many plants. Barring some animal cells this phenomenon of totipotency is restricted to plants. Totipotency in plants has several applications like micropropagations of horticultural plants, production of disease free plants, microforestry etc.

7.2. STRUCTURE OF PROKARYOTIC AND EUKARYOTIC CELLS :

On the basis of cellular organization in living organisms two types of cells are recognized: prokaryotic cell with no organized nucleus and eukaryotic cell with organized nucleus bound by nuclear enevolope.Prokaryotes (Gk. Pro - primitive; Karyon - nucleus) include primitive organisms like bacteria, cyanobacteria and mycoplasma. Eukaryotes (Gk.Eu -true) include higher organisms.

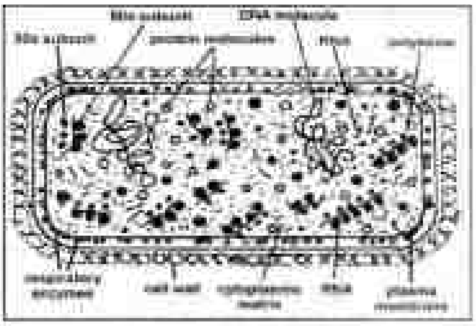


Fig.7.3 : A Typical prokaryotic cell

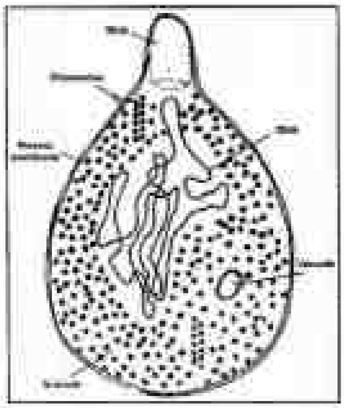


Fig.7.4 : A Mycoplasma

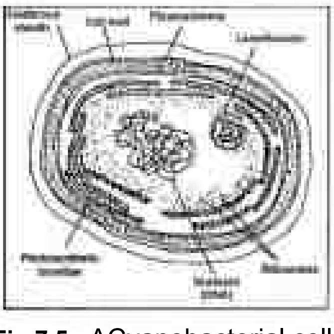


Fig.7.5 : ACyanobacterial cell

7.2.1. Prokaryotic Cell:

Prokaryotic cells are the simplest kind of cells. The cells are smaller in size, consisting of cytoplasm surrounded by a cell membrane and encased within a rigid cell wall(except in Mycoplasma).These cells do not have interior compartments. These cells vary in size from 0.1 pi m - 0.25 pi m (as in Mycoplasma), a few pi m in length as in bacteria and a little larger in Cyanobacteria.The cellular contents constitute a dense cytoplasm and a less electron dense nuclear area but no organized nucleus. The nuclear material or prokaryotic chromosome is a variously coiled **naked DNA** molecule without any histone protein and not enclosed within an envelope. It is known as **genophore** or **nucleoid** or **incipient nucleus.** Some prokaryotes like bacteria also contain extra chromosomal, additional small DNA entities called **plasmids.** Cyanobacteria and photosynthetic bacteria posses layered membranes involved in photosynthesis. These membranes appear to be derived from the infoldings of the cell membrane. Membrane bound cell organelle like mitochondria, endoplasmic reticulum, Golgi comlex, lysosomes etc. are absent. Microtubules are also absent. The prokaryotic cell contain 70s **ribosomes** for protein synthesis as compared to 80s ribosomes in eukaryotes.

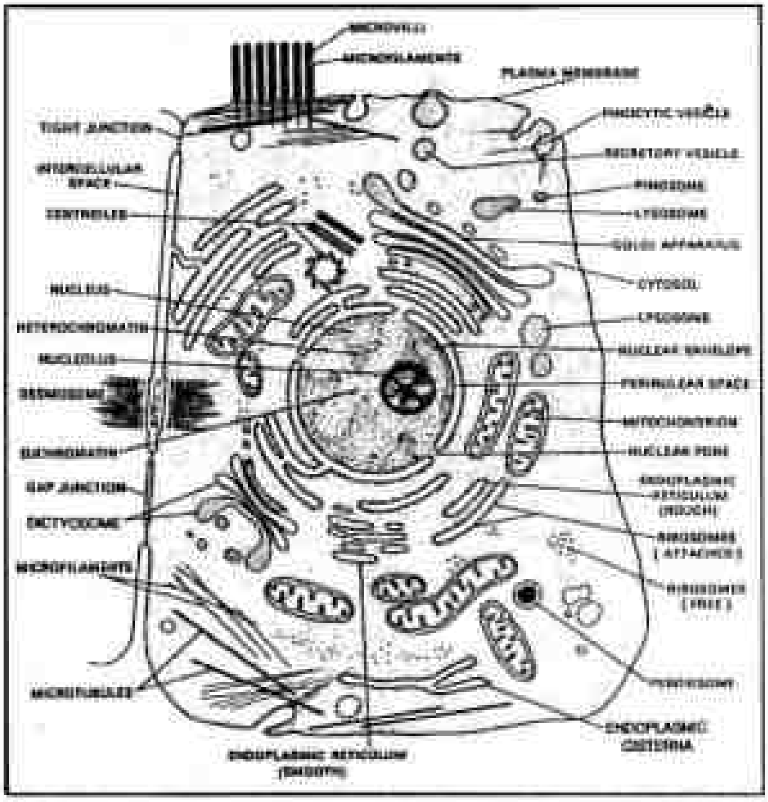


Fig.7.6 : A Typical Animal Cell

The cytoplasm does not show streaming movement or cyclosis and spindle fibers are never formed during cell division (refer Cell division).True vacuoles are absent. Some prokaryotes contain flagella but the internal organization of prokaryotic flagellum is different from that of eukaryotes. The bacterial cell divides by simple fission and both the bacteria and cyanobacteria form resting spores to pass off adverse conditions.

7.2.2. Eukaryotic Cell:

The eukaryotic cells found in higher forms of plants and animals are far more complex structures than procarbotic cells. The characteristic features of eukaryotic cell is the presence of a membrane bound **organized nucleus** enclosing the genetic materials and also the compartmentalization of the interior of the cell by extensive **endomembrane system,** (fig 6.12 & 6.13).The exterior of the cell is bound by a plasmamembrane in animal cell. The plant cells have rigid cell walls external to plasma membranes. The cytoplasm contains a number of membrane bound organelles like mitochondria, endoplasmic reticulum, Gogi complex, lysosomes. Cytoskeleton, microfibrils and microtubules are found in eukaryotic cells. The eukaryotic ribosome is 80s type.

TABLE - 7.1

Differences between prokaryotic and eukaryotic cell

Features	Prokaryote	Eukaryote
Cell size	Generally 1-10|im in linear dimension.	Generally 10-100|im in linear dimension.
Protoplasm	Relatively rigid, nonvacuolated, resistant to dessication,osmotic shock and thermal denaturation.	More fluid, vacuolated, more sensitive to dessication,osmotic shock and thermal denaturation.
Organelles	Membrane bound organelles absent.	Membrane bound organelles like mitochondria, endoplasmic reticulum etc. present
Nucleus	True nucleus absent; no nuclear membrane,no nucleolus,no nu - cleoplasm.	True nucleus present with nuclear membrane, nucleolus and nucleo-plasm
Ribosome	Small, 70s type.	Large, 80s type. (organelles like mitochondria and chloroplasts have 70s ribosomes)
Chromosome	Single naked DNA without histone protein.	DNA organized with hitones to form distinct chromosomes.
Photosynthetic apparatus	Membranes with chlorophyll a and phycocyanin in blue-green algae,bacteriochlorophyll in bacteria.	Chloroplasts with chlorophyll a and b in stacked grana.
Cell wall	composed of amino sugars and mur-amic acid	cell wall wherever present is cellulosic.
Flagella	lack 9+2 fibrillar structure.	Posseses 9+2 fibrillar structure.
Cell division	No mitosis\meiosis. Cell divides by fission.	By mitosis and meiosis, rarely by fission.
Sexual process	Typical sexual process lacking, genetic materials exchanged by parasexual means.	Sexual process well developed.
Cellular movement	Cytoplasmic streaming, Only endocytosis found	Cytoplasmic streaming, exo- and endo-cyclosis found.

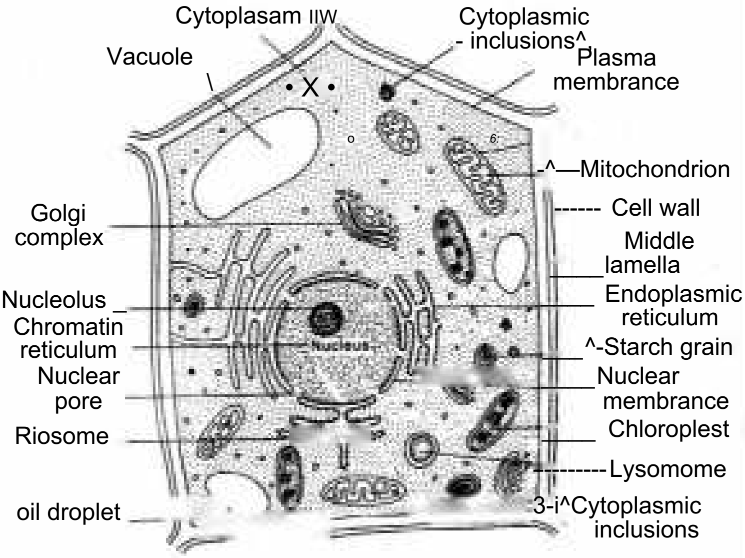


Fig.7.7 : A Typical Plant Cell

7.2.3. Plant Cell and Animal Cell :

The structures of typical animal cell and a typical plant cell are given in Fig. 7.6 and Fig. 7.7. Actually typical cells do not exist in nature as cells differ from one another. Therefore, a typical cell is a concept where all the structures associated with different types of cells are incorporated into single cell. Most of the components are common in both plant and animals cell. The basic differences are given in Table 7.2.

TABLE-7.2

Differences between plant and animal cells.

Features	Plant Cell	Animal Cell
Size	Comparatively large	Comparatively small
Cell Wall	It is rigid, porous, dead and cellulosic	Absent
Vacuole	Contains large central vacuole	Mostly absent, if present small, and scattered.
Chloroplast	Green plastids present in green plants. Also coloured and colourless plastids found.	Absent except in some protozoa like ***Euglena.***
Centriole	Generally absent except in certain lower forms like motile algae and motile sex cells of primitive plants	Present
Cillia and flagella	Motile plant cells have cilia or flagella	Present only in protozoa and spermatozoa.
Cytokinesis	During cell division cytoplasm divides by constriction.	Cytoplasm divides by by cell plate formation

7.3. CELL ENVELOPE :

Some prokaryotic cells like bacteria have an external covering outside the cell wall and cell membrane which are collectively known as cell envelope. That gelatinous envelope on the outer surface of the cell wall is composed of only polysaccharides forming viscous layer. It is known as slimy layer. But when nitrogenous substances are present along with polysaccharides then it is called capsule. The slime layer of capsules protects the cell from desiccation and antibodies. The encapsulated bacterial also remain unaffected by phagocytes. Besides some algae have mucilaginous layers as envelope which help them in floating in aquatic habitat.

7.3.1. Cell wall :

Cell wall is a fairly rigid, protective and supportive layer surrounding the cell external to plasma membrane of plants, bacteria, archaea, fungi and algae. It is absent in animals and most protists. It was first observed by **Robert Hooke** in 1665. It is not an entirely rigid structure as the cell wall expands due to the growth of the cell. It varies in thickness from 0.1 p m to 10 p m. In most of the cells, cell wall is present from the very beginning to the last, but in slime molds (Myxomycetes) cell wall is present for a very short time.

The cell wall is made of different materials depending on cell type. Only plant cell walls have **cellulose** which is an unbranched polysaccharide of D-Glucose linked together by |3 — 1, 4 - glycoside bonds. Bacterial cell walls are composed of **peptidoglycan.** The cell walls in Archaea are composed of various substances including glycolproteins-layers, pseudopeptidoglycan or polysaccharides. Fungi have cell walls made up of **chitin** and algae have **glycoprotein** and **polysaccharides.** However, certain algae have **silicic acid** and often other accessory molecules found anchored to the cell wall.

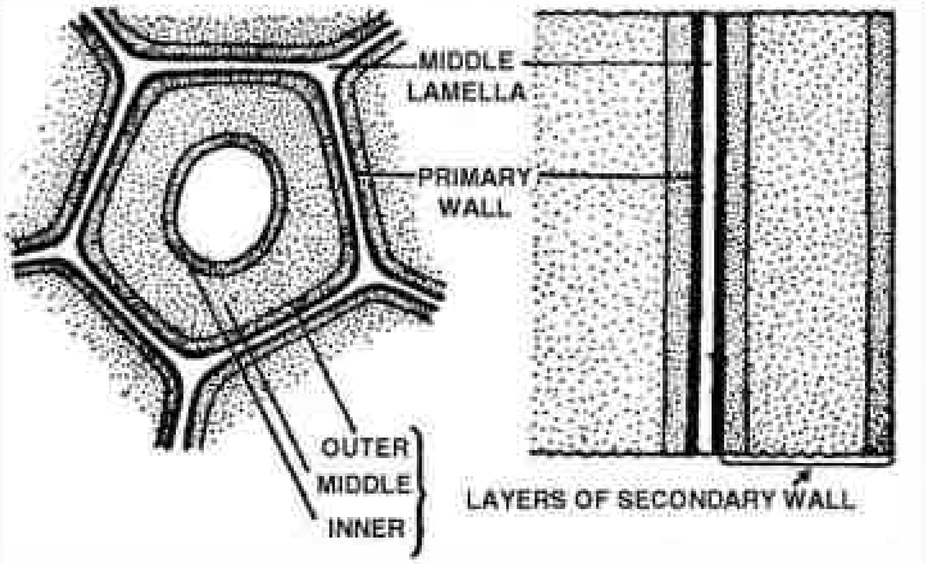


Fig.7.8 : Cell wall Showing Three Layers of Secondary Wall in Transverse section (left) and Longitudinal section (right).

In general, the plant cell wall consists of **middle lamella, primary wall** and **secondary wall** and is derived from the living protoplast.

Middle Lamella It is the cementing layer of a thin amorphous substance between two adjacent cells. This layer is the first formed layer and is laid down during cytokinesis. The primary wall is deposited inner to middle lamella. The surface cells on their outer or exposed sides lack middle lamella. It is constituted by ***Calcium*** and ***Magnesium pectate.*** The actual structure is not clearly defined and several models are there to explain the structure of the middle lamella. They are, co-valently linked crossed model, teether model, diffuse layer model and stratified layer models. The pectic substances of this layer are enzymatically converted to partially soluble substances during the ripening of fruits causing the ripe fruits to soften. It can be done artificially by spraying strong acids.

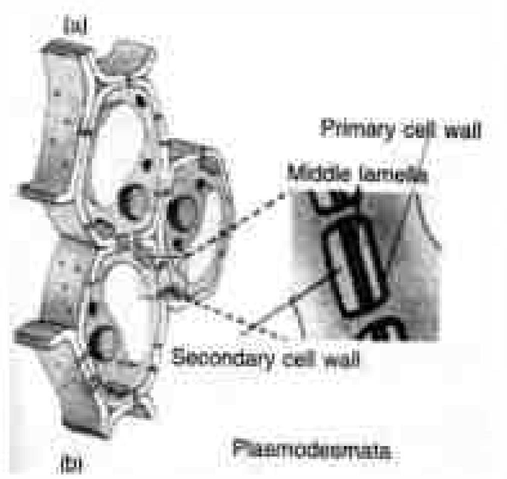


Fig.7.9 : Cell wall showing middle lamella Primary wall and secondary wall

Primary wall: This layer is laid down inner to the middle lamella. During the cell enlargement the primary wall remains relatively thin and elastic. Thickening and rigidity come only after the completion of cell enlargement. Major carbohydrates making up the primary wall are **cellulose, hemicelluloses** and **pectin.** The cellulose micro fibrils are linked via hemicellulose teethers to form the cellulose-hemicellulose net work which is embedded in pectin matrix. Out of the three subgroups of hemicelluloses like the xylans, the mannans and the galactans, **xylans** or **xyloglycans** is the most common in primary wall. Pectin, the polymers built up mainly of a-**D galacturonic acid** fills the spaces of the matrix. In brown alga the polyuronic acid constituting

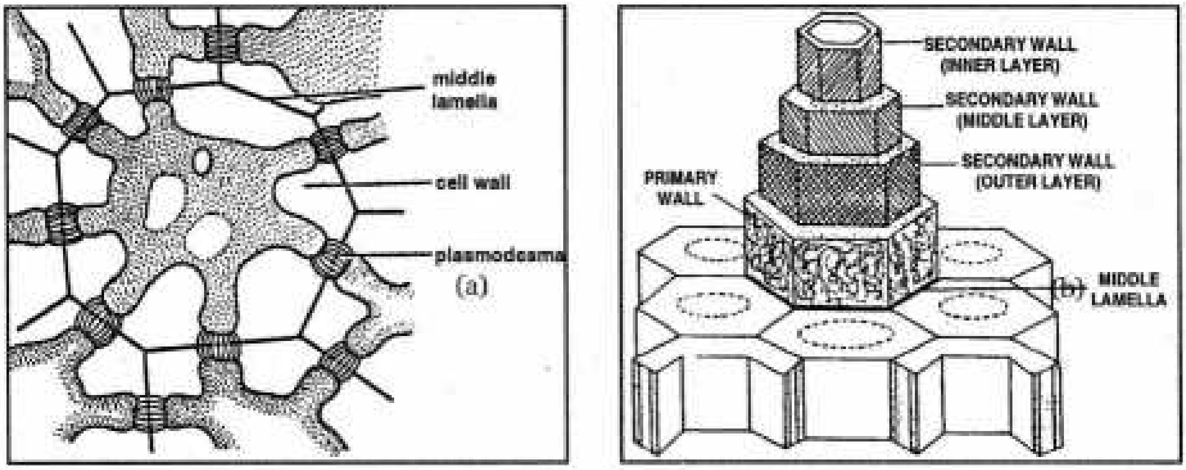
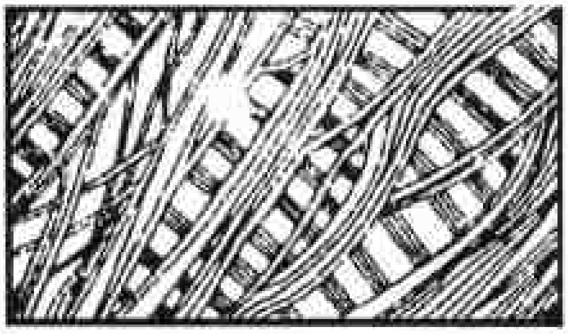
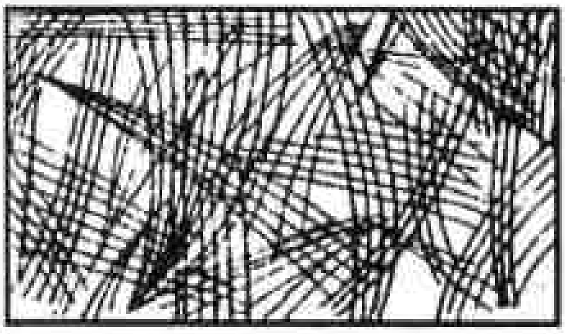


Fig.7.10 : (a) Plasmodesmata present between adjacent cells, (b) Layers of cell wall

pectin is structurally different and is called **alginic acid.** The cellulose micro fibrils are aligned at all angles and are held together by hydrogen bonds to provide high tensile strength. Plant cell walls also incorporate a number of enzymatic and structural proteins. Numerous **hydrolases** have been found in cell walls including invertase, glucanases, pectin methyl esterases and various phosphatases. Several **oxidases** are also present including **ascorbic acid oxidase** and **laccase** involved in lignin formation. The most abundant structural proteins are hydroxyl-proline rich glycoprotein **(HRGP)** also called **extensin;** the arabinogalactan protein **(AGP),** the glycine rich proteins **(GRPS)** and proline rich protein **(PRP).** Except GRPS the rest are glycoproteins and contain hydroxyl-proline. Extensin connects pectin and hemicelluloses.



(A)



(B)

Fig.7.11 : Arrangement of fibrils in (A) primary wall and (B) secondary wall

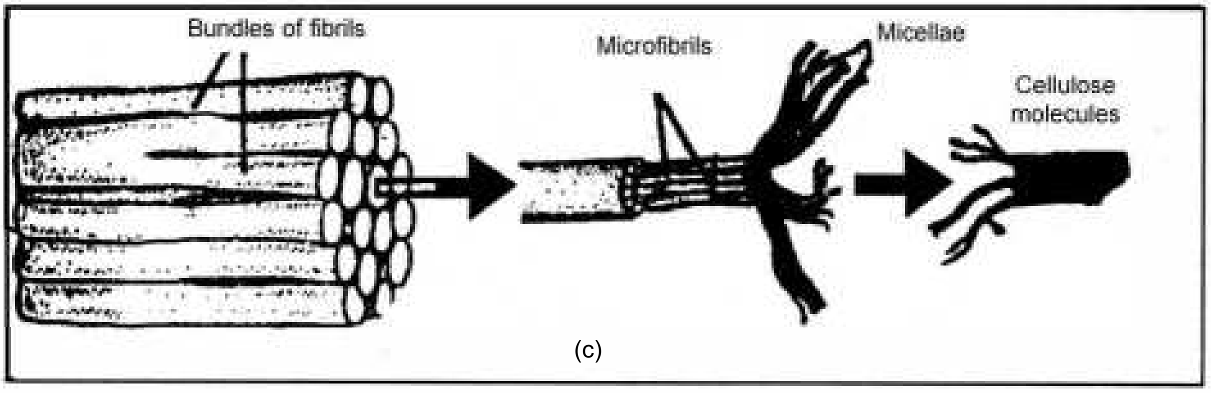


Fig.7.12 (c): Ultra structure of cellulose molecule

Secondary wall

In some plants and cell types, after the maximum growth is reached a secondary wall is laid down inner to the primary wall. Unlike the Primary wall the cellulose micro fibrils are aligned mostly in same direction and with each additional layer of the secondary wall the direction of alignment slightly changes. The secondary wall is multilayered consisting of at least **three layers.** The secondary wall is strengthened by the deposit of **lignin.** In general lignin is found in mechanical and conducting (Vascular) tissues. Lignin also occurs in the cell walls of pith, roots, fruits, buds, bark and cork. Lignins are polymers of **phenyl propane** residues. The lignin of monocots, dicots and gymnosperms are structurally different. In the walls of cork and endodermal cells a special fatty substance called **suberin** is deposited making the walls impermeable to water. Another fatty substance called **cutin** is laid down as a distinct layer on the outside of epidermal cell walls. This layer is known as **cuticle** that checks transpiration from the surface cells. The secondary wall is laid down by a process called accretion or deposition of materials over the surface of existing structure. Secondary walls are laid down in trachieds, vessels, fibers and collenchymas etc. In certain tissues of gymnosperms the innermost layer of the multilayered secondary wall is chemically different from other layers due to the presence of xylans. This layer is then called **tertiary wall.** Inorganic compounds like calcium **carbonates** and **calcium silicate** are found in the cell walls of some plants. Siliceous cell walls occur amongst the diatoms (Algae), Equisetaceae (Pteridophyte), Cyperaceae, and Poaceae (Angiosperms).

The growth of the cell wall takes place in two ways: (1) **Intussusceptions -** growth from within. Area of the cell wall increases in this way. The primary wall is stretched and material of secondary wall are deposited.

(ii) **Apposition -** growth from outside. The thickness of the cell-wall increases in this way. Materials of secondary walls are deposited in thin layers.

The cells having secondary wall are rigid. They communicate with adjacent calls through pits in the secondary wall that allow **plasmodesmata** to connect through. Pits develop as depressions on secondary wall forming a **pit chamber.** The primary wall and middle lamellum constitute the **pit membrane.** The pits may be **simple** or **bordered.** In simple pits the pit chamber has uniform width. The bordered pits have flask-shaped pit chambers. The plasmodesmata are cytoplasmic bridges between adjacent cells that develop through minute pores of cell wall. They form a protoplasmic continuum called **symplast.** It is lined by plasma membrane and has tubular extension of endoplasmic reticulum called **desmotubule.** Tangle in 1879 first observed plasmodesmata and these were extensibly studied by Strasburger in 1901 .Plasmodesmata can be simple or branched.

Function

1. Protects the cell and gives a definite shape to it
2. It provides a filtering mechanism for the cell
3. It prevents the cell from over expansion and bursting due to endosmosis.
4. It forms a protective barrier against pathogens.
5. It protects the protoplasm from mechanical injury.
6. Cell wall having cutin and suberin checks water loss from the cell.

Intercellular spaces: In mature cells three kinds of cavities or space are found, which are of following types:

(i) **Schizogenous cavities** (Schizein-to split) The cell walls of mature cells separate and form schizogenous cavities, e.g. resin canals in Pinus.

(ii) **Lysigenous cavities** (Lysis-breakdown) These cavities are formed by the breakdown of cell walls, e.g. Citrus oil cavities.

(iii) **Schizo-lysigenous cavities** These cavities are formed both by the separation and breakdown of cell walls e.g. protoxylem of maize.

7.3.2. Cell Membrane :

Cell membrane or plasma membrane or plasma lemma is the outer limiting membrane in most animal cells and it lies inner to cell wall in plant cells. Many cell organelles of eukaryotic cells also have membrane covering. Vacuoles also are separated from cytoplasm by a membrane called tonoplast. The cell membrane or plasma membrane and the subcellular membranes together constitute the biological membranes, or biomembranes. Biomembranes are dynamic, quasifluid, selectively permeable and film like structure of about 7.5 nm (75 A,) in thickness.

Chemical composition

In 1895, **C. Overton,** applying the idea, **"like dissolves the like"** concluded that biomembranes are made of lipids. He based his findings on the observations that lipid-soluble substances entered cells much more rapidly than water-soluble substances. Twenty years later, membranes isolated from Red Blood cells were chemically analyzed and found to be composed of **proteins** as well as **lipids** and small amount of **carbohydrates.** The proportional compositions of these substances vary from membrane to membrane. For examples, Myelin membranes have 18% protein, 79% lipid and 3% Carbohydrates. Human erythrocyte membranes have 49% protein, 43% lipid and 8% Carbohydrates where as Spinach lamella has 70% protein, 30% lipid and no carbohydrates. Mitochondrial inner membrane has 76% protein and 24% lipids. The lipids found in biomembranes can be **phospholipids, glycolipids, sterols, and sphingolipids.** The most abundant membrane lipids are phospholipids. About one hundred different types of phospholipids are associated with membranes. The sterols can be **cholesterols, phytosterols and ergosterols.**

The Carbohydrates are mostly associated either with lipids as **glycolipids** or proteins as **glycoproteins.** These carbohydrates are branched or unbranched oligosaccharides of **hexoses, fucoses, hexosamines, sialic acid** etc. The proteins can be **structural proteins, carrier proteins, receptor proteins** or **enzyme proteins.** Many enzymes (about 30 or more) are associated with biomembranes.

The ability of phospholipid to form biomembranes is built into their structures. A phospholipid is an **amphipathic/amphiatic** molecule, meaning it has both a hydrophilic (water loving) or polar region and hydrophobic (water hating) or nonpolar region. Other types of membrane lipids are also amphipathic. In case of phospholipids except cardiolipin, two long non polar hydrocarbon tails are attached to a hydrophilic phosphate head. The hydrophilic regions of the lipids stay at the surface of the membrane in contact with water and the hydrophobic regions remain inside the core of the membrane sealed away from water. The proteins may have hydrophilic and hydrophobic regions. The hydrophilic or polar regions of protein remain towards outside and the hydrophobic regions are folded inside the core or establish hydrophobic interactions with core lipid portion.

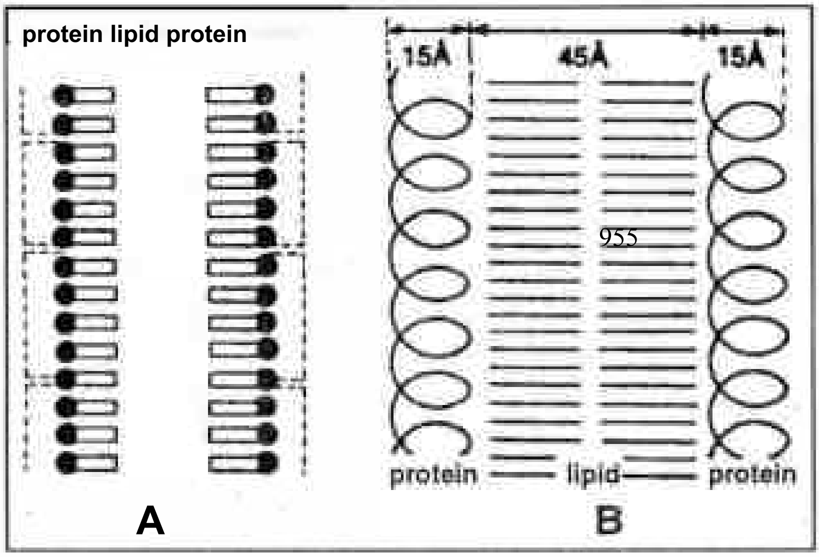


Fig 7.13 : Models of cell membrane as proposed by :
A. Danielli & Davson ; B. Robertson.

Two Dutch scientists **E. Gorier** and **F. Grendel** in 1925 compared the amount of lipid extracted from erythrocyte membranes to the total surface area of the cell and concluded that phospholipids form a bilayer. Cell membranes are actually a bilayer, two molecules thick. Such a bilayer could exist as a stable boundary between the two aqueous compartments (one is the exterior of cell and the other is the cytoplasm). This bilayer arrangement of lipids shelters the hydrophobic regions in the core of the membrane away from water and exposes the hydrophilic regions on the surface of the membrane.

Several models have been put forward explaining the arrangement of lipids and proteins in a biomembrane. People actually started constructing molecular models of cell-membrane much before its structure was actually resolved under electron microscope. **H. Davson** and **J. Danielli** in 1935 advocated the protein-lipid-protein sandwich model. As per this model the lipid layer is sandwiched between two layers of protein. It was later modified to pleated-sheet model. Here the proteins form continuous sheets on both sides of lipid layer. In 1950 the electron micrographs obtained by heavy metal (osmium) staining of cell membrane showed a **triple-layered** structure of membrane.

There were two electron-dense bands separated by an electron transparent (unstained) layer. Basing on this observation in 1959 **J. David Robertson** put forward the **Unit membrane concept.** According to this concept all biological membranes have the basic unit membrane structure of three layers-two outer electron dense layers and one middle electron transparent layer. Each dense layer is constituted by protein of 15 A thickness and the transparent layer is of bilayer of lipid of 45 A thickness.

Objections to unit membrane concept

(1) Not all membranes look trilamellar under electron microscope. The inner mitochondrial membrane appears like row of beads.

(2) All membranes are not alike as plasma membrane is 7-8nm in thickness, mitochondrial membrane in only 6nm.

(3) The chemical compositions of all membranes are not same. Membranes with different functions have different chemical compositions.

(4) Membrane proteins also have hydrophobic regions. If all the proteins are placed on the surface of the membrane then the hydrophobic regions of the proteins will be exposed to water. This will make the membrane unstable.

Fluid-mosaic model

In 1972 **S. Singer** and **G. Nicolson** advocated a revised membrane model. According to them a bilayer of phospholipids is not coated with solid sheets of proteins rather the proteins are dispersed and individually inserted into the phospholipids bilayer. Only the hydrophilic portions of the proteins protrude far enough from the bi layer to be associated with water. This arrangement views membrane as a mosaic of protein molecules bubbling in a fluid bi-layer of lipids. This molecular arrangement would be a stable one because it would maximize the contact of hydrophilic regions of proteins and phospholipids with water while providing the hydrophobic

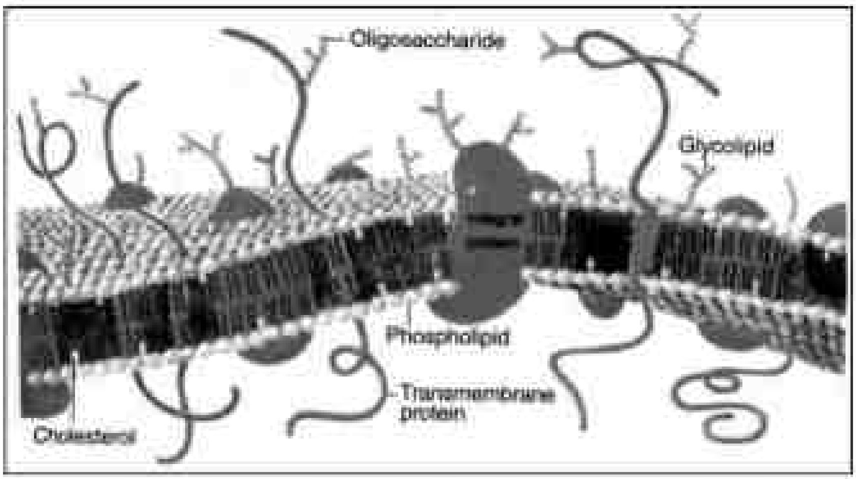


Fig. 7.14 : Fluid mosaic model of plasma membrane.

parts with a non aqueous environment. A method of preparing cells for electron microscopy called **Freeze-fracture** technique has provided the most compelling evidence that proteins are embedded in lipids. In this preparation the interior of membrane under electron microscope gave a **cobble-stoned** or bumpy appearance. Other experiments proved that the bumps are proteins in lipid bilayer. The lipids are arranged in bilayer so that their hydrophilic head groups are towards the surface and the non-polar tails of both layers face each other at the core of the membrane.

Depending on their arrangement the proteins found in the membrane are of two broad categories. The **extrinsic** or **peripheral** proteins are those which do not interact directly with the hydrophobic core of the membrane. They are usually bound to the membrane either indirectly by interactions with integral membrane proteins or directly by interactions with lipid polar head groups. Most Peripheral proteins are soluble in aqueous solutions and are bound to internal membrane proteins by ionic and weak interactions. They can be easily removed from the membrane either by solutions of high ionic strength or by chemicals that bind bivalent cations such as Mg^{++}. Most peripheral proteins are not solubilised by detergents since they are not bound directly to the hydrophobic core. The proteins **spectrin** and **ankyrin,** the cytoskeletal proteins that are bound to inner face of erythrocyte cell membrane are some examples of extrinsic proteins. Other peripheral proteins are localized to outer surface of plasma membrane, such as certain proteins of glycocalyx (discussed later).

The integral membrane proteins are internal membrane proteins which pass into the lipid bilayer to different depths. They are not soluble in water and contain at least one very hydrophobic segments of 10 to 20 amino acid long. A few intrinsic proteins are anchored to the membrane mainly by glycophospholipids that is attached covalently to the carboxyl terminus of the protein. They are held to the membrane by **three** types of interactions like hydrophobic interactions with lipid interior, ionic interactions with polar heads of lipids or specific interactions with defined structures of lipid. Some intrinsic proteins can span across the membrane from outer face to inner face. These membrane spanning proteins may span the membrane only once so that only one segment of the protein is within the membrane. These proteins are called **single pass proteins,** e.g., **Glycophorin** of RBC. Multipass proteins span the membrane many times so that more than one segment of the proteins are within the membrane. Bacterial **Rhodopsin** spans the membrane seven times. Integral membrane proteins can be removed from the membrane by the action of detergents which displaces the lipid bound to hydrophobic side chains of proteins. The transmembrane or membrane spanning proteins either singly or in groups function as **tunnel proteins** providing channels for diffusion of water and water soluble substances. Some of them behave as **permeases** allowing facilitated diffusion. There are transmembrane proteins involved in active transport known as **carrier proteins.** Some cell surface membrane proteins act as **signal receptors** and on the inner side of the membrane there are proteins which anchor the membrane to cytoskeleton.

The two faces of the membrane (the exterior and the cytoplasmic face) can be studied separately by freeze-fracture technique. This reveals that the two faces of the membrane are not the same. The amount and type of the proteins found on two faces are different. The cytoskeletal anchor proteins are always towards the cytoplasmic face. The lipids also vary in their amount and type on both the faces. On the erythrocytes membrane sphingomyelin, phosphatydylcholine are more on outer face than on inner face. While phosphatidyl serine is only found on the inner face. The oligosaccharides attached to glycolipids and glycoproteins are found only on the outer surface. The proteins found on one face never **flip-flop** across the membrane as such movement would be energetically unfavorable

Functions

(1) Forms the boundary of cells enclosing the semi fluid contents of the cells.

(2) Sub cellular membranes help in compartmentalization of cells in eukaryotes.

(3) Infolding of plasmalemma in bacteria form mesosomes required for nucleoid replication and cell division.

(4) Grows over cilia and flagella, forming sheaths.

(5) Form functional complexes like tight junction in epithelial cells, gap junction between adjacent cells for connections, plasmodesmata in plant cells, and desmosomes in epithelial cells .

(6) Form microvilli or striated border or brush border on the free surfaces of absorbing cells, e.g., intestinal cells, hepatic cells etc.

(7) Membrane proteins transport materials in and out of the cells

(8) Signal receptor proteins receive signals from hormones and such other chemicals and transmit those signals to the interior of cells.

(9) Membrane proteins also act as anchor for cytoskeletal components and extra cellular matrix.

(10) Membrane proteins on the outer face of the membrane endow the cells with individuality to allow them to assort appropriately during differentiation.

(11) Various enzymes associated with cell and sub cellular membranes allow different chemical reactions to be catalyzed in different parts of the cell.

7.4. CELL ORGANELLES - STRUCTURE AND FUNCTION :

Eukaryotic cells contain a number of cytoplasmic organelles associated with different functions. These organelles may be membrane-bound like nucleus, mitochondria, chloroplasts etc. or non-membranous like ribosome, centriole etc. The membrane bound organelles compartmentalize the eukaryotic cells so that each compartment carries out a specific function. This compartmentalization is absent in prokaryotes.

7.4.1. Endomembrance System :

The eukaryotic cells have an extensive network of internal membranes or endomembrane system connecting or spreading from the outer neuclear enevelop to the cell membrane. This is primarily reponsible for internal trafficking as well as modification of macromolecules like proteins and lipids. This system comprises of endoplasmic reticulum, Golgi complex, lysosomes and vacuoles functioning in a continuum.

7.4.1.1. Endoplasmic Reticulum (ER) :

The largest internal membrane system in a cell is the endoplasmic reticulum. Endoplasmic means "within the cytoplasm" and reticulum in Latin means "a little net". This endo membrane system packs the interior of eukaryotic cells and is not visible under light microscope. This was discovered independently by **Porter** and **Thompson** in 1945 and the name was given to it by **Porter.** ***This is a compartment comprising of a network of interconnected, closed, membrane bound vesicles dividing the cells into compartments, channeling the passage of molecules through the interior of the cells and providing surfaces for the synthesis of lipids and some proteins.*** Often it constitutes more than half of the total membrane in a cell, although the extent of endoplasmic reticulum varies from cell to cell. Metabolically active cells like cells of pancreas, liver and those responsible for production of hormones and antibodies have extensive network of ER. The storage cells like the adipose cells have simple ER only in the form of tubules. ER is absent in eggs, mature erythrsocytes, embryonic cells and prokaryotic cells. In spermatocytes ER is reduced and present in the form of a few vesicles. Of the many compartments in eukaryotic cells the larger two are the inner region of the ER called **cisternal space,** and the region exterior to it is the cytosol. The endoplasmic reticulum is composed of regions with ribosomes and regions without ribosomes. The regions with ribosomes are called **Rough Endoplasmic Reticulum** or **RER** and those without ribsomes are called **Smooth Endoplasmic Reticulum** or **SER.** The RER and SER may be continuous with one another, with plasma membrane and with nuclear envelope. SER is also called **agranular endoplasmreticulum** as it lacks ribosome on its membranes.

The synthesis of fatty acids and phospholipids occurs in SER. Although many cells have very little SER it is abundant in hepatocytes, interstitial cells, adreno- cortical cells, muscle cells, retinal cells etc. Enzymes in the smooth ER of hepatocytes modify or detoxify hydrophobic chemicals such as pesticides and some carcinogens by chemically converting them into more water soluble conjugated products that can be excreted from the body. In muscle cells smooth ER known as **Sarcoplasmic reticulum** stores Ca++ to be released during muscle contraction. In brain cells smooth ER is associated with the synthesis of male and female hormone. It is also involved in production and storage of steroids. It also stores ions and is involved in the synthesis of phospholipids, cholesterol, glycogen, ascorbic acid and visual pigments from vitamin A. The SER is typically a network of tubules and serves as a transition zone from where synthetic products of RER are passed on to Golgi after being packed in transport vesicles.

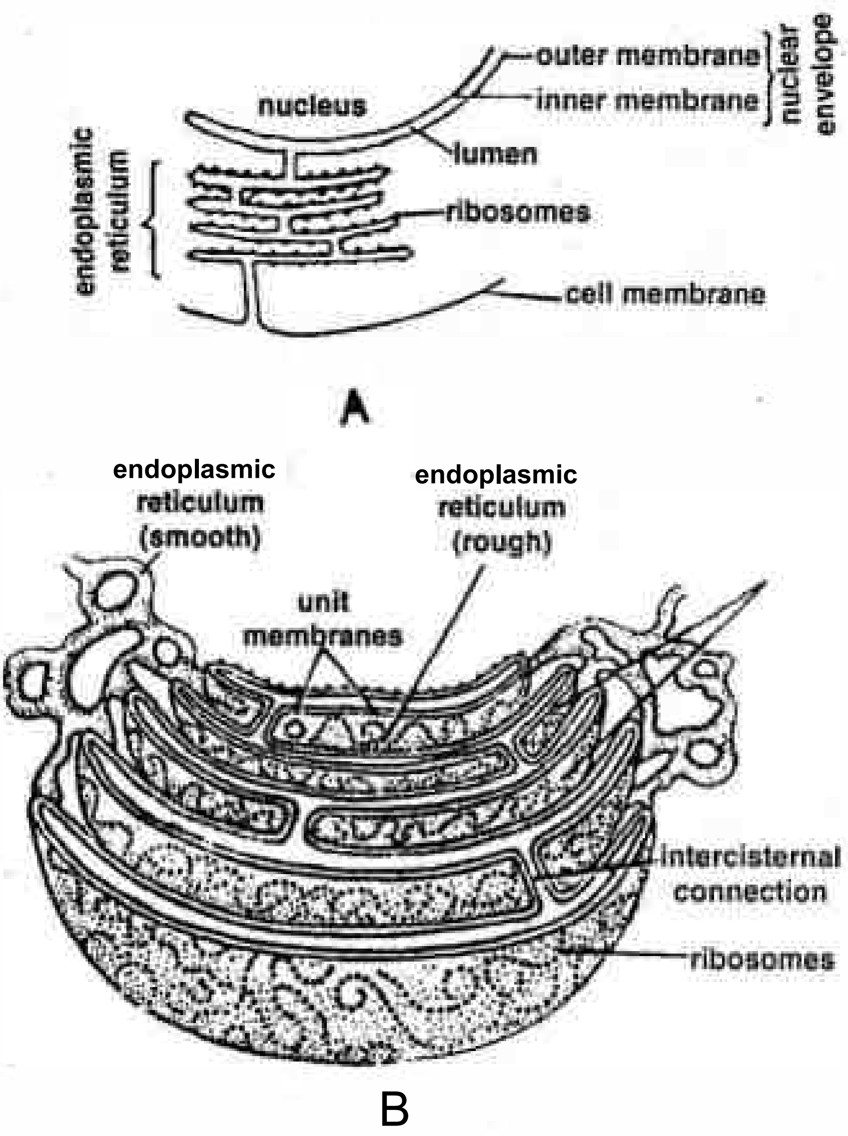


Fig. 7.15 : Endoplasmic reticulum: (A) as seen in cross section, (B) a 3-D view of a part

The RER is responsible for manufacturing and transport of membrane bound and secretory proteins. In leukocytes the RER produces antibodies. In pancreatic cells RER is involved with Insulin production. The RER is composed of a series of flattened sacs. This flattened sac like appearance is due to the presence of transmembrane proteins called **Ribophorin I** and **Ribophorin II.** Ribophorins assist the attachment of ribosome to the RER membrane. A protein **translocon** is present near the site of attachment of ribosome. This is a passage for the new protein synthesized at the attached ribosome to enter into the lumen of RER.

The proteins synthesized by attached ribosomes on the surface of RER are destined to be exported from the cell or to be sent to the lysosomes or vacuoles or to be embedded in the membrane. All these proteins contain a special amino acid sequences called ***signal sequences*** *or* ***signal peptide.*** *At first the free ribosomes synthesize the signal sequences of these proteins in the cytosol. Then, a multi subunit* ***Ribonucleoprotein*** *called* ***signal receptor protein (SRP)*** *present in cytosol recognizes the signal. The SRP then binds to ribosome and stops further protein synthesis. The SRP - Ribosome complex is then guided to the surface of RER. The ribosome is then bound to Rough ER membrane through interaction with Ribophorin I and II present in the membrane of RER. The SRP is then removed through the hydrolysis of GTP Now further protein synthesis begins and the protein enters into the ER lumen through the passage or translocon present near the Ribophorin. These proteins are then added with oligosaccharides and sent to Goligi for further modifications.*

Functions

1. Formation of a skeletal frame work inside the cytoplasm.
2. RER is responsible for manufacturing and transport of membrane bound and secretory proteins.
3. In leukocytes RER produces antibodies and in pancreas it is involved with insulin production.
4. Glycosylation of proteins begins in RER.
5. Synthesis of fatty acids, phospholipids occur in SER
6. Enzymes present in SER of hepatocytes detoxify hydrophobic chemicals.
7. In muscle cells, SER known as 'Sarcoplasmic reticulum' sequesters Ca^{++} for muscle contraction.
8. SER stores ions and is also involved with the synthesis of ascorbic acids and visual pigments from vitamin A.

7.4.1.2. Golgi Apparatus :

Golgi apparatus also known as Golgi body, Golgi complex, Golgi material orGolgiosome is named after the Italian Zoologist **Camillo Golgi** who in 1898 for the first time observed it. In plants and lower invertebrates Golgi apparatus is known as **dictyosome.** It actually refers to stacks of single membrane bound vesicles that are important in packaging macromolecules for transport to elsewhere in the cell and out of the cell. Although it is characteristic feature of eukaryotic cell, in some of the eukaryotic cell Golgi complex is not found, e.g. cells of fungi, mature sieve tubes, mature sperms, RBC, male gametes of bryophytes and pteridophytes. The number of Golgi bodies a cell contains ranges from 1 to a few in protists to 20 or more in animal cells and several hundreds in plant cells. They are abundant in glandular cells responsible for secretion.

Structure: The Golgi is composed of membrane bound sacs known as **cisternae** or **saccules, tubules** arising from the periphery of cisternae and **vesicles** surrounding the main cisternae. About 5 to 8 sacs form a cisterna, although, up to sixty sacs have been reported. The tubules form a highly branched anastomosing network. The vesicles bud off from the cisternae is of two types: (i) **Smooth vesicles or secretory vesicles** and (ii) **coated vesicles.**

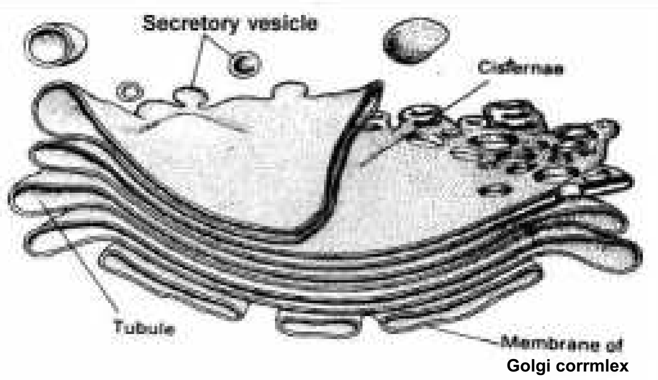


Fig.7.16 : Golgi Apparatus

A Golgi apparatus has a distinct **polarity** with a front and a back having distinct membrane compositions at the two ends. The front or receiving end or formation end is convex and is called the **cis face** and the back or maturing end is concave and is called the **trans face.** The cis face is located towards the Endoplasmic reticulum. Materials from ER move to cis face of Golgi packed in transport vesicles that bud off from ER. These ER-synthesized molecules then move from cisterna to cisterna of Golgi until they reach the trans face where they are discharged out side in secretory vesicles. As they pass through the Golgi apparatus the materials are variously modified. Mostly addition of short sugar chains (oligosaccharides) to proteins occur resulting in the formation of glycoprotein. When sugar chains are added to lipids or sugar chains of lipids are modified it results in the formation of glycolipids. Inside the Glogi apparatus glycolipids and glycoproteins made in the ER are modified by enzymatic cleavage of one or more sugars. The finished products are finally packed in membrane bound vesicles that pinch off from the trans cisternae and move to other locations in the cell or out of the cell. For this reason Golgi apparatus is also known as **Delivery system** of the cell.

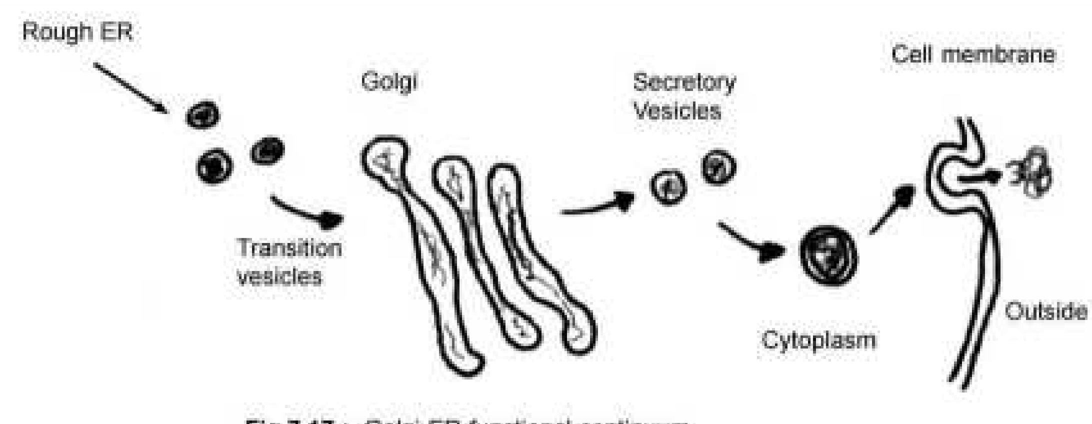


Fig.7.17 : Golgi-ER functional continuum.

Function

Some of the major functions of Golgi apparatus are:

1. Modifications of proteins and lipids to Glycoproteins and Glycolipids.
2. Synthesis of Proteoglycans molecules present in the extra cellular matrix of animals, and is also a major site of carbohydrate synthesis.
3. Polysaccharides like glycosaminoglycans (GAGS) are synthesized in Golgi.
4. Phosphorylate certain molecules with Golgi resident kinases like Casein kinase. One molecule that is phosphorylated in Golgi is Apolipoprotein found in blood serum as VLDL (Very low density lipid).
5. Synthesis and secretion of cell wall materials like pectin and other carbohydrates.
6. Secretion of gum and mucilage.
7. Formation of lysosomes.
8. Transformation of one type of membrane to another.
9. Secretes antibodies, neuro transmitters.
10. Sorting and transporting proteins to different intracellular destination.

7.4.1.3. Lysosomes :

Lysosomes are polymorphic organelles of membranous bags of hydrolytic enzymes used for the controlled intracellular digestion of macromolecules. Lysosomes were discovered by Belgian biochemist **Christian de Duve** in 1955, though lysosomal enzymatic studies in liver homogenates were carried out in 1949. Lysosomes were identified by electron microscopic cytochemistry by **Novikoff** in 1956. Some **50 enzymes** are known to be contained in different types of lysosomes. They are all **hydrolytic enzymes** including proteases, nucleases, glycosidases, lipases, phospholipases, phosphatases and sulfatases. All these enzymes are acid hydrolases optimally active near pH. of 5 maintained within these organelles. The pH of near 5 is maintained inside the lysosomes by a **proton pump** present in the membrane of lysosome that pumps H^+ or protons from cytoplasm into the lysosome. The membranes of lysosomes are impermeable to the hydrolytic enzymes contained in them. If, however, leakage of enzymes occur due to accidental damage to lysosomal membrane and these enzymes are released to cytoplasm, the higher pH value of the cytoplasm render these enzymes inactive. Due to the presence of this large number of hydrolases, lysosomes are called as **"Suicidal bags".**

Lysosomes are found in all eukaryotic cells. Some cells like pancreatic cells, liver cells, spleen cells, leucocytes, meristematic cells of plants are used for study of lysosomes. The inter communicative network of Golgi complex, ER, nuclear membrane and lysosomes form the endomembrane system. Some regions of endomembrane system constituting more of Golgi

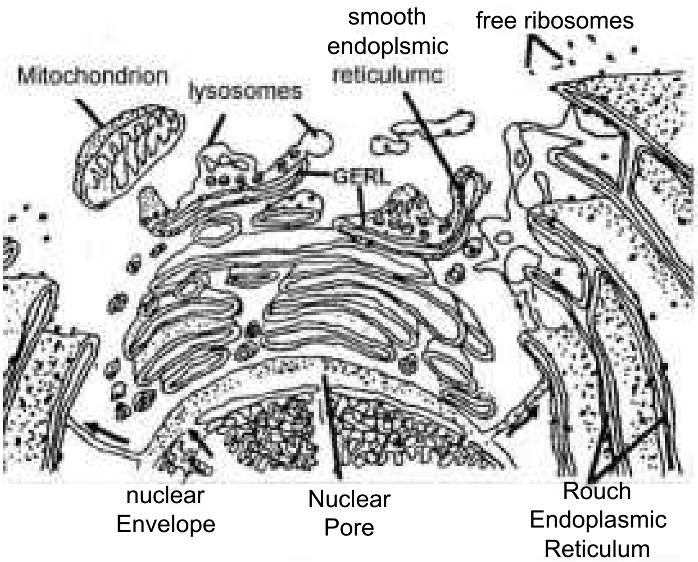


Fig.7.18 : Endo-membrane system of the cell showing inter relationship among ER, Golgi and lysosomes,

complex are often called as GERL (Golgi-ER-Lysosome Complex). Liver lysosomes are spherical bodies / vesicles of 0.5 pt m in diameter with an electron dense core that is packed with hydrolases which constitute 60% of the core by weight. The lysosomes are formed from the trans most Golgi as enzyme packed vesicles called as **primary lysosomes or protolysosomes.** Lysosomal enzymes are synthesized by ribosomes attached to ER. These enzymes then loaded inside transport vesicles move to Golgi from ER. These enzymes have one oligosaccharide attached to it. So all lysosomal enzymes are glycoproteins. The oligosaccharide part of the lysosomal enzyme has one **Mannose - Phosphate** residue as a marker and this marker is essential for packaging of lysosomal enzymes into Golgian vesicles.Golgian vesicles are **clathrin** (a type of protein) coated vesicles which fuse with endosomes to produce lysosomes.

Two general classes of lysosomes are usually distinguished. **Primary lysosomes -** which are newly formed and, therefore, not yet encountered the substrate for digestion and **secondary lysosomes or heterophagosomes** which are membranous sacs of diverse morphology that contain substrates and hydrolytic enzymes. Secondary lysosomes result from repeated fusion of primary lysosomes with a variety of membrane bound substrates. The secondary lysosomes, therefore, present a variety of morphology depending upon the internalization and packaging of different substrates. So lysosomes are polymorphic - large ones resulting from phagocytosis, small ones from endocytosis and so on. Secondary lysosomes can be of different types: (i) Large **digestive vacuoles** result from phagocytosis of large bodies like bacteria (ii) **multivesicular bodies** are membranous bags containing numerous vesicles of ~50 nm in diameter and (iii) **autophagic values** or **autophagosomes** or **cytolysosomes** are lysosomal structures containing intracellular membranous organelles such as mitochondria or secretory vesicles for digestion.

Lysosomal disorder results in **Hurler's** disease in man where bone deformities develop. This is due to accumulation of large amount of mucopolysaccharides in the cell due to absence of lysosomal activities.

Functions:

1. Digestion and turnover of intra and extra cellular constituents.
2. Programmed cell death during embryogenesis.
3. Digestion of phagocytosed micro organisms.
4. Principal site of cholesterol assimilation from endocytosed serum lipoprotein.
5. Removal of carcinogens from cells.
6. Help in bone formation from cartilage as it causes breakdown of existing matrix so that it can be replaced by new one.

7.4.1.4. Vacuoles :

The vacuoles are non-cytoplasmic areas bounded by a single membrane bilayer present in the cytoplasm. Large vacuoles are characteristic of matured plant cells. Young or growing plant cell contains many small vacuoles which coalesce to form a large central vacuole. Similarly animal cells have either many very small vacuoles or totally absent. In a mature plant cell the central vacuole may occupy about 90% of the cell volume. As a result the cytoplasm is pressed against the cell membrane as a thin layer and the nucleus becoming lateral. The, membrame surrounding the vacuole is known as **tonoplast** and the aqueous solution inside is called **cell sap** or **vacuolar sap.** This sap contains digestive enzymes and ions, metabolites and waste products. The tonoplast is differentially permeable and regulates the movement of ions and metabolites into the vacuole. Like the lysosomes the pH inside the vacuole is slightly lower than surrounding cytoplasm. This lower pH inside the vacuole is maintained by pumping in of hydrogen ions by hydrogen pump present in tonoplast membrane. High concentration of salts, sugar and many water soluble pigments are present in vacuole. Pigments like anthocyanin present in the vacuole gives the plant parts its specific colour. (Deep purple or red) The vacuole originates from the fusion and enlargement of small vacuoles present in meristematic cells which are believed to originate from endoplasmic reticulum.

Functions

1. Storage of reserve food like sucrose.
2. Stores and concentrates minerals.
3. As they contain solute in high concentration water enters the vacuole resulting in an outward turgor pressure on the cytoplasm and the cell wall. This results in turgidity of the cell.

4. Store waste products
5. Contain water-soluble pigments to impart coloration to the plant parts.
6. some plant vacuoles have hydrolytic enzymes acting at acidic pH. These vacuoles function like lysosomes.
7. Secondary metabolites like tannin, latex etc. are stored in vacuoles.
8. Contractile vacuoles found in some protists and algal cells take part in osmoregulation and excretion.
9. Gas vacuoles or pseudovacuoles or air vacuoles found in prokaryotes provide buoyancy and also mechanical strength.

7.4.2. Mitochondrion :

Mitochondria (singular: mitochondrion) are membrane enclosed organelles found in the cytoplasm of all eukaryotic cells. They are generally described as **"Cellular Power Plants"** or **"Power house of cell"** as they generate most of the cell's supply of ATP, used as a source of chemical energy. Mitochondria were first observed by **Koliker** (1850) in striated muscles of insects and **Benda** (1897) coined the present name (Gk. Mitos - thread, Khondrion- granule). Number of mitochondria per cell varies widely with organism and tissue type. It can be only one mitochondrion per cell as in certain algae (like green alga *Microsterias),* about twenty odd in sperm cell, several hundreds in kidney cell to several thousands in some oocytes. In some protozoans the number reaches even up to 500,000. Green plant cells containing chloroplasts have less mitochondrion than non-green plant cells and animal cells. In unspecialized cells they are randomly distributed throughout the cytoplasm but usually they are abundant in cells and parts of the cells that are associated with active processes. For example, they are concentrated around the base of flagellum; in cardiac muscle they surround the contractile elements. Their number is quite high in germinating seeds. In absorptive and secretory cells they lie in peripheral cytoplasm.

Mitochondria are commonly cylindrical or rod-like. They may also be spherical, tubular, cylindrical, and filamentous or sausage shaped. In *Chlorella* the single mitochondrion is branched. The shape may also depend on physiological conditions and may regularly change. The normal size is 1 - 10 pm in length and 0.6 - 2.0 pm in diameter.

Mitochondrion is a double membranous structure and can be described as a large wrinkled bag packed inside the smaller smooth bag. Because of the two membranes there are five distinct compartments within the mitochondrion. They are: the smooth outer membrane, the intermembrane space (the space between two membranes), the folded inner membrane , the cristae space (formed by infoldings of inner membrane) and the matrix (the space within the inner membrane). The outer membrane enclosing the entire organelle is smooth, has a protein to phospholipids ratio similar to eukaryotic plasma membrane. It contains numerous integral proteins called **porins** rendering it permeable to molecules of 10 kilo Daltons or less. Ions, nutrients. ATP, ADP etc. can pass through the outer membrane. Some of the enzymes of lipid synthesis are located in it. Its protein content is less than that in the inner membrance.

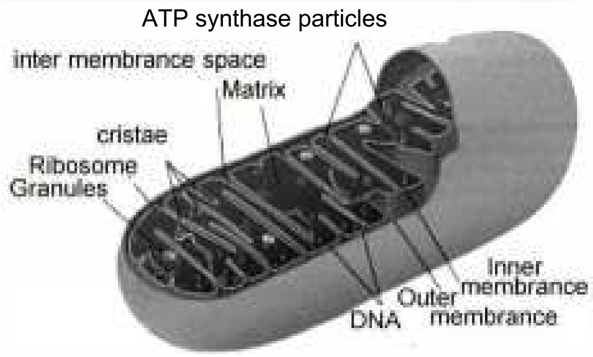


Fig.7.19 : Mitochondrion

The intermembrane space is the space (6-10 nm) between the outer and inner membrane. It is also known as **outer chamber** or **perimitochondrial** space. It contains some enzymes.

The inner mitochondrial membrane is folded forming a complex structure. It contains a special type of phospholipids called cardiolipin for which it is not permeable to ions. It is freely permeable only to oxygen, carbon dioxide and water. It contains proteins with four types of functions, viz.

(1) Proteins that carry out oxidation - reduction reactions of respiratory chains, (2) ATP synthesis proteins which make ATPs in the matrix, (3) specific transport proteins for passage of metabolites into and out of matrix (4) Protein import machinery. The wrinkles or folds of the inner membrane are organized into lamellae (layers) called the cristae (singular: crista). The cristae greatly increase the total surface area of the membrane. By special techniques inner and outer membranes can be separated to get a fraction containing only the inner membrane and the matrix called **"Mitoplasts".** The inner membrane has a series of small knob-like **elementary particles, F_o-F_1 particles** or **Oxisomes.** Each elementary particle or oxisome has a base-piece (F_o), a stalk and a head (F^. The rectangular base-piece buried in the membrane is about 11 nm by 1.5nm. The stalk is 5nm long and 3.5nm broad. The head is about 10 nm in diameter. It functions as ATP- ase during oxidative phosphorylations, to synthesize ATP.

In a typical liver mitochondrion, the surface area of inner mitochondrial membrane including the cristae is about five times that of outer membrane. Mitochondria of cells which have greater demand for ATP, such as muscle cells contain more cristae than typical liver mitochondria. Mitochondria as the sites of cellular respiration was first suggested by **Kingsbury** (1912).

The mitochondrial Matrix is semi fluid and is contained, in the inner chamber. It houses the enzymes responsible for citric acid cycle or Krebs cycle, and also contains dissolved oxygen, water, carbon dioxide, the recyclable intermediates. In addition, the matrix also contains mitochondrial ribosomes 55s to 70s in nature, tRNAs and several copies of mitochondrial DNA (2-10 copies). The mitochondrial DNA makes the organelle **semiautonomous.** Some of the

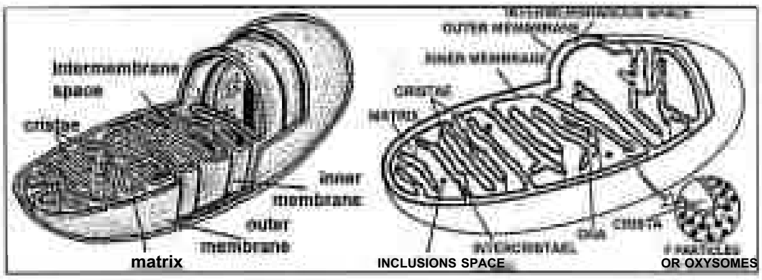


Fig.7.20 (A): L.S. of mitochondrian (diagrammatic)

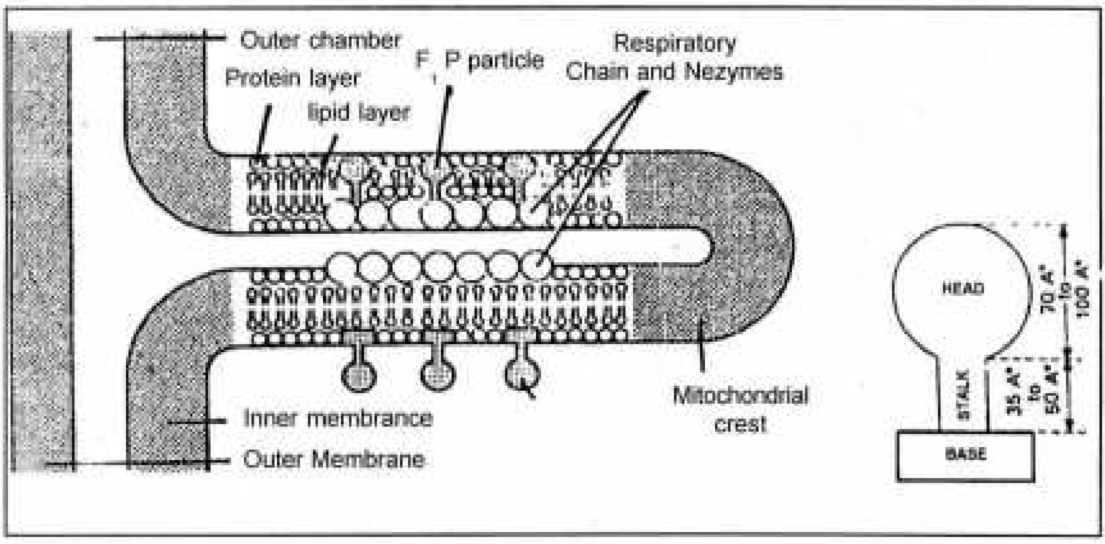


Fig.7.20 : (B) Detailed structure of a crista (C) Structure of F_o-F, Particle

proteins required in mitochondria are synthesized by their own DNA. A human cell mitochondrion has about **37 genes,** out of which **24 are rRNA** and **t RNA genes** and **13 are peptide genes.** The 13 mitochondrial peptides in humans are integrated into inner mitochondrial membrane, along with other proteins encoded by nuclear genes. Mitochondria replicate their own DNA and divide mainly in response to the energy needs of the cell. The mitochondrial genes are inherited mainly through maternal inheritance. Mitochondrial genes lack introns (c.f. nuclear genes).

As the mitochondria have their own DNA, they are also responsible for inheritance of certain characters. This type of inheritance being independent of nuclear genes is known as cytoplasmic inheritance. Petite character in yeast and cytoplasmic male sterility in maize are examples of mitochondrial inheritance.

Mitochondria are believed by many scientists to be bacterial endosymbionts of eukaryotic cells. The most compelling evidences for such belief are:

- They have their own nucleic acids and ribosomes.
- They divide independent of cell division cycle.

- Similarity exists in bacterial and mitochondrial membranes.
- Both mitochondria and bacteria carry out energy conversion processes on the inner side of the membranes.

Functions

1. Convert organic materials into cellular energy in the form of ATP, hence acts as power house of the cell.
2. Synthesis of heme, steroids, and elongation of fatty acids.
3. Apoptosis - Programmed cell death.
4. Regulation of cellular redox-state.
5. Storage and release of calcium.

7.4.3. Ribosome :

Ribosomes are non-membranous, basophilic granules, rich in Ribonucleic acid and distributed in the cytoplasm of both prokaryotes and eukaryotes. They were first isolated and named by **Palade** (1955). So ribosomes are also called Palade's particles. Ribosomes are made up of rRNA and proteins and are the center of protein synthesis. These are the **smallest cell organelles** with a diameter of about 150 - 300 $\overset{0}{\Lambda}$. They occur either freely in the cytoplasm or attached to the endoplasmic reticulum or nuclear membrane of eukaryotic cells. A large number of ribosomes occur in a single cell. Each E.coil (colon bacterium) cell contains about 15,000 or more ribosomes making about a quarter of the dry weight of the cell.

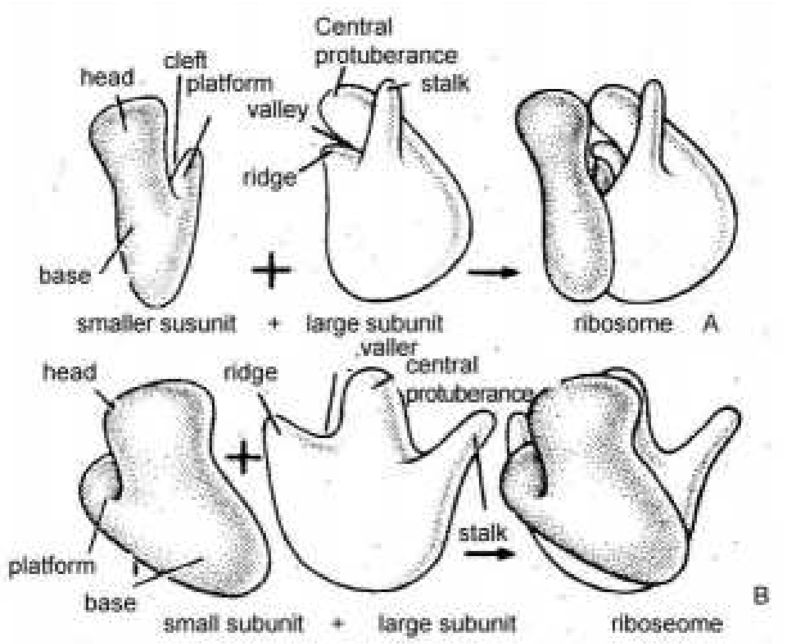


Fig. 7.21 : Ribosome

Each ribosome has two subunits: a **smaller subunit** which fits like a cap over a **larger subunit** (Fig.7.21) The two units associate in presence of Mg^{++} ion at and slightly above a critical concentration of 0.0001 Mole. The two subunits dissociate below this critical concentration of magnesium ion. As the ribosomes are isolated from cells by differential centrifugation (Refer chapter 6) depending on their sedimentation coefficient(s)* ribosomes are of two types: the **70s ribosomes** and **80s ribosome.** 70s ribosomes are found in prokaryotic cell as well as eukaryotic organelles like mitochondrion and chloroplast, 80s ribosomes are found in the eukaryotic cells .

The 70s ribosome is constituted by **30s smaller subunit** and **50s larger subunit.** 80s ribosome similarly is constituted by **40s smaller subunit** and **60s larger subunit.** During protein synthesis many ribosomes arrange in a chain on a common messenger RNA (mRNA) strand and are called as polysomes or polyribosomes.

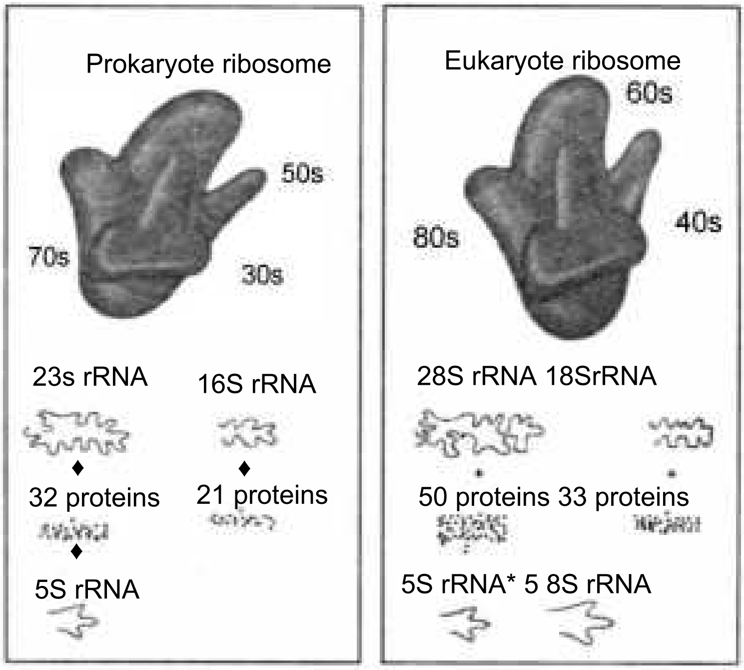


Fig. 7.22 : Ribosomes: comparative account

Ribosomes are chemically composed of ribosomal RNA (rRNA) and various types of proteins (molecular weight ranging from 6000 to 75000). A prokaryotic 70S ribosome has the rRNA - about 65% and protein about 35%, while the eukaryotic ribosomes have more protein and less r RNA.

The 30s submit is composed of 16s r RNA (1500 nucleotides) and 21 different proteins (s1 to s21), whereas 50S subunit contains 23s r RNA (3000 nucleotides), 5Sr RNA (120 nucleotides) and more than 30 proteins (L1 to L34). In eukaryotes, 60s subunit contains 28s

*[Sedimentation co-efficient as a function of rpm and gravity is expressed in Svedberg units abbreviated as 's'].

rRNA(5000nucleotides), 5.8S r RNA(160 nucleotides) and 5s r RNAand 50 proteins. The 40s subunit of eukaryotic ribosome has 18s r RNA and 33 Proteins.

Ultra structure

The smaller subunit consists of a head, a base and a platform. The platform separates head from base by a cleft. The larger subunit has a ridge, a central protuberance and a stalk. The ridge is separated from central protuberance by a valley. When the two subunits. (Fig.7.21) assemble / associate a tunnel occurs between the two subunits for smooth passage of mRNA.

Function: Ribosomes provide the sites for protein synthesis (translation). This is done:

(i) by accepting the correct new amino acid coming to it bound to transfer RNA (tRNA) at A-site.

(ii) By forming peptide bonds between amino acids by peptidyl transferase activity. This is done by the ribozyme (RNA - enzyme) activity of larger subunit site.

(iii) Translocation of growing peptide still attached to t RNA to 'P - site / peptidyl site.

(iv) Exit to emptied tRNA from 'E' -site / exit site.

7.4.4. Plastids :

Plastids are major organelles found in plants including algae. The term plastid was coined by **E. Haeckel** in 1866. These are double membrane organelles with their own DNA and are responsible for photosynthesis, storage of starch and for synthesis of many classes of molecules such as fatty acids and terpenes. Some protists like **Euglena, Dinophyceae** and **diatoms** also have plastids. Plastids are the largest cell organelles. All plastids are derived from proplastids, formerly known as **eoplasts** (eo-early). In plants plastids may differentiate into several forms depending upon the types of function they need to play in the cell. Undifferentiated **proplastids** may develop into any of the following forms:

- **Chloroplasts :** for photosynthesis. The chloroplast with nitrogen fixing genes (nif genes) constitutes **nitroplast.**
- **Chromoplasts:** for pigment synthesis and storage. The pigments associated with them are xanthophylls (yellow) and carotene (orange - red) as seen in colored petals and fruits.
- **Leucoplasts:** for monoterpene synthesis. Leucoplasts sometimes differentiate into more specific plastids like :
- **Amyloplasts:** for starch storage as in the case of potato tubers, wheat and rice grains.
- **Elaioplasts:** for storing fats as in the case of seeds of castor and peanuts.

• **Proteinoplasts:** for storing and modifying proteins. The aleuronoplasts of maize is one such example.

Plastids have the ability to differentiate and rededifferentiate to different forms. The chromoplasts may be developed either form leucoplasts or chloroplasts. The lamellae degenerate partially or completely during chromoplast development. When green fruits ripen they become variously colored due to transformation of green chloroplast to the colored chromoplasts.

Further in algae the term leucoplast (=leukoplast) is used for all unpigmented plastids. Their function differs from the leucoplasts in plants. Etioplast, amyloplast and chromoplast are found in higher plants but do not occur in algae. The chloroplast in algae other than green algae is called **chromatophores** (e.g. rhodoplast in red algae and phoeoplasts in brown algae). The plastids of algae may also differ from those of the plants in that they contain **pyrenoids** (Beyond algae, Pyrenoids are also found in the chloroplasts of *Anthoceros* (Bryophyte) and *Selaginella* (Pteridophyte).

Inheritance of Plastids: Mostly plastids are inherited through maternal inheritance or cytoplasmic inheritance. Many gymnosperms, however, inherit plastids from male parent. In algae also the plastid inheritance is from one parent only. The plastid DNAof the other parent is thus completely lost.

Origin of plastids

Plastids are thought to have originated as endo-symbionts.Presence of plastid DNA and their division independent of cell division cycle are some of the evidences of their endo-symbiotic origin.Some dinofiagellates take up algae as food but retain the plastids of the digested algae to profit from photosynthesis, (after a while the plastids are also digested). **Apicomplexa,** the obligate parasitic protozoans which include the causative agents of malaria and many other human or animal diseases also harbor a complex plastid called **apicoplast.** The apicoplast is not capable of photosynthesis and is a promising target for antiparasitic drug development. Such type of plastid also point to the endo-symbiotic origin.

Chloroplasts: Schimper (1883) coined the term chloroplast. These are the photosynthetic pigment containing plastids found in green algae and plants. The shape, size and number of the chloroplast vary greatly. In higher plants the chloroplasts are mainly ovoid, spherical, discoid or lens-shaped. In algae, the shape shows a great variation. It is **cup-shaped** in *Chlorella* and ***Chlamydomonas, girdle-shaped*** in *Ulothrix, star-shaped* in *Zygnema,* spiral in *Spirogyra, reticulate* in *Oedogonium* and *discoid* in *Vaucheria.* Generally the chloroplast is about 4-8p in size but in polyploids the size is bigger. In sciophytes (shade plants) chloroplasts are bigger than in heliophytes (light plants). A single chloroplast per cell is found in some algae like *Chlamydomonas, Ulothrix, Chlorella* etc. Two chloroplasts per cell are found in *Zygnema* and 2-14 chloroplasts per cell are found in *Spirogyra.* In higher plants 20-40 chloroplasts per cell have been reported.

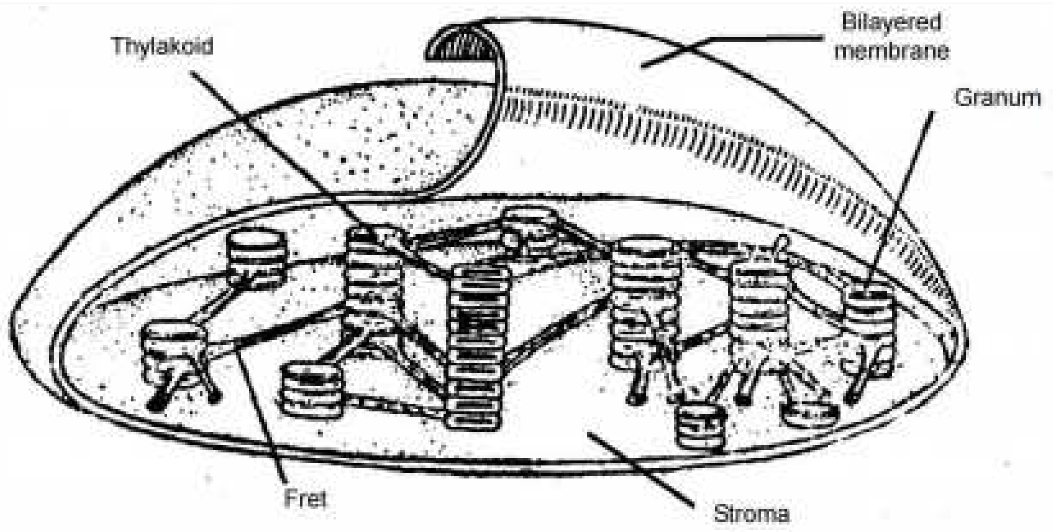


Fig.7.23 : Detailed structure of chloroplast

Ultrastructure

Like Mitochondrion, the chloroplast is enclosed by two membranes. But the chloroplasts are larger and more complex than the mitochondria. In addition to the outer and inner membranes the chloroplasts also have a closed compartment of stacked membrane called **grana** (singular, granum) that lie internal to the inner membrane. In one chloroplast there may be hundred or more grana. Each granum contains from a few to several dozens disc-shaped structures called **thylakoids.** The smaller thylakoids are placed one above the other like stacks of coins to form the granum. The larger thylakoids are large membranous structures known as **inter granal lamellae** or **stroma lamellae** or **fret channels.** Surrounding the thylakoid is a fluid matrix called **stroma.** The dark reaction of photosynthesis occurs here. Stroma is a proteinaceous matrix. The photosynthetic pigments are housed on the surface of thylakoids. The space between the two membranes surrounding the chloroplast is known as **periplastidial space.** The algal chloroplasts are **agranal** as they lack grana.

Like the mitochondrion the chloroplast also contains its own DNA. Plastid DNA exists as large protein-DNA complex associated with the inner envelope and are called "plastid nucleoids'. Each nucleoid particle may contain more than ten copies of the plastid DNA. The proplastid contains a single nulcleoid located at the centre of the plastid. The developing plastid has many nucleoids localized at the periphery of the plastid bound to the inner envelope. During differentiation of proplastids to chloroplasts as also when plastids convert from one type to an other, nucleoids change in morphology, size and location. The chloroplast DNA contain genes for the synthesis of specific protein components necessary to accomplish photosynthetic reactions. Majority of the proteins needed in chloroplasts are synthesized by nuclear genes and imported into chloroplast. There are approximately **120 genes** in chloroplast DNA of which about **60 genes** are involved in RNA transcription and translation including genes for rRNA, tRNA, RNA polymerase subunits and ribosomal proteins. About **20 genes** encode subunits of chloroplast electron transport complexes and the ATPase complexes. The large subunits of the photosynthetic enzyme RUBISCO are also encoded by chloroplast genome.

Chemical composition: Chloroplast is constituted by 45-50% proteins, 20-25% phospholipids, 10% chlorophylls, 1-2% carotenes, RNA, DNA, enzymes, coenzymes, magnesium, copper, iron, zinc and manganese.

7.4.5. Microbodies :

These are single unit membrane bound small spherical bodies. They have been discovered with the help of electron microscope. The microbodies are lysosomes, peroxisomes, sphaerosomes, glyoxysomes and lomasomes.

7.4.5.1. Peroxisomes :

Peroxisomes are a kind of micro bodies present in almost all the eukaryotic cells. Normally they co-sediment with lysosome in density gradient centrifugation.Their existence as a separate intracellular organelle became generally recognized only in 1960s by **DeDuve** et.al. **Beaufaytt and Berther** (1963) gave the name peroxisome to it. It is a single membrane bound vesicle with a diameter of about 0.5 pi m having a concentrated source of at least three oxidative enzymes in liver cells: **D-amino acid oxidase, urate oxidase** and **catalase.** Small peroxisome or microperoxisomes with a diameter of about 0.15 - 0.25 |i m are ubiquitous in mammalian cells. Photosynthetic plant cells may have about 70 - 100 peroxisomes where it performs photorespiration being associated with chloroplasts and mitochondria.

Like mitochondria peroxisome is a major site of oxygen utilization. In fact, peroxisomes are thought to be the vestige of some ancient organelle involved in carrying out all kind of the oxygen metabolism. Later on Mitochondria evolved with a mechanism of coupling oxygen metabolism with ATP synthesis. The oxidative reaction carried out by peroxisomes are still useful to cell despite the presence of the mitochondria.

It is thought that certain integral membrane proteins unique to the peroxisomes are synthesized in the ER membrane to from a pre-organelle. This pre-organelle then forms a bud from the region of smooth ER. Several major peroxisomal enzymes including catalase and urate oxidase are synthesized in the cytosol and transported into peroxisome as it is forming. Most of the mature peroxisomes remain attached to smooth ER by a thin sleeve like projection (Fig.7.24).

Oxidative enzymes contained in peroxisomes remove hydrogen atoms from specific substrates using molecular oxygen and forming hydrogen peroxide. Hydrogen peroxide is toxic and is thus broken down to water and molecular oxygen by the catalase enzyme present in peroxisomes.

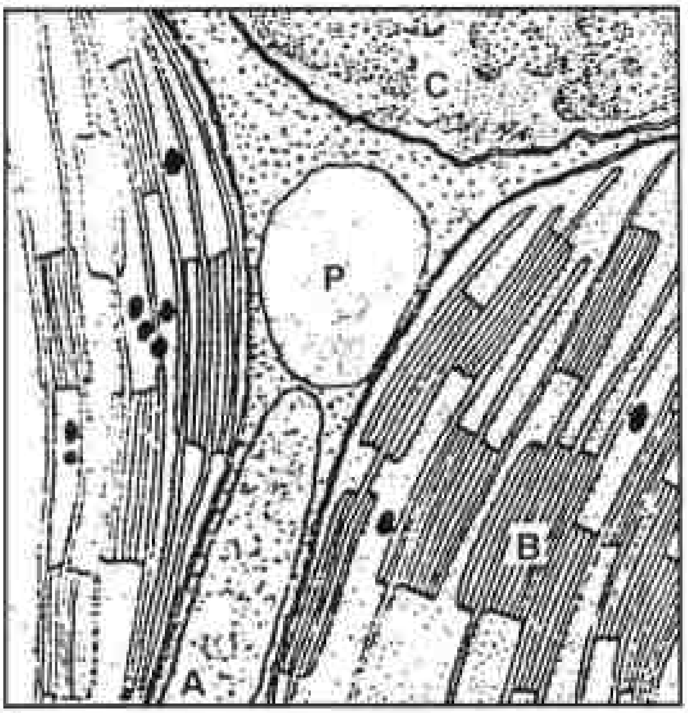


Fig.7.24 : Electron micrograph of peroxisome (P) in a leaf

$$\underset{\text{Substrate}}{RH_2+O_2} \xrightarrow{\text{Oxidation}} R+H_2O_2 \text{ (hydrogen peroxide)}$$

$$2H_2O_2 \xrightarrow{\text{Catalase}} 2H_2O+O_2$$

Other functions of peroxisomes include:

1. In photorespiration in C_3 plants where glycolate from chloroplasts enter peroxisome get oxidized with molecular O_2 to form glyoxylate. Hydrogen peroxide is the by-product, which is split by catalase. Glyoxlate is then converted to amino acid glycine that condenses to form serine and CO_2.
2. Long chain and branched fatty acids are broken down in peroxisome.
3. A special kind of peroxisomes called **glyoxysomes** is found in plant tissues like germinating seeds. Here it serves to convert the fatty acids stored in the seed into sugars needed for the young plants. This is accomplished through a series of reactions called glyoxylate cycle. Two molecules of acetyl COA produced by fatty acid breakdown in peroxisome, are used to make succinic acid which is converted to glucose.
4. In animal cells peroxisome detoxify a number of substances like phenols, methanol, ethanol etc. The alcohol consumed by a person is partly detoxified in the liver cell peroxisomes.

7.4.5.2. Sphaerosomes:

Sphaerosomes were previously considered as lysosomes of plant cell as they contain enzymes most of which are identical to those of lysosomes. But, now it is known that sphaerosomes contain some additional enzymes. These microbodies are small single unit membrane bound vesicles of 0.2-0.8 p. m in diameter. Their main function is synthesis and storage of fats and oils.

7.4.5.3. Lomasomes:

Lomasomes are small vesicles present between the cell wall and plasma membrane in plant cells. They are associated with the synthesis of cell wall materials.

7.4.6. Cytoskeleton :

Cytoskeleton is a cellular 'scaffold" of "Skeleton" contained in the cytoplasm of eukaryotic cell.* This is a dynamic structure of extensive net-work acting as the skeleton and muscle of the cell, for movement of stability. They are also involved with distribution and orientation of cell organelles and cellular division. Eukaryotic cells contain three main kinds of cytoskeletal filaments. They are Microfilaments, intermediate fiaments and microtubules.

Mircofilaments / Actin filaments

Microfilaments are long, narrow cylindrical protein filaments of about 7 nm in diameter. Being the thinnest of the cytoskeletal filaments, they are called as microfilaments. These filaments are formed by a family of proteins called actin proteins and for this reason these filaments are also known as actin filaments. Monomers of actin protein form long thin chains like **'strings of pearls'.** Two chains of actin closely twin around each other to form a filament. These filaments are mostly concentrated below the plasma membrane, to maintain cellular shape and in some cases form cytoplasmic protuberances (like pseudopodia and microvilli).

Functions

1. By forming a band below the plasma membrane they maintain the shape of the cell and also provide strength to the cell.
2. Generate locomotion in some cells like WBC and amoeba (Pseudopodia formation)
3. Interact with myosin muscle fibers for muscle contraction.
4. Link trans membrane proteins (e.g. surface receptors) to cytoplasmic proteins.
5. Anchors centrosomes at the opposite poles of cell during cell division.

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* (There are recent reports indicating the presence of cytoskeleton like protein structures in prokaryotes. Tubulin like proteins FtsZ is the first protein to be identified in Prokaryotes. Though these proteins form filaments like tubulin the filaments do not group into bundles. In the bacterium *Caulobacter crescentus* one protein called crescentin is found which is related to intermediate filaments. This is believed to maintain the cell shape like that of eukaryotic cytoskeleton.)

6. Cytoplsmic streaming movement is cause by the action of microfilaments.
7. Form cleavage furrows at the time of cytokinesis.

Intermediate filaments

These are filaments of 8 - 11 nanometers in diameter, more stable than actin filaments and form heterogeneous constituents of cytoskeleton. These filaments are constituted by fibrous protein molecules twined together in an overlapping arrangement. There are four types of intermediate filaments:

- Vimetins: common structural support of many cells. Provide mechanical strength to muscle and other cells.
- Keratin: Found in skin cells, hair and nails, form tonofibrils of desmosomes.
- Neurofilaments: Found in axons and dendrons of nerve cells; strengthen the long axons and dendrons of nerve cells; strengthen the long axons of neurons.
- Hamin: gives structural support to nuclear envelope.

The nucleus in epithelia cells is held within the cell by a basket-like network of intermediate filaments made up of keratins. Different kinds of epithelial cells use different keratins to build up their intermediate filaments

Functions

1. Provide support and strength to cell membrane and nuclear envelope.
2. Form a skeletal network in the cytoplasm.
3. Found as constituents of hair, nail and skin (keratin).
4. Tonofibrils support the desmosomes.
5. Neurofilaments strengthen the axons.
6. Provide mechanical strength to muscle (vimetins)

Microtubules

Microtubules are thin, branched, hollow cylinders of about 20 - 25 nm in diameter and several microns in length. They were first observed in nerve cells by **De Roberties** and **Franchi** (1953). About a decade later these were studied in plant cells by Ledbetter and porter (1963). Most commonly each microtubule is composed of a ring of about 11-13 longitudinal strands of protein protofilaments (Fig. 7.25). The right encloses a central core of about 12 -15 nanometer. The protofilaments are constituted by the polymerization of a and p tubulin protein subunits. The tubulins continuously polymerize and depolymerize to present a dynamic structure. The half-life of tubulin ranges from 10 minutes in nondividing cells to 20 seconds in dividing cells. In many cells microtubules organize from nucleation centers near the centre of the cell and radiate towards the periphery. Both the ends of microtubule possess distinct polarity and are designated as "+' end (away from nucleation centre) and '-' end (toward the nucleation centre). The microtubules **grow** at each end by polymerization of tubulin dimmers (of *a* and p tubulin) powered by the hydrolysis of GTP and **shrink** at each end by depolymerization. However, both processes always occur more rapidly at 'Plus (+) ends'.

Functions

1. Maintain the form of the cells.
2. Constitute the axoneme of cilia and flagella responsible for their movements.
3. Constitute the mitotic spindle responsible for movement of chromosome during nuclear division. (Alkaloids like colchicines and vinblastine inhibits microtubules assembly by binding with tubulin).
4. Synthesis of the cell plate during cytokinesis of plant cell division.
5. Special motor proteins move cellular organelles around the cell on microtubules using ATP. Kinesin protein move organelles toward plus end (periphery) and dyneins move toward minus end. **Charcot marie** -tooth disease is a rare disorder due to mutation of kinesin gene. In these patients axon-transport is defective accounting for muscle weakness.

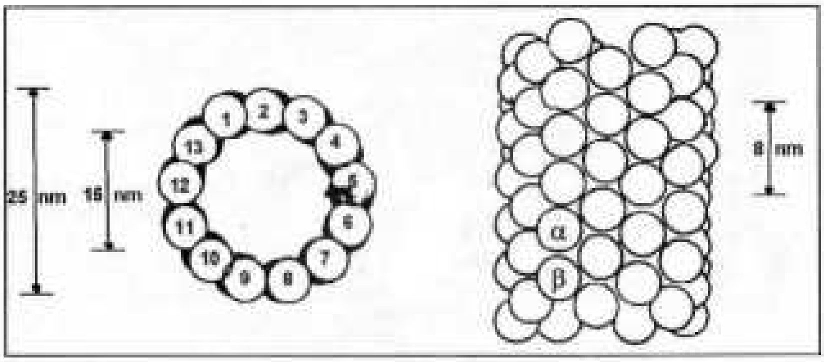


Fig.7.25 : Construction plan of Microtubules

7.4.7. CILIA and FLAGELLA :

Cilia and flagella are specially differentiated, fine, hairlike, filamentous extensions of cytoplasm associated with either the locomotion of cells (e.g. sperms) or to move fluid past the cells (e.g. ciliated epithelial cells). Both cilia and flagella are constructed from microtubules and both are identical in their morphology and physiology. They differ in their lengths, numbers per cell and patterns of movement. Flagella are longer (10 microns to several millimeters) where as cilia are shorter (0.2 to 10 microns) in length. Only one or a pair of flagella are present in a cell, whereas cilia are much more in umber per cell.

Each cilium or flagellum consists of a shaft constituted by bundle of microtubules called **axoneme** entirely ensheathed by the extension of plasma membrane. The axoneme is made of a cylindrical array of 9 evenly spaced microtubules each with a partial microtubule attached to it. This gives the structure of English numerical "8" appearance. Two single microtubules run up through the centre of the bundle of 9 microtubules so as to form a **"9 +2"** arrangement. The motion of the cilia and flagella is created by the microtubules sliding past one another.

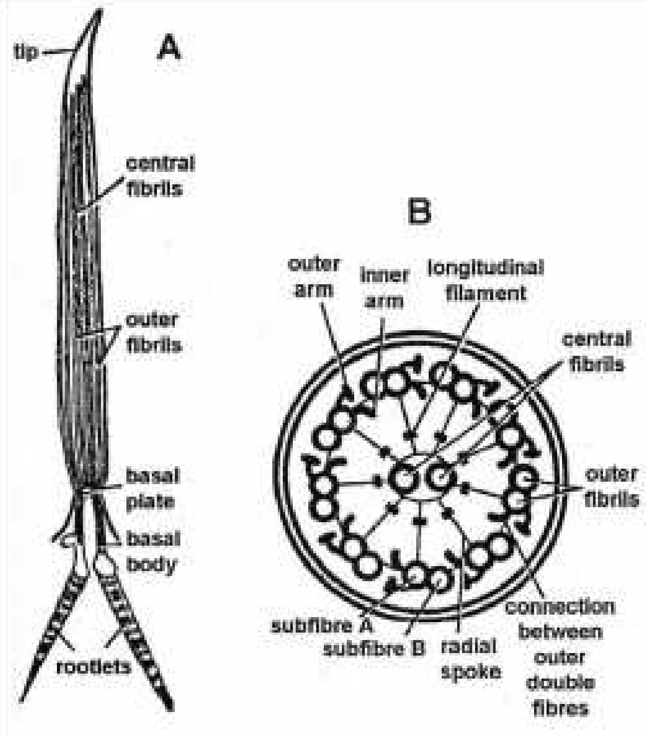


Fig.7.26 : (A) Diagramatic Presentation of flagellum (B) T.S. as seen under electron microscope

Each cilium or flagellum grows out from, and remains attached to a **basal body** or **kinetosome** or **basal granule** embedded in the outer part of cytoplasm. Basal bodies have the same structures as the centriole, with triplets of microtubules present at the periphery without central fibril (9 + 0 arrangement)

Rootlets develop from the outer lower part of basal body to provide support to it. Rootlets are striated fibrilar outgrowths made of bundles of microfilaments.

Some vertebrate cells carry a single cilium which lack the central pair of microtubules in the axoneme (9+0 arrangement). These are called primary cilia. As they lack the central pair of micro filaments, they cannot beat. These cilia are involved in sensory reception. The primary cilium extending from apical surface of epithelial cells lining the kidney tubules monitor the flow of fluid in Kidney tubules and act as Mechanoreceptors. Inherited defects in their formation cause polycystic kidney disease in man. The primary cilium of olfactory neurons acts as chemoreceptor in detecting odour. The outer segments of the rod-cells in the vertebrate retina are derived from primary cilia acting as photoreceptors.

The movement or beats of cilia always involve two types of strokes - **Power stroke** and **recovery stroke** (Fig.7.27) The power stroke is by a bending motion that moves the surrounding fluid with a jerk in the direction of the stroke. As a result the cell moves in opposite direction. The bending is achieved by the length-wise sliding of microtubule doublets along each other. During the recovery stroke the cilium returns to its original position with a flexible and slow movement without causing much disturbance in the surrounding fluid medium. This action is

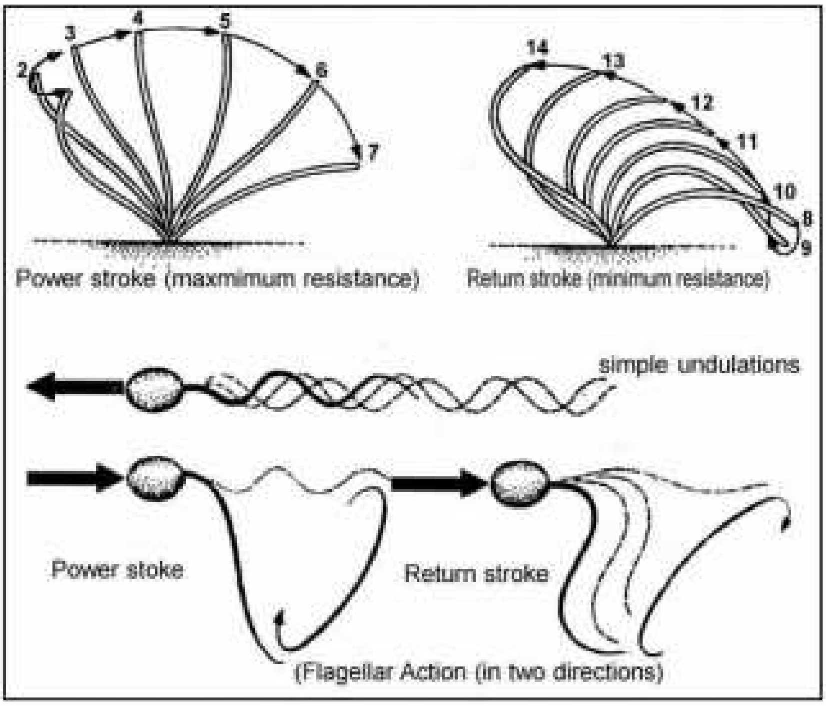


Fig.7.27 : Cilliary and flagellar movement

analogous to rowing a boat where the ores provide backward stroke that propels the boat forward and the ores are brought back to their original state by them above water. But the flagellum shows a number of simultaneous undulating waves moving up from base to tip and pulling the cell along instead of pushing it.

Functions

1. Motility: Protozoa and some have characteristic cilliary locomotion. Invertebrate larvae move in water with the help of cilia. Sperms have flagella for movement.

2. Nutrition: Fresh water mussels, rotifers, herdmania, amphioxus etc. have characteristic cilliary feeding.

3. Respiration: The activity of flagella and cilia cause water current that helps in gaseous exchange.

4. Circulation: In many annelids and starfishes, movement of coelomic fluid is facilitated by flagellar activity.

5. Excretion: Movement of material in uriniferous tubules of kidney and genital duct is aided by cilia/flagella. Cilliated cells near the oral end of sea-anemones remove undesirable particles.

6. Cillia and flagella act as sensory structures.

7.4.8. Centrioles :

T. Boweri (1888) coined the term centrosome to denote a clear region near interphase nucleus. It is present in all animal cells and in some lower plant cells like fungi, bryophytes, ferns, gymnosperms and algae (except red algae). Each centrosome consists of a pair of barrel shaped centrioles arranged perpendicular to each other. The two centrioles of each set of centrosome are known as diplosomes. Around the centrioles there is a clear area know as centrosphere. These are essentially microtubule organising centres. In animal cells (and lower plant cells) during cell division centrosomes occupy the poles, from which spindle fibres orient in different directions.

7.4.9 Nucleus :

Nucleus (pl. nuclei; L. nucleus or nuculeus- kernel) is a double-membrane enclosed organelle found in most eukaryotic cells, containing most of the cell's genetic material. It as nucleoproteins organized to chromatin, functioning to maintain the integrity and expression of the genetic materials in order to control the metabolic activities of cells and transmission of characters. Organized nucleus with a limiting membrane is absent in prokaryotic cell.

Nucleus was first described by **Franz Bauer** in 1802. But Scottish botanist **Robert Brown** in 1831 described the nucleus in detail. He observed an opaque area in the cells of outer layer of orchid flowers which he called **areola** or nucleus. In 1838 **Matthias Schleiden** suggested a possible role of nucleus in generating new cells and introduced the name **cytoblast-** meaning cell builders. Between 1876 and 1878 **Oscar Hertwig** published several papers showing that an individual develops from a single nucleated cell which is formed by the fusion of sperm nucleus with that of ovum. **Edward Strasburger** in 1884 reported the similar results in plants. The function of the nucleus in cell division and as a carrier of genetic information became clear only after the process of mitosis was discovered, and the Mendelian rules were rediscovered at the beginning of the 20th century. Presence of hereditary information inside the nucleus was demonstrated by **Joachim Hammerling** in 1953 in his experiment on single-celled alga *Acetabularia.*

Nucleus is usually central in position but in plant cells, due to the presence of a large central vacuole, it is pushed to the periphery. In green filamentous alga *Spirogyra* nucleus is suspended in the central vacuole by cytoplasmic strands. In adipocytes nucleus is peripheral and in glandular cells nucleus is basal. In a typical mammalian cell the average diameter of nucleus is 11 to 22 pi m (micrometer) and it occupies about 10% of the total volume of a cell.

There are cells which do not have nuclei and are called anucleated cells e.g. human RBC. The anucleated cells cannot divide to produce daughter cells. Mature human RBC in the young stage contains nucleus and loses the same during the process of maturation. RBC or erythrocytes undergo the process of erythropoiesis in the bone marrow where they lose nucleus and other organelles. The nucleus is expelled from an erythroblast to form reticulocytes, which is the immediate precursor of erythrocyte. Anucleated cells can also arise from defective cell division in which one daughter cell is anucleate and the other is binucleate. Natural binucleate condition of the cells is also seen in the case of a protist Paramaecium where out of the two nuclei in the cell one controls the metabolic activities and the other possess the hereditary information. Polynucleated cells contain multiple nuclei. In humans, the skeletal muscle cells called myocytes, become polynucleate during development, the resulting arrangement of nuclei near the periphery of the cell allows maximum intracellular space for myofibrils. The multinucleate condition found in fungi and plants is a result of free nuclear division without cytokinesis (division of cytoplasm) called **coenocytic** cells. Coenocyitic condition is due to the absence of septa or partition walls. Fungi like Rhizopus and algae like *Vaucheria* have coenocytic conditions.

The shape of the nucleus depends on cell type. Generally spherical in shape, nucleus can be oval or elliptical in plant cells due to the presence of large vacuole. It is disc shaped in squamous epithelial cells, irregularly branched in silk-spinning cells of insects. The surface of the nucleus is usually smooth but as in leucocytes, the surface can have infoldings giving the nucleus a lobed appearance.

ULTRA STRUCTURE The nucleus of a non-dividing yet metabolically active cell is known as interphase nucleus. Atypical interphase nucleus has five parts: **nuclear envelope, nuclear lamina, nuclear sap, chromatin and nucleolus.**

The nuclear envelope consists of two membranes, each 70-90 Å thick arranged parallel to one another and separated by a **perinuclear** space of about 10 to 50 nm. It completely

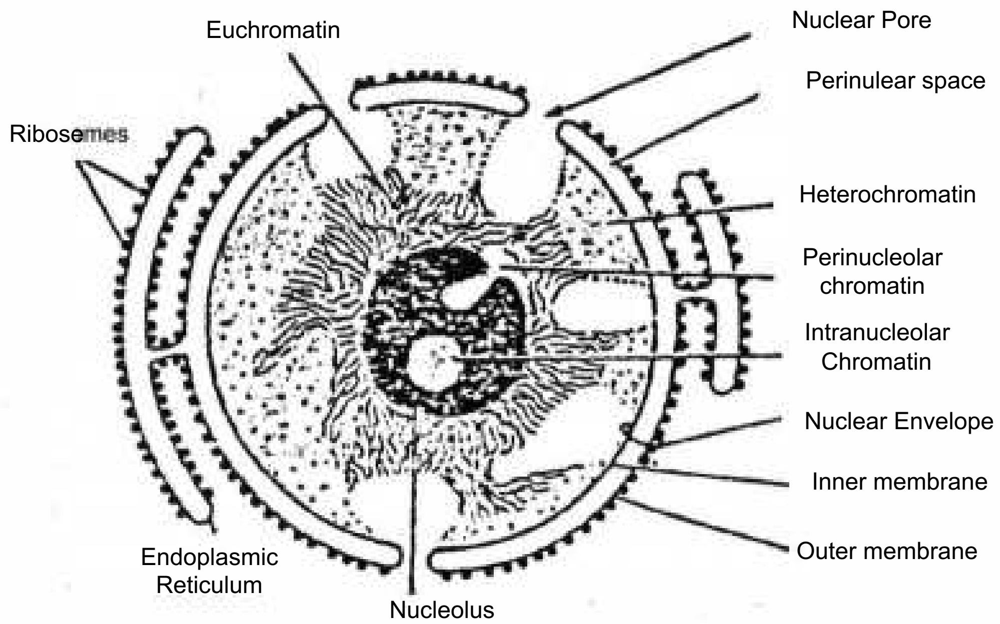


Fig. 7.28 : Nucleus

encloses the nucleus separating its contents from the cytoplasm. The outer nuclear membrane is continuous with the membrane of endoplasmic reticulum and similarly may be studded with ribosomes at some places giving it a rough appearance. The inner nuclear membrane is smooth.

A large number of **nuclear pores** or perforations present on the nuclear envelope provides for aqueous channels. These pores are composed of proteins collectively known as **nucleoporins.** The pores are about 100nm in total diameter enclosing a passage of about 9 nm wide through which the molecules freely diffuse. The central passage through the pore is reduced in width because of regulatory systems present within the centre of the pore. The pores are about 125 million Daltons in molecular weight and consist of around 50 (in yeast) to 100 proteins (in vertebrates). The nucleus of a typical mammalian cell may have about 3000 to 4000 pores on its envelope, each of which has a eightfold-symmetric ring shaped structure at a position where the inner and outer membranes fuse. Attached to the ring is a structure called **nuclear basket** that extends into the nucleoplasm, and a series of filamentous extensions that reach into the cytoplasm. Both these structures mediate binding to the nuclear transport proteins called **Karyopherins.** Most proteins, ribosomal subunits and some RNAs are transported through the pores in a process mediated by karyopherins. The karyopherins mediating movement out of nucleus is called **exportins** and those into the nucleus are called **importins.** In some cases (like mammals) the nuclear pores may have **blebs** or **annuli.** In such pores there are one central ring surrounded by eight fold peripheral symmetric ring shaped structures.

Below the envelope, the nuclear matrix forms a dense fibrous network called **nuclear lamina,** to provide structural support for nuclear envelope and anchoring sites for chromosomes and nuclear pores. It is mostly composed of **lamin** proteins. Lamin monomers form two types of intermediate filaments called **lamin A** and **lamin B,** which forms the mesh work of nuclear lamina. The lamins are also found inside the nucleoplasm where they form another structure called **nucleoplasm veil.** Here the lamin binds to chromatin. The interphase nucleus contains an intact nuclear envelope, which breaks down during cell division by the depolymerization of lamin and then reappear after nuclear division due to repolymerisation of lamins.

The **nuclear sap** or nucleoplasm is also known as **karyolymph** or karyoplasms. The interphase nucleus is filled with a homogenous, transparent, semi fluid granular, acidophilic ground substance known as nuclear sap. It contains enzymes required for synthesis and maintenance of DNA, RNA and nucleoproteins, and also some proteins essential for spindle formation during cell division. The chromatin materials are found scattered in the nucleoplasm. One or more **nucleolus** is also found in the nucleoplasm.

The nucleus contains the hereditary materials, DNA in the form of DNA- protein and RNA in thread like net work called **chromatin network** or chromatin reticulum. In 1882 **Walter Flemming** used the term 'chromatin network' for the first time as it gets stained with some basic dyes (chroma meaning colour). The composition and properties of chromatin vary from one cell type to the other, during development of a specific cell type and also at different stages

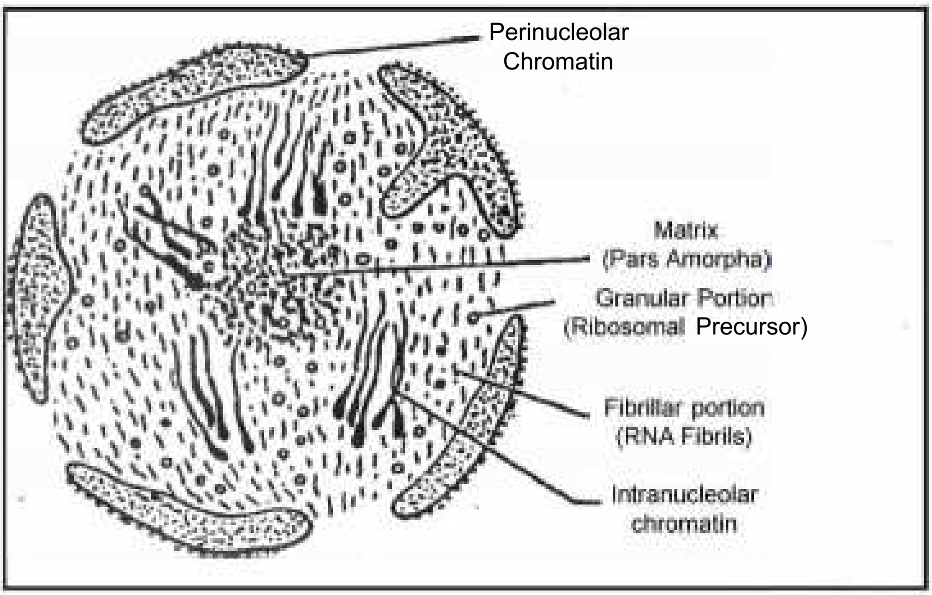


Fig.7.29 : Detailed structure of a nucleolus

of the cell cycle. Besides DNA and proteins associated with packaging the DNA within the nucleus, many enzymes are also associated with chromatin reticulum. They are the enzymes involved in DNA transcription, replication and in post translational modifications of histone proteins. Scaffold proteins encompass chromatin proteins such as insulators, domain boundary factor and cellular memory module (MMs). Inter chromatin granule clusters also known as **spicing speckles** associated with chromatin are rich in Sn RNPs (Small nuclear Ribonucleo protein) and other splicing proteins necessary for pre-mRNA processing. The chromatin fibres in the interphase nucleus are distributed throughout the nucleoplasm and are differentiated into two regions : **euchromatin** and **hetero chromatin.** Euchromatin is less compact DNA for which it stains lightly and is present in the form of diffused fibres. Heterochromatin is more compact form of DNA for which it is darkly stained and is present in condensed, granular form. The functional part of chromatin is found in the region of euchromatin to take part in transcription. The heterochromatin is further categorised into **facultative** heterochromatin consisting of genes that are organized as heterochromatin only in certain cell types or at certain stages of cell development while **constitutive** heterochromatin is found in all cell types at all stages of development. Constitutive heterochromatin form the structural components of chromosomes like telomeres and centromeres. Interphase nucleus has chromatin organized into discrete individual patches called chromosome territories and the active genes found in euchromatin regions tend to be located towards the boundary of chromosome territory.

The **nucleolus** (plural- nucleoli) is a nonmembranous, densely stained sub organelle found in the nucleus. It was first discovered by **Fontana** in 1781 and named by **Bowman** in 1940. Generally 1 - 4 nucleoli are found in a nucleus but the number can be as hig as 1600 as in the

Oocytes of *Xenopus.* They are found attached to the **nucleolar organizer region** (NOR) of the chromatin. The nucleolar organizer regions on DNA are constituted by tandem repeats for transcription of rRNA. The main role of nucleolus is to process ribosomal RNAs and assembly ribosomal components. The transcription, post-transcriptional processing and assembly of rRNA occurs in the nucleolus aided by small nucleolar RNA (Sn RNA) molecules. According to **Wilson** there are two kinds of nucleolus: **Plasmosome** - these are positive to acidic stains, have transparent exterior and dense interior and **karyosome:** these are positive to basic dyes. In some instances plasmosomes and karyosomes combine to form amphinuleoli (e.g. Molluscans eggs). Fine structure of nucleolus includes three components - **Granular portion, Fibrillar portion** and **Amorophus Matrix.**

A. Granular portion: This is the peripheral region of the nucleolus composed of granules of size 150-250 Å The granules are composed of ribonucleic acid and protein. The nucleolus is non membranous. The presence of granular portion makes the border of nucleolus distinct from surrounding chromatin and nucleoplasm.

B. Firbrillar portion: This is also known as nucleolonema. Fibrils of ribonucleoproteins of size 40 to 80 Å form a fine network. The number and size of the fibrillar components varies with cellular activity and ribosome production.

C. Amorphous matrix: This is the electron dense, amorphous ground substance of nucleolus. The matrix is first to disappear at the time of cell division. This region is also known as pars amorpha.

Recent studies have indicated additional functions of nucleolus like

- Trafficking of various small RNAs
- Regulation of cell cycle
- Interaction with viral components
- Regulation of tumor suppressor and oncogene activities
- Assembly of signal recognition particles.
- Control of ageing and modulating telomerase function.

Chromosome

Chromosomes (Gk. Chroma - colour, soma - body) are the deeply stained condensed from of chromatin fibers formed during nuclear division. They are the bearers of hereditary materials or genes. The name was given by German anatomist **Heinrich Von Waldeyer** in 1888. The chromosomal behavior in animal cells (Salamander) was described by **Walter Flemming** in 1882. The chromosomes in their true sense (i.e. DNA complexed with histone proteins) are found only in eukaryotic cells. Naked DNA (devoid of histone) found in prokaryotes and RNA / DNA in viruses are also sometimes referred to as prokaryotic and viral chromosomes respectively because of functional similarity.

The number of chromosomes per cell in eukaryotes varies from 2 *(Ascaris)* to more than thousand (1600 in *Aulacantha* - a haploid protozoa). But the chromosome number is generally fixed or constant for a species. The chromosomes are found in single set in haploid forms and two sets in diploid forms. Diploid organisms having two sets of chromosomes produce gametes (sperm and ovum) with only one set of chromosomes. The haploid set of chromosome number is referred to as **'n'** and the diploid set of chromosome number is referred to as **'2n'.** In diploid cells each of the the chromosomes in the haploid set finds a partner or homologue in other set. The homologous pair of chromosomes are identical in size and carry identical or similar genes in the corresponding positions or loci. The general morphology of a set of chromosomes is known as **Karyotype** and its diagrammatic presentation is known as **idiogram.**

During interphase the chromosomes are present in the nucleus as fine threads and their shape is not clearly visible under light microscope. However, during cell divisions the chromosomes are distinctly visible as the fine thread like chromatins get condensed to shorter and thicker structures.

Gross Morphology: The metaphasic chromosome consists of two halves or **chromatids.** The two chromatids are actually two daughter chromosomes yet to be separated. During cell division each chromosome replicates into two and form two chromatids held together at a point called **centromere** or **primary constriction** (Fig-7.12)

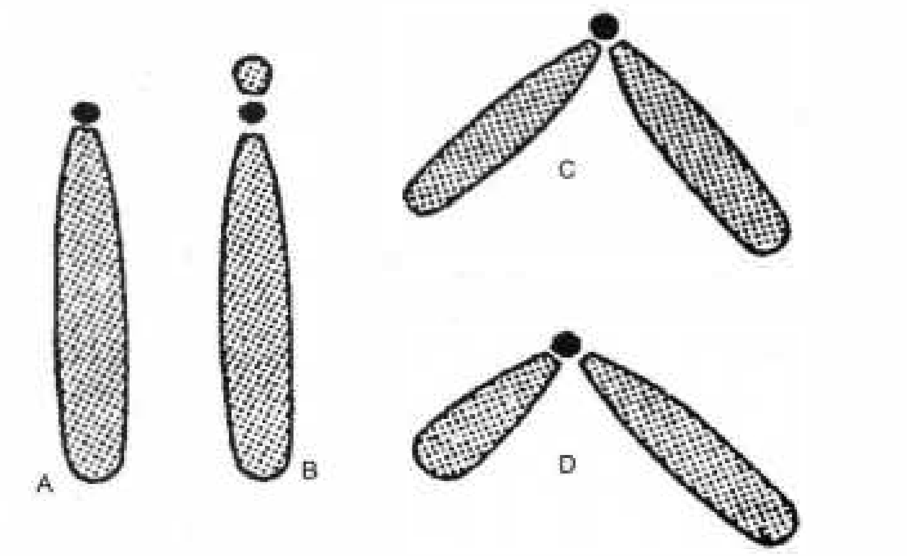


Fig 7.30 : Chromosome shape:
A. Telocentric, B. Acrocentric, C. Metacentric, D. Submetacentric

* Telocentric chromosomes are rarely found in the plants. Mark (1957) considered them as unstable chromosomes causing genetic imbalance.

The two chromatids separate into two poles during anaphase (next to metaphase). The centromere or the primary constriction has a darkly staining granule surrounded by a relatively clear region. Spindle fieres formed during cell division attach to the chromosomes at a specialized structure in the centromere called **kinetochore.** Usually there is one centromere in a chromosome (chromosome is monocentric). But di-or polycentric chromosomes are also there in some species. Basing on the position of centromere, **four types** of chromosomes are found (fig.7.11). They are **metacentric** with centrally located centromere, **submetacentric** with centromere being one sided resulting in two unequal chromosome arms ; **acrocentric** when the centromere is close to one end of the chromosome; **telocentric*** with terminal centromere. Chromosomes may also be **acentric** with complete absence of centromere.

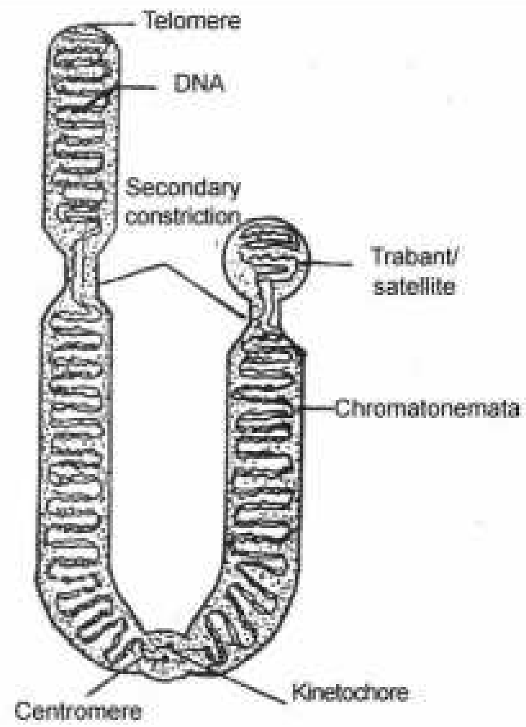


Fig 7.31 : Structure of a typical somatic chromosome at anaphase.

When the two arms of chromosomes are equal as in metacentric chromosome it is said to be **isobrachial** and otherwise it is **heterobrachial.** Some chromosomes may possess an additional constriction called **secondary constriction.** Often, the chromosomes bear a small fragment or rounded body separated by secondary constriction called **satellite** or **trabant.** These satellite regions are without **thymonucleic** acid (Sine Acedo Thymonucleirico=SAT). The secondary constrictions are associated with ribosomal RNA synthesis that induces the formation of nucleolus. Hence this region is also called **nucleolar organizing region.**

The tips of the chromosome are called **telomeres.** Telomeres stabilize the chromosome. Yeast telomere is about 100 base pair long and is constituted by repeated sequences of DNA. According to classical cytogeneticists each chromatid is constituted by very thin and highly coiled subunits called **chromonemata.** Cytologists observe the presence of certain bead-like structures formed due to accumulation of chromatin material which are visible along the entire length of the chromonema. These are called **chromomeres** and are believed to be the regions representing genes. Contrary to the observations made under light microscope by classical workers a chromosome is actually formed by direct condensation of a single chromatin.

Chemical composition

Chemically eukaryotic chromosomes are DNA associated with some amount of RNA and proteins. The DNA-protein ratio is almost 1:2. Out of the proteins 70% are the **basic**

histone proteins and rest is **acidic non-histone proteins.** The histone proteins interact specifically with each other and with DNA to give it a compact packaging. The non-histone proteins that are found associated with chromatin fall into several functional categories like :

- chromatin-bound enzymes
- high mobility group (HMG) proteins
- transcription factors
- Scaffold proteins.
- Transition proteins (testis specific proteins)
- Protamines (present in mature sperm).

Unlike most other proteins which have an overall negative charge, the histones have positive charge, owing to an abundance of basic amino acids viz., arginine and lysine.

NUCLEOSOME CONCEPT

The DNAs in eukaryotic chromosomes are very large molecules. Atypical human DNA is 1.4 x 10^{o} nucleotides (about 1100 Micrometer) long. This DNA is to be accommodated in a functional state inside a cell which is much less in linear dimension than the DNA. Further, in one eukaryotic cell there may be more than one chromosomes. This requires proper packaging of DNA inside the chromosome in such a way that the DNA is not only in a compact state but also remains functional. This is achieved by compacting of DNA with the help of histone proteins into repeating units of **nucleosomes. Roger Kornberg** gave the concept of nucleosomes in 1974. According to this concept five major types of histone proteins are found in eukaryotes. They are H_1, H_2A, H_2B, H_3 and H_4. Two molecules each of H_2A, H_2B, H_3 and H_4 together form an octamer called as the **core** of the nucleosome or **core particles** or **Nu-bodies.** A DNA fragment of the about 146 base pair wrap around the core 1.75 times and one molecule of H1 associate with it at the point where the wrapping DNA strands emerge forming a **chromatosome.** The entire DNA molecule is thus arranged into repeating units of nucleosomes looking like a chain of beads under electron microscope. The gap between two repeated units of nucleosomes has about **200 base pair** long DNA known as **linker DNA.** According to **A. Klug** (Nobel Prize winner, 1982) this chain of nucleosomes is coiled into cylindrical **solenoid fibril** of 10nm.having about six nucleosomes per turn. This is further coiled to **super solenoid of 30nm** that represents the interphase chromatin. The chromonema as observed under light microscope is actually the 30nm fibril. During metaphase when the chromatin condenses to chromosome the 30nm fibrils are more compactly arranged by radial looping of super solenoids into rosettes around a preexisting scaffold protein (fig-7.33, 7.34).

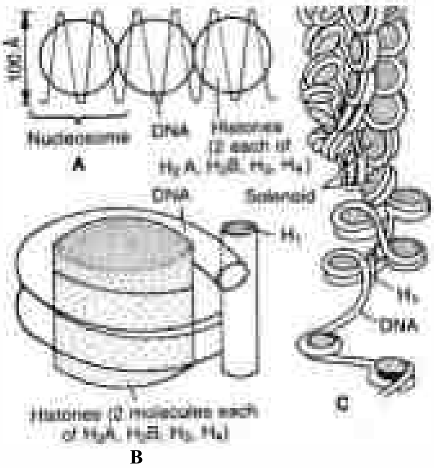


Fig. 7.32 : Chromosomal organization A.Nucleosome units, B. Nucleosome, C. Solenoid model

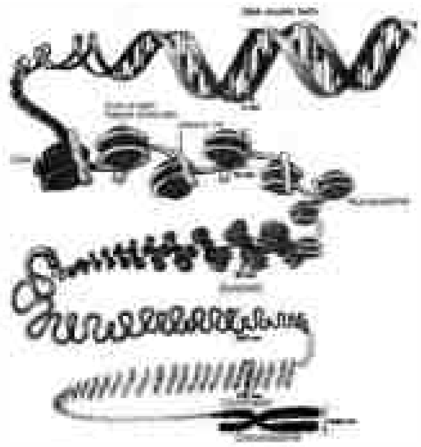


Fig. 7.33 : Various steps in folding and packaging of the chromatin.

Sex *Chromosome*

Sex chromosome provide chromosomal basis of sex determination in animals. There is thus sexual dimorphism in animals. They are also called allosomes, and, other chromosomes present along with allosomes but do not determine sex are called autosomes. Two types of sex chromosomes are found: X and Y. These two sex chromosomes differ in shape, size, DNA content and sedimentation rate. In birds and lepidopteron they are called Z and l/IZ

Giant Chromosomes:

There are two types of giant chromosomes: (Polytene choromosomes: and lamp brush chromosomes). Polytene chromosomes otherwise called salivary chromosomes are commonly found in the salivary glands of insects. They are also found in antipodal cells (embryo sac), endosperm and suspensor cells of embryo. These chromosomes can reach a length of 2000pm and can contain 1000 times more DNA than that of normal chromosomes. These chromosomes are the result of repeated DNA replications without separation of daughter DNA molecules. They can also be formed by somatic pairing of homologous chromosomes. Lamp brush chromosomes occur in most oocytes and in alga like Acetabularia. These chromosomes occur in pairs giving out lateral projections or loops giving them the appearance of lamp brush. They are actually specially synapsed deplotene bivalents.

SAMPLE QUESTIONS

A. FILL IN THE BLANKS :

1. ----------is the cytoplasmic organelle, responsible for cellular respiration.
2. ----------proposed the unit membrane concept.
3. ----------is the largest cytoplasmic organelle in plant cell.
4. ----------is the smallest cytoplasmic organelle.
5. ----------is a vesicle containing digestive enzymes found in a cell.
6. Intracellular digestion is associated with-------------------
7. ------------maintains the cytoplasmic continuity between neighboring cells.
8. Singer & Nicholson proposed the-------------------- model for plasma membrane.
9. Presence of DNA in chloroplast and mitochondria make them-------------------
10. Colored plastids found in flowering plants are known as------------------------
11. A chromosome lacking a centromere is--------------------------
12. Prokaryotic cells contain------------- ribosomes.
13. Histone proteins are----------by nature.
14. The portion of DNA between two repeating units of nucleosomes is known as----------------DNA.
15. When two solutes move across the cell membrane in opposite directions the transport is known as-------------------------

B. MULTIPLE CHOICE QUESTIONS :

1. Which one of the following organelles is without membrane envelop?

   a. Golgi complex b.ribosome c. peroxisome d. tonoplast
2. The fingures of cork cells as seen by Robert Hooke were phblished in his book

   a. origin of species b. plant kingdom c. genera plantarum d. micrographia
3. Prokaryotic cell is that which has

   a. premitive nucleus b. true nucleus c. two nuclei d. four nuclei
4. Which of the following cells does not contain a nucleus

   a. yeast b. nerve cells c. mature WBC d. mature RBC
5. Protein and RNA are the principal constituents of

   a. ribosome b. chromosome c. endoplasmic reticulum d. peroxisome.
6. 70s ribosomes are found in

   a. mitochondria and bacteria b. mycoplasma and eukaryotic cell c.RBC and WBC d. epidermal cells and hepatic cells.

7. Which of the following cell organelles is bound by a single unit membrane?

   a. Golgi apparatus b. chloroplast c. mitochondrion d. lysosome

8. Which of the followings is the site of steroid synthesis/

   a.rough endoplasmic reticulum b.ribosomes c. smooth endoplasmic reticulum

   d. mitochondrion

9. The physical basis of life is

   a.nucleus b.protoplasm c. cell d. food

10. Every living cell possesses

    a. chloroplast b. cell membrane c. cell wall d. food vacuole.

11. The chemical substance most abundantly present in the middle lamella is

    a. lignin b. suberin c. chitin d. pectin.

12. The latest model proposed to explain the structure of plasma membrane is

    a. molecular model b. sandwich model c. unit membrane model d. fluid-mosaic model.

13. The peripheral proteins can be easily removed from the membrane by

    a. the action of detergent b. solutions of high ionic strength.

    c. keeping them in buffer d. enzyme action.

14. Tonoplast is a differentially permeable membrane surrounding

    a. cytoplasm b. mitochondrion c. vacuole d. nucleus

15. F1 particles are present in

    a. chloroplast b. mitochondrion c. dictyosome d. nucleus.

16. Double membrane is absent in

    a. nucleus b. chloroplast c. mitochondrion d. lysosome

17. Polyribosomes are aggregation of

    a. ribosomes on r-RNA b. only r-RNA c. peroxisomes d. ribosomes on m-RNA

18. Ribosomes are attached to ER through

    a. ribophorins b. r-RNA c. t-RNA d. hydrostatic force

19. The cytoplasmic ribonucleoprotein that binds to free ribosomes so that protein synthesis stops till ribosomes get associated with ER is known as

    a. SPR b. SRP c. PRS d. PSR

20. Lysosomes are called "suicidal bag" because they have

    a. hydrolytic enzymes b. parasitic activity c. anabolic enzymes d. oxidizing enzymes

21. In plant cells the vacuole contains

    a. gases b.vacuum c. dissolved minerals d. only water

22. ATP, the energy currency of cell, is synthesized mostly in

    a. ribosomes b. mitochondria c. lysosomes d. nucleus

23. Ribosomes are made up of

    a. RNA and DNA b. DNA and proteins c. RNA and proteins d. RNA alone

24. When green tomatoes turn red

    a. chromoplasts change to chloroplasts b. chloroplasts change to chromoplasts

    b. new chromoplasts are synthesized d. new chloroplasts are synthesized

25. Thylakoids are seen in the plastids of

    a. higher plants b. bacteria c. algae d. blue green algae

26. Foldings of inner mitochondrial membrane are called

    a.cristae b. grana c. sacs d. dictyosomes

27. Ribosomes of prokaryotes are of

    a. 30s type b. 50s type c. 70s type d. 80s type

28. If the ribosomes of a cell are destroyed or blocked, then

    a. respiration will stop b.digestion will stop c. reproduction will stop

    d. protein synthesis will stop

29. Site of formation of immature ribosomal sub-units in eukaryotic cell is

    a. cytoplasm b. nucleus c. nucleolus d. nuclear pore complex

30. The main function of Golgi complex is

    a. translocation b. fermentation c. protein glycosylation d. phosphorylation

31. peroxisomes contain

    a. transferase enzymes b. hydrolytic enzymes c. isomerase enzymes d. oxidizing enzymes

32. Nucleoli are rich in

    a. DNA and RNA b. DNA, RNA and proteins c. DNA d. RNA

33. Nucleus was first discovered by

    a. Leewenhoek b.Schwann c. Robert Brown d. Robert Koch

34. Microtubules are made up of

    a. myosin b.actin c. tubulin d. globulin

35. Centromere is a part of

    a. ribosome b. chromosome c. spherosome d. glyoxisome

36. Chromosomes with equal arms are called

    a. submetacentric b. polycentric c. acentric d. metacentric

37. The hydrophobic chemicals like pesticides and carcinogens are detoxified by enzymes found in

    a. a.mitochondrion b. lysosome c. Golgi d. SER

38. Which of the followings is a prokaryote

    a. Agaricus b. Salmonella c. Volvox d. Saccharomyces.

I. Differentiate between

1. cell wall and plasma membrane
2. chloroplast and mitochondrion
3. cilia and flagella
4. cytoplasm and karyolymph
5. leucoplast and chloroplast
6. chromatin and chromosome
7. nucleus and nucleolus
8. SER and RER
9. intrinsic proteins and peripheral proteins
10. primary cell wall and secondary cell wall

II. Write notes on:

Cellwall, Mitochondrion, Plastids, Ribosome, ER, Golgi complex, Lysosome, Vacuole, Flagella, Nuclear pore, Microtubules, Nucleosome, Unit membrane cocept

C. LONG ANSWER TYPE QUESTIONS :

1. What are chromosomes? Describe their structure and functions.
2. Explain the fluid-mosaic model of plasma membrane with suitable diagrams.
3. What are organelles? Give an account of principal organelles of a cell and mention their functions.
4. What are the different types of plastids seen in plants? Describe the structure and function of chloroplast.

CHEMICAL CONSTITUENTS OF LIVING CELLS

CHAPTER S

BIOMOLECLUS :

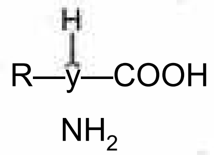
Cell is the basic structural and functional unit of organism. As described earlier cell is a self contained unit. Every cell has the necessary metabolic machinery to meet its requirements. Inspite of a great diversity among the living organisms, the construction pattern and the metabolic activities of all kinds of cells are remarkably similar. Components of all kinds of cells are made up of almost of the same six elements (C,H,O,N,P & S). About 5% of cellular materials also consist of non-metals like chlorine, iodine and metals like calcium, phosphorus, sulphur, potassium, sodium, magnesium and iron, which are known as *minor elements.* Carbon, oxygen, hydrogen and nitrogen are called *major elements.* Other non-metals like silicon, boron, fluorine, selenium and metals like copper, zinc, cobalt, molybdenum, chromium and aluminium are present in very small amount and are known as *trace elements.* All the chemical compounds, ions and elements together constitute the cellular pool. In the cellular pool, the chemicals occur in aqueous and non-aqueous phases. In the aqueous phase soluble molecules like starch, amino acids, fatty acids and inorganic salts form transparent homogeneous solution. Other molecules like starch, proteins, nucleic acids etc. form colloidal solution. The non-aqueous phase contains mainly the organic molecules, such as components of plasma membrane, cell-wall and cell organelles. Depending upon their size, molecular weight and solubility, the constituents of cellular pool are divided into *micromolecules* and *macromolecules.* The micro-molecules are of small size, low melocular weight and high solubility. These include water, minerals, sugars and amino acids. The macromolecules are of larger size, high molecular weight and have relatively less solubility. They are formed by the polymerization of micromolecules. Polysaccharides, lipids, proteins and nucleic acids are the common macromolecules. The cell inclusions or ergastic substances or deutoplasmic substance include the reserve or storage substances, secretory substances and excretory substances.

8.1. PROTEINS:

Proteins are polymers of aminoacids. Amino acids are linked covalently by peptide bonds to from a polypetide and one or more polypeptides fold appropriately to form protein. In early 1950s, Frederick Sanger for the first time sequenced the insulin protein and then it became clear that in a particular polypeptide, amino acids are arranged in specific sequence. All proteins have well defined three dimensional structures or conformations. The conformation of a protein is very important as it determines the protein function.

8.1.1. AminoAcids:

Amino acids are an important group of organic acids having both an acidic carboxylic group (-COOH) and a basic amino (-NH_2) group.



Fic.8.1 : General structure Qf gn Amjno Acjd

The first carbon atom of an aminoacid is the part of carboxyl group and the second carbon atom is known as *a* -carbon (alpha- carbon) to which the four different groups are attached :

1) One hydrogen atom

2) One -COOH group with a potential negative charge ($-COO^-$). The carboxylic group is responsible for the acidic property of amino acids.

3) One $-NH_2$ group with a potential positive charge ($-NH^+{}_3$). Proline is an aminoacid where the amino group is not free but a part of a ring structure, hence it is referred to as imino acid.

4) A variable side group (-R) that is different in different amino acids. In glycine, R is only an hydrogen atom (H), and in alanine the R is a methyl group ($-CH_3$). Hence glycine having the simplest R-group is the simplest amino acid. In other amino acids the R-group may be a straight or branched chain or a cyclic group.

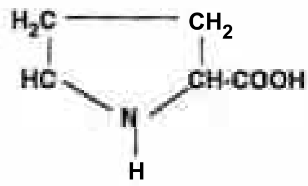


Fig.8.2 : Proline

The side chain further, may be polar (as in serine, glutamic acid) or non-polar (as in alanine).

Except glycine, in all other amino acids four different groups are attached to the oc-carbon atom making the a-carbon asymmetric. Because of the a symmetric a-carbon all amino acids except glycine exists in two optically active froms : those having $-NH_2$ group to the right are designated as D-forms and those having $-NH_2$ group to left are L-forms.

Out of the many kinds of naturally occuring amino acids, only 20 different types of amino acids and amides are found as constituents of proteins. Certain proteins also contain some modified amino acids derived from the 20 standard amino acids. These derived amino acids are known as non-standard amino acids. Hydroxyproline (derived from proline) and hydroxylysine (derived from lysine) are non-standard amino acids found in high percentage in collagen (an important structural proteins of animals).

The standard twenty amino acids found in proteins are grouped into seven different categories.

1. Aliphatic amino acids : The hydrocarbon chain (R-group) is neutral, nonpolar as in glycine, alanine, valine, leucine, isoleucine.

2. Hydroxy amino acids : The side chain having -OH group as in Serine, Threonine.

3. Sulphur containing amino acids: The side chain having sulphur group as in cystine, methionine.

4. Dicarboxylic amino acids and amides : The side chain has extra carboxylic group as in glutamic acid and aspartic acid. They are also known as acidic amino acids. These amino acids also exist in their respective amide forms such as glutamine and asparagine.

5. Basic amino acids : They have an additional amino group without forming amides. These amino acids are diamino-mono carboxylic acids. Examples of such amino acid are lysine, arginine and histidine.

6. Aromatic amino acids : They have a cyclic structure with a straight chain bearing carboxylic and amino groups. Examples of such amino acids are Phenylalanine, tyrosine, tryptophan.

7. Heterocylic amino acid : Here the nitrogen group is in the ring structure, ex- proline.

There are about 300 additional natural amino acids which are not found as constituents of proteins but have some other roles in metabolism. These are known as non-protein amino acids. Some examples of non-protein amino acids are :

L- ornithine and L-citrulline are metabolic intermediates in urea-cycle.

P - alanine, an isomer of alanine, occurs free in nature and also as a constitutent of an important vitamin pantothenic acid and of co-enzyme A.

Functions

1. They are building blocks of proteins (both structural proteins and enzymes).
2. They serve as storage of nitrogen in the form of amides.
3. Amino acids like p -alanine takes part in the formation of vitamin pantothenic acid and co-enzyme A.
4. Glycine, cysteine and glutamate form the co-enzyme glutathione.
5. Surplus amino acids are deaminated in liver to organic acids, which in turn are changed to glucose (gluconeogeneiss) or used in metabolism.

Peptide Formation

A peptide formation occurs due to a condensation reaction between the carboxylic (-COOH) group of one amino acid and amino (-NH_2) group of another amino acid with the elimination of a water molecule. This peptide bond is actually an amide bond of about 0.132 nm. Upon hydrolysis a peptide yields equal number of amino and carboxylic groups. A peptide may be a dipeptide having only two amino acids or tripeptide having three amino acids and so on. If there are a few amino acids in a peptide chain it is known as oligopeptide and if there are many amino acids the peptide chain is a polypeptide. A peptide chain has an amino group at one end which is knwon as amino terminus or N-terminus. At the other end it has a carboxylic group and the end is known as carboxylic terminus or C-terminus.

Peptides participate in a number of biological activities :

1) In protein formation
2) As constituents of a group of compounds known as alkaloids
3) Serve as growth factors (ex- folic acid)
4) Peptide hormones are found in higher animals
5) Peptides like glutathione act as co-enzyme

8.1.2. Levels of Protein Structure :

Traditionally, it is considered that proteins have four levels of structural organisation: primary, secondary, tertiary and quaternary. With the increasing informations available about proteins two additional levels of structures have been distinguished by molecular biologists : motifs and domains.

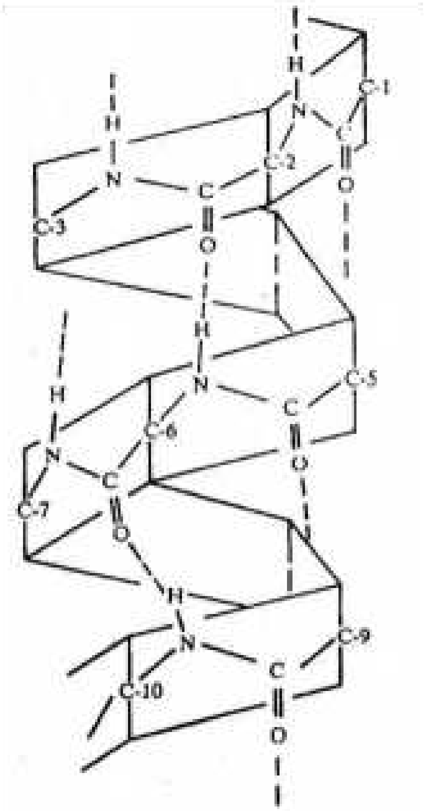


Fig.8.3 :The right handed α helix

Primary Structure :

It is the specific linear sequence of amino acid residues making up a polypeptide chain. The sequence of amino acids is determined by the nucleotide sequence of the gene that encodes the protein. Only peptide bonds are associated with the primary structure.

Secondary Structure

Secondary structure results from the hydrogen bonding between the aminoacids of polypeptides. Two patterns of hydrogen bonding occur in proteins. In one pattern, hydrogen bonds are formed along a single polypeptide chain, linking one amino acid to another, which is four amino acids down the chain. This tends to pull the chain into a coil, called alpha (a) helix. In another pattern, hydrogen bonds are formed between amino acids across two chains. Often many chains are linked in this pattern, forming a pleated sheet like structure called beta (P) sheet. The two chains may be oriented in a parallel or antiparallel manner forming parallel p-pleated sheets and antiparallel p-pleated sheets respectively.

Tertiary structure :

Tertiary structure results from extensive folding of polypeptide chain into a complex, rigid and globular structure. Most secondary structures fold compactly due to interactions between amino acid residues present far apart. Ionic bonds between oppositely charged side groups bring region into close proximity. Hydrogen bonds, hydrophobic interactions and disulfide linkage also lock particular regions of proteins together.

Quaternary structure :

When two or more polypeptide chains associate to form a functional protein, a quaternary structure results. Here, each polypeptide in known as a subunit (protomer). When the subunits are identical, the structure is homogenous. Enzyme phospholipase has two identical subunits but each sub unit alone is catalytically inactive. It is only when two subunits are joined as a dimer, a functionally active enzyme is formed. Hemoglobin, is composed of four subunits; two alpha (a) subunits and two beta (P) subunits. In proteins with such quaternary/subunits structures, the interfaces where the subunits contact one another are often nonpolar. These, interfaces play key role in coordinating the activities of subunit. Loss or change of activity in one of the subunits can have profound effect on the protein's functioning. In sickle cell hemoglobin a mutation alters only one amino acid of the subunit which results in hemoglobin molecules to stick to one another resulting in sickle cell anemia.

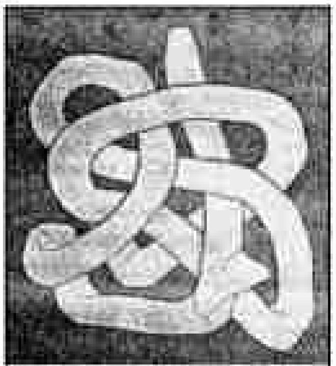


Fig.8.4 : Globular protein

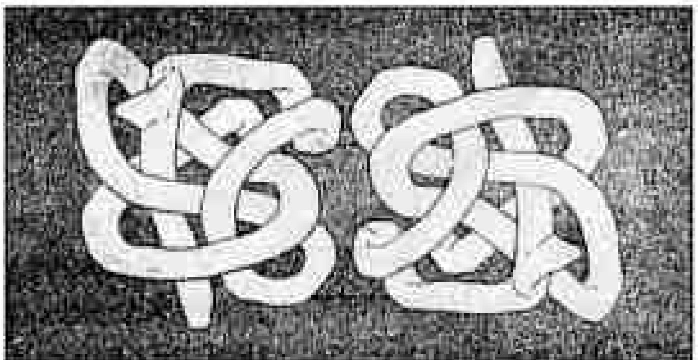


Fig. 8.5 : A quaternary structure illustrated by two interacting polypeptides (protomers)

Motifs

In a protein the elements of secondary structure sometimes combine in characterstic ways called motif or "super secondary structure". The motifs are specific regions on proteins to bind to other structures such as nucleic acids.

Domains

Many proteins are encoded in sections by different exons. These sections typically of 100 to 200 aminoacids long encoded by different exons fold into structurally independent functional units called domain. As the polypeptide chain folds, the domains fold into their proper shape, each more or less independent of the others. Often the domains of a protein have quite separate functions. For example, one domain of an enzyme many bind to a cofactor, while the other to the substrate.

8.1.3. Classification of Proteins

Classification based on the source of proteins: Traditionally proteins are divided into animal proteins and plant proteins depending on the sources from which they are obtained. Animal proteins are considered betten than the plant proteins for human nutrition.

Classification based on the shape of protein : On the basis of shape of the protein molecule there are two broad categories : globular protein and fibrous proteins.

Globular proteins

These are extensively folded and compact polypeptide possessing a relatively spherical or ovoid shape. The globular proteins have axial ratio (length : width) of less than 10 (usually 3 or 4). They are usually soluble in water or aqueous media containing acids, bases, salts or alcohol and diffuse readily. Almost all enzymes, protein hormones, blood transport proteins, antibodies and nutrient storage proteins are globular proteins.

Fibrous proteins :

These proteins consist of long chain polypeptides held in groups by several forces like intra-chain and inter-chain hydrogen bonds, disulfide bridges etc. They have axial ratio greater than 10 and resemble long ribbons or fibres in shape. They are mainly of animal origin and insoluble in all common solvents such as water, dilute acids, alkalies and salt solutions. They serve as structural or protective proteins. **There are three different conformations :** (a) a-keratin, (b) p-keratin and (c) collagen.

(a) a-Keratin (alpha keratin) : These are ectodermal proteins; form the major constituents of epithelial tissues like skin, hair, feathers, horns nails, fur, claws etc. It consists mostly of right handed a-helices. Each helix is stabilized by intra-chain hydrogen bonds and inter-chain di-sulfide bridges. These proteins, therefore, contain large amounts of sulfur in the form of cysteine amino acids. Human hair has about 14% cysteine.

(b) P-Keratin (beta-keratin): It is found in silk fibre. Here, many parallel popypeptides are held by inter-chain hydrogen bonds. Individual polypeptide are almost completely stretched without any intra-chain hydrogen bonds. Hence the polypeptides form pleated p -sheet. The adjacent polypeptides may run in the same directions with their N-terminus and C-terminus on same sides or in opposite direction. Accordingly they are termed as parallel or antiparallel p -sheets.

(c) Collagen: These are mesenchymal in origin and form the major protein components of white connective tissues (tendons, cartilage) and bone. They contain three left-handed helical polypeptides, wound round each other forming a right handed triple helix. More than half of the total proteins in mammalian body is collagen. When acted upon by boiling water, dilute acids or alkalies produce soluble gelatins. These are rich in hydroxyproline and poor in sulfur.

Classification based on composition :

There are two groups of proteins basing on the composition.

Simple proteins :

Proteins made exclusively of amino acids. No non-protein structure forms a part of the protein. Majority of structural proteins and peptide hormones are simple proteins.

Conjugate proteins :

Functional proteins having non-protein components associated with them are known as conjugate proteins. The non-protein part is essential for the functioning of the protein. Most of the regulatory enzymes are conjugate proteins. Other examples are glycoproteins, lipoproteins, phosphoproteins and metallo proteins.

Functions :

1. Structural proteins constitute the body of living organism. It forms the bulk of intra-cellular and extra-cellular materials.
2. Specific proteins characterise specific cell types. For example actin and myosin characterise muscles cells.
3. Structural, enzymatic and carriers proteins are the constituents of biological membrances.
4. Cell surface proteins help in cell to cell interaction and tissue formation.
5. Some cell surface proteins act as signal receptors to coordinate cellular activities in multicellular organisms.
6. Many peptide hormones regulate growth and metabolism.
7. Proteins like immunoglobin are involved in antigen-antibody reactions.
8. Biocatalysts or enzymes are mostly proteins.

9. Proteins like tubulin, actin, **ankyrin and spectrin** are involved in the formation of cytoskelaton.

10. Histone proteins are responsible for packaging of DNA.

8.2. CARBOHYDRATES:

Carbohydrates are polyhydroxy aldehydes or ketones and the compounds derived from these. These are compounds of carbon, hydrogen and oxygen atoms. The simplest forms of carbohydrates have the empirical formula $C_n(H_2O)_n$ where 'n' is a number. This formula indicates as if the simplest carbohydrates are hydrates of carbon and hence the name is carbohydrates. But, some carbohydrates do not have this empirical formula. Carbohydrates are otherwise known as saccharides meaning sugar (derived from Greek- saccharon; Latin- saccharum; Sanskrit- sarkara).

Broadly, carbohydrates are classified into three categories : (i) monosaccharides, (ii) oligosaccharides, and (iii) polysaccharides.

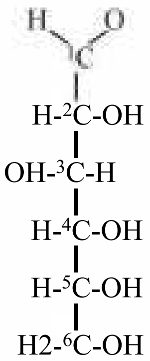
(i) Monosaccharides

These are the simplest carbohydrates with single polyhydroxy aldehyde (aldose) or ketone (ketose) units each. They cannot be further hydrolyzed into simpler monosaccharides. Glucose is a single polyhydroxy aldehyde or aldose while fructose is a single polyhydroxy ketone or ketose. The minimum number of carbon in a monosaccharide is three and it can go upto seven. They have the empirical formula of $C_n(H_2O)_n$. The monosaccharides are named as trioses, tetroses, pentoses, hexoses and heptoses depending on the presence of three, four, five, six or seven carbon atoms respectively. Depending on the number of carbon atoms and types of functional group (aldehyde/ketone) monosaccharides can be named as aldohexose (glucose) or keto hexose (fructose), aldotriose or ketotriose, aldopentose or ketopentose etc.

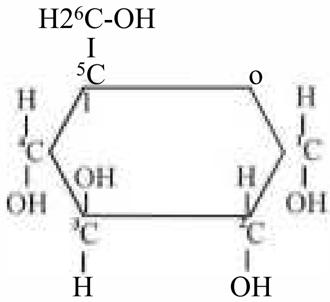
Sl. No.	No. of carbon atoms	Name based on no. of cabron atoms	Name of the Monosaccharides		
			Aldehyde form (Aldose)	Ketone form (Ketose)	Empirical Formula
1.	3	Triose	Glyceraldehyde (Aldotriose)	Dihydroxyacetone (Ketotriose)	$C_3H_6O_3$
2.	4	Tertrose	Erythrose (Aldotetrose)	Erythrulose (Ketotetrose)	$C_4H_8O_4$
3.	5	Pentose	Ribose (Aldopentose)	Ribulose (Ketopentose)	$C_5H_{10}O_5$
4.	6	Hexose	Glucose (Aldohexose)	Fructose (Ketohexose)	$C_6H_{12}O_6$
5.	7	Heptose	—	Sedoheptulose (Ketoheptose)	$C_7H_{14}O_7$

The hexose sugars are generally sweet in taste and crystalline in structure. Fructose, a ketohexose is the sweetest sugar and is also known as fruit sugar as it is commonly found in fruits except a few like grapes. Grapes contain glucose; hence glucose is known as grape sugar (also as blood sugar as it occurs in blood). Fructose is also found in nectar and honey. Similarly glucose is found in corn and is known as dextrose. Fructose is known as levulose.

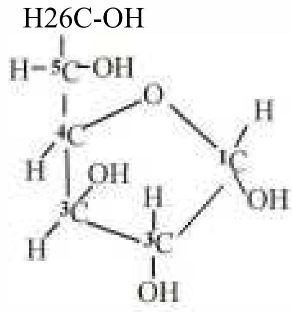
The pentoses and hexoses can exist either in open chain structure or in ring structure. Two types of ring structure are common with pentoses and hexose : These are pyranose from and furanose form. Pyranose has a six membered ring with five carbon atom and one oxygen atom. The furanose form has five membered ring with four carbon atoms and one oxygen atoms. The rest of the carbon atoms remain out side the ring.



Open chain structure of glucose



Gluco-pyranose



Gluco-furanose

In solution the pyranose forms of sugars are more stable than the fruranose forms.

Isomerism

Isomers are compounds having same molecular formulae but different molecular structures. Monosaccharides show isomerism. The presence of an asymmetric carbon atom (a carbon atom to which four different groups or atoms are attached) make possible the formation of isomers of a compound. The isomers are of two types : structural isomers and sterioisomers.

Structural isomers have same molecular formula but different structures due to difference in chain lengh (chain isomers), position of substituent groups (positional isomers) or different functional groups. Glucose and fructose are structural (functional) isomers as both have same molecular formula ($C_6H_{12}O_6$) but have different functional groups, aldehyde and ketone respectively.

Sterioisomers have same molecular formula, same structures but differ only in spatial configuration. Optical isomers are one type of stereoisomers where the isomers appear as mirror image of each other around the asymmetric carbon atom.

In glyceraldehyde the carbon atom number two is asymmetric. In D-glyceraldehyde the OH-group is to the right side and H-group is to the left. In L-glyceraldehyde the OH-group is to the left of the asymmetric carbon atom and H-group to the right. But there are sugars with two or more asymmetric ccarbon atoms. In that case the orientation of - H and -OH group around the lowermost asymmetric carbon atom (the penultimate carbon atom) is considered for determination of D- and L-forms. These D-and L-forms are called enantiomers. The majority of monosaccharides found in human body are D-type. Some sugars do occur naturally as L-forms such as L-arabinose. The possible number of optical isomers formed by a monosaccharide depend upon the number of asymmetric or chiral carbon atoms. Glucose has 4 asymmetric carbon atoms hence can have 2^4 or 16 number of optical isomers. But in all these enantiomers the D and L forms are designated depending upon the orientation of -H and - OH group around 5th carbon atom. So it will have 4x2 = 8 enantiomers.

```
    H
    I
   iC- O
    I
H-²C-OH
    I
 H-3C-0H
    I
    H
```

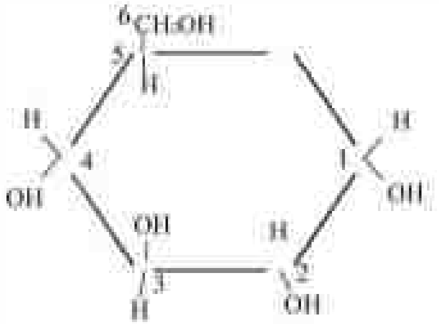
D - glyceraldehyde

```
       H
       I
       C - O
       I
OH  -C - H
       I
H   -C - OH
       I
       H
```

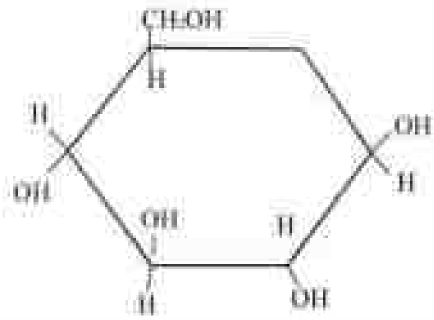
L- glyceraldehyde

In ring forms the carbon atom number 1 is called anomeric carbon atoms The orientation of-H and -OH groups around carbon atom 1 will give rise to two isomers known as anomers. In one form the -OH group is below and this is the a-form and in other form the -OH group is above and is called the 0- form.

Many monosaccharides can rotate plane polarized light to right (D, dextrorotatory, +) or left side (L, levorotatory, -). Some monosaccharides are known as derived monosaccharides as they are derivatives of monosaccharides. Deoxyribose sugar found in deoxyribonucleic acid is an aldopentose with one oxygen atom less than ribose. Aminosugars are monosaccharides having amino group (-NH_2). Glucosamine is an aminosugar which forms chitin found in fungal cell wall. There are sugar acids like glucuronic acid and galacturonic acid which occur in mucopolysaccharides. Sugar alcohol like glycerol are involved in fat or lipid formation. Mannitol is another sugar alcohol found as storage carbohydrates in some fruits and brown algae. Monosaccharides are also reducing sugars as they posses free aldehyde or keto groups.



a -D- glucose



P -D- glucose

(ii) Oligosaccharides

Oligosaccharides (oligo = a few) are carbohydrates formed by condensation products of 2-9 monosaccharides. The monosaccharides are joined by glycosidic bonds, which is formed when hydroxyl groups attached to two adjacent monosaccharides react and eleminate a molecule of water. This is a condensation reaction forming C-O-C bond. The oligosaccharides can be disaccharide (when two monosaccharides are involved, trisaccharides (when three mono saccharides are involved), tetrasaccharides and so on. Smallest and commonest oligosaccharides are disaccharides.

TABLE : Commonly occuring disaccharides.

SI.No.	Name	Monomers involved	Occurence / common name
1.	Maltose	a-D. Glucose + a-D. Glucose	Malt - Malt sugar
2.	Lactose	p -.D. Galactose + a-D. Glucose	Milk - Milk Sugar
3.	Sucrose	a-D. Glucose + p -D. Fructose	Sugar cane - Cane Sugar/ Table Sugar

(iii) Polysaccharides:

Polysaccharides, commonly called as glycans, are polymers of many (10 or more) monosaccharides or their derivatives. When a polysaccharide contain a single type of monosaccharides it is called homopolysaccharide and when it contains different types of monosaccharides it is called heteropolysaccharide. Polysaccharides can be branched or unbranched and may be structural polysaccharides or storage polysaccharides. Some important polysaccharides are :

1. Starch : It is a polymer of a-D-glucose and is a homopolysaccharide. It is a storage polysaccharide and is the most important resesrve food materials of higher plants. Natural starch consists of two components : amylose and amylopectin. Amylose is a long unbranched straight chain of a-D-glucose and amylopectin is a branched chain polysaccharide of a-D-glucose.

2. Glycogen : - It is the major reserve food in animals and also in fungi. It is often referred to as animal strach. It is a branched chain polymer of a-D-glucose like strach and resembles the amylopection. But it has more glucose units per molecule and is about 1.5 times more branched. The chains are also shorter than amylopectin and, therefore, molecule is more compact.
3. Cellulose : It is the most abundant biomolecule in the biosphere as it is the component of cell-wall of higher plants. It is a structural homopolyaccharide composed of p - D-glucose.
4. Chitin : It is probably the second most abundant polysaccharide in the nature. It is a structural homopolysaccharide found in fungal cell wall and exoskeleton of arthropods. It is often known as fungus cellulose. It is polymer of nitrogen containing glucose derivative known as N-acetyl glucosamine.
5. Inulin : It is a storage polysaccharide in the members of family Compositae. It is stored in the tubers and roots of the plants. It is also found in onion and garlic. It is a polymer of P -D-fructose.
6. Pectin - It is a structural homopolysaccharide of D-galacturonic acid. It is present in the cell wall as a ground material in which the cellulose-hemicellulose net work is embedded. It is also abundant in fruits like guava, apple, pear and tomato.
7. Hemicellulose : Xylans, xyloglucans and other related substances are collectively called hemicellulose. They are not structurally related to cellulose. The hemicellulose can either be homopolymers of pentoses (xylose, arabinose) or hexoses (mannose, galactose) as well as sugar acids. The polymers of xylose (xylans) is considered as the representative of hemicellulose and is the next most abundant polysaccharide along with chitin. Hemicelluloses are structural components of plant cell walls.
8. Mucopolysaccharides : The polysaccharides forming slimy substances or mucilages and composed of mixture of simple sugars and their derivatives such as amino sugars and uronic sugars are called as mucopolysaccharides. Hyaluronic acid is the most abundant member of mucopolysaccharides.

Reducing Sugars :

The sugars possesing free aldehyde groups or free keto groups posses reducing properties. This reducing property is exhibited by Fehling's test where the Cu^{2+} ion in Fehling's solution is reduced to Cu^{+} ion. All monosaccharides are reducing sugar. In disaccharides sucrose is non reducing as the aldehyde group of glucose and keto group of fructose are involved in the formation of glycosidic linkage. Other disaccharides like lactose, maltose etc. are reducing sugars.

Artificial Sweetener: These are non-sugar sweetener mostly used by diabetics and health conscious people. They have no nutritive value.

Saccharin (C_6H_5CH^ is the most widely used artificial sweetener.

Sucaryl Sodium is 30 times sweeter than sucrose/Monellin is a protein sweetener and 2,000 times sweeter than sucrose.

Functions :

1. Many monosaccharides like trioses, tetroses, pentosies are important metabolic intermediates.
2. Pentoses like ribose and deoxyribose form parts of the ribonucleic acid and deoxyribonucleic acid respectively.
3. Pentoses form the parts of co-enzymes like CoA, FAD, NAD, NADP and ATP etc.
4. Glucose is the blood sugar and fructose is the common fruit sugar.
5. Oligosaccharides forming the part of glycoprotein function as membrane component. These oligosaccharides from the cell coat or glycocalyx.
6. In some plants like sugarcane disaccharides sucrose is the reserve food.
7. Polysaccharides like collulose, chitin and pectin are structural components of cell wall.
8. Starch, glycogen, innulin are storage polysaccharides.

8.3. LIPIDS :

Structure of Lipids

Unlike carbohydrates, which constitute a family of homogeneous compounds, lipids form a very heterogeneous class of compounds of widely differing structures. Lipids may be defined as compounds containing in their molecule an aliphatic chain (chain consisting of -CH_2-) of at least 4-carbon atom.

The term fats and oils denote mixtures of lipids which are respectively solid or liquid at ordinary temperature. Simple lipids yield an alcohol and one or several fatty acids on hydrolysis while complex lipids on hydrolysis liberate alcohol and fatty acids but also phosphoric acid, carbohydrate etc.

Fatty acids

They are found in small quantities in free state, but in large quantities as part of lipids. As a general rule, these are monocarboxylic, straight unbranched chain acids containing an even number of carbon atoms (between 4 and 36). They may be saturated or unsaturated and sometimes hydroxylated or branched.

1. Saturated fatty acids

The general formula is: CH_3-$(CH_2)_n$-COOH. The most frequent are palmitic acid (C_{16}) and stearic acid (C_{18}). Longer fatty acids (up to 36 carbon atoms) are present in numerous cells (bacteria, unicellular eukaryotes, plants, vertebrates). They are generally present in some types of lipids. Milk on the contrary, is rich in short-chain fatty acids.

2. Unsaturated fatty acids

These are fatty acids having one or more double bonds in their hydrocarbon chain.

a. Monounsaturated fatty acids (1 double bond) $C_nH_{2n-1}COOH$

Oleic acid (C_{18}) has a double bond between carbon atoms C_9 and C_{10} with a molecular formula-

CH_3-$(CH_2)_7$-CH=CH-$(CH_2)_7$-COOH The common sources of oleic acid are animal and plant fats.

b. Polyunsaturated fatty acids (several double bonds)

In the most common of such acids, a methylene group separates the non-conjugated double bonds, e.g. linoleic acid having the molecular formula-

CH_3-$(CH_2)_4$-CH=CH-CH_2-CH=CH-$(CH_2)_7$-COOH

In mammals, polyunsaturated fatty acids can have up to 22 carbon atoms and 6 double bonds, but in plants these acids do not exceed 18 carbon atoms and 3 double bonds. Common sources of linoleic acid plant based oils. They are also compnent of biological membranes.

An important physical property of fatty acids is that their melting points decrease with increasing number of double bonds. For example, the melting point of stearic acid is 70°C whereas that of oleic acid is 13°C and that of linoleic acid is -5.8°C.

3. Hydroxylated fatty acids

Plants can synthesize a series of hydroxylated fatty acids like ricinoleic acid with the molecular formula-

CH_3-$(CH_2)_5$-CH(OH)-CH_2-CH=CH -$(CH_2)_7$-COOH

Some of these hydroxylated fatty acids lead to the formation of cutin that are found in the cuticle of epidermal cells of plants. The common source of ricinoleic acid is castor oil.

4. Branched fatty acids

Example: 15-methylhexadecaenoic acid with a molecular formula-

$(CH_3)_2$-CH-$(CH_2)_{13}$-COOH

The above type of fatty acid is particularly abundant in $Gram^+$ bacteria.

Polyisoprenic lipids

1. Polyisoprenic hydrocarbons

Avery large number of compounds present in plants are formed by the polymerization of isoprene units, e. g. rubber is formed by the condensation of thousands of isoprene units. Similarly the phytol chain, which is a part of the structure of chlorophyll pigment, is an acyclic diterpene.

Some lipids can be considered as derivatives of isoprene (steroids, carotenoids).

2. Sterols and steroids

These compounds are derived from a polycyclic ring of cyclopentanophenanthrene. The stereochemistry and nomenclature problems of steroids are very complex.

8.4. NUCLEIC ACID:

Nucleic acids are macromolecules present in all living cells either in free state, or in combination with other substances. These are polymers consisting of units called nucleotides; they are hence called polynucleotides. Nucleic acids are of two types:

1. Deoxyribonucleic Acid (DNA)

DNAs are found in the chromosomes in the nucleus of plant and animal cells. In prokaryotes also DNA, forms the chromosomes. Some viruses, especially animal viruses have it as their genetic material. Furthermore, it is also found in mitochondria of plant and animal calls and in chloroplasts of photosynthetic organisms.

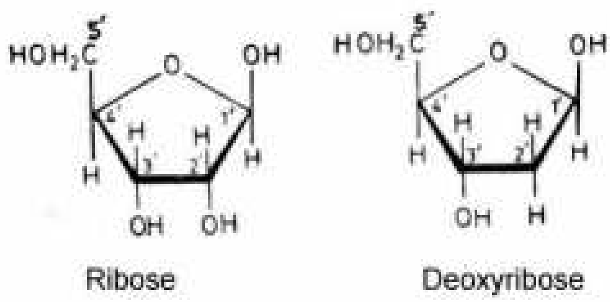
2. Ribonucleic Acid (RNA)

RNAs mainly found in the cytoplasm of cells. There are various types of RNAs (rRNA, tRNAs, mRNA) involved in the expression of genetic information.

Each nucleotide in nucleic acids is composed of pentose sugar, pentose nitrogenous base and phosphoric acid.

Pentose sugar

In ribonucleic acids, the sugar is ribose; in deoxyribonucleic acids it is deoxyribose. These two sugars differ in their chemical nature on carbon 2 as shown below.

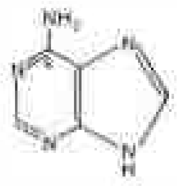


Nitrogenous base

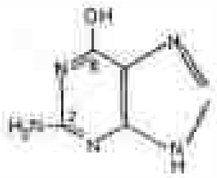
All nitrogenous bases derive from two heterocyclic bases, purine and pyrimidine.

1. Purine base

Two principal purine bases found in deoxyribonucleic acids as well as ribonucleic acids are adenine and guanine.



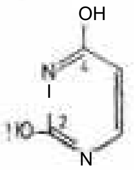
Adenine



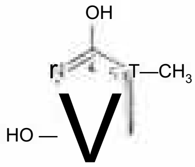
Guanine

2. Pyrimidine bases

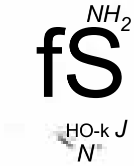
Cytosine and uracil are found in ribonucleic acids; cytosine and thymine, in deoxyribonucleic acids.



Uracil



Thymine



Cytosine

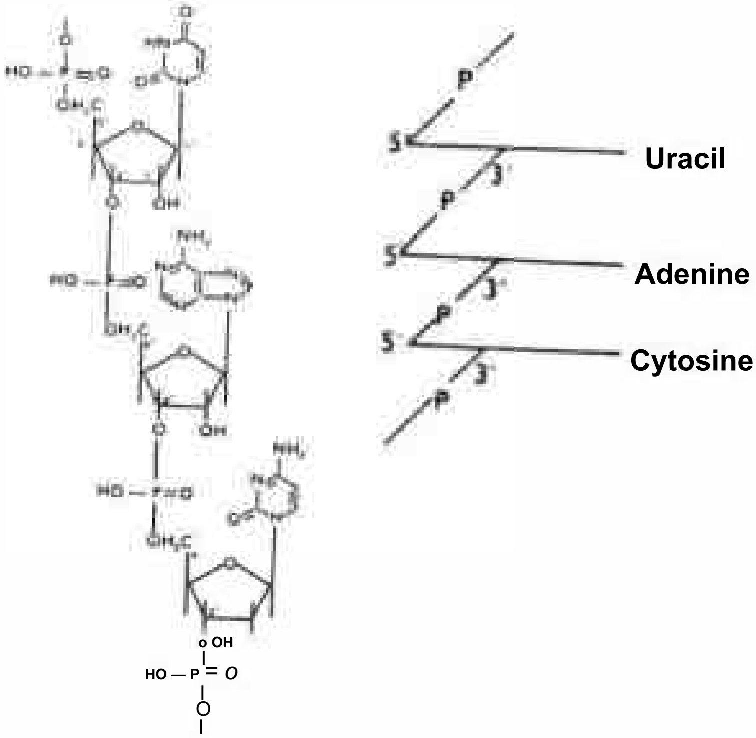
Nucleosides

Nucleosides are formed from the linkage of a purine or pyrimidine base with ribose or deoxyribose sugar. This linkage joins nitrogen 9 of the purine base, or nitrogen 1 of the pyrimidine base with carbon 1 of pentose. The nucleosides are called ribonucleosides or deoxyribonucleosides depending upon wheather ribose or deoxyribose sugars are bonded with nitrogenous bases respectively. The following table indicates the nomenclature of the main nucleosides.

Base	Ribonucleoside	Deoxyribonucleoside
Adenine	Adenosine	Deoxyadenosine
Guanine	Guanosine	Deoxyguanosine
Uracil	Uridine	Deoxyuridine
Cytosine	Cytidine	Deoxycytidine
Thymine	ribothymidine	Deoxythymidine

Nucleotides

Nucleotides are the phosphoric esters of nucleosides. Depending on the nature of the pentose sugar one will have ribonucleotides and deoxyribonucleotides. A ribonucleoside has 3 positions of carbon, which can be phosphorylated (2', 3' and 5') while a deoxyribonucleoside can be phosphorylated only in two positions (3' and 5'). This results in the formation of nucleosides -monophosphate.



Detailed structure of oligoribonucleotide

A second phosphate group can be bound to the phosphate of a nucleoside-monophosphate to form a nucleoside-di-phosphate. Likewise a third phosphate group can also be attached to the second forming nucleosides-tri-phosphate.

Primary structure of DNA

In deoxyribonucleic acids the nucleotides are joined by 3'-5' phosphodiester bonds; in other words each phosphate group (except those present at the end of chains) esterifies to the 3' hydroxyl group of a pentose and to the 5' hydroxyl group of the next pentose. Therefore the polydeoxyribonucleotide chain consists of alternating deoxyribose and phosphate residues.

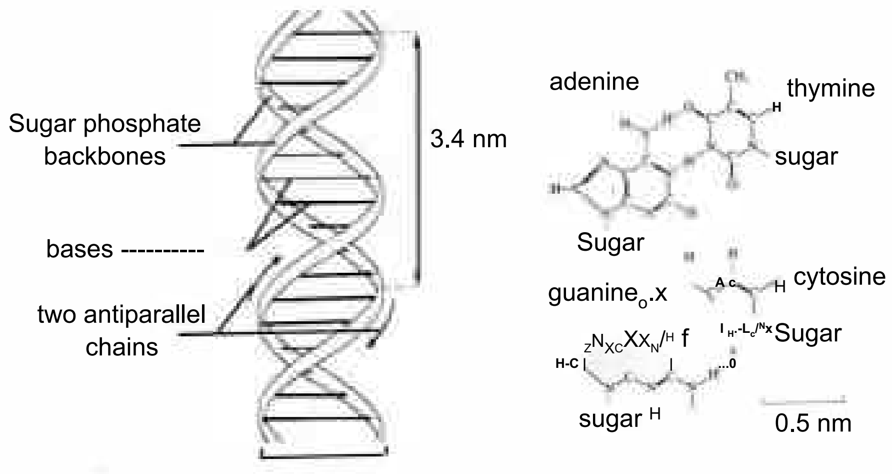
Secondary structure of DNA

DNA in solution state, takes the form of a secondary structure. Watson and Crick in 1953 proposed the secondary structure of DNA in the form of the famous double helix model for which they shared the Nobel Prize in 1962 along with Wilkins. They worked out the double helical model of DNA basing an the following observations made available to them.

a. It was known through base analyses that there is as much adenine as thymine and as much guanine as cytosine (A/T and G/C = 1). Therefore, the sum of purines is equal to the sum of pyrimidines (A+G = C+T). It is known as Chargaff's rule.

b. X-ray diffraction studies (Wilkins, 1952), suggested a helical configuration.

According to this model, DNA has a double stranded structure where two polydeoxyribonucleotide chains twisted around one another in a double helix. Both the helices are held together by means of hydrogen bonds formed between the nitrogen bases. The diameter of the DNA molecule is 20 Å (2nm). The length of the DNA in one complete turn is 34Å(3.4nm), which incorporates 10 base pairs. Therefore the distance between two adjacent base pairs is 3.4 A



Both the strands have sugar phosphate backbone and are antiparallel to one another. The antiparallel nature is given by orientation of the deoxyribose sugarwhich is opposite in both the strands. Therefore the 5th carbon atom of the sugar molecule, which is exposed at one end of a strand (5' end), faces the 3rd carbon atom of the sugar in the opposite strand (3' end). The strands are also complementary to each other. This nature is based on the purine-pyrimidine links i.e. if one strand is having a purine base (adenine or guanine) other strand must have a pyrimidine counterpart (cytosine or thymine) e.g. A = T and /G ≡ C. In DNA the nucleosides are joined by means of phosphodiester bonds.

RNA

RNA is a polynucleotide made of ribonucleotide units having ribose sugar, phosphoric acid and one of the nitrogen bases (Adenine, Guanine, Cytosine, Uracil). It is single stranded.

Cellular RNAs are non-genetic and are of three types. DNA serves as the template for the synthesis of these RNAs.

Messenger RNA (mRNA)

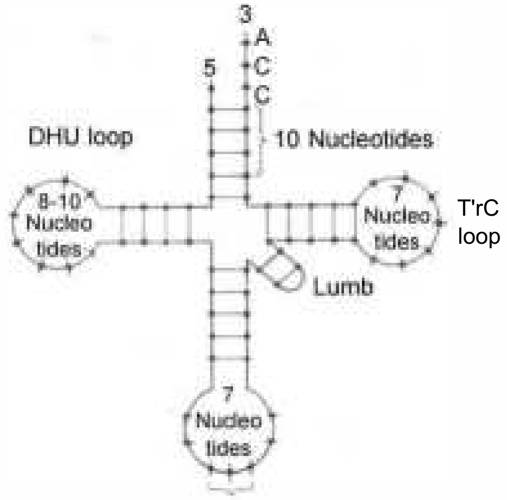
It is the RNA formed during the protein synthesis. Five to ten percent of cellular RNA is of this type. The molecular weight of m RNA varies from 30000-1000000. It is short lived. DNA transfers the genetic information to ribosome through this type of RNA during the protein synthesis.

Ribosomal RNA (rRNA)

The most stable form of RNA in the cell is the r RNA. About 80% of cellular RNA is of this type. The molecular weight of r RNA ranges from 40000-1000000. It may have some folds to have a complex structure, r RNA units along with protein constitute the protein synthesizing factory or the ribosome.

Transfer RNA (tRNA)

It is smallest form of RNA made of only 75 to 100 nucleotides. It is also known as the soluble RNA. It forms about 10-15% of total cellular RNA. The molecular weight of tRNA varies from 25000-30000. It transfers the amino acids from the cytoplasm to the ribosome.



A simplified model of tRNA

In 1964 Holley gave the detailed structure of tRNA through the ‘Clover leaf model’. In that model it was proposed that tRNA has three loops and a lump. The anticodon loop has the complementary base sequence with respect to a codon of mRNA facilitating the attachment oft RNA with the iter. Other two hops aie TTC loop or ribosomal binding loop and DHU loop or amino acyl synthetase binding loop. The 3’ end oft RNA ends with CCA-OH, which acts as the amino acid attachment site. The other end ends with G.

8.5. ENZYMES :

Life, at its most basic level, is a chemical phenomenon or, more specifically, a biochemical phenomenon. Living cells continuously carry out a large number of biochemical reactions to sustain life process. Many of these reactions would occur too slowly or at imperceptible rates unable to cope with the various activities associated with life. To overcome this, nature has provided the living cells with powerful catalysts to greatly accelerate the rates of these biochemical reactions. These biological catalysts are called **enzymes.**

In an enzyme catalyzed reaction, the reactant is called **substrate** and the product is called **product.** For example, if A is converted into B by an enzyme catalyzed reaction, then A is called the substrate of that enzyme and B is called the product.

$$A \xrightarrow[\text{catalyzed}]{\text{enzyme}} B$$

Almost all enzymes catalyze reactions that are reversible. In that case which one is a substrate and which one is a product is often arbitary. It depends upon the direction in which the actual reaction is taking place in the cell. For example in the following reaction:

$$A \underset{\text{catalyzed}}{\overset{\text{enzyme}}{\rightleftharpoons}} B$$

if in the cell the reaction leads to the net production of B, then A is the substrate. But if the reaction leads to the net production of A from B such as:

$$B \underset{\text{catalyzed}}{\overset{\text{enzyme}}{\rightleftharpoons}} A$$

then B is the substrate of that enzyme. The enzyme may convert one or more substrates into one or more products. Thus, the enzymes are accordingly said to catalyze **monosubstrate, bisubstrate** or **multisubstrate** reactions.

Chemical Nature of Enzymes

The name "enzyme" was coined by Fredrich Wilhelm Kuhne in 1878. This name comes from the Greek, *"enzume"* meaning *"in yeast'.* He emphasized that there is something in yeast, which catalyzes the synthesis of ethanol from glucose, a process known as alcoholic fermentation. However, Edward Buchner (1897) demonstrated that cell-free yeast extract can also carry out the reactions of fermentation. Later, during 1905 - 1910, Arthur Harden and William Young separated the cell-free yeast extract, by dialysis, into two fractions - a nondializable, heat labile fraction which they named as **zymase;** and a dialyzable, heat stable fraction which they called **cozymase.** It was later shown by others that zymase is a mixture of enzymes and that cozymase is mixture of cofactors. The chemical nature of enzymes remained in dispute until 1926, when James B. Sumner became successful in purifying and crystallizing the enzyme urease from jack bean. His results established that the enzyme urease is a protein. Subsequently, John H. Northrop and Wendell M. Stanley, purified and characterized a series of digestive enzymes. They confirmed Sumner's result and proved without doubt that *enzymes are proteins.* Northrop and Stanley shared the 1947 Nobel Prize with Sumner for their work on enzymes. Since then thousands of enzymes have been purified and characterized, and *all enzymes are found to* be *protein.*

Until the 1980's, all biological catalysts (enzymes) were believed to be proteins. However, Tom Cech and Sidney Altman independently discovered that certain RNA molecules can be effective catalysts. These RNA catalysts are known as **ribozymes.**

Although all enzymes are proteins made up of only amino acids, many enzymes depend on the presence of smalll molecules termed as **cofactors** for their catalytic activity. In the absence of cofactors such an enzyme is catalytically inactive. An enzyme plus cofactor complex is called **holoenzyme.** An enzyme that has had its cofactor removed is called an **apoenzyme.** The *holoenzymes are catalytically active whereas apoenzymes are catatytically inactive.*

Apoenzyme (inactive) + Cofactor = Holoenzyme (active)

Protein part of enzyme	Nonprotein part of enzyme	Complete enzyme

Cofactors may be of two groups: *metal ions* and *small organic molecules.* Many enzymes require metal ion cofactors (also called *metal ion activators)* fortheir activity. A *metal ion* cofactor may be transiently associated with the enzyme (e.g., Mg^{2+} requirement for hexokinase, puruvate kinase etc) or is tightly bound to it (e.g., Zn^{2+} in carbonic anhydrase, Ni^{2+} in urease and Fe^{2+} in catalase). An enzyme that has a tightly bound metal ion is known as a **metalloenzyme.** Cofactors that are *small organic molecules* are called **coenzymes.** Coenzymes can be either transiently associated with the enzyme, (e.g., NAD^+/NADH in alcohol dehydrogenase and other dehydrogenases, ATP in hexokinase etc) or are tightly bound to it. Tightly bound coenzymes are called **prosthetic groups** (e.g., Fe-porphyrin in catalase, FAD/$FADH_2$ in succinate dehydragenase, biotin in pyruvate carboxylase etc).

Properties of Enzymes

Enzymes are biochemical catalysts. At this point it is necessary to refresh your mind as to what catalysts are. Catalysts are chemical substances which in *minute quantity accelerate the rates* of chemical reactions without themselves being *altered, destroyed* or *used-up* during the course of the reaction and are *recovered* after the reaction is catalyzed. Going by this definition, enzymes fall into the category of catalysts. However, enzymes (biological catalysts) are very efficient catalysts, often far superior to ordinary chemical (non-biological) catalysts. Enzymes differ from ordinary chemical catalysts in many other ways. All these are because of their biological origin. The properties of enzymes and their differences or similarities with ordinary chemical catalysts are discussed below.

Catalytic Power

Most of the reactions in biological systems do not take place in perceptible rates in the absence of enzymes. Enzymes increase the rates of biochemical reactions by 10^6 to 10^{12} times of the uncatalyzed reactions. For example, one molecule of carbonic anhydrase can hydrate 10^6 molecules of CO_2 per second. This reaction is 10^7 times faster than the uncatalyzed reaction.

$$CO_2 + H_2O \xrightleftharpoons{\text{<5rbonic anhydrase}} H_2CO_3$$

Similarly, one molecule of catalase can decompose 10^5 molecules of H_2O_2 per second. The enzyme catalase has iron in its active site which helps in the decomposition of H_2O_2. The efficiency of catalase in decomposing H_2O_2 can be realized by comparing the decomposition of H_2O_2 with iron salts. One mg of iron in catalase is as effective as 10^4 kg of inorganic iron in decomposing H_2O_2.

$$2H_2O_2 \xrightarrow{\text{catalase}} 2H_2O + O_2$$

These examples indicate the great catalytic power of enzymes compared with non-biological catalysts.

Substrate Specificity

Enzymes are highly specific for the reactions they catalyze and for their choice of substrates than that of chemical catalysts. They can discriminate between closely related substances, i.e., they have high degree of substrate specificity. A modified substrate may not be acted upon by the enzyme. For example, sucrase (also known as invertase) can hydrolyze sucrose but not sucrose phosphate.

$$\text{Sucrose} + H_2O \xrightarrow{\text{sucrase}} \text{Glucose} + \text{Fructose}$$

Similarly, the enzyme urease can hydrolyze urea to form ammonia and carbondioxide but cannot hydrolyze a slightly modified form of urea (e.g., chlorinated form of urea).

$$NH_2\text{-}CO\text{-}NH_2 + H_2O \xrightarrow{\text{urease}} 2NH_3 + CO_2$$

The above two enzymes show **absolute specificity** towards their respective substrates.

Some enzymes act on closely related substrates and catalyze reactions involving a particular chemical group. For example, the enzyme hexokinase transfer phosphate group from ATP to several different hexose sugars. Another example is the enzyme alcohol dehydrogenase which catalyze the oxidation of ethanol as well as other alcohols. Such enzymes exhibit **group specificity.**

A third group of enzymes exhibit **stereo chemical specificity.** These enzymes discriminate between mirror images of the same substrates. For example, L-amino acid oxidase catalyzes the oxidation of L-amino acids but does not act on its stereoisomer, D-amino acid.

Mild Reaction Conditions

Enzymes function in aqueous solutions under very mild conditions of temperature and pH. There are exceptions, however. Some protein-digesting enzymes operate in vacuoles with a pH near 4.0. And enzymes isolated from many thermophilic bacteria growing in hot springs can remain active at temperatures close to 100°C. Most of the enzymes, however, catalyze biochemical reactions under the conditions far milderthan those required for most of the chemical reactions.

Enzymes, being protein in nature, are thermolabile. Most of the enzymes are denatured and lose their activity beyond 40-45°C. At high temperature, the enzymes are inactivated probably due to heat coagulation phenomenon or due to the change in the three dimentional structure of enzyme protein.

Reversibility of Reaction

With very few exceptions, enzymes catalyze biochemical reactions which are reversible in nature. Depending upon the cellular requirement, the reactions are catalyzed either in the forward direction or in the backward direction. This is not the case with the chemical catalysts. Enzymes like hexokinase and sucrase catalyze irreversible reactions. Carbonic anhydrase, alcohol dehydrogenase, succinate dehydrogenase and many other enzymes catalyze reversible reactions.

Capacity for Regulation

Enzymes regulate biochemical reactions to an extent not possible for chemical catalysts. Enzymes follow several strategies to regulate biochemical reactions and metabolic pathways. For example, enzymes can regulate metabolic pathways depending upon the requirement of the final product of the pathway by the cell. If the final product of a metabolic pathway is not required by the cell, then this product may inhibit the first enzyme of the pathway, thereby preventing further formation of the product. This type of regulation is called **feed back inhibition.**

Factors Affecting Enzyme Activity

There are several factors that affect the rate of an enzyme catalyzed reaction as detailed below:

Effect of Enzyme Concentration

At a fixed substrate concentration, an increase in enzyme concentration increases the rate of an enzyme catalyzed reaction until the substrate concentration becomes the limiting factor. When the substrate concentration is not limiting, the rate of an enzyme catalyzed reaction is directly proportional to the enzyme concentration (Fig 8.1). The rate slows down when [S] starts becoming the limiting factor. The rate remains unchanged at high [E] when [S] is the limiting factor.

Effect of Substrate Concentration

At a fixed enzyme concentration, an increase in substrate concentration increases the rate of an enzyme catalyzed reaction until the enzyme concentration becomes the limiting factor. When the enzyme concentration is not limiting, the rate of an enzyme catalyzed reaction is directly proportional to the substrate concentration (Fig.8.2). By increasing [S], when [E] starts becoming the limiting factor, the rate of the enzyme catalyzed reaction slows down. At high [S], the rate remains unchanged because [E] becomes the limiting factor.

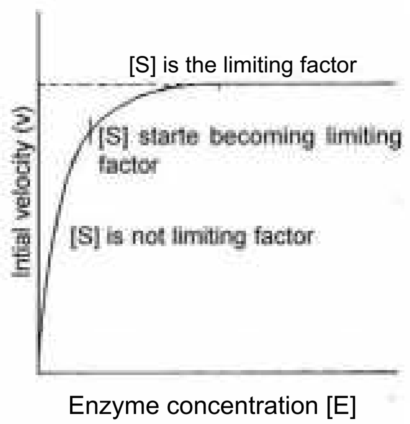


Figure 8.1 : Plot of initial velocity, v versus enzyme concentration, [E] for an enzyme-catalyzed reaction at a fixed substrate concentration, [S]

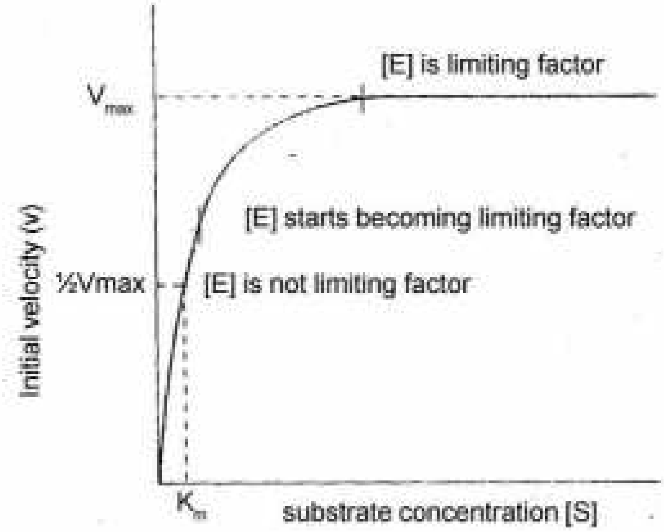


Figure 8.2: Plot of initial velocity, v, versus substrate concentration, [S] for an enzyme-catalyzed reaction at a fixed enzyme concentration, [EJ. Vmax is the maximal velocity of the reaction when sustrate concentration is not limiting. Km, the Michaelic constant, is the value of [S] which gives 1/2 Vmax. The curve of v versus [S] is part of a rectangular hyperbola.

Effect of pH

Enzymes, being proteins, are affected by the changes in the pH of the reaction medium. Most of the enzymes are, in fact, active only within a narrow range of pH, typically pH 5 to pH 9. The most favourable pH at which an enzyme activity is the maximum is known as the optimum pH for that enzyme. The optimum pH value varies from enzyme to enzyme. The pH affects the degree of ionization of the side chains of the amino acid residues of proteins and thereby their three dimensional structure. Further more, ionization state of amino acid side chains present in the active site of enzymes are responsible for the catalytic activity of enzymes (see later in this chapter).The pH also affects the ionization characteristics of the substrates and coenzymes, and thereby, their binding with the enzyme. Thus pH of the reaction medium affects the catalytic activity of the enzyme. The catalytic activity of the enzyme as a function of pH usually appears as a bell-shaped curve, (Fig.8.3).

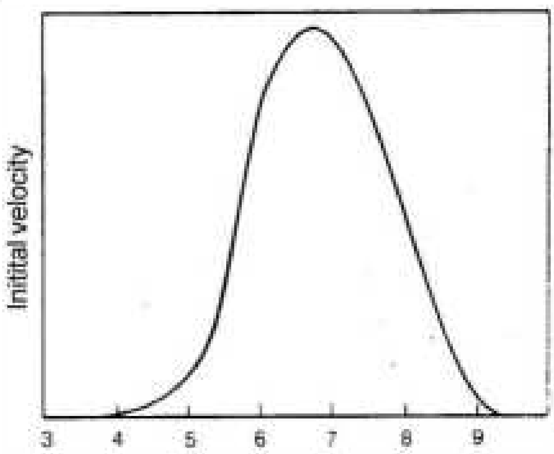


Fig.8.3 : The plot shows the variation of initial velocity of an enzyme catalyzed reaction at different pH value of the reaction mixture. The shape of the plot and the optimum pH vary from enzyme to enzyme.

Effect of Temperature

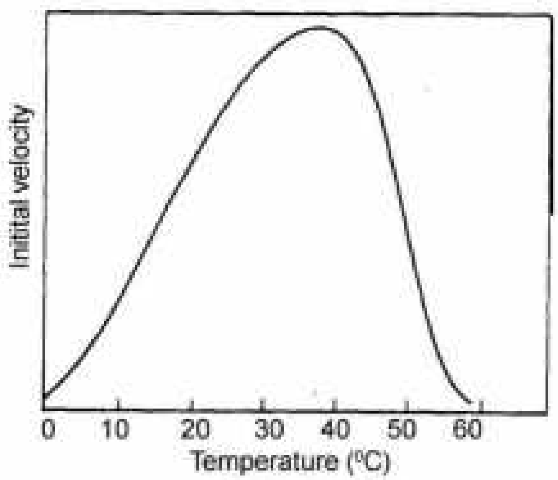


Figure 8.4 : The plot shows the effect of temperature of the reaction mixture on the initial velocity of an enzyme-catalyzed reaction. The shape of the plot varies from enzyme to enzyme. Some enzymes even show good activity at 90°C and above.

Like most of the chemical reactions, the rate of an enzyme catalyzed reaction increases with the increase in temperature of the reaction medium. However, enzymes being proteins are gradually denatured and lose their activity at the temperature beyond 40 - 50°C. Some enzymes, however, remain active even at the temperature as high as 100°C. Each enzyme has an optimum temperature at which its activity is the maximum (Fig.8.4).

Effect of Inhibitors and Activators

Many molecules and ions, when present in the reaction medium, affect the rate of enzyme-catalyzed reactions. These substances bind to the enzyme or the enzyme-substrate complex, thereby, affecting the rate. Substances which lower the reaction rate are called **enzyme inhibitors** and substances which increase the rate are known as **enzyme activators.** Inhibitors and activators are very important in the cellular regulation of enzymes.

Inhibitors can be classified as reversible or irreversible. **Reversible inhibitors** bind with the enzyme by weak noncovalent bonds and can be removed by dialysis to restore the active enzyme. On the other hand **irreversible inhibitors** bind with the enzyme by covalent bonds and can not be removed from the enzyme by dialysis.

Mechanism of Enzyme Action

Enzymes, as explained before, acelerate the rates of biochemical reactions and show great deal of substrate specificity. Therefore, any theory on the mechanism of enzymatic reaction must take these two facts into account.

Activation Energy

The conversion of reactants to products in any chemical reaction is accompanied by continuous change in energy. During the reaction pathway, the reactants pass through a transition state. This transition state of the reactants has higher free energy than either the ground state reactants or products. The difference in free energy between transition state and ground state reactants is called the activation energy. Activation energy, thus, is the energy required to activate the reactants to move them to the transition state. In the activation pathway, the transition state has the maximum energy. As the reaction continues, the energy of the system decreases until it reaches a new minimum in the products. The energy changes for a simple chemical reaction as the function of the progress of the reaction (or reaction pathway) is graphically represented in Figure 8.5.

The magnitude of the activation energy influences the rate of the chemical reaction - the higher the activation energy (or energy barrier), the slower the reaction rate. *Catalysts speed up the reaction rate by lowering the energy of activation required for the reactants to reach the transition state.* Enzyme catalyzed reactions obey the same laws of chemistry as the corresponding uncatalyzed reactions. Similar to ordinary chemical catalysts, *enzymes also speed up the rate of biochemical reactions by lowering the energy of activation of the substrates to reach the transition state.* An enzyme lowers the activation energy by forming an enzyme-substrate complex and thereby increasing the reaction rate.

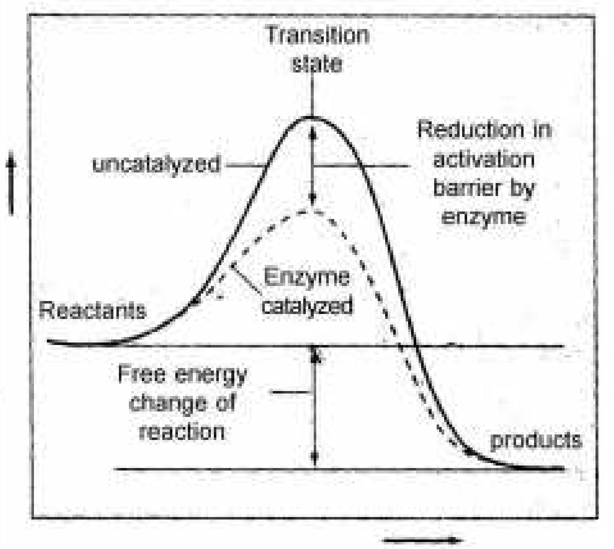


Fig. 8.5 : Plot shows the requirement of energy of activation for the enzyme catalyzed and uncatalyzed reactions. Enzymes reduce the activation barrier for a reaction.

As shown in Figure 8.5, the difference in energy between the substrate and the product is not altered by the enzyme. This difference in energy between the substrate and the product determines the equilibrium point of the reaction. As *with the chemical catalysts, enzymes do not alter the equilibrium constant of the reaction they catalyze.*

Formation* of *Enzyme-Substrate Complex

Enzyme catalyzes the conversion of the substrate molecule to form the product molecule. To do this job of catalysis, the enzyme must interact with the substrate molecule. In fact, the first step in an enzyme catalyzed reaction is the reversible binding of a substrate molecule (S) with the enzyme molecule (E) to form an enzyme-substrate complex (ES) which then dissociates to release the product molecule (P), and the enzyme becomes free.

$$E + S \rightleftharpoons ES\text{^^}E + P$$

The free enzyme is then available to bind with another molecule of substrate to repeat the reaction.

The site on the enzyme protein where the substrate binds and the catalysis occurs is known as the **active site** of the enzyme. The active site takes up a relatively small portion of the total volume of the enzyme. It is usually located in a **cleft** or **pocket** or a **Pit** in the folded three dimensional structure of the enzyme protein molecule. The active site contains amino acid side chains and/or cofactors that can function as catalysts. Common amino acid side chains present in the active site are carboxylic (-COO^-), amino (-NH_2), sulfur (_S"), hydroxyl (-OH), imidazole and other groups. The amino acid side chains present in the active site are different for different enzymes. These amino acids in the active site need not be adjacent to one another in the linear polypeptide. They are brought together into proximity by the folding of the linear protein molecule. One or more of the amino acid side chains recognizes and binds the substrate with the enzyme while other amino acid side chains catalyze the reaction once the substrate or substrates have been bound. Thus the active site has **substrate-binding site** and **catalytic site,** which are adjacent to each other in the active form of the enzyme. Sometimes the catalytic site is a part of the substrate-binding site. The substrates are bound to the enzymes at the active site by one or more of the relatively weak forces such as *ionic bonds, hydrogen bonds, van der Waals attraction* and *hydrophobic interactions.*

Models for Enzyme-Substrate Complex

Based on the high specificity of binding of the substrate to the enzyme, two hypotheses for the enzyme-substrate complex have been proposed:

Lock-and-Key hypothesis: Emil Fischer proposed this hypothesis in 1890 when the chemical nature of the enzyme was not known. However, the experimental observations that enzymes are very much specific to their substrate led him to propose the lock-and-key hypothesis. He assumed that the substrate molecule must have complementary shape to fit closely with the enzyme molecule in the same way as the key (substrate) fits into the lock (enzyme) as shown in Figure 8.6. Some authors now prefer to rename the lock-and-key hypothesis as **direct-fit hypothesis** for the reason you will be cleared in the following paragraph.

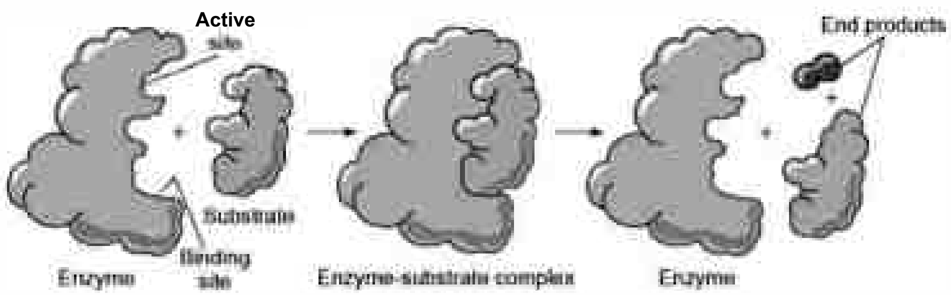


Fig.8.6 : This shows the interaction of an enzyme (E) and a substrate (S), where the substrate fits directly into the binding site of the enzyme to form ES complex. This is called lock-and-key mechanism or direct fit mechanism.

Induced-Fit hypothesis: It is now well known that the three dimensional structure of many enzymes are flexible. The binding of the substrate induces a conformational change in the active site of the enzyme so that the substrate fits perfectly well with the enzyme to form the ES complex (Fig.8.7). This was postulated by Daniel E. Koshland, Jr in 1958. Hexokinase is a good example of an enzyme that exhibits this type of conformational change (Fig. 8.8).

Catalysis

The details of the catalytic mechanism differ from one type of enzyme to another. But the facts discussed above are involved in all enzyme catalysis. When E and S are mixed, the S molecule comes into close contact with the E molecule. A temporary intermediate compound called ES complex is formed. The S molecule is transformed into the P molecule by catalytic mechanisms which differ from enzyme to enzyme. The P moves away from the E molecule. The E, now freed, interacts with another S molecule to repeat the process of catalysis.

Types of Enzymes

Enzymes are commonly named by appending the suffix **-ase** to the name of the substrate or the catalytic action of the enzyme. Thus the enzyme which catalyzes the hydrolysis of urea is named as urease and the enzyme, which catalyzes the oxidation of glucose is named as glucose oxidase. But there are many enzyme names which convey little or nothing about the nature of the reactions they catalyze. For example, the enzyme which catalyzes the decomposition of H_2O_2 to H_2O and O_2 was named as catalase, the name that tells nothing about its nature or function. Many enzymes are named even without the suffix -**ase.** For example, the proteolytic enzyme secreted by the pancreas is named as trypsin. With the discovery of large number of enzymes, their systematic nomenclature and classification was needed, so that any given

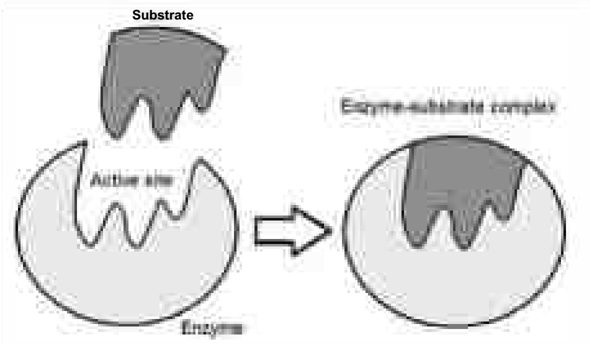
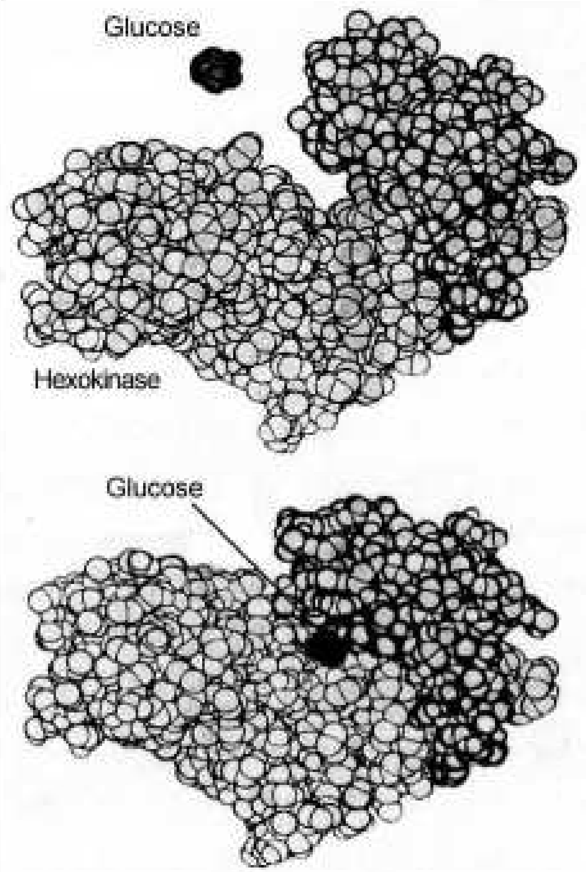


Fig.8.7 : This shows the interaction of an enzyme (E) and a substrate (S) where the substrate induces a conformational charge in the enzyme so that the substrate can properly position itself on the enzyme to form the ES complex. This is called induced fit mechanism.



Glucose—hexokinase complex

Fig.8.8 : This shows an example of induced-fit hypothesis. The conformation of hexokinase changes markedly when it binds the substrate glucose. The two lobes of the enzyme come closer together to surround the substrate molecule.

enzyme can be precisely identified. A scheme for the systematic functional classification and nomenclature of enzymes was adopted in 1961 by the Enzyme Commission set up under the auspices of the International Union of Biochemistry (IUB) and the International Union of Pure and Applied Chemistry (IUPAC). The list of enzymes has since been modified, some enzymes renamed and new enzymes added. At present there are about 3196 enzymes and the responsibility of reviewing and adding new enzymes to the list now lies with the Nomenclature Committee of the International Union of Biochemistry and Molecular Biology (NC- IUBMB).

Enzymes are now named and classified according to the nature of the biochemical reaction they catalyze. The Commission on Enzymes has recognized six major classes of enzymes basing on the type of reactions they catalyze.

Class 1. ***Oxidoreductases:*** These enzymes catalyze reactions in which one substrate is oxidized and another substrate is reduced. Thus, these enzymes catalyze the transfer of hydrogen, oxygen or electrons between the substrates for oxidation-reduction reactions. The enzymes **alcohol dehydrogenase** and **catalase** belong to this class.

Class 2. ***Transferases:*** These are enzymes involved in the transfer of chemical groups such as one-carbon groups (e.g., methyl group), aldehyde or ketonic groups, phosphoryl groups etc from one substrate to another. The enzyme **hexokinase** and **citrate synthase** belong to this class.

Class 3. ***Hydrolases:*** These enzymes catalyze the hydrolytic cleavage of C-O, C-N, C-C, P-O and other single bonds. The enzymes **sucrase, urease** and **phosphatase** belong to this class.

Class 4. ***Lyases:*** These enzymes catalyze the removal of groups, other than by hydrolysis or oxidation-reduction reactions, often leaving a double bond. The enzymes **fumarase** and **isocitrate lyase** belong to this class.

Class 5. ***Isomerases:*** These enzymes catalyze reactions involving intramolecular rearrangement of groups in the substrate molecule to form a product which is a different isomeric form of the substrate. The enzymes triose phosphate **isomerase** and **phosphoglycerate mutase** belong to this class.

Class 6. ***Ligases*** (also known as ***Synthatases):*** These enzymes catalyze the joining or ligation of two substrates at the expense of ATP (or other nucleoside triphosphates) hydrolysis. The enzymes **aminoacyl-tRNA synthetase** and **glutamine synthetase** belong to this class. Note here that some enzyme named as **synthases** (e.g. citrate synthase, glutamate synthase) do not belong to this class.

SAMPLE QUESTIONS

1. Short Answer Type Questions :

A. Fill in the blanks :

1. D-glucose and L-glucose from a pair of-------------.
2. An aldehyde containing monosaccharide having six carbon atoms is generally called as.
3. Inulin is found as a storage plysaccharide in the members offamily.
4. is known as imino acid.
5. The dervied aminoacids are also known asamino acids.
6. is the building block of nucleic acids.
7. The pentose sugar present in DNA is known as.
8. Butyric acid is the only fatty acid withnumber of carbons.
9. Tocopherols are known as Vitamins.
10. p -Carotene yields Vitamins.

B. Suggest one word expression for each of the following :

1. The polysaccharide found as reserve food in animal.
2. The compound rotating the plane of polarized light to the right.
3. The polysaccharide found in the exoskeleton of arthropods.
4. The branched strach is called as:
5. The secondary structure exhibited by silk protein.
6. A protein conformation having two or more subunits.
7. Compounds consisting of a N-base, pentose sugar and phosphoric acid.
8. Compounds obtained by esterification of alcohol group of glycerol with fatty acids.

C. Choose the correct option.

1. The name enzyme was coined by :

   (a) Edward Buchner, (b) Arthuze Harden, (c) Fredrich Kunhe, (d) Names Summer
2. The first enzyme furified and crystalised :

   (a) Urease, (b) Hexokinase, (c) Alcohol dehydrogenase, (d) Catalase.
3. Chemically ribozyme is.

   (a) Protein, (b) RNA, (c) DNA, (d) Lipoprotein.
4. Which of the following is known as fruit sugar ?

   (a) glucose (b) fructose (c) sucrose (d) maltose.

5. Which of the following elements is not present in nitrogenous bases found in nucleic acids.

   (a) Nitrogen (b) Hydrogen (c) Carbon (d) Phosphorous.

6. A nucleoside is a compound of

   (a) N-base + sugar + phosphate (b) N-base + sugar

   (c) N-base + phosphate (d) Sugar + phosphate.

7. Maltose is a disaccharide composed of

   (a) D-Glucose & D-Glucose (b) D-Galactose & D-Glucose

   (c) D-Glucose & D-fructose (d) D-Glucose and L-Glucose

8. Which of the following is a sulphur containing amino acids.

   (a) methionine (b) Serine (c) Valine (d) Leucine

9. Name the hydroxy aminoacid from the followings

   (a) Threonine (b) Tryptophan (c) Phenyl alanin (d) Valine.

10. Which one of the followings is a basic amino acid

    (a) Lysine (b) Glycine (c) Tryptophan (d) Leucine.

11. Which one of the followings is an ectodermal protein

    (a) Kertin (b) Antibodies (c) Storage proteins (d) Enzymes.

D. Write notes on :

I. Disaccharides. 2. Anomers. 3. Homopolysaccharides. 4. Mucopolysaccharides.

5. Quaternary structure of proteins. 6. Non-standard amino acids. 7. Non-protein amino acids. 8. Classification of proteins based on shape. 9. Polyunsaturated fatty acids.

II. Chemical nature of enzyme. 12. Activation energy. 13. Activation energy. 14. Enzyme substrate comtlex.

E. Long Answer Type Questions :

(a) Describe the structure of DNA.

(b) Describe the structures of different types of RNA.

(c) Describe the properties of enzymes indicating how they differ from chemical catalysts.

(d) Write the mechanism of enzyme actions.

❑ ❑ ❑

CHAPTER 9

CELL DIVISION CYCLE

The most remarkable feature of the cells and the entire organism is their ability to reproduce. The cells of an organism can grow only up to a limited extent and not beyond and, therefore, growth can be accomplished only by cell division in multicellular organisms,. Every organism starts its life from a single cell which divides and redivides to form tissues and organs. The larger the organisms the more are the number of cells they have. There is no such thing that the bigger animals or plants shall have large cells and the smaller ones have small cells. The size of the cell is genetic character that seldom changes.

The cell after attaining a certain size can duplicate itself. The simplest type of cell reproduction is the division of a "parent" cell into two "daughter" cells. This occurs as part of the **cell cycle,** a series of events that prepares a cell to divide followed by the actual division process, called **mitosis.** The eukaryotic cell cycle has at least four stages (Fig.9.1). The chromosomes and the DNA they carry are copied during **S (Synthesis}** phase. The **M Phase** is marked by changes at the chromosome level, which is visible under microscope. Both the M and S phases are preceded by two gap stages, the **G_1 phase** and the **G_2 phase** respectively. During these gap stages, m-RNA and proteins are made in sufficient quantity to be used to produce two equal halves with complete chromosomal set-up in each.

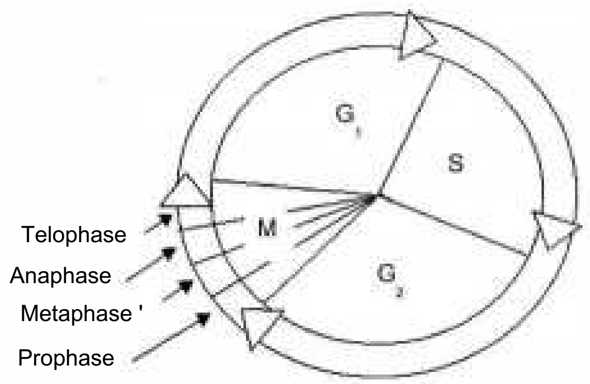


Fig. 9.1 : The interphase consisting of G_r S and G_2 phase roughly doubles the cell mass. Replication of DNA during S leaves the cell with double the number of chromosomes. In the mitotic (M) phase, the chromosomes are evenly separated into two daughter cells. The division process is completed after the division of cytoplasm into two equal halves.

9.1. MITOSIS (M Phase) :

While changes during interphase are biochemical and not visible, the M-Phase is clearly visible under a microscope. This phase is divisible into **Prophase, Metaphase, Anaphase** and **Telophase,** each phase being characterized by the morphological changes associated with the chromosomes.

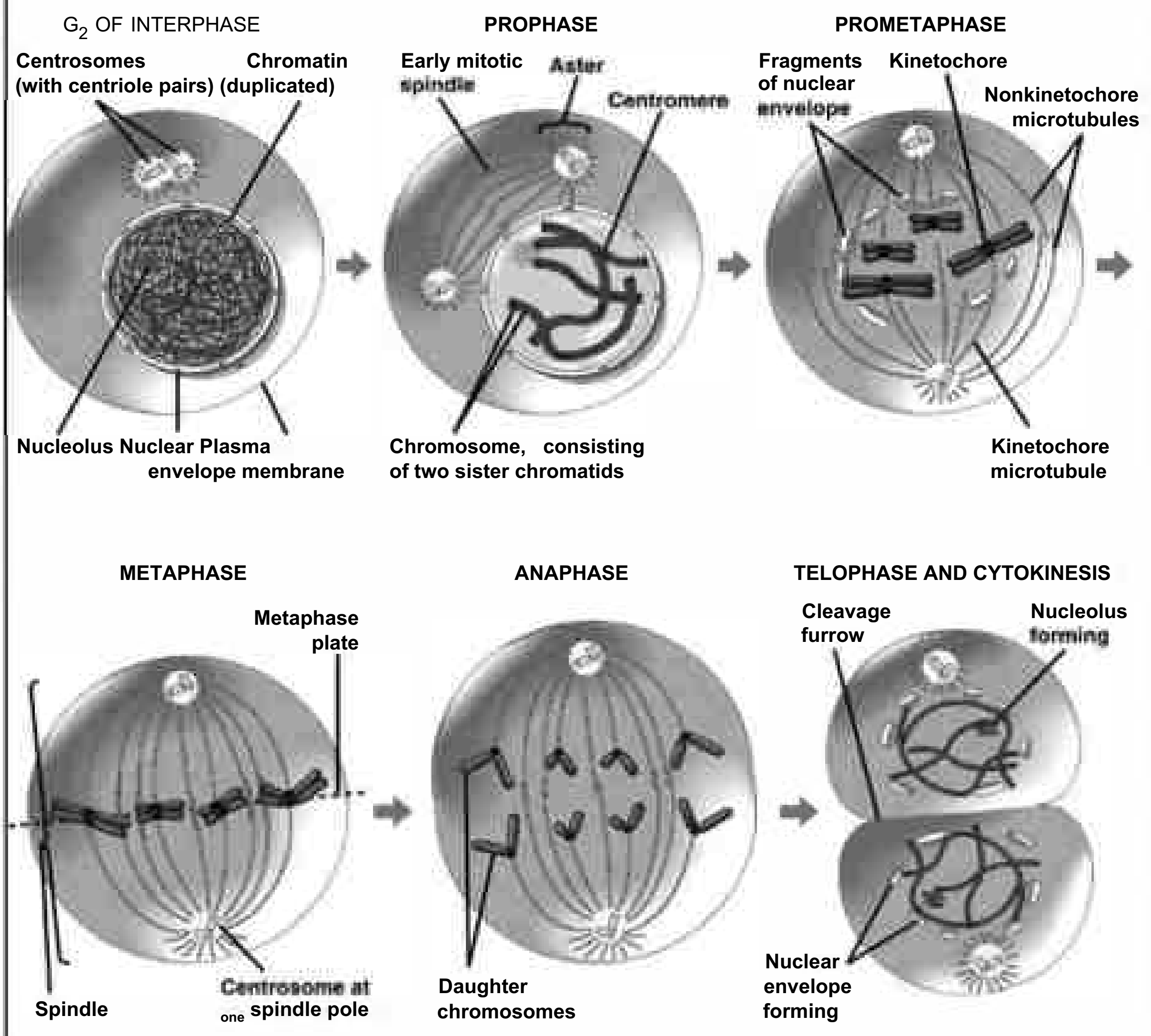


Fig 9.2 : Different stages of mitotic cell division (mitosis)

9.1.1. Prophase :

It is the longest phase of division. In the early part, the diffused chromatin of interphase slowly condenses to form well-defined chromosomes. Later, the chromosomes are splitted longitudinally to form two chromatids each. Both the chromatids are, however, associated at the **centromere** region. Cytoplasmic microtubules are organized to form mitotic spindle near the poles. In the final stage the nuclear membrane and nucleolus disappear and chromosomes are found in the cytoplasm. In plants due to the complete absence of **centriole,** no astral arrangement is seen and hence the spindle is called **anastral spindle.** In animals spindle formation is dependent on centrioles, where each 'centriole pair' at the pole acts as mitotic center. Short microtubules (astral rays) radiate from the centrioles and so the spindle is called **astral spindle** (aster means star).

9.1.2. Metaphase :

This phase begins with the complete disappearance of the nuclear membrane. The chromosomes get themselves arranged at the central part of the cell or the equatorial portion of the spindle called as the **equatorial plate** or **metaphasic plate.** The orientation of the chromosomes is such that their centromeres lie in the equatorial plate while the arms are projected freely in the cytoplasm.

9.1.3. Anaphase :

In this phase, the centromere holding the chromatid pairs gets divided simultaneously. Now the chromatids are called daughter chromosomes. Soon the daughter chromosomes repel from each other and start moving in opposite direction towards the respective poles. The spindle fibres help the movement of the chromosomes.

The spindle fibres are of three types viz. pole to pole, pole to centromere and centromere to centromere. Together by contraction and expansion of spindle fibres of pole to centromere and centromere to centromere respectively, the chromosomal movement is facilitated. During the movement, the chromosome may assume the shape of V, J or I depending upon the chromosome structure.

9.1.4. Telophase :

This phase starts after the full set of chromosomes reach the opposite poles. The spindle fibres disappear and nuclear membranes are formed around the chromosome sets. The nucleolus reappears in each nucleus forming two daughter nuclei in the cell.

At the end of M-phase, cytoplasm of the parent cell is divided into two halves by the formation of a cell-plate in the middle in case of plant cells and simply by inward constrictions on either side in case of animal cells. Some authors also call this division of cytoplasm as D-phase but the process is called **cytokinesis.**

9.1.5. Amitosis :

There are many unicellular plants and animals that divide differently from the pattern followed by mitosis. Such divisions go by the general name **amitosis.** In some algal and fungal forms there is direct division of the cell nuclei. Also some old cells of higher plants show such direct division of nuclei.

In some cases there is free nuclear division where the cells are not separated by cell walls and several nuclei remain scattered in the cytoplasm of large cells. Such cells are called **coenocytic cells.**

In yeast, the cells divide by a process called budding. Here the protoplast of parent cell bulges out to which a daughter nucleus migrates later to form a daughter cell.

9.2. MEIOSIS :

This type of division is restricted to only the sex organs. In plants meiosis occurs in the flowers in the anthers (male meiosis) and in the ovary (females meiosis) and in animals such divisions occur in male and female gonads.

Meiosis is relatively long (sometimes very long) and complex where single diploid (2n) cells are reduced to form haploid (n) cells or **gametes.** For example, if the somatic cells of *Allium cepa* have 16 chromosomes in the nucleus, the meiotic products shall have 4 cells with 8 chromosomes in each. All the sexually reproducing plants and animals have this type of cell division to produce gametes. The gametes of opposite sex (male and female) unite to produce a zygotic cell, which forms the first cell of a sporophyte. A plant or an animal has a fixed number of chromosomes in its nucleus and this number is maintained for generations through the process of meiosis, which reduce the number of chromosomes of the uniting gametes to half before their union. The process of meiosis is completed through two major phases viz. Meiosis - I and Meiosis-II.

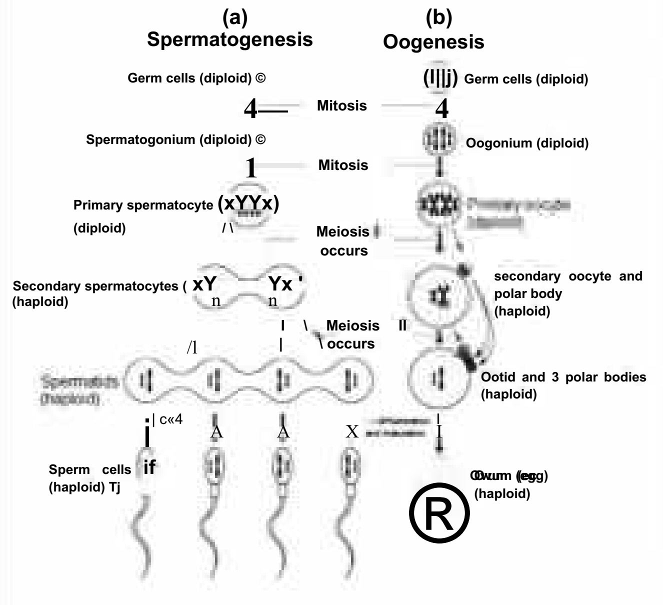


Fig.9.3 : Meiosis (a) spermatogenesis, (b) oogenesis in human

9.2.1. Meiosis-I :

It consumes a lot of time and major events occur in this phase. This has been divided into prophase-I, metaphase-I, anaphase-I and telophase-I with prophase-I taking the longest duration among them. Prophase-I is sub-divided for convenience to **Leptotene, Zygotene, Pachytene, Diplotene** and **Diakinesis,** based on the appearance of chromosomes during the progress of meiosis. Each of the sub-stages has characteristic features of chromosomes, which are normally clearly visible under microscope. Prophase-I is quickly followed by metaphase, anaphase and telophase in succession to wind up the process of Meiosis-I resulting in two cells. After a short gap, the cells enter the second phase of division, the Meiosis-II that is more or less similar to mitosis.

The end result is formation of 4 haploid cells from every **meiocyte.** Like mitosis, meiosis - I is initiated only after S phase where the parental chromosomes are replicated to produce identical sister chromatids. But the pattern of chromosome segregation in meiosis-I is dramatically different from that in mitosis. The sequence is as follows in next page:

Prophase -1 :

Leptotene (Thin thread)

This is marked by an increase in nuclear volume. The chromosomes start to appear clearly as a result of condensation and coiling of chromatin fibres. The appearance of chromosomes here are like thin threads and hence the name. In some cases, there are certain deeply stained regions along the length of the chromosome and such regions are called **'chromomeres'.** During this stage the nucleolus enlarges as RNA synthesis continues.

Zygotene (Yoked thread)

During this stage, the homologous chromosomes (one paternal and one maternal), which are of identical size and structure pair in such a way that there is exact alignment of portions of chromosomes including the genes. A cementing substance made of proteins help binding the pair of chromosomes tightly. This pairing is called **'synapsis'** and the cementing material is called **'synaptonemal complex'.** The chromosomal pairs are called **'bivalents'**whose number corresponds to the haploid chromosome number of any species.

Pachytene (Thick thread)

In this stage, the bivalents become more condensed and therefore thicker. In addition, each chromosome becomes doubled and the bivalent turns to a **'tetravalent'** with two paternal sister chromatids and two maternal sister chromatids. Also in this stage, exchange of genetic material occurs. This is made possible by the formation of a few breaks at identical site in the chromatids. The broken segments then reunite with or without exchanges of chromatid segments.

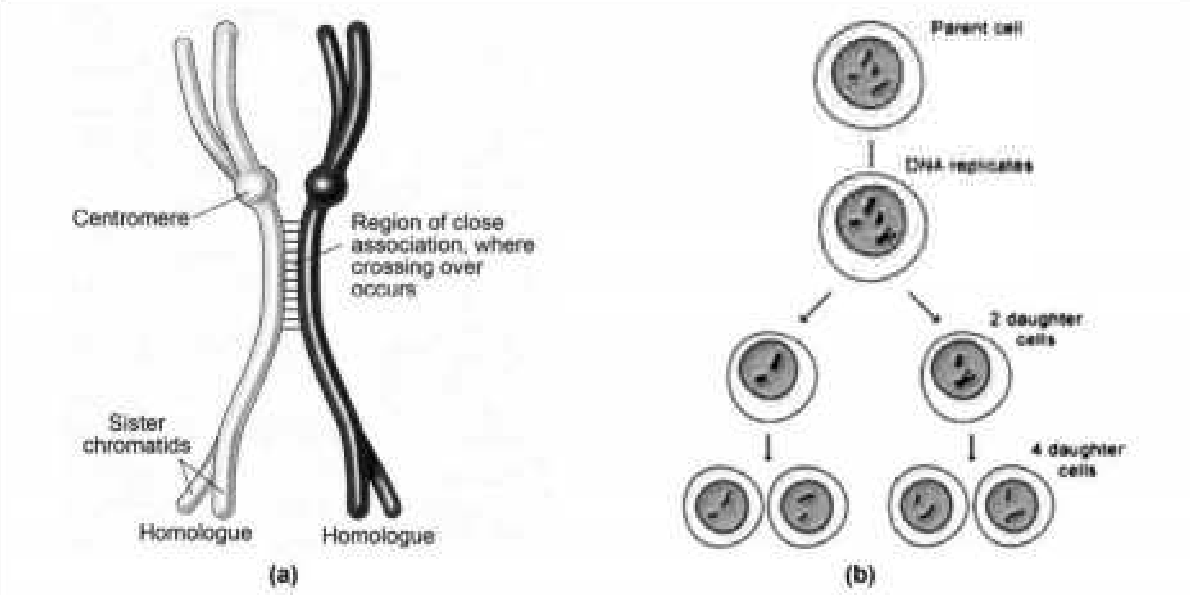


Fig.9.4 : Unique features of meiosis. (a) synapsis draws homologous chomosomes together to physically exchange parts, process called crossing over. (b) a relative division meiosis I followed by meiosis II.

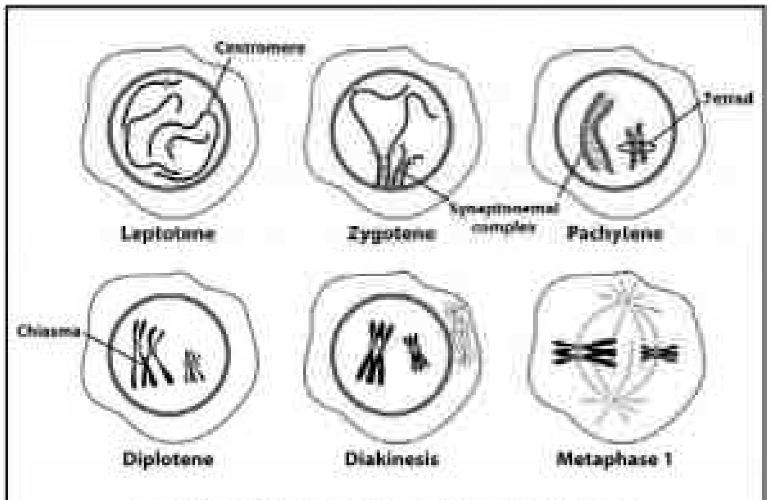


Fig.9.5 : Prophase-I of Meiosis (diagrammatic)

The process of exchanges of segments between non-sister chromatids is of great genetic consequence since it results in reshuffling of parental genes which are present in the chromatids. This process is also called **'crossing over'.**

Diplotene (Double thread)

With the condensation process still continuing, the tetravalents appear thicker. Now, the pairing homologous units undergo a process of repulsion and start moving apart. However, two non-sister chromatids are held united at the points of exchanges. Such points are called **chiasmata.** It gives a characteristic chromosomal configuration as given in the diagram.

Diakinesis (Double ending)

This stage is the last of pairing process and the end of prophase I. Here the chromosomes appear very thick and they move away from each other and spread towards periphery. The chiasmata found at the points of crossing over between chromatids undergo a process called **terminalization** whereby some departing chromosomes are found held up only terminally as shown in the diagram.

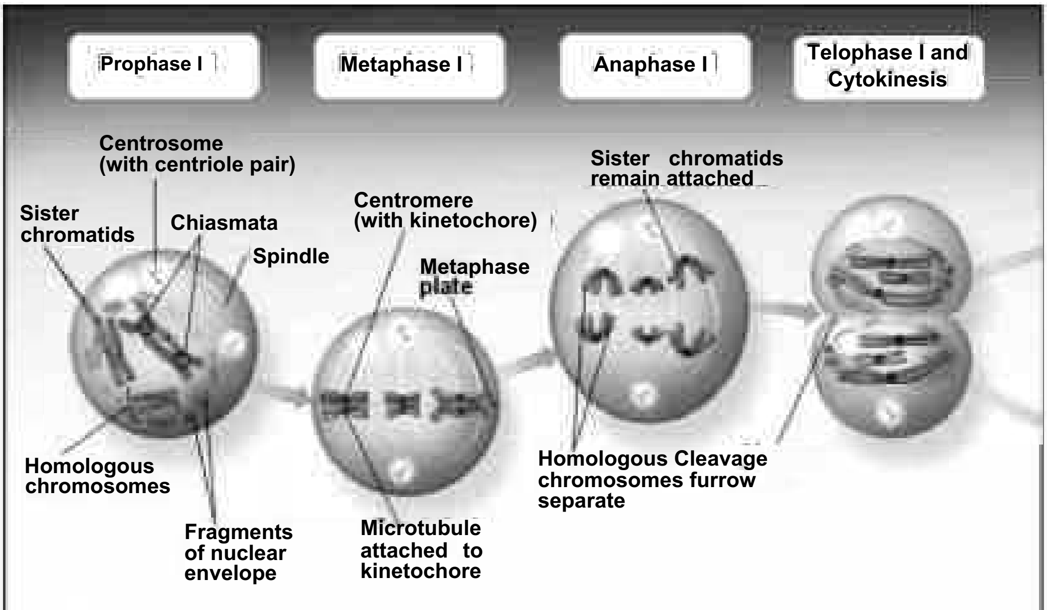


Fig.9.6 : Stages of Meiosis I

This stage is also marked by the breakdown of the nucleolus and nuclear membrane and organization of spindle at the poles.

Metaphase -1

Here the bivalent chromosomes align at the equatorial plate vegion of the spindle. In contrast to mitosis, the centromeres of sister chromatids are adjacent to each other and oriented in the same direction, while the centromeres of homologous chromosomes are pointed towards opposite spindle poles. So, the microtubules from the same pole of the spindle attach to sister chromatids, while microtubules from opposite poles attach to homologous chromosomes.

Anaphase -1

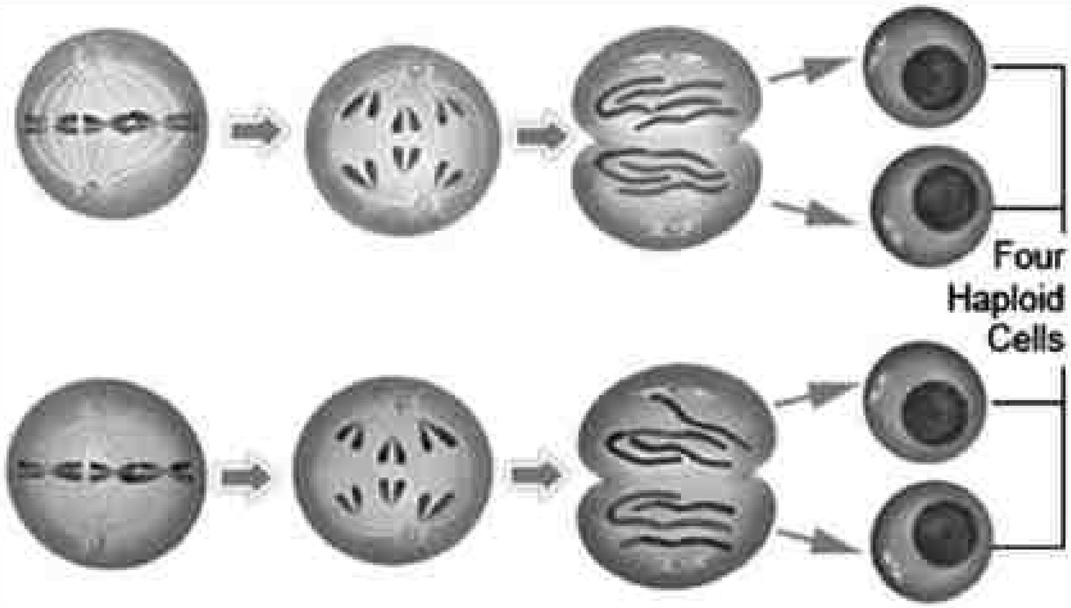
This phase is initiated after complete disruption of the chiasmata at which homologous chromosomes are joined. The homologous chromosomes then separate while sister chromatids remain joined at the centromeres.

Telophase - I

This marks the completion of meiosis and formation of two daughter cells that have acquired one number of each homologous pair consisting of two sister chromatids.

9.2.2. Meiosis - II :

It is initiated immediately after cytokinesis (in some cases no cytokinesis occur at this stage), before chromosomes have fully descended. In contrast to meiosis-I, this is just another mitosis with prophase-II, metaphase-II, Anaphase-II and Telophase-II. At metaphase-II, the



Prophase II Metaphase n Anaphase n Telophase II

Fig.9.5 : Metaphase, Anaphase, Telophase of Meiosis II (diagrammatic)

chromosomes align on the spindle with microtubules from opposite poles of the spindle attached to the centromeres of sister chromatids. The link between the centromeres of sister chromatids is broken in anaphase-II and sister chromatids segregate to opposite poles. Cytokinesis occurs after telophase-II and now four haploid daughter cells are formed.

9.3. CONTROL OF CELL CYCLE :

One of the most exciting developments in contemporary cell biology is the discovery of molecular mechanisms that control the progression of eukaryotic cells through the cell cycles (mitotic and meiotic). It is now well established that there is a conserved set of protein kinases in all eukaryotic cells which is involved in the process of triggering major cell cycle transitions. There is in-built genetic mechanisms that prevent entry into next phase of the cell cycle until the events of the earlier phase is completed.

Scientists have discovered signal systems that regulate progression through specific control points in the division cycles. There are also checkpoints and feedback controls to coordinate events during the progress of cell cycle. For example, once DNA replication is over, initiation of a new S phase is prevented until the cell completes mitosis.

There are some drugs e.g. **colchicine,** which prevents the formation of spindle fibres and thereby not allowing the chromosomes to move to opposite poles. This results in a cell with double the number of chromosomes. Hence, the drug finds application is inducing **polyploidy** (cells with multiple chromosome number).

9.4. SIGNIFICANCE OF CELL DIVISIONS :

9.4.1. Mitosis :

1. Growth: Mitotic cell division adds new cells and thus helps in growth of multicellular organisms.
2. Vegitative and asexual propagation : This mode of reproduction is common for unicellular organisms where the mitotic division helps in increasing the number of organisms. Vegetative propagation in plants by tubers, buds and bulbils are also due to mitotic division.
3. Tissue repair: Dead and damaged tissues are repaired by replacing dead cells with new cells arising from mitotic divisions.

9.4.2. Meiosis :

1. Meiosis results in formation of gametes involved in sexual reproduction.
2. Crossing over between homologous chromosomes during prophase-1 of meiosis results in new genetic recombinations.
3. It also helps to maintain the somatic chromosome number.

SAMPLE QUESTIONS

A. Very short type questions :

Choose the correct word :

1. During cell division, the replication of DNA occurs during

   (a) M-phase, (b) S-phase (c) G-phase (d) Prophase
2. In male flowers, meiosis is seen in

   (a) sepals, (b) androecium (c) petals, (d) gynoecium.
3. From every meiocyte the spores formed is (are) :

   (a) One (b) two (c) four (d) eight

Express in one word

1. The pairing of homologous chromosome.
2. The points of exchange of chromosome segments.
3. The process of end of exchange of chromosomal segments.
4. The process of division of cytoplasm into two cells.
5. Cells with multiple chromosome numbers.

Fill in the Blanks

1. can disrupt spindle fibre and is also used to induce polyploidy.
2. Duringthe chromosomes are aligned at the equatiocial plate.
3. Where the cells are not separated by cell walls and nuclei lie scattered are called condition.
4. In yeasts, the cells divide by.
5. During pachytenechromosomes pair.

B. Short type Questions.

1. Write short notes on

   (a) Control of cell cycle, (b) Chromosomal pairing, (c) S-phase of cell cycle.

   (d) Anaphase of mitosis, (e) Amitosis.

C. Long Type Questions.

1. Describe the phrophase -I of meiosis with suitable diagrams. What is the significance of this type of division ?
2. Give an account of different phases a somatic cell undergoes during division process.
3. What is the significance of mitosis ? Give details of the phases in between two successive M-phases.
4. Give major points of comparision between mitosis and meosis.

TRANSPORT IN PLANTS

CHAPTER 10

10.1. MOVEMENT OF WATER, NUTRIENTS AND GASES

Plants require water, mineral nutrients, gases such as carbon dioxide and oxygen, and sun light for their normal growth, development, reproduction and for survival. Generally, plants absorb water and mineral nutrients from the soil by their highly ramified root system. These absorbed water and mineral nutrients then move upward in the plant body through the xylem tissue reaching almost all parts of the plant including the growing tip of a tall tree which may be sometimes more than 370ft high. A large proportion of the absorbed water is lost to the atmosphere in vapour form through the stomata present in leaves and young stem by a process called transpiration. On the other hand, atmospheric $C0_2$ enters the leaves through the stomata. Leaves fix the $C0_2$ into simple sugars using the energy of the sun in a complex process called photosynthesis. Water and mineral nutrients have a role in this process. Photosynthates produced by the leaves are transported both upward and downward direction by the phloem tissue reaching different parts of the plant including the growing tip of the shoot and root where these are utilized for the life processes. Photosynthates are also transported to the storage organ from where these are later re-transported in all directions. Gases like CO_2 for photosynthesis and O_2 for respiration enter the plant by diffusion in the gaseous state and then transported within the plant body both in gaseous and dissolved state. Like water in the vapour form, CO_2 and O_2 also diffuse out of the leaves through the stomata under different situations. These transport of substances involving the plant is shown in Figure 10.1.

From the above paragraph, it is clear that materials absorbed or produced by different organs of the plant are transported to other parts of the plant and such transportation can be upward, downward or lateral depending upon the type of material transported and tissue involved. Transport in plants can occur in 3 levels: (1) **Cellular transport -** which involves the single cell, e.g., uptake of water and mineral nutrients from soil solution into the cell, and movement of water from leaf cells to the intercellular spaces, through the plasma membrane; (2) **Cell to cell transport -** which probably takes place mostly by diffusion through plasmodesmata, e.g., water and mineral ion transport between cortical cells of root, and transport of substances by an active process requiring expenditure of metabolic energy as in case of phloem loading and unloading during sugar transport. Both these transport processes are called **short-distance transport.** (3) **Long-distance transport -** it includes transport of substances between the roots and leaves, e.g., upward transport of water and mineral nutrients through the xylem, and both downward and upward transport of organic and inorganic substances through the phloem.

Transport of substances within the plant body takes place in the dissolved state in the medium of water. Plants continuously absorb water from the soil and lose a large portion of the absorbed water to the atmosphere as water vapours. This continuous flow of water from soil to the atmosphere through the plant body is what is known as **the soil-plant-atmosphere-continuum** or **SPAC.** The upward flow of water in the xylem and downward flow of water in the phloem distributes inorganic and organic nutrients respectively throughout the plant body. But how does this water movement take place from soil to plant, within the plant up-hill and from plant to the atmosphere? What is the driving force for this up-hill water movement? What is the mechanism of phloem transport? While searching answers to these questions, we will find a well coordinated physiological interdependence between these transport processes in plants.

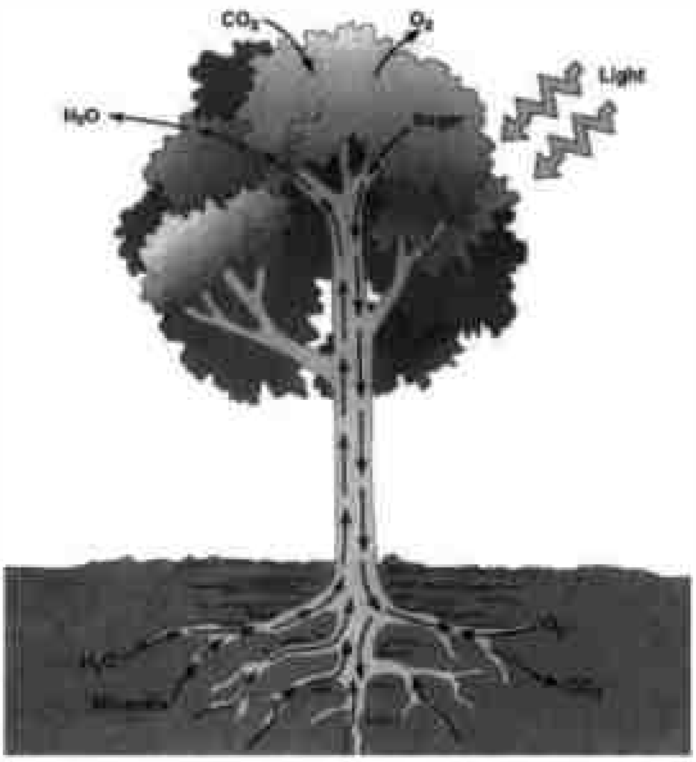


Fig.10.1 : Uptake, transport and removal of substances in a plant.

10.2. SHORT DISTANCE TRANSPORT :

Movement of water, gases and dissolved substances into the cell from the environment and from the cell to the environment is very important for cellular processes. Equally important is the cell to cell movement of water and other substances within the plant. The barrier to such movement is imposed by the cell membrane; water and the dissolved substances must move across it to make transport effective. How do these substances move across the cell membrane?

Some substances of biological importance move into the cell or out of it by simple diffusion which is a passive process occurring down the concentration gradient of the substance. Some proteins present in the cell membrane also mediate the transport of substances either passively down the concentration gradient or actively against the concentration gradient using metabolic energy. The extent to which membrane allows the movement of substances across it is called membrane permeability, which is different for different ions and molecules.

10.2.1. Diffusion

Molecules and ions in solution are in constant random motion colliding with one another also randomly. This random motion, however, results in net movement of molecules from one region in solution to another. Diffusion is the spontaneous movement of molecules from region of high concentration to the region of low concentration, i.e., down the chemical potential gradient. For example, if some salt crystals are placed in the bottom of a beaker containing water, after sometime the salt crystal become dissolved in water and uniformly distributed throughout the medium (Fig. 10.2). Diffusion is a passive process, and is the most effective mode of transport of water and substances dissolved in it across the cell membrane (Fig. 10.3) and also in the cell cytosol. Diffusion of water across a selectively permeable barrier, such as a cell membrane, is called osmosis, which will be discussed later in the chapter. The rate of diffusion is called as **flux density,** which is the amount of a substance crossing a unit cross-sectional area per unit time. **Diffusion coefficient** is a characteristic of a substance; it is a measure of how easily a substance moves through a particular medium. Diffusion coefficient is inversely proportional to molecular size and is dependent upon the nature of the medium and its temperature. Diffusion rate increases with increase in temperature.

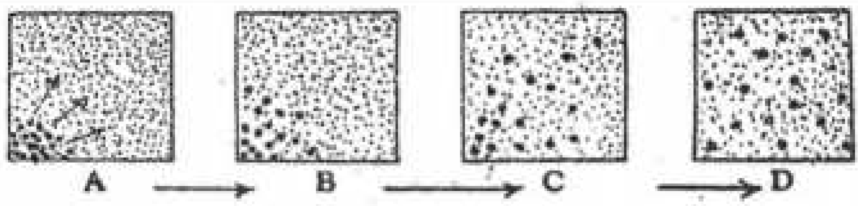


Fig.10.2 : Stages of diffusion

There are some transmembrane proteins called channels which mediate the passive transport of solutes across the membrane. These channel proteins form a transmembrane pore, the interior being lined with surface charges, through which solutes diffuse down their concentration gradient (Fig. 10.3). The size of the pore and the nature of surface charges on its interior lining make the channel very specific to solutes. Transport through channels is passive, responsible mainly for the diffusion of ions and water. Diffusion through channels is faster than the unaided simple diffusion through the lipid bilayer of the membrane. The channel pore is regulated by a structure called gates which open and close the pore in response to signals received from hormones, light, chemical modification of the protein (e.g., phosphorylation) and membrane potential difference.

10.2.2. Facilitated diffusion

Facilitated diffusion is passive transport of solutes across a membrane mediated by a transmembrane protein called carrier. Unlike channel proteins, the carrier proteins do not form transmembrane pores through which diffusion of solutes could occur. Rather the solute to be transported is initially bound to a specific site on the carrier protein which, in turn, releases the solute on the other side of the membrane without the expenditure of metabolic energy. Binding causes conformational change in the carrier protein which helps release the solute on the other side of the membrane (Fig. 10.3). The presence of specific binding site makes the carrier protein highiy specific for a particular solute to be transported across the membrane. In the facilitated diffusion system, the net flux of the solute is down a chemical potential gradient similar to simple diffusion. Transport of solutes across the cell membrane by facilitated diffusion is faster than those expected for simple diffusion. The carriers exhibit a high degree of selectivity for certain type of solutes. They become saturated when external concentration of solute transported is raised sufficiently.

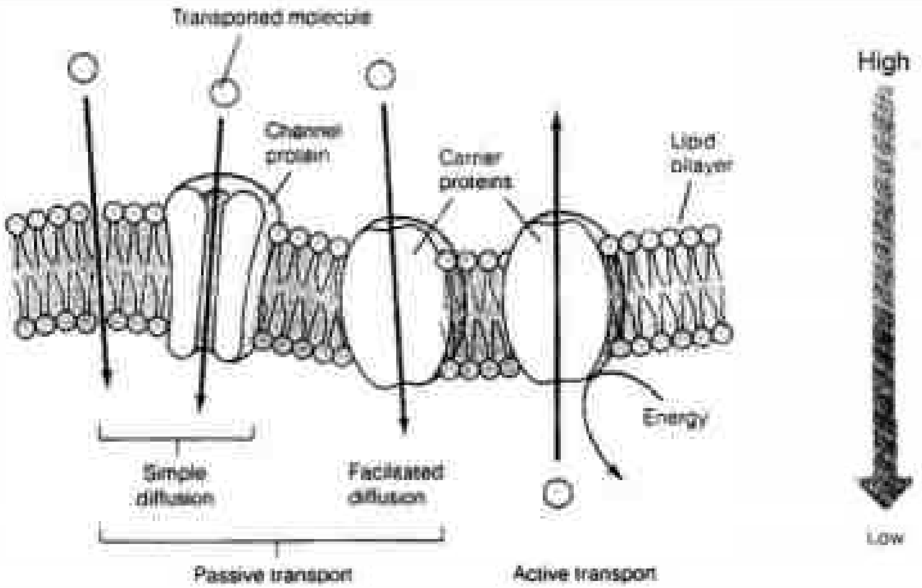


Fig.10.3 : Classes of membrane transport proteins. In active trasport the source of energy may be the hydrolysis of the ATP as in primary active transport or proton (H^+) gradient as in secondary active transport.

10.2.3. Active transport

The movement of solutes against a concentration gradient carried out by membrane proteins using metabolic energy is called active transport. This can be either *primary active transport* or *secondary active transport* depending upon the way energy is used. Membrane proteins carrying out primary active transport hydrolyse ATP and use the released energy for the transport of solutes (Fig. 10.3). These carrier proteins are called **pumps.** On the other hand, carrier proteins carrying out secondary active transport use energy of the proton (H^+) gradient formed by a different process to transport solutes. Along with the transport of solutes, proton is also transported down its concentration gradient and this process is known as **cotransport.** There are two major types of cotransport: **symport** and **antiport.** When the proton and the solute move in the same direction through the membrane, it is called symport. Antiports move the proton and the solute in opposite direction (Fig. 10.4). When a solute is transported across the cell membrane by a membrane protein independent of other solutes, the process is called **uniport.**

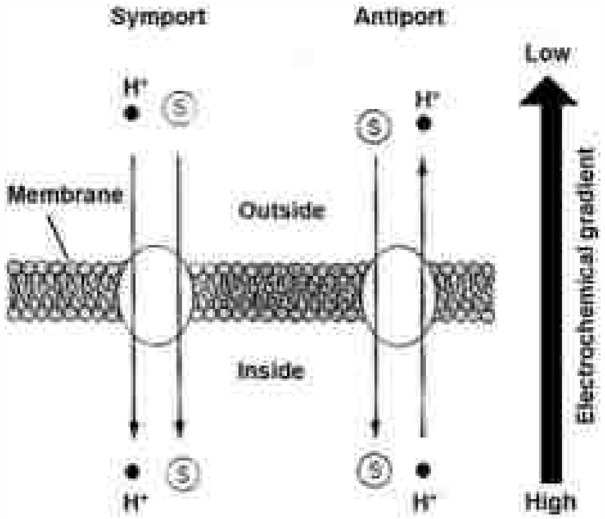


Fig.10. 4 : Hypothetical model of cotransport - symport and antiport.

10.3. PLANT WATER RELATION

10.3.1. Imbibition

Imbibition is a physical process mainly concerned with adsorption of water. If a living (e.g seed) or a dead plant (eg. dry wood) material is kept in water, it absorbs water and swells up considerably leading to increase in volume. These substances (seeds, dry wood etc) are called imbibants. The liquid (water) which is absorbed is termed as imbibed substance and the phenomenon is referred to as imbibition. Imbibition may be defined as a physical process in which living or dead materials take up water or liquid mainly by adsorption due to the presence of hydrophilic colloids inside them through the submicroscopic capillaries present on their general surface of the body. In plants, imbibition of water takes place by the constituents of cell wall and protoplasm such as carbohydrates, proteins etc.

Conditions necessary for imbibition

(i) The existence of a diffusion pressure gradient between the imbibant and the substance imbibed.

(ii) The existence of certain affinity between components of the imbibant and the imbibed substance.

Dry plant materials and seeds possess too much negative water potential. As a result water moves into them, when the plant materials are placed in water. The movement of water into plant materials continues till a dynamic equilibrium is attained. An imbibant does not necessarily imbibe all kinds of liquids. For example, dry plant materials immersed in ether do not swell appreciably. However, rubber, a plant product does imbibe in ether and swell appreciably if submerged in it. On the other hand rubber does not imbibe water. This shows, there exists some affinity or attractive force between the imbibant (rubber) and the liquid ether. A considerable amount of materials such as proteins, carbohydrates etc. occur as hydrophillic colloids inside the cells. They have a strong affinity for water.

Imbibition Pressure :

It represents the pressure that an imbibant develops when submerged in water. This pressure can be of tremendous magnitude. This fact becomes clear from the splitting of rock brought about by inserting dry wooden stakes in the crevices of rock and soaking them with water. Why does rock split ? Because too much imbibition pressure develops due to imbibition. The imbibitional pressure also helps in breaking soil profiles by germinating seeds.

Factors affecting the rate of imbibition :

(i) Temperature : The rate of imbibition increases with the increase in temperature.

(ii) Concentration of the Solute : The presence of solutes in water affects the rate of imbibition. The rate is more in pure water than in a solution. Increase in concentration of the solute decreases imbibition. Imbibition totally ceases at a very high concentration of solutes in external solution.

Biological importance of imbibition :

(i) Imbibition plays a key role in the initial stage of water absorption by the roots.

(ii) Imbibition initiates seed germination.

(iii) The imbibition force is useful in adhering water to the walls of xylem elements.

(iv) It helps fruits to retain water.

(v) It also plays a major role in young and actively growing tissues.

10.3.2. Water Potential

The water molecules possess free energy. The free energy is the energy of a system available for doing work. Thus it is the energy that determines the direction in which physical and chemical changes would occur. The chemical potential is the free energy per mole of any substance. Chemical potential of water is of great importance in explaining movement of water from soil to plant and within plant. Water potential may be defined as the difference in free energy per mole, between pure water and osmotically constrained, matrically bound, or pressurized water (e.g., solution) at the same temperature and pressure. Water potential is denoted by the symbol v (Psi, a Greek letter) and is measured in terms of pressure e.g., in bars or atmospheres or in megapascal (MPa).

The water potential of pure water is arbitarily set at zero. When a solute is added to pure water, the water potential becomes negative as the free energy gets decreased. Thus the water potential of all solutions is always less than zero (a negative value). When pure water is compressed or heated the water potential becomes positive as the free energy increases. A difference in water potential between two regions determines the movement of water. Water moves from higher potential to lower potential. For example, if two regions (A& B) in an aqueous system have water potentials v_A and v_B respectively, the difference in water potential will be : Ary = v_A - v_B If v_A is greater than v_B then Av will be positive and the water will move from A to B region. If v_B is greater than v_A, Av will be negative and water will move from B to A.

If the two systems having different water potentials are separated by a semipermeable membrane, the movement of water molecules always takes place from the system having higher water potential (dilute solution) towards the system having lower water potential (concentrated solution). The movement of water will continue till the water potentials of the two systems become equal and a stage of equilibrium is reached. At this stage, the net movement of water molecules will cease.

Components of water potential:

The water potential (v) of a living cell has three major component potentials such as **osmotic** or **solute potential** (v_s), **pressure potential** (v_p) and **matric potential** (v_m) Water potential of a solution is actually the sum of all the above three potentials.

$$V = V_s + V_p + \psi_m$$

(a) Solute potential (v_s)

This is due to the presence of solutes in a solution. Solute potential is also otherwise known as osmotic potential. The presence of solute in water lowers the value of water potential. With increase in solute concentration, the value of solute potential decreases further. The value of solute potential of a solution is same as that of osmotic pressure of that solution but with a negative sign . For example, if osmotic presure is 0.5 atmosphere, then v_s is -0.5 atmosphere of the same solution.

(b) Pressure potential (y_p):

The term pressure potential (y_p) is the hydrostatic pressure that the protoplasm exerts on the cell wall due to osmotic entry of water into the cell. It is the actual pressure exerted and has positive value. It increases the free energy of water and this raises water potential (y). It is equivalent to turgor pressure (TP).

(c) Matric Potential (y_m):

The term matric (pl. matrices) is used for such surfaces which can adsorb water molecules, e.g., cell walls, colloidal substances present in protoplasm, and soil particles etc. Matric potential (y_m) is the component of water potential influenced by the presence of a matrices in the solution and has negative value. The ψ_m in case of plant tissues and cells is often neglected because of its insignificant low numerical value. Thus the equation can be written in simplified form as follows:

$V = V_S + V_p$

i.e., the water potential of a plant cell or any solution is the sum of solute potential and pressure potential. When a cell is fully turgid, its water potential is the highest (=zero), so v_s = w_p(remember, w_s has negative value). When a cell is flaccid, the pressure potential is zero, so $V=V_s$. The relationship between water potential and its components are presented in Figure 10.5.

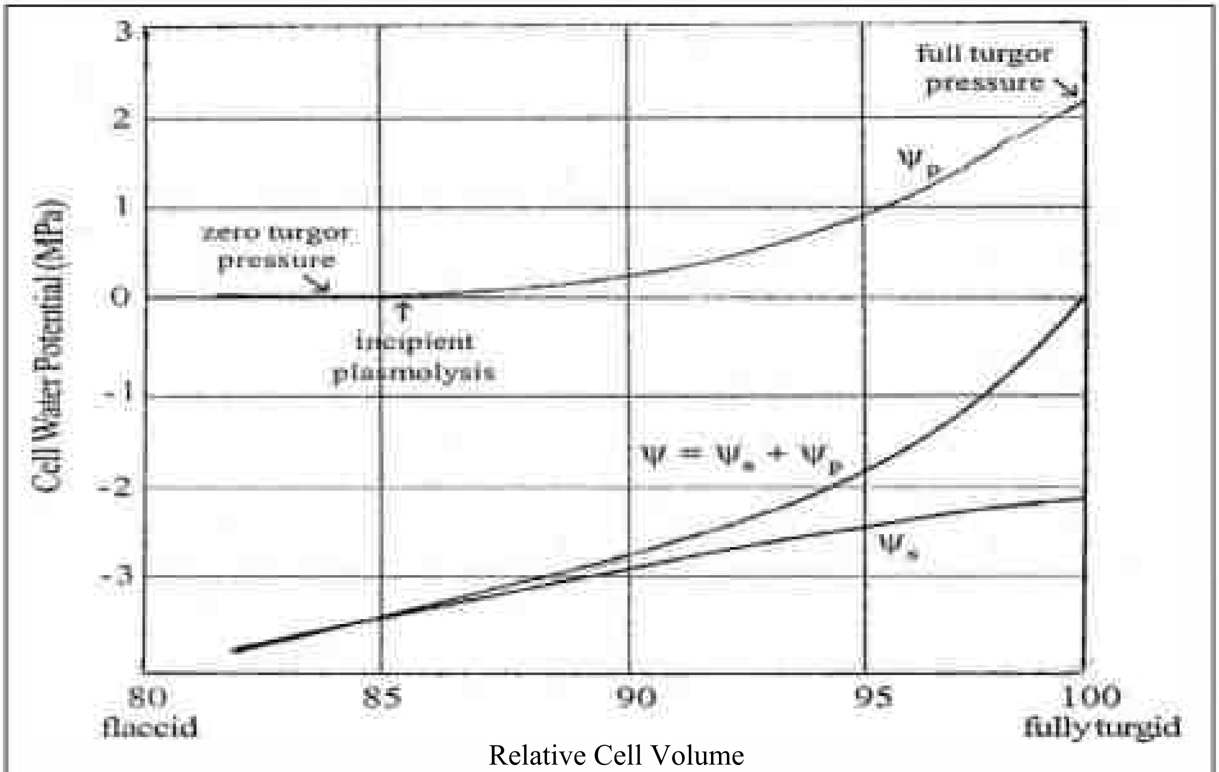


Fig.10.5 : Relation between cell water potential (v) and its components, solute potential (v_s) and pressure potential ($\backslash|/_p$), and relative cell volume. This diagram with thermodynamic terminology is the modified version of Fig. 10.8. Note that unlike as in Fig. 10.8., in this figure the values of y and $v_s$have negative sign.

10.3.3. Osmosis

Osmosis is a physical process and is considered as a special type of diffusion. In osmosis, only the solvent molecules move from their region of higher concentration to the region of their lower concentration across a semipermeable membrane.

If there are two sugar solutions, solution A having greater concentration than solution B and they are separated by a semipermeable membrane, then water will move from B to A as there are more number of water molecules in B than that of A. This spontaneous movement of water molecules from B to A is caused due to the phenomenon of “osmosis”. Thus, osmosis can be defined as the movement of water (or any solvent) from a solution of lower concentration to a solution of higher concentration when both the solutions are separated by a semipermeable membrane.

Such membranes which only allow passage of solvent molecules (water) and do not allow solute molecules to pass through it are called semipermeable membrane. Parchment paper, fish bladder, white membrane of eggs, animals bladder etc. are the examples of semipermeable membrane.

Osmosis can be demonstrated by a simple experiment in the laboratory. Take a long stemmed thistle funnel. Close the mouth of the funnel by stretching parchment paper across it. Take sucrose solution in the inverted thistle funnel and note the level of sucrose solution in the stem of it. Now place the inverted thistle funnel containing the solution in a beaker of water in a vertical manner with the help of a stand as shown in the Figure 10.6. Initially keep the height of sucrose solution in the stem of the funnel and the height of water in the beaker at the same level. After sometime the level of the solution in the stem of thistle funnel will rise. This rise of solution in the stem of thistle funnel is due to the entry of water (solvent) molecules from the beaker into the thistle funnel across parchment paper which is a semipermeable membrane.

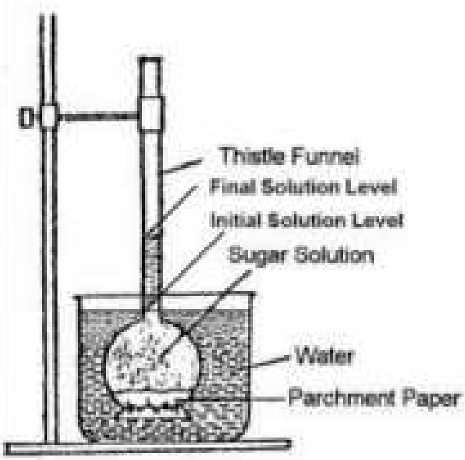


Fig.10.6 : Demonstration of Osmosis

The pressure which develops in a solution when it is separated from its pure solvent by a semipermeable membrane under ideal conditions of osmosis is called osmotic pressure. It may be defined as the actual pressure which may be applied to the solution, when the solution is separated from its pure solvent (water) by means of a semipermeable membrane, in order to prevent the inflow of solvent to the solution. Osmotic pressure is measured in terms of atmosphere or bars or megapascal (MPa) and is denoted by the symbol *it.* It is directly related to the concentration of the solute; more the solute particle, more is the osmotic pressure. Increase in temperature increases the osmotic pressure of the solution.

If a living plant cell or tissue is placed in water or hypotonic solution (whose osmotic pressure is lower than that of cell sap), water enters into the cell by osmosis. This process is called as *endosmosis.* As a result of entry of the water into the cell sap, a pressure is developed inside the cell which presses the protoplasm aganist the cell wall and the cell becomes turgid. This pressure is called as **turgor pressure.**

Similarly if a living plant cell or tissue is placed in a hypertonic solution (whose osmotic pressure is higher than that of cell sap), the water comes out of the cell sap into outer solution and the cell becomes **flaccid.** This process is called *exosmosis.*

Osmosis is of immense importance to plants as described as below.

(i) Large quantities of water are absorbed by root and root hairs from soil by osmosis.

(ii) The movement and distribution of water across the cells of the plant takes place by the process of osmosis.

(iii) Endosmosis and exosmosis are responsible for opening and closing of the stomata. The turgor of guard cells is absolutely essential for opening of stomata.

(iv) The form and shape of many cells and the keeping of the plasmamembrane near the cell wall are dependent upon osmotic phenomena.

(v) High osmotic concentration increases the resistance of plants to freezing temperature and desiccation.

(vi) In lower plants as well as in leaves and young stems of vascular plants, turgor pressure provides mechanical strength.

(vii) Growth of young cells is brought about by the osmotic pressure and turgor pressure of these cells.

(viii) Many plant movements involve changes in turgor which are brought about by osmosis.

(ix) The various cell organelles such as chloroplasts, mitochondria etc. collapse if they are not able to maintain a proper osmotic concentration of solutes.

Osmotic quantities of a plant cell and their relationship :

Osmotic pressure, turgor pressure and diffusion pressure deficit are the three osmotic quantities of a plant cell because they control the osmotic behaviour of the cell.

Osmotic Pressure (OP)

Osmotic pressure of a solution (in water) is defined as the actual pressure which is to be applied to it in order to prevent any inflow of water when the solution is kept separated from pure water by a semipermeable membrane.

Turgor Pressure (TP)

When a plant cell is placed in water, water enters into the cell due to endosmosis. As soon as the water enters into the cell, it exerts a pressure on cell inclusions and organelles and ultimately on the cell wall. This pressure which develops in the cell wall due to osmotic entry of water is called turgor pressure. The turgor pressure is variable. It is maximum when the cell is fully turgid and is zero when the cell is flaccid.

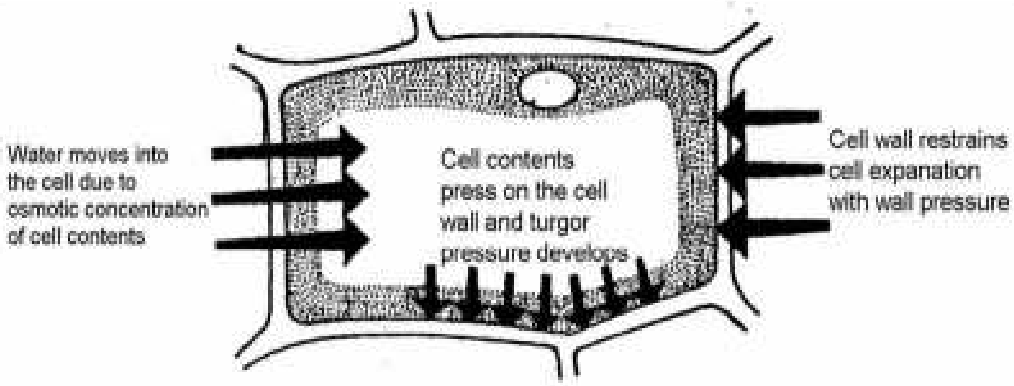


Fig.10. 7 : Demonstration of Osmotic concentration, TP and WP.

Due to increase in turgor pressure, the cell wall stretches to-wards outside. Since the cell wall provides a definite shape to the cell and is elastic in nature, it also exerts a pressure on cell sap in opposite direction, equal to turgor pressure. The pressure exerted by the cell wall on the cell sap is called **wall pressure.**(Figure 10.3) The wall pressure resists turgor pressure and prevents bursting of cell wall.

Diffusion Pressure Deficit (DPD)

Liquids have diffusion pressure. A pure solvent is supposed to have maximum diffusion pressure. When certain solute particles are added to the pure solvent, the diffusion pressure of the solvent molecules in the resulting solution is decreased. The amount by which the diffusion pressure of the molecules of solvent in a solution is lower than that in pure solvent at the same temperature and atmospheric pressure is called the **diffusion pressure deficit (DPD).** Suppose the diffusion pressure of the solvent molecules is X atmosphere and diffusion pressure of solvent molecules in solution is Y atmosphere. Then the diffusion pressure deficit of the solvent molecules in solution will be (X-Y) atmosphere. DPD is increased by the addition of solute, lowering of temperature and pressure. The DPD of any cell is the measure of water absorbing capacity of that cell. It is also called **suction pressure.** Thus suction pressure is a measure of the ability of a cell to absorb water.

Each and every cell has certain values of TP, OP and DPD. When a cell is fully turgid, its DPD becomes zero as it cannot absorb any more water. But at this stage the cell has OP and TP because the cell contains dissolved solutes and their (OP, TP) values can not be zero. These three quantities i.e. OP, TP and DPD are related in a plant cell as: **D P D = OP - TP.**

When a cell is placed in a hypertonic solution, the water from the cell cytoplasm goes out by the process of exosmosis resulting in increase in the OP and decrease in TP of cell cytoplasm. As a result of ex-osmosis, the cytoplasm contracts and moves away from the cell wall. Such a cell is called plasmolysed cell and this stage as flaccid stage. When the cell becomes completely plasmolysed, at that time the TP of the cell is reduced to zero. At that stage, **DPD = OP.**

When a cell is placed in pure water, it becomes fully turgid, its DPD become zero, because the cell no longer can absorb water. At that stage OP = TP. The relation of DPD, TP, Op and the volume of the cell is expressed in Fig. 10.8.

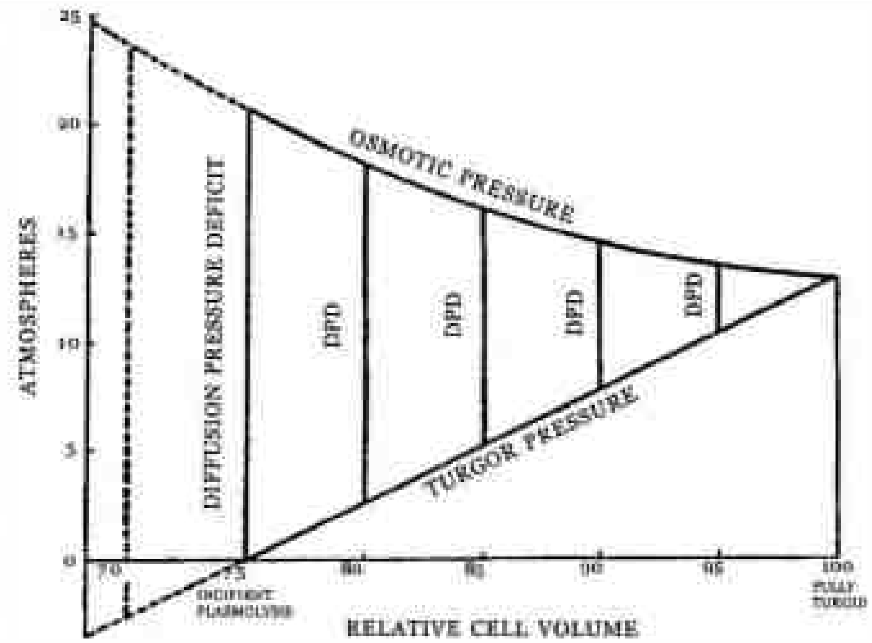


Fig. 10.8 : Relationship between Diffusion Pressure Deficit (DPD), Osmotic Pressure (OP) and Turgor Pressure (TP) in a cell. The dashed lines represent extrapolated values. See Fig. 10.5 for the differences in the terminology.

10.3.4. Plamolysis

If a living plant cell containing sap is immersed in a hypertonic solution, then exosmosis will take place, i.e. water will come out of the cell sap through the cell membrane into the outer solution. Loss of water from the cell contents causes contraction of the protoplasm which moves away from the cell wall and form an irregular mass at the centre or in one corner of the cell. This phenonenon of shrinkage of the protoplasm which moves away from the cell wall by the influence of certain hypertonic solution is called plasmolysis.

The stage at which the first sign of shrinkage of the cell contents from the cell wall becomes detectable is referred to as incipient plasmolysis. The space in between the cell wall and the cell membrane contains the hypertonic solution.

The various stages of plasmolysis can be seen under microscope (Fig. 10.9). Plasmolysis is easily observed in cells containing colored protoplast (eg., epidermal cells of *Rhoeo discolor)* since the presence of colors makes the shrinking protoplast easy to observe.

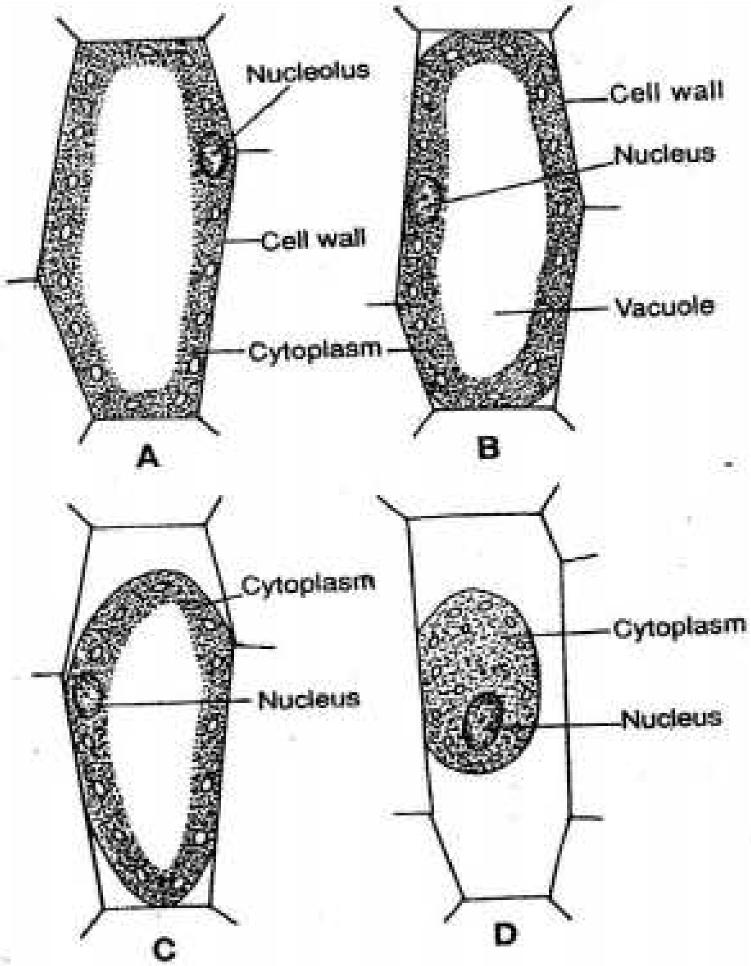


Fig.10.9 : Various stages of Plasmolysis in a cell. A. Normal Cell, B, C and D Plasmolysed Cells.

If a plasmolysed cell is immersed in pure water or in a hypotonic solution, endosmosis takes place. The protoplasm and the cell as a whole attain their original shape and size. This phenomenon is called deplasmolysis. It is the reverse of plasmolysis.

The importance and applications of plamolysis are:

(i) It signifies the semipermeable nature of the plasma membrane.

(ii) The appropiate osmotic concentration of cell sap and consequently the osmotic pressure can be determined by plasmolysis.

(iii) It determines the living nature of the cell; since no plasmolysis can occur in dead cells due to absence of semipermeable cytoplasmic membrane.

(iv) It is used for preservation of jams, jelly, prickles from the growth of fungi and bacteria by the addition of concentrated sugar solutions.In concentrated sugar solution, the organism will plasmolyse and die.

(v) The phenomenon is utilised in salting of meat and fishes to keep them unspoiled for some period.

(vi) The phenomenon of deplasmolysis proves the healthy nature of the cell.

10.4. LONG DISTANCE TRANSPORT

10.4.1. Absorption of Water

The movement of water from the soil through the unicellular root hair and cells of epiblema upto the metaxylem of root via cells of cortex, endoderims, pericycle etc. is defined as absorption of water.

Importance of water in plant life :

Water plays a vital role in plant life which may be discussed as follows :

(i) Nearly 80% of the fresh weight of the plant tissues is comprised of water.

(ii) Water is absolutely essential for the protoplasm. The hydration of the protoplasm is essential for its proper organisation and correct functioning of the cell organelles.

(iii) Water serves as a medium for the movement of various dissolved substances like gases, minerals, organic solutes etc. in the xylem and phloem tissues.

(iv) Water takes direct part in many metabolic reactions taking place in the cell viz. photolysis of water during photosynthesis, as reactant with hydrolytic enzymes.

(v) Absorption of water compensates the water loss by the plants caused due to transpiration. Transpiration helps in thermoregulation in plants.

(vi) Water stabilizes structural organisation of a number of biomolecules.

(vii) Water molecules form shells around electrolytes, ions and hydrophilic nonelectrolytes. This provides them sufficient space to function independently.

Availability of soil water

Plants absorb water from the soil by means of root hairs. The main source of water in soil is rainfall. The total amount of water present in the soil is termed as holard. Out of this, the available water to the plants is called the chesard and which can not be absorbed is termed as echard. When rain falls on soil surface, a part of water drains away. It is known as run-away water which is not available to plants. A part of rain water percolates downwards through large pores between the soil particles under the influence of gravity which is called gravitational water. It accumulates in the water table much below the reach of root system. This water is of no use to the plants. However, a good amount of water is retained by the soil particles and is known as field capacity moisture. This water may be present in three forms. **Capillary water, hygroscopic water** and **chemically combined water.** Water which fills the spaces between noncolloidal soil particles is known as capillary water. It is the available water for the plants. Roots and root hairs enter into the capillaries of the soil particles to absorb this water. Water which is held by soil particles of colloidal complex due to adhesive force constitutes hygroscopic water. Hygroscopic water is of no use to plants. A small portion of water is chemically bound with the soil elements, it mostly occurs in the form of oxides of aluminium, iron, silicon etc. This water is practically not available to plants.

Water absorbing organs of the plant

Roots are the main water absorbing organs of the land plants and floating hydrophytes. Certain epiphytic plants absorb water from atmosphere by their hygroscopic hanging roots containing a special tissue called velamen. A root consists of five distinct regions based on their function : root cap, meristematic zone or zone off cell division, zone of cell elongation, root hair zone and zone of maturation (Fig.10.10).

Root cap : It is a multicellular cap like structure present at the tip of the root. It protects the growing point of the root. Water of soil solution can not enter through root cap.

Meristematic zone : It lies just behind the root cap. It consists of small compactly arranged thin walled isodiametric cells having conspicuous protoplast. It adds new cells to the root. Absorption of water is restricted in this region because of dense protoplasm and lack of xylem elements.

Zone of cell elongation : It lies behind the meristematic region. The zone consists of cells which are elongating and is responsible for the increase in length of the root. Very slow entry of water takes place in this region.

Root hair zone : It occurs just above the zone of cell elongation. Xylem and phloem are well developed in this zone. This zone has thousand of root hairs. Maximum absorption of water take place in this zone. Root hairs are tubular hair like extension of epiblema cells which are closed at its tip. The root hairs project almost at right angles to the long axis of the piliferous cells. Root hairs are meant for absorption of water. They enter into the capillaries of soil particles. Due to high concentration of their cell sap and permeability of cell wall and cell membrane, they draw water from the soil.

Zone of maturation : The rest of the root lying above root hair zone consists of mature cells which impeds water uptake.

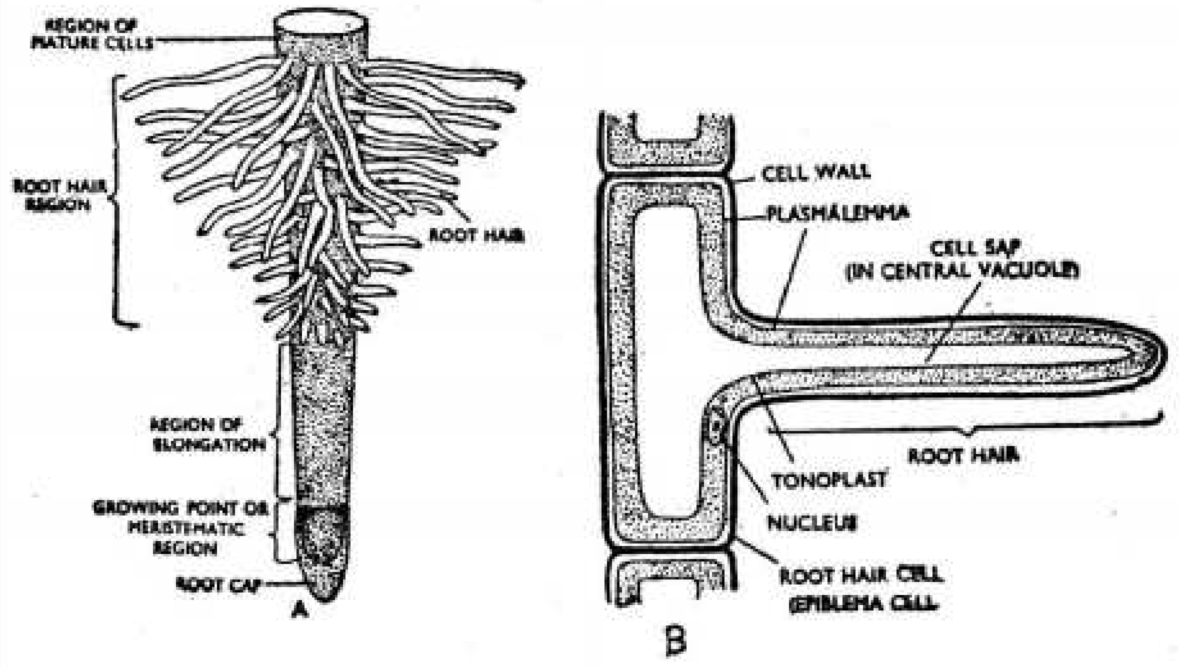


Fig.10.10 : A, Terminal region of a typical root; B, Structure of a root hair

Mechanism of water absorption :

The absorption of water takes place by active and passive processes. In active process, water is absorbed by the force developed in the root system. Active absorption generally takes place in slowly transpiring and well-watered plants. In passive absorption process, the forces responsible for the absorption of water develop in the shoot system, which are ultimately transmitted to the root system. The roots play a passive role in this mechanism. Passive absorption is, generally found in rapidly transpiring and ill-watered plants.

Active absorption of water: Two types of theories such as osmotic theory and non osmotic theory have been proposed to explain active absorption of water by plants.

(i) Osmotic Theory : The osmotic theory explains that the root hairs act as osmometers and there exists a typical condition so that water can move across osmotically from the soil solution to the root cells. The theory assumes that translocation of water takes place by means of diffusion along a gradient of decreasing water potential (\|/)- Absorption of water means translocation of water from soil solution to the xylem of root. The xylem sap, according to this theory, possesses a lower water potential (y) than that of soil solution. So water moves from the soil to the root xylem by cells to cell osmosis.

(ii) Non-osmotic theory : The non-osmotic theory assumes that when the driving forces are zero, water absorption takes place at the expenditure of metabolic energy released in respiration. Thus this theory explains the absorption of water by roots when the water potential of soil water is lower than that of the root hair cell sap. The non-osmotic active water uptake can also be supported by the following facts (i) There is a correlation between the rate of water absorption and respiration, (ii) Auxin-induced water uptake (iii) The factors such as low temperature, oxygen tension and respiratory inhibitors which affect respiration rate and in turn the absorption rate. The serious draw back of this theory is that it fails to explain the exact manner of utilization of metabolic energy in the process of water uptake.

Passive Absorption : In case of passive absorption, the root system does not play a significant role in absorption of water. It merely provides the surface for absorption of water. The main driving force responsible for absorption of water originates in the aerial portion of the plant. The water at the top of the plant develops a large tension or a negative hydrostatic pressure due to loss of water by transpiration from leaves. This tension pulls water through the xylem.

Water in the plant can be considered a continuous hydraulic system connecting the water in the soil with the water vapour in the atmosphere. The upper terminus of water in the plant system is represented by the meniscus of water in the substomatal cavities. The lower terminus of water is represented by epiblemal cells and root hairs. The mesophyll cells within the leaves are in direct contact with the atmosphere through an extensive system of air spaces. Initially water evaporates from a thin film of water lining air spaces. Subsquently water evaporates from the wall of mesophyll cells during transpiration. The water potential of the cell wall decreases. Thus water is absorbed by the cell wall from the protoplasm which in turn takes water from the vacuole of the cell. The water potential of the mesophyll cell decreases due to loss of water. This mesophyle cell absorbs water from the adjoining mesophyll cells and ultimately from the xylem or the veins of leaf. The tension developed due to transpiration acts as a pull from above on the whole water column of the plant. The tension is transmitted all the way down the unbroken water column through the stem to the absorbing part of the root. Due to the rapid rate of transpiration, transport of water through the whole system reflects a progressive decrease in water potential from soil to the atmosphere. A water potential difference develops between the root and soil. Thus soil water enters into root hairs and cells of epiblema and ultimately to xylem of roots via cortical cells.

Water moves through soil predominantly by bulk flow driven by pressure gradient. As plants absorb water from the soil, they deplete the soil water near the surface of the roots. This depletion reduces i|/P in the water near the root surface. Also it establishes a pressure gradient with respect to neighbouring regions of soil that have higher \|/P values. Because the water filled pore spaces in the soil are interconnected, water moves to the root surface by bulk flow through these channels down the pressure gradient.

In the passive mechanism, transpiration rate is very high and a large quantities of water are absorbed at a relatively faster rate.The best evidence in support of passive absorption comes from the experimental finding that the rate of absorption of water by a plant is approximately equal to the rate of transpiration, provided water is available in optimum quantity in the soil.

Path of water across the root:

If a potential gradient is established by any means, water moves centripetally across the epiblema and root hairs and then through the cortex to the xylem via endodermis and pericycle. The possible pathways of water transport across these regions are (Fig.10.11; Fig.10.12):

i. **apoplast pathway**
ii. **symplast pathway**
iii. **transmembrane pathway.**

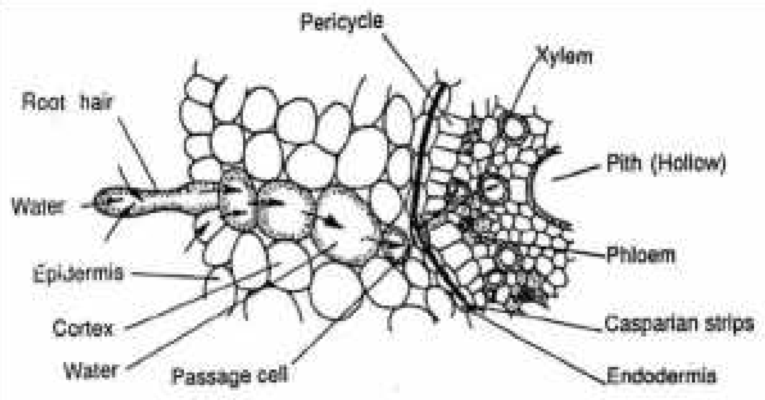


Fig.10. 11 : Movement of water from the soil into the plant.

The apoplast consists of nonliving components of the root that roughly equates with free space, that is, cell walls, intercellular air spaces and the xylem vessels. The symplast consists of cytoplasm interconnected by plasmodesmata. In the symplast pathway water moves from one cell to next via plasmodesmata. In the transmembrane pathway water enters a cell on one side, exits the cell on the other sides. In other words water crosses atleast two membranes for each cell in its path (the plasmamembrane on entering and on exiting).

The initial flow of water across the surface layer of root upto innermost layer of cortex is considered to be mainly through apoplast pathway. At the endodermis the apoplast pathway is obstructed by the casparian strip. Thus the movement of water across the endodermis occurs through the plasmamembrane. In certain cases poorly suberized passage cells allow the entry of water across the endodermis. The vascular cylinder offers little resistance to the movement of water from endodermis. Water on reaching the xylem is translocated upwards.

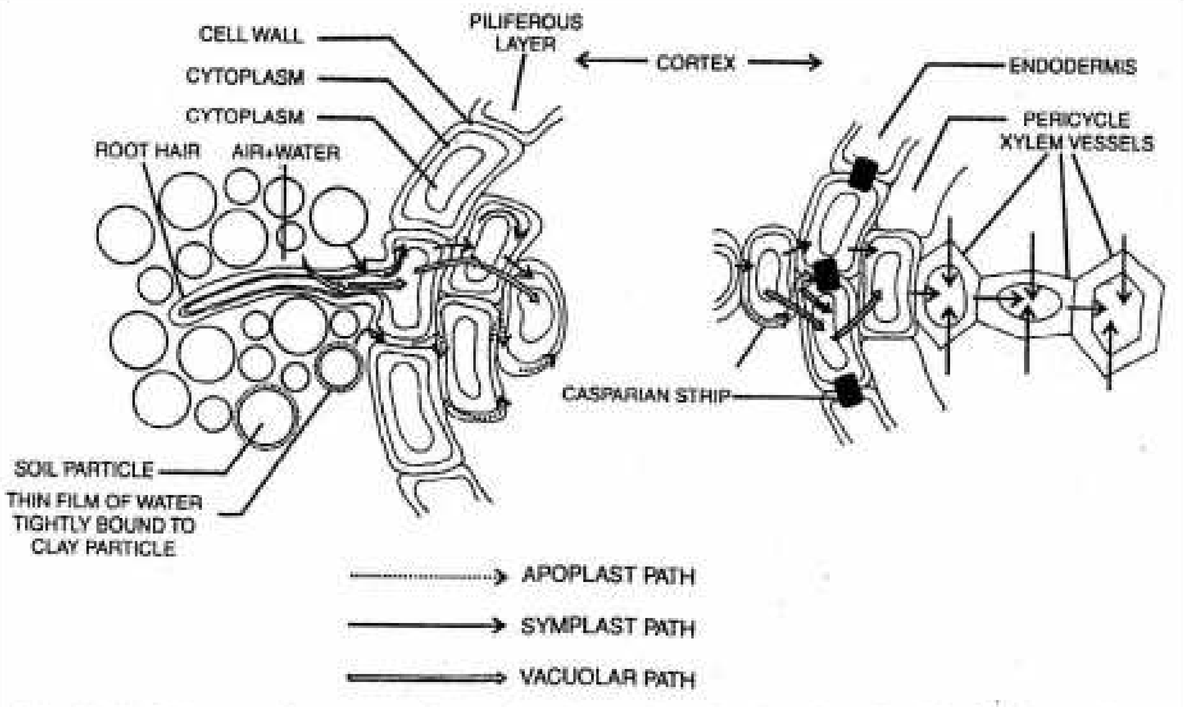


Fig.10.12 : Pathways of movement of water : Apoplast pathway (involves the cell walls), Symplast pathway (involves cytoplasma and plasmodesmata) and symplast pathway (from vacuole to vacoule)

Factors affecting absorption of water

The important factors which affect the rate of absorption of water are of two types.

I. External envirnomental factors.

II. Plant factors or internal factors.

I. External environmental factors :

(i) Soil temperature: The variation of temperature affect the rate of absorption of water. Water absorption is optimum within the temperature range of 20°C - 30°C. Any increase or decrease in temperature beyond this range decreases the rate of absorption of water. Moderately high temperature increases the rate of absorption of water and a very high temperature kills the cell. Lowering of temperature reduces the absorption process due to (a) slower elongation of root thus preventing its contact with new areas (b) decreased permeability of cell membrane (c) increased viscosity of water and protoplasm (d) reduced rate of metabolic activities (e) reduced rate of diffusion of soil water.

(ii) Availability of water: The rate of water absorption is generally influenced by the available soil water, i.e., the range of water amount between the field capacity (actual water holding capacity) and permanent wilting percentage (water loss that causes wilting at normal conditions). Decrease in the soil water below the permanent wilting percentage causes considerable decrease in the absorption of water. Appreciable increase in water beyond the field capacity affects the aeration of soil and decreases the absorption rate.

(iii) Soil aeration : Water is absorbed more efficiently in a well aerated soil than in poorly aerated soils. The deficiency of oxygen in soil inhibits the growth and metabolism of roots. Besides an accumulation of CO_2 in non-aerated soil increases the viscosity of protoplasts and decreases the permeability of cell membrane. The above factors severely reduce the rate of water absorption. These may be the reasons of plant death in flooded areas.

(iv) Concentration of soil solution : Water absorption depends upon the concentration of the soil solution. If the concentration of soil solution is greater than the cell sap, roots become unable to absorb water from soil. This is why the plants fail to grow in highly saline soil.

II. Plant factors or Internal Factors :

(i) Transpiration : High rate of transpiration increases the rate of water absorption because of the development of water potential gradient between root system and leaves.The water potential of leaves is lower than that of root system due to transpirational pull of water.

(ii) Metabolism : The metabolism of the root system and absorption of water by roots are closely related. It is experimentally observed that factors inhibiting respiration such as poor aeration, application of respiratory inhibitors etc. reduce the rate of absorption of water.

(iii) Root system : The efficiency of water absorption depends upon the root system. The presence of number of root hairs accounts for the rate of absorption.

10.4.2. Translocation of water or Ascent of sap

The upward movement of water from the metaxylem of roots upto the substomatal cavities of leaves via xylem of the stem and veins of leaves is called "ascent of sap" or conduction of water in an upward direction (Fig. 10.13). It has been experimentally verified that xylem is the main water conducting tissue. Various theories have been proposed to explain the mechanism involved in ascent of sap. Some scientists are of the opinion that living cells are actively involved in pumping water in an upward direction while others explain the mechanism of ascent of sap is independent of life activity. The various theoris can be broadly dealt under three headings.

I. Vital theories

II. Root pressure theory

III. Cohesion-tension theory

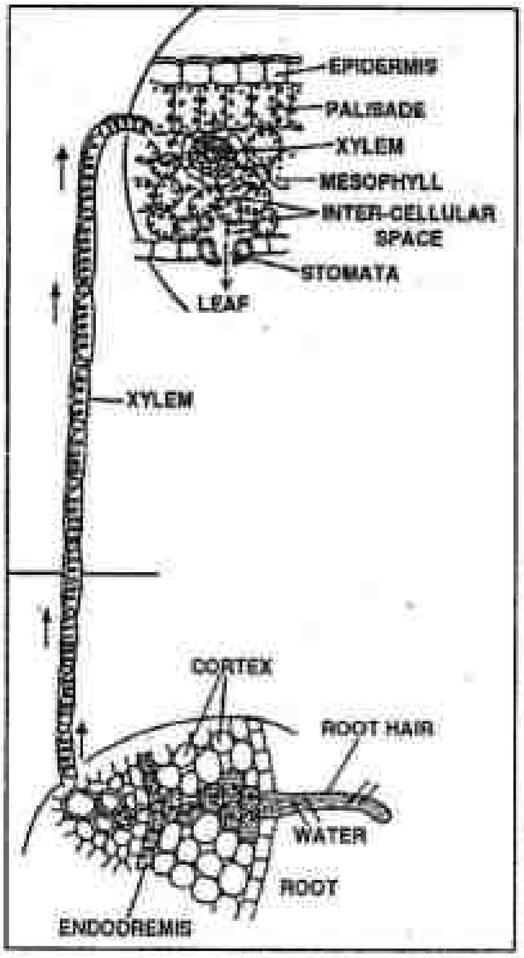


Fig.10.13 : Path of translocation of water.

I. Vital theories

All those theories which consider living cells to be responsible to effect ascent of sap are dealt under vital theories. Westermeir, Godlewski, Janse stated that the living cells play an essential role in ascent of sap.

Godlewski proposed relay pump theory to explain ascent of sap. According to him there was a rhythmic change in the osmotic pressure of the living cells of xylem parenchyma and medullary rays which brought about a pumping action of water in an upward direction. The tracheids and vessels acted as water reservoirs. Janse supported Godlewski and showed that if the lower portion of a branch was killed, the leaves above were affected.

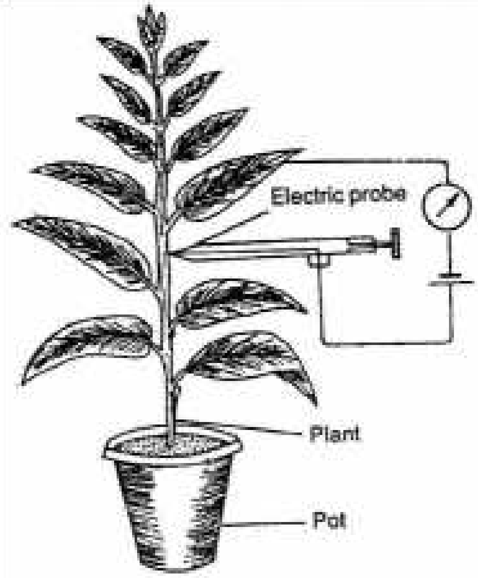


Fig.10.14 : Sir. J.C. Bose's pulsation theory explained by this device.

Sir J.C. Bose (1923) advocated pulsation theory to explain ascent of sap. He experimented to prove that the living cells of innermost layer of cortex lying just outside the endodermis were in a state of rhythmic pulsations which caused the pumping of water from cell to cell in an upward direction (Fig.10.14).

The vital theories are no more accepted as the possible mechanism of ascent of sap as no adequate experimental proof could be obtained in their support.

II. Root pressure theory

If the stem of a plant is cut near its base or incisions are made in the stem, xylem sap is seen to flow out through them. This phenomenon is called "exudation" or "bleeding". Pristley explained that this process of upward movement of water was due to a hydrostatic pressure developed in the root system known as root pressure. If a vertical tube is attached to a bleeding stump, a column of sap will rise in it (Fig.10.15). Since the living roots are essential for the development of root pressure, it seems most reasonable to think that root pressure is an active process.

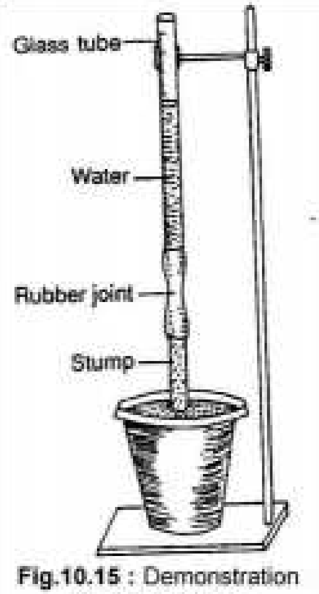


Fig.10.15 : Demonstration of root pressure

Kramer, Steward, Dixon and Joly have objected very strongly the involvement of root presure in causing ascent of sap. It is true that root pressure is a dynamic process, but in itself it is not sufficient to drive water in case of tall trees ranging in height from 200 to 300 feet. Further root pressure has not been observed in all plants. No or little root pressure is measurable in gymnosperms. Besides, root pressure has been found to be lowest during summer when the rate of transpiration is very rapid, whereas, it is highest in spring when the rate of transpiration is quite slow.

III. Transpiration pull and cohesion-tension theory

This theory was proposed by Dixon and Joly (1894) and has been supported by Curtis and Clark (1951), Levitt (1969). The above theory is also konwn as Dixon theory of ascent of sap. The theory assumes that water is pulled from up, but not pushed from below. The theory has two essential features such as (i) cohesion of water and adhesion between water and xylem tiusses, (iii) Transpiration pull.

(a) Cohesion of water and adhesion between water and xylem tissues

Cohesion is the phenomenon of attraction between similar molecules. The water molecules remain attracted by the cohesive force and can not be easily separated from one another. Further, there is attraction between water molecules and the inner wall of xylem ducts. Then water column cannot be pulled away from the wall of xylem ducts due to strong adhesive and cohesive properties of water and the continuity of water column is maintained from roots to leaves.

The forces acting against the cohesive force of water and which try to break up the water column in the plant are the weight of water column itself, the resistance encountered by water in crossing the tissues of the root, the stem and the mesophyll cells of the leaf. All these forces combined together have been found to be of the value of 50 atmosphere in tall trees. But the magnitude of the cohesive force of water alone is about 300 atmosphere, which is sufficient for maintaining the continuity of water column in plants.

(b) Transpiration pull

It is the pulling force responsible for lifting the water column. As water is lost in the form of water vapour to atmosphere from the mesophyll cells by transpiration, a negative hydrostatic pressure is created in the mesophyll cells which in turn draws water from veins of the leaves. The negative tension is then gradually transmitted downwards via xylem tissues of the leaf, stem and finally to the roots. As a result there is a continuous upward movement of water column in the plant.

Thus, the transpiration pull acts as pull from above on the whole of water culumn of the plant which draws water of xylem vessels of roots towards leaves i.e. in an upward direction.This continous water column does not break because of the strong cohesive force between water molecules and adhesive forces between water and xylem tissue. This is how ascent of sap takes place in plant.

10.4.3. Transpiration

Plants absorb a large quantity of water, from soil by means of roots and root hairs. However, only a small fraction (1-2%) of the absorbed water is utilised by the plants for its metabolic activities. The remainder (98-99%) of absorbed water is lost to the atmosphere by the physiological process known an transpiration. Transpiration is defined as the loss of water in the form of water vapour from the internal tissues of living plants through the aerial parts of plants such as leaves, green shoots etc. Transpiration occurs through two successive stages :

(i) At first water is lost from the mesophyll cells of the leaf into the intercellular spaces.

(ii) Subsquently water diffuses from the intercellular spaces into the outer atmosphere in the form of water vapour either through the stomata or general surface of epidermis of leaves.

Leaves and green shoots are the principal organs of transpiration. Transpiration may occur through the cuticle, lenticels or stomata. Accordingly it is called cuticular, lenticular or stomatai transpiration.

(i) Cuticular Transpiration : Cuticle is a layer of wax-like covering on the epidermis of leaves and herbaceous stems. It is meant to check transpiration. However, some water may be lost through it. Thus the loss of water in the form of water vapour through the cuticle is known as cuticular transpiration. Cuticular transpiration accounts nearly 20 percent of the total water loss by a plant.

(ii) Lenticular transpiration : Loss of water in the form of water vapour taking place through the lenticels present in woody stem and fruits is called as lenticular transpiration. It amounts 1-5 percent of the total water loss by the plant. (Fig. 10.16)

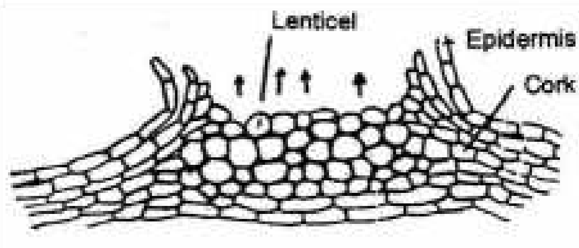


Fig.10.16 : Lenticels showing lenticular transpiration.

(iii) Stomatai transpiration : Stomata are minute pores confined to epidermis of green shoot and leaves. Opening and closing of stomata are controlled by guard cells. Maximum loss (about 80 percent of the total water loss) of water from the plant tissues takes place through the stomatai openings. The loss of water in the form of water vapour through the stomata of the plants is known as stomatai transpiration.

Structure of stomata

Stomata are minute pores of elliptical shape surrounded by two specialised epidermal cells known as guard cells. The guard cells are kidney shaped in dicots. The portion of guard cell wall lying close to stomatai aperature is thick and inelastic. The remainder of the cell wall is thin, elastic and permeable. Each guard cell has a cytoplasmic lining and a central vacuole containing cell sap. Its cytoplasm contains a nucleus and a number of chloroplasts. The epidermal cells surrounding guard cells are specialised and are known as subsidiary cells (Fig 10.17 A, B). They support the movement of guard cells. The size, shape and number of stomata of guard cells vary from plant to plant.

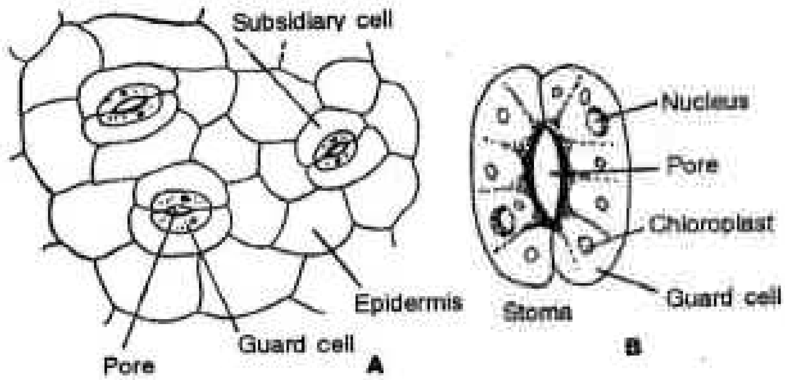


Fig.10.17 : A - epidermal peeling of leaf showing stomata and B - a single stoma enlarged.

General mechanics of opening and closing of stomata

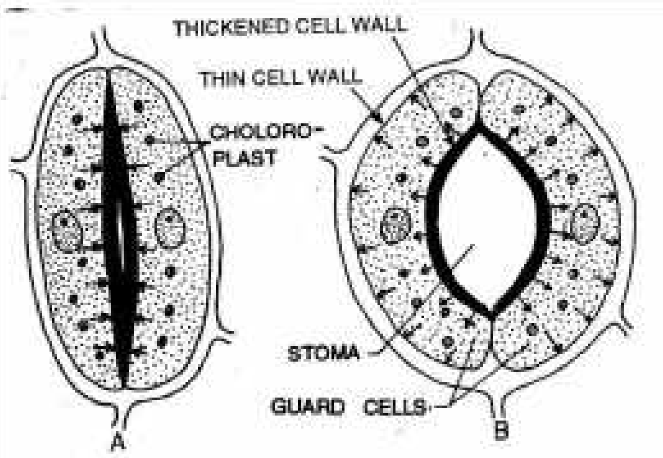


Fig.10.18 : Stomatal movements (A) Closed. (B) Open

Stomata generally open during the day time or lighted hours and close in the night.The opening and closing of stomata are brought about by changes in the volume and shape of the guard cells. The expansion and contraction of the guard cells is caused due to their attainment of turgid and flaccid conditions respectively (Fig. 10.18). When the guard cells absorb water from the surrounding cells, they become turgid. As the turgidity increases, the outer thin walls of guard cells stretch outward. The outward bulging causes the pulling apart of the inelastic inner thick walls which become concave in shape resulting in the opening of the stomata. When the guard cells become flaccid by loss of water, the thick walls revert to their original position, narrowing the stoma and ultimately closing it. This is the mechanics of guard cells.

The mechanism of stomatai opening and closing

Various theories have been put forwarded to explain opening and closing of stomata.

I. Theory of starch - glucose interconversion :

With the discovery of presence of phosphorylase enzyme in guard cells by Yin and Tung (1948), Steward (1964) proposed the theory of starch-glucose interconversion (Fig. 10.19). The following sequence of reactions occur at high pH in day time.

i. Starch + POr $\xrightarrow[\text{Phosphorylase}]{\text{High pH}}$ Glucose-1-P0_4

II. Glucose-1-PO, Ph^Phoglueomutase Glucose-6-po

iii. Gluscoe-6-PO $_4 \xrightarrow{\text{Phosphatase}}$ Glucose +PO $^{=}_4$

Formation of glucose in the guard cells increases the turgor of guard cells. Thus stomata gets opened in day time.

In night or dark condition the reverse reaction occurs and glucose is first converted to glucose -1- PO_4 with the help of ATP, and then to starch.

However, there are some objections to this theory for which it is not universally accepted. The objections are as follows :

(a) Sugar has never been observed to accumulate in the guard cells when starch disappears at the time of opening of stomata. On the other hand starch gets converted to organic acids.

(b) In monocotyledons, guard cells do not synthesize starch.

(c) Stomatai closure occurs even at midday although there is light and there is no change in starch contents.

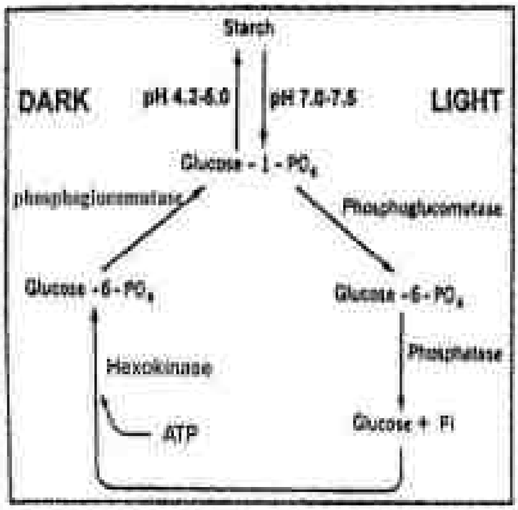


Fig.10.19 : Starch-glucose interconversion during opening and closing of stomata

Potassium ion theory

Experimental evidences show that stomata also open even in CO_2 free air as well as in absence of light by increasing the K^+ concentration in the guard cells. Imamura and Fujino (1959) observed accumulation of K^+ in the guard cells, and they proposed the K^+ ion theory to explain this.

The sequence of events taking place in guard cells are as follows:

1. Morning sunlight, particularly the blue light, is the cause behind stomatai opening. Blue light activates H^+-ATPases (proton pumps) of guard cell plasma membrane.

2. By using ATP, the pumps force H^+ to the cell wall of guard cells, and as a result of which the cell interior becomes rich in negative charges. The cell wall side of the plasma membrane has high H^+ concentration and the cytoplasmic side has negative charges.

3. Due to such difference in charges across the membrane it is said to be **hyper-polarised.** This leads to opening of the K^+- gated channels and K^+ ions enter the

cell *en masse.* In a very short time of falling of blue light in gurard cell, it contains more K^+ ions as compared to negative ions.

4. Following this Cl^- ions also enter the guard cells from the sorrounding cells.

5. Within the guard cells malic acid is formed from pyruvic acid which comes from carbohydrate metabolism.

Phosphoenolpyruvic acid + HCC>3– -> Oxaloacetic acid + Pi

Oxaloacetic acid + NAD(P)H -> Malic acid + $NAD(P)^+$

Malic acid ionizes to malate^{2-} and two H^+

The above mentioned ions (K^+, malate2" and Cl") are pumped into the vacuole. These osmotically active solutes lower the water potential in guard cells. As a result of this water enters guard cells due to endoosmosis, they become turgid and bulge away creating the stomatai pore.

The sequence of events taking place during closing of stomata are :

1. At night photosynthesis stops, CO_2 concentration builds up making substomatal cavity acidic
2. Concentration of ABA (Abscisicacid) in guard cell increases resulting in opening of Ca^{2+} - channels and increase of Ca^{2+} in cytoplasm
3. K+ efflux from guard cells takes place, following this water also leaves the guard cells by exosmosis
4. Turgor pressure decreases and guard cells move inward closing the pore.

Stomatai opening in succulent plants :

In case of succulent plants like *Opuntia, Bryophyllum sp.* etc. stomata open at night (called **scotoactive opening)** and close during day time. In these plants there is incomplete oxidation of carbohydrates during night. This causes accumulation of organic acids without liberation of CO_2. The organic acids produced in night leads to their dissociation and increase in H^+ ion and the rest of the processes lead to stomatai opening. However, during daytime organic acids are metabolized releasing CO_2 plentily which keep the stomata closed. The day closing and night opening of stomata solve the problem of water balance of succulents growing in dry and hot habitats (see under photosynthesis)

Factors affecting the rate of Transpiration :

The rate of transpiration is affected by a number of internal (plant factor) and external factors.

I. Internal or plant factors :

(i) **Root - shoot ratio :** If all other conditions are favourable for transpiration, the water absorbing capacity of root surface and transpiring capacity of the leaf suface regulate the rate of transpiration. If absorption surface is lower than transpiration surface, a water deficit results, causing reduction in transpiration rate. In other words, a low root/shoot ratio decreases the rate of transpiration.

(ii) **Leaf area :** The greater the leaf area, the higher will be the water loss due to transpiration.

(iii) **Stomatai frequency :** Stomatai frequency means the total number of stomata per unit leaf area. Stomatai frequency varies with different species. Greater the frequency of stomata, higher is the rate of transpiration.

(iv) **Structure of leaf :** Presesnce of thick cuticle, wax layers, sunken stomata and trichomes on the surface of leaves reduce the rate of transpiration.

II. External or Environmental factors

(i) **Light -** There is a close relationship between the opening of stomata and presence of light. Light affects the rate of transpiration in two ways. Firstly, light causes stomata to open. As a result the saturated interior cells of leaf are exposed to the outer atmosphere. Consquently, the rate of transpiration is increased in bright sunlight. Secondly, it increases the temperature of leaf and thus affects the rate of transpiration.

(ii) **Wind -** The increase in the wind velocity increases the rate of transpiration by removing the water vapour of the atmosphere from the vicinity of transpiring surface and lowering relative humidity.

(iii) **Temperature -** The increase in temperature increases the rate of transpiration. This is due to increase in the rate of evaporation of water from cell surface and decrease in the humidity of the external atmosphere. However, there is a limit in rise of temperature in relation to loss of water by transpiration. At very high temperature, usually beyond 35°C the rate of transpiration gradually falls due to inactivity of the protoplasm.

(iv) **Humidity of the air -** Humidity is expressed as the percentage of water vapour present in the atmosphere. The relative humidity of the atmosphere affects the rate of transpiration to a great extent because it influences the water potential gradient between the intercellular spaces and outside atmosphere. The higher the relative humidity of the outside atmosphere the lower will be the rate of transpiration. Conversely the lower the relative humidity of the outside atmosphere the higher will be the rate of transpiration.

(v) **Atmospheric pressure -** The reduction of atmospheric pressure reduces the vapour density of the external atmosphere. This allows more rapid diffusion of water. The plants growing on hills show higher rate of transpiration because of low atmospheric pressure and thus they develop xerophytic characters.

(vi) **Water Supply -** Deficiency of water in soil decreases the rate of transpiration. This is due to low absorption of water from the soil.

Significance of Traspiration

Transpiration has of immense importance in plant life. Beneficial roles of transpiration are:

(i) Gaseous exchange - Transpiration is essential in the life of land plants. It helps in the absorption of carbon dioxide (CO_2) from the atmosphere during photosynthesis as the opening of stomata in day time facilitate gaseous exchange.

(ii) Cooling effect - The leaves absorb the radiant energy. Some of the light energy is utilized in photosynthesis, rest is converted into heat energy resulting in an increase in leaf temperture. However, rapid evaporation of water in the form of water vapour from the aerial parts of the plant through transpiration brings down their temperature. Transpiration thus provides a significant cooling effect which keeps the plant from being over heated.

(iii) Effect on mineral transport - Mineral salts remain dissolved in the soil water and are absorbed by the roots. Minerals that are absorbed and accumulated in the xylem duct of the root move up and are distributed in the plant by the transpirational pull of sap.

(iv) Effect on water movement - The absorbed water is transported from roots to leaves through the xylem vessels which is greatly influenced by transpirational pull. Water loss due to transpiration results in the development of low water potential in the leaf tissues. Thus water moves from the xylem vessels to the leaf cells and helps in the ascent of sap.

(v) Development of mechanical tissues - Greater amount of transpiration helps in the development of mechanical tissues in plants. The plants become healthier and more compact. The cell walls become thick and cutinised and the plants are able to resist the attack of fungi and bacteria.

(vi) Maintenance of turgidity- Transpiration maintains an optimum degree of turgor in cells. Under favourable conditions plants absorb excess amount of water, which is given off by transpiration to maintain the optimum turgor for better growth.

According to *Curtis* transpiration is a necessary evil because of the following facts :

(i) A large amount of absorbed water is lost during transpiration which is harmful to plants.

(ii) Unnecessary wastage of energy takes place during the process of water absorption which is lost due to transpiration.

(iii) When the rate of transpiration is high in plants growing in soil defcient in water, an internal water deficit develops in plants which may affect metabolic process.

(iv) Many xerophytic plants undergo structural modifications and adaptations to check transpiration.

Considering both the beneficial and harmful effects of transpiration, it may be concluded that it is definitely advantageous inspite of its harmful features.

Antitranspirants

The term antitranspirant is used to desigante any material applied to plants for the purpose of slowing down transpiration. Some of the main antitranspirants are colorless plastics, silicon oil, low viscocity wax, phenyl mercuric acetate, abscisic acid, CO_2etc. Colorless plastics, silicon ils and low viscocity waxes constitute one group, as these are spread on the leaves with the purpose of forming a film permeable to oxygen and carbondioxide but not to water. Carbondioxide is an effective anti-transpirant. A little rise in CO_2 concentration from the natural 0.02% to 0.05% induces partial closure of stomata. To check transpiration in drought condition, dryice (solid CO_2) can be spread in the field. The advantage of antitranspring substances is to reduce the transpiration rate without adversely affecting exchange of gases during photosynthesis, respiration and growth. The application of antitranspirants is beneficial to agriculture for improving crop productivity during drought situations.

10.4.4. Guttation

When conditions are such that the absorption of water greatly exceeds transpiration, the excess of water escapes from the plant in the form of liquid trough structures called hydathodes present at the vein ending margins of leaf. This type of exudation of water is called guttation. The phenomenon of guttation is not universal, and is seen in some plants.

Guttation is mostly exhibited by herbaceous plants such as Balsam, Colocasia etc. growing in moist, warm soil and humid conditions of atmosphere. It mostly takes place at night or early in the morning, when there is no transpiration and root pressure is high. The fluid which oozes out in guttation, contains a variety of dissolved inorganic and organic substances.

Guttation takes place through structures called hydathodes (Fig. 10.20). The hydathodes remain open whole day and night and are conected with veins. Each hydathode opens to the exterior by a pore called stoma. The stoma is surrounded by two guard cells and open internally into an air chamber. Just below the air chamber there is a group of parenchymatons cells with intercellular spaces called epithem. It lies inside the leaf below the epidermis mostly towords the margin or tip of the leaf. The xylem vessels and tracheids open just behind the epithem. The exudation of water in the form of liquid drops takes place through stoma.

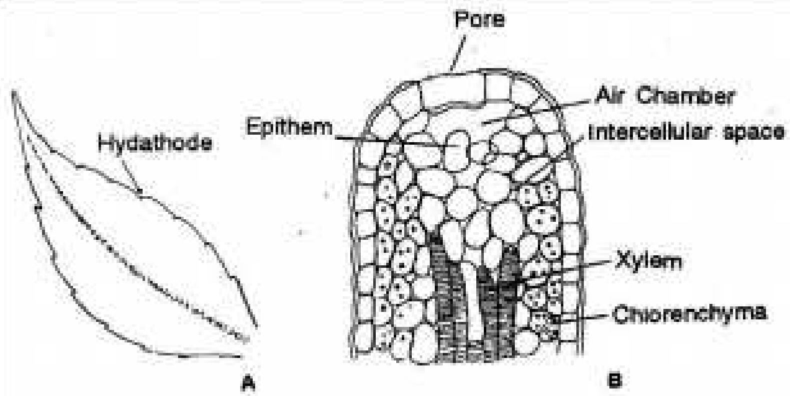


Fig. 10.20 : Hydathode. A - entire leaf showing position, B - V.S. of leaf through hydathode.

Guttation is caused due to a positive hydrostatic pressure (root pressure) which develops in the xylem ducts of the root.

Differences between transpiration and guttation :

Transpiration

(i) It occurs through stomata, cuticle and lenticels.

(ii) Water is lost in the form of water vapour.

(iii) It occurs only in day time.

(iv) The stomata of leaves usually remain open during day and get closed at night.

(v) Water (inform of vapour) is pure and contains no salt.

(vi) Major loss of water takes place through stomata present in leaf surface.

(vii) It takes place in all higher terrestrial plants.

(viii) Transpiration controls the temperature of the plant.

(ix) Root pressure is not involved.

Guttation

(i) It occurs through hydathodes in the leaves.

(ii) It is exuded in the form of liquid.

(iii) It takes place either in the morning or during the night.

(iv) The hydathode remain open whole day and night.

(v) Oozed out water is not pure and contains disolved inorganic and organic substances.

(vi) It occurs through hydathodes present in the leaf margin.

(vii) It takes place mostly in herbaceous plants.

(viii) It does not control leaf temperature.

(ix) It takes place due to development of root pressure.

10.4.5. Uptake and Transport of Mineral Nutrients

Plants absorb most of their required mineral nutrients and water from soil solution by roots and move them upward in the xylem for distribution throughout the aerial parts of the plants.

Uptake of mineral nutrients in ionic form from soil solution is carried out by the entire root surface; but uptake is more pronounced in root hair zone than in the meristem and elongation zones. Mineral ion concentration in the soil solution is usually much lower than its concentration inside the plant. Therefore, ion uptake by root cells require an expenditure of metabolic energy provided by the hydrolysis of ATP, i.e., by an active process as discussed earlier. Some mineral ions can be taken up by roots passively. Ion uptake by roots can be through the symplast or through the apoplast. In the symplastic mode, ions cross the plasma membrane of the epidermal cells, and, once inside, the ions diffuse radially in the cortex from one cell to the other through the plasmodesmata connections finally reaching the endodermis. In the apoplastic mode, an ion can diffuse in through the polysaccharide lattice of the cell wall between the epidermal cells or may be carried in passively by the inward water flow. In the cortex, the ions and other solutes may diffuse radially through the apoplast up to the endodermal layer. At the endodermal layer, the apoplastic movement of nutrients is blocked by the Casparian strip, which is a ring present in the radial walls of endodermal cells being impregnated with hydrophobic wax like substance, suberin. Thus Casparian strips in the radial walls of endodermis separates the outer apoplast from the inner apoplast and prevents any free flow of water, mineral ions, and other solutes between the outer and inner apoplasts. Therefore, water and nutrients must enter the symplast from outer apoplast before they can enter the stele. During this radial apoplastic movement, these nutrients may cross the plasma membrane of the cortical cells at any point and then reach the endodermal layer by symplastic mode.

Once inside the endodermis, ions continue to diffuse from cell to cell into the stele. Stele consists of living xylem parenchyma and dead xylem tracheary elements (tracheids and vessel elements). Being dead, xylem tracheary elements have no plasmodesmata or cytoplasmic connections with xylem parenchyma. Therefore, ions which reached xylem parenchyma from endodermal layer must leave the symplast by crossing the plasma membrane to be loaded into the xylem tracheary elements (the inner apoplast). The plasma membrane of xylem parenchyma has specialized transport proteins like channels, carriers and pumps which unload the solutes from symplast to apoplast. The process by which solutes leave the xylem parenchyma cells (symplast) and enter the xylem tracheary elements (apoplast) is called as **xylem loading.** After entering the conducting tissue of xylem, the mineral nutrients move upward along with water and reach the growing parts of plant as has been described for ascent of sap.

10.4.6. Transport of Food - Phloem Translocation

Photosynthetic products, particularly sugars, are synthesized in the mature leaves from where these are translocated by the phloem tissue to the areas of growth, including shoot tips and roots. On reaching the destination, sugars are used as substrate for respiration to provide building material and energy for cell wall formation, growth and differentiation. In the root, the metabolic energy is used for ion uptake from soil and for xylem loading. Sugars are also translocated to various storage organs such as fruits, tubers, and storage stem and storage roots. During germination of seeds or tubers, the stored sugars are retranslocated to form different plant organs including the growth and differentiation of leaves to carryout photosynthesis again. In deciduous plants, stored sugars of shoot and roots are retranslocated to be used for new leaf formation. Along with sugars, other organic compounds (e.g., amino acids) and mineral ions are also translocated. Thus, translocation through the phloem tissue is bidirectional whereas, transport through xylem tissue, as discussed above, is unidirectional. The cells of phloem that help transport sugars and other organic materials throughout the plant are the sieve elements, which are living cells specialized for translocation unlike the conducting cells of xylem which are dead cells. How do sugars from leaves are translocated to the roots and other organs? The overall pattern of phloem transport is a source to sink movement of products of photosynthesis. Sources include any exporting organ, typically a mature leaf, while sinks include nonphotosynthetic organs such as roots, tubers, developing fruits and immature growing leaves.

Mechanism of Phloem Translocation

The pressure-flow hypothesis (also called as mass-flow or bulk-flow hypothesis).first proposed by Ernst Munch in 1930, is widely accepted as the probable mechanism of translocation in the phloem tissue. Taking the translocation of sugars from leaves (source) to the roots (sink) as a specific example, as per this hypothesis, a pressure gradient is established as a consequence of phloem loading of sugars in the mature leaves and phloem unloading at the root tissues. In the mature leaves, sucrose, the translocable form sugar, is loaded into the sieve elements by an active process using metabolic energy. This results in the increase in the osmotic pressure in the sieve elements, causing a drop in the water potential. Water from the surrounding xylem tissue enters the sieve elements, causing the turgor pressure to increase in the source. In the roots, unloading of sucrose from the sieve elements takes place leading to a lower osmotic pressure and the water potential of the phloem tissue increases above that of the xylem tissue. In response to the water potential gradient, water comes out of the phloem tissue causing the turgor pressure to decrease in the sink. Thus a pressure gradient is established between the source and the sink, which drives the water movement and the sugars dissolved in it. A schematic diagram is presented below (Fig.10.21).

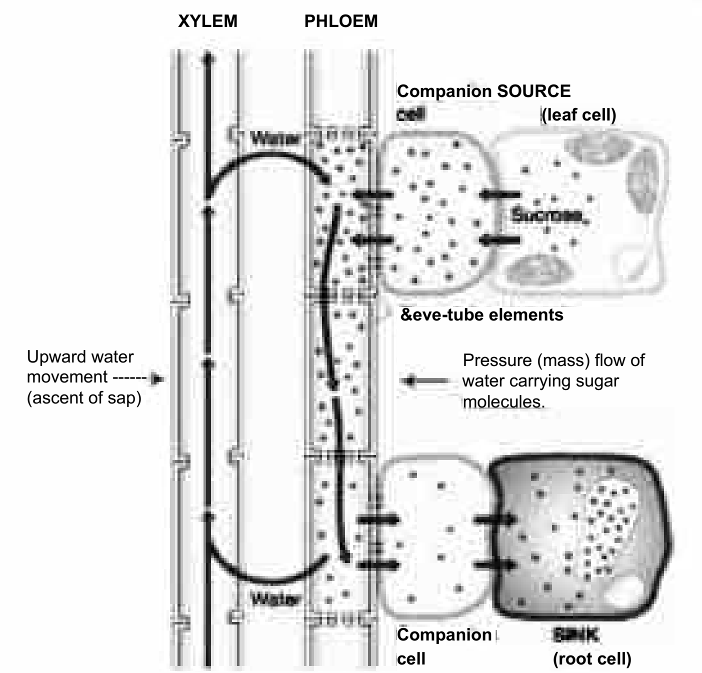


Fig. 10.21 : Pressure-flow mechanism of sugar translocation in phloem tissue from leaf (source) to root (sink) in plants based on Munch's hypothesis.

10.4.7. Diffusion of Gases into Plants

Plants require atmospheric gases like CO_2 and O_2 to perform two important physiological processes, photosynthesis and respiration respectively. These gases enter the plants by diffusion in gaseous state and then move within the plant both in gaseous state and in dissolved state. During photosynthesis, atmospheric CO_2 diffuses into the leaf through the stomatai pore in gaseous state. Upon reaching the substomatal cavity, CO_2 then diffuses in to the intercellular air spaces between the mesophyll cells also in a gaseous state. Then CO_2 enters the chloroplast passing successively through the water layer of wet walls of mesophyll cells, plasmamembrane and cytosol by diffusion in liquid phase. Oxygen, on the other hand, diffuses slowly in aqueous solution. It reaches the mitochondria by gaseous diffusion through the net work of intercellular air spaces found in plant tissues and also by diffusion in aqueous phase. In flooded soil, the plant root may resort to anaerobic (fermentative) metabolism, e.g., in rice plant. In certain mangrove plants, roots may protrude out of water or mudded soil as pneumatophores through which O_2 diffuses into the roots through gaseous pathway.

SAMPLE QUESTIONS

A. Multiple choice type :

1. When a cell becomes fully turgid being kept in water for sometime, which of its osmotic components becomes zero?

(a) OP		(a)	Osmotic potential
(b) TP		(b)	Pressure potential
(c) DPD	or	(c)	Water potential
(d) WP		(d)	Wall potential

2. When a cell becomes flaccid being kept in a solution for sometime, then:
   (a) Pressure potential = zero
   (b) Osmotic potential = zero
   (c) Water potential = Pressure potential
   (d) Pressure potential = Osmotic potential

3. When sucrose is dissolved in water, its water potential :
   (a) increases (c) becomes zero
   (b) decreases (d) is not affected

4. If a cell is placed in hypertonic solution , what will happen ?
   (a) Endosmosis (c) Deplasmolysis
   (b) Exosmosis (d) Nothing

5. If a cell volume decreases when placed in 0.25M sucrose solution , then the cell sap concentration is :
   (a) Equal to 0.25 M (c) More than 0.25M
   (b) Less than 0.25 M (d) Unpredictable

6. Root pressure is maximum when :
   (a) Absorption of water is high and rate of transpiration is high
   (b) Absorption of water is low and rate of transpiration is low
   (c) Absorption of water is high and rate of transpiration is low
   (d) Absorption of water is low and rate of transpiration is high

7. When starch is converted to glucose in guard cells,their water potential:
   (a) increases (b) decreases
   (c) becomes zero (d) is not affected

8. Ascent of sap in plants takes place through:
   (a) xylem (b) phloem
   (c) cambium (d) Both xylem and cambium

9. Ascent of sap in tall tree is best explained by:

(a)	Root pressure	(b)	Cohesion-tension theory
(c)	Capillary force	(d)	Imbibition

10. Which one is associated with stomatai regulation in plants ?

(a)	K^+	(b)	Na^+
(c)	Mg^{++}	(d)	PO_4^-

B. Fill in the blanks :

1. Stomata opens when guard cells become.
2. Water potential of leaves arethan that of roots during active transpiration.
3. Cohesion-tension theory of ascent of sap was proposed by.
4. The water coming out through hydathode contains.
5. Pulsation theory of ascent of sap was advocated by.
6. In a flaccid cell, y =.
7. Water potential of pure water is taken as.
8. The density of a substance (d) is related to its rate of diffusion (r) by the relation , r =.
9. A plant cell placed in water reaches its maximum volume when its v_s =.
10. If $v|z_s$ of a solution kept in a beaker is -0.5 MPa , then its y =.

C. Short answer type :

I. Symplast	2. Apoplast
3. Root pressure	4. Transpirational pull
5. Mechanics of stomatai opening	6. Significance of transpiration
7. Hydathode	8. Stomata
9. Diffusion	10. Imbibition
II. Water potential	12. DPD
13. Turgor pressure	

D. Long answer type :

1. Describe the mechanism of water absorption by plant roots .
2. Describe the factors affecting water absorption by plant roots.
3. Describe the transpirational pull and cohesion-tension theory of ascent of sap.
4. Write how potassium ions regulate the opening and closing of stomatai pore.
5. Describe the factors affecting the transpiration in plants.
6. What do you mean by water potential ? Describe its components.
7. Describe the relationship between DPD ,OP and TP of a cell.
8. Give an account of diffusion.

CHAPTER 11

MINERAL NUTRITION

All organisms are ultimately composed of several chemical elements. The final reservoirs of these elements on earth are the rocks, soil, oceans and the atmosphere. Only the green plants and certain microorganisms can primarily extract simple inorganic compounds and ions from the environment without being dependent on other living orgnisms. For this reason these organisms are called autotrophic or self-feeding. All inorganic requirements of plants except carbon, hydrogen and oxygen, are obtained directly or indirectly from soil. In 1804, de Saussure for the first time demonstrated that the inorganic elements contained in plant ash are obtained from the soil via the root system. These elements are essential to the growth and development of the plant. As the sources of these inorganic requirements are minerals, the elements are known as mineral nutrients and the nutrition is called mineral nutrition. Scientific approach to determine the mineral content of plants started by Sachs and Knop in 1830. Culturing the of plants in acqueous nutrient solution, they prepared a list of elements essential to plant life.

Criteria of essentiality :

An essential element has following criteria :

(i) It is indispensable for the growth of the plant. The plant cannot complete its life cycle without it.

(ii) The action of the element must be specific and should not be replaced by any other element.

(iii) The element must be directly involved in the nutrition of the plant, i.e. it should be a necessary component of an essential metabolite.

(iv) The absence or deficiency of the element should produce physical or physiological disorders.

Out of 92 natural elements nearly 40 elements are found in the living cells, of which 17 elements have been found to be essential. They are carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, iron, manganese, copper, zinc, boron, molybdenum, chlorine and nickel. The other elements are called non-essential elements or nutrients.

On the basis of the quantities required for plant growth and development, the essential elements have been divided into two categories : macronutrients and micronutrients.

Macronutrients

The mineral elements needed by plants in comparatively greater amounts or are found in high quantities in plants are termed macronutrients. Of the 17 elements listed above, carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorous, potassium, magnesium and calcium are known as macronutrients.

Micronutrients

The mineral elements needed by plants in small amounts or in traces are called micronutrients. They are copper, boron, managanese, zinc, molybdneum, iron, chlorine and nickel.

11.1. ROLE OF MINERAL ELEMENTSAND THEIR DEFICIENCY SYMPTOMS

11.1.1. Macronutrients

1. Carbon, Hydrogen and Oxygen :

Although these elements are not minerals in the true sense, they are still included in the list as they are most essential for plant life. These three lements are also called *framework* elements.

These elements are involved in the synthesis of compounds like carbohydrates, fats, proteins, enzymes, organic acids, nucleic acids, hormones etc. In short they build up the protoplasm. Plants absorb them from air and soil in the form of carbondioxide and water. Deficiency of either water or carbon dioxide causes retradation of growth and ultimately death of the plant.

2. Nitrogen :

The sources of nitrogen are soil and atmosphere. Nitrogen is absorbed from the soil in the form of nitrates, nitrites and ammonium salts. Atmospheric nitrogen can be fixed and made available to the plant by certain bacteria.

Specific role :

- It is important constituent of proteins, nucleic acids, porphyrins, alkaloids, some vitamins, co-enzymes and chlorophyll. Porphyrins are important part of chlorophylls and cytochromes. Thus it plays very important role in metabolism, growth, reproduction and heredity.

Deficiency symptoms :

- Nitrogen deficiency causes yellowing i.e. chlorosis of leaves. Older leaves are affected first.
- In some cases production and accumulation of anthocyanin pigment is found. As a result a purplish coloration appears in stems, petioles, and the lower leaf surfaces.

- Flowering is suppressed or delayed.
- Plant growth remains stunted.

3. Phosphorus:

It is present in the soil in inorganic and organic forms. It is absorbed primarily as the monovalent inorganic phosphate anions.

Specific role :

- It is a constituent of nucleic acids, phospholipids, NADP, ATP etc.
- Through nucleic acids and ATP, it plays important role in protein synthesis.
- Phospholipids along with proteins form important constituents of cell membranes.
- Phosphorus is also an essential part of all the sugar phosphates in photosynthesis and other metabolic processes
- High amounts of phosphorus are found in the meristematic tissues.

Deficiency symptoms :

- Phosphorus deficiency may cause premature leaf fall.
- Dead necrotic areas may be developed on the leaves, petioles or fruits.
- The plants show a general overall stunted appearance with often dark green coloration.

4. Potassium :

It is absorbed in the form of K^+ ions from the soil.

Specific Role :

- This element functions mostly as a catalytic agent in several enzymatic reactions, e.g., pyruvate kinase
- It is essential for translocation of sugars.
- Stomatai opening in higher plants requires potassium.
- It has a definite role in the regulation of water relations of plant cells.
- It helps in transport of ions across cell membrances.
- It maintains hydration, permeability and reactive state of protoplasm.

Deficiency symptons :

- Mottled chlorosis of leaves occurs.
- Plant growth remains stunted with marked shortening of internodes.

- Potassium deficient cereal grains develop weak stalks and their roots become susceptibe to root rotting organisms.

5. Calcium :

It is absorbed as divalent Ca^{2+} from soil.

Specific role :

- It is required for the formation of calcium pectinate, which is the important constituent of middle lamella in cell wall.
- Calcium salt of lecithin, a lipid compound, is involved in the organisation of cell membrane.
- Calcium ions protect plants from the injurious effects of hydrogen ions, high salt concentration in the environment, and toxic effects of other ions in the environment.
- It serves as a cofactor or may act as an activator for certain enzymes like amylase, ATPase etc.
- Calmodulin, a Ca^{++}-binding protein, has a regulatory role in cells.

Deficiency symptoms :

- Calcium deficiency causes stem collapse and subsequent termination of growth in the apical meristematic regions of stem, leaf and root tips.
- Roots become short, stubby and brown.
- Chlorotic patches appear near the margin of younger leaves.
- Disfiguration of the growing shoot tips is characteristic of calcium deficient plants.
- Cell walls become rigid and brittle in calcium deficient plants.

6. Magnesium :

It is present in the soil in water soluble, exchangeable and fixed from. It is taken up by plants as Mg^{++}.

Specific role :

- Magnesium is a component of the chlorophyll structure.
- It plays an important role in binding ribosomal particles during protein synthesis.
- The release of energy in the hydrolysis of high energy compounds like ATP is greatly influenced by Mg^{2+}. It is a cofactor in all kinase reactions.

Deficiency symptoms :

- Magnesium deficiency causes interveinal chlorosis of the leaves.
- Dead necrotic patches appear on the leaves.
- Anatomically magnesium deficiency causes extensive chlorenchyma development and scanty pith formation.

7. Sulphur:

Sulphur is taken up by the plants from the soil as divalent sulphate anions (SO_4^{2-}).

Specific role :

- Sulphur is important constituent of some amino acids (cystine, cysteine, methionine)
- It is a constituent of biotin, thiamine, coenzyme A and lipoic acid which are involved in cellular metabolism.
- It is a constituent of volatile oils which give characteristic pungent adours to cruciferous plants.
- Disulphide linkages help to stabilize the protein structure.
- Sulfhydryl groups are necessary for the activity of many enzymes.

Deficiency symptoms :

- A deficiency of sulphur results in chlorosis or yellowing of the leaves. The younger leaves are affected first.
- Tips and margins of the leaf roll inward.
- Sulphur deficiency results in marked decrease of stroma lamellaae and an increase in grana stacking

11.1.2. Micronutrients or Trace elements :

1. Manganese:

Manganese exists in the soil as divalent, trivalent, and tetravalent forms, but it is absorbed largely as the divalent manganous cation (Mn^{2+}).

Specific functions :

- Manganese is involved in oxidation-reduction processes together with decarboxylation and hydrolytic reactions.
- Photosystem II in chloroplast contains manganese protein.
- RNA polymerase has an absolute requirement for manganese.
- Manganese is the predominant metal ion of Krebs cycle reactions. It acts as an activator for the enzymes nitrite reductase, hydroxyl amine reductase and indole-3-acitic acid (auxin) oxidase.

Deficiency symptoms :

- Manganese deficiency causes chlorotic and necrotic spots in the interveinal areas of the leaf.

2. Boron :

Boron is absorbed by the plants from the soil as undissociated boric acid (H_3BO_3). The essentiality of boron for all green plants is not absolute.

Specific functions :

- In higher plants, boron is essential for sugar transport.
- Boron helps in germination and growth of pollen grains.
- Boron is concerned with the cell wall metabolism.
- Boron is essential for DNA synthesis.

Deficiency Symptons :

- Root tip elongation is inhibited.
- Shoot apices die.
- Nodule formation in legumes is inhibited.
- The branches at the end of twig form a rosette.

3. Molybdenum :

It is absorbed by the plants as molybdate ions.

Specific functions :

- Molybdenum is found to be essential in nitrogen fixation by legumes.
- Molybdenum is a component of the enzyme nitrate reductase, nitrogenase etc.

Deficiency symptoms :

- Molybdenum deficiency causes chlorotic interveinal mottling of the leaves with marginal necrosis and infolding of leaves.
- Causes “white tail” disease in cauliflower.
- The flowers abscise before fruit setting.

4. Zinc:

Zinc is absorbed as divalent Zn^{2+} ion.

Specific functions :

- Zinc is associated with the biosynthesis of indole-3-acetic acid (an auxin)
- Zn^{2+} is required for the activity of the enzyme phosphodiesterase and alcohol dehydrogenase.
- Zn^{2+} induces synthesis of cytochrome.

Deficiency symptoms :

- Growth is stunted in severe zinc deficiency.
- The leaves become smaller and the internodes shorten to give a rosette form.

5. Iron :

Iron is mainly absorbed by the plant in the ferrous form, but ferric ion may also be absorbed. Acid soil favours availability of soluble forms of iron.

Specific role :

- It functions both as a structural component and as a co-factor for enzymatic reactions.
- It is an important constituent of iron-porphyrin containing proteins like cytochromes peroxidases, catalases as well as in iron-sulfur proteins.It is required for chlorophyll biosynthesis.
- It is very important constituent of ferrodoxin (an iron-sulfur protein) which plays important role in biological nitrogen fixation and primary photochemical reaction in photosynthesis.

Deficiency symptoms :

- Iron deficiency causes rapid chlorosis of the leaves which is interveinal. The deficient symptom first appears in young leaves.

6. Copper:

It is absorbed as both monovalent and divalent cations.

Specific functions :

- Copper is a component of cytochrome-c oxidase which in a terminal electron transport chain component in mitochondria. It is also a component of plastocyanin (the mobile electron donor of PSI) and the vitamine, cyanocobalamine.
- Copper is found in a group of enzymes in which oxygen is used directly in the oxidation of substrate.

Deficiency Symptoms :

- Copper deficiency results in *exanthema,* a disease of fruit trees.
- Blackening of potato is also caused by copper deficiency.

7. Chlorine:

Chlorine is absorbed as Ch.

Specific function :

- Chlorine helps in the photooxidation of water in photosynthesis.
- It is required for the normal production of fruits.

Deficiency Symptoms :

- Leaves become wilted.
- Leaves develop bronze colour.
- Fruit formation is retarded.

8. Nickel:

Nickel is absorbed by plants in ionic form as Ni^{2+}.

Specific function :

- Nickel is a component of enzymes like urease in higher plants and hydrogen-uptake hydrogenase in microorganisms.

Deficiency Symptoms :

- Nickel deficiency causes urea to accumulate in leaf tips and leaf tip necrosis develops.
- Nickel dificient seeds are incapable of germination.

11.2. HYDROPONICS

Owing to the complex nature of soil, it is difficult to conduct experiments to determine the elements essential for plants. Hydroponics is used to determine the essential elements more easily and accurately. The technique of growing plants with their roots immersed in nutrient solution is called **hydroponics.** It was first developed and used extensively by Julius von Sachs in 1860. The hydroponic solution must be well-aeretaed to provide oxygen for root respiration. The pH of a nutrient solution must be maintained because it changes very often with the uptake of ions by roots. Hoagland's solution and Evan's solution are often used for hydroponics, where the concentration of nutrients is greater than that of the soil, and which promotes rapid growth of the plants with nutrient depletion taking place quickly. So nutrients must be added at intervals for keeping plants growing continuously.

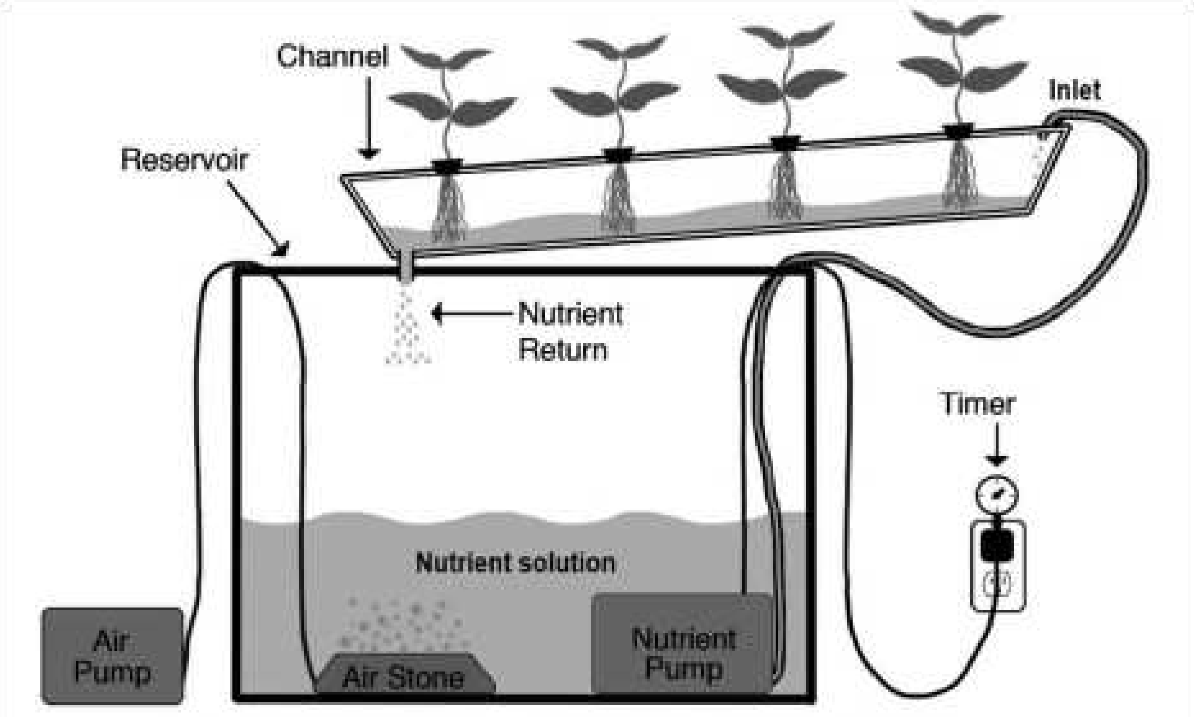


Fig.11.1 : Growing plants in nutrient solution by nutrient film technique.

As hydroponic solution is of known strength, eliminating a particular nutrient from it can be used to know the role played by that particular element in the plant body. This also helps in determining the deficiency symptoms or that particular element. Now-a-days, hydroponics is used for growing salad crops like cucumber, lettuce and tomato. The nutrient film technique as shown in the Figure 11.1 is used where the nutrient is continuously circulated allowing a monitoring of the pH and solution composition.

11.3. NITROGEN METABOLISM

Nitrogen is an essential macroelement FOR plant growth. It is the main constituent of proteins, enzymes, nucleic acids, hormones, alkaloids etc., which are used for the formation and functions of cellular components. The main source of nitrogen is air which contains 78 percent nitrogen by volume. Most of the plants can not utilise atmospheric nitrogen in its gaseous form. Only certain bacteria, including cyanobacteria can utilise the atmospheric nitrogen. These organisms are termed as nitrogen fixing organisms. Plants utilize nitrogen only when the nitrogen is fixed i.e., it is converted into nitrate (NO_3~) and ammonium (NH_4^+) ions. The fixation of atmospheric nitrogen (N_2) into NO_3~ and NH_4^+ with the help of microorganisms to make it available for absorption by plants is called biological nitrogen fixation.

11.3.1. Biological nitrogen fixation

Biological nitrogen fixation is of two types - asymbiotic nitrogen fixation and symbiotic nitrogen fixation.

11.3.1.1. Asymbiotic Nitrogen Fixation

The fixation of N_2 by the microorganisms living freely i.e. outside the plant cell is called asymbiotic or non-symbiotic biological nitrogen fixation. Free living bacteria and cyanobacteria can fix nitrogen in the soil. The nitrogen fixing cyanobacteria are *Anabaena, Nostoc, Spirulina, Stigonema, Scytonema* etc. These cyanobacteria have some thick walled cells called heterocysts which fix atmospheric nitrogen. Some free living aerobic bacteria such as *Azotobacter, Derxia* and anaerobic bacteria such as *Clostridium, Desulphovibrio, Methanobacterium* are capable of nitrogen fixation. Besides, *Rhodotorula,* a yeast can fix atmospheric nitrogen in the soil.

Mechanism of Asymbiotic Nitrogen Fixation : J.E. Carnahan in 1960 first reported the conversion of atmospheric nitrogen into ammonia by the free living nitrogen fixing bacteria, *Clostridium pasteurianum.* The fixation of nitrogen takes place as follows : Phosphorolytic breakdown of pyruvate results in the production of electrons, acetyl phosphate and hydrogen. Ferredoxin accepts electrons coming from pyruvate and itself get reduced. Acetyl-phosphate reacts with ADP to generate ATP. In the presence of reduced ferredoxin and ATP, molecular nitrogen is adsorbed on the surface of the enzyme nitrogenase. Rduction of N_2 to $2NH_3$ is a six-electron transfer reaction which is ultimately provided by reduced ferroedoxin via the enzyme nitrogenase enrgized by the hydrolysis of ATP (Fig. 11.2). The details of nitrogenase action is shown in Fig. 11.5.

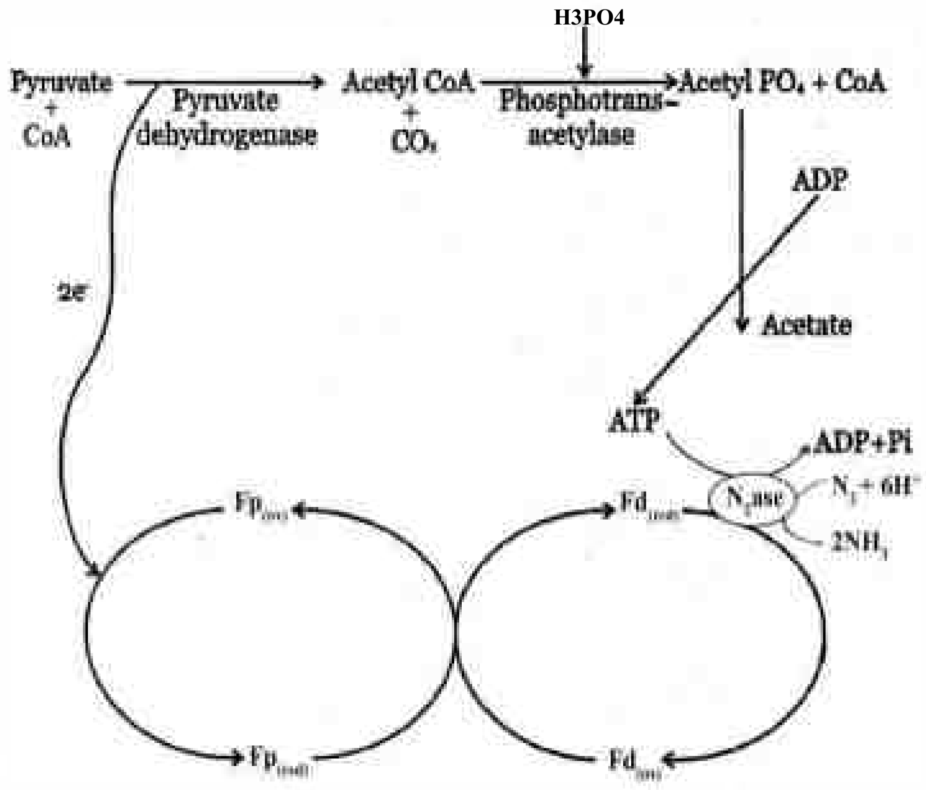


Fig.11.2 : Asymbiotic nitrogen fixation in free-living bacteria.
(Fp - flavoprotein; Fd - ferredoxin; N_2ase - nitrogenase)

11.3.1.2. Symbiotic Nitrogen Fixation :

The fixation of free nitrogen of air by microorganisms living symbiotically inside the plants (roots) is called symbiotic nitrogen fixation. The symbiotic system consists of bacteria of the genus *Rhizobium* infecting the roots of many members of the family Leguminosae, such as peas, beans etc. to form nitrogen fixing co-operative. The actual site of nitrogen fixation is the *nodules* formed on the roots of the legume plants as a result of the penetration of *Rhizobium.*

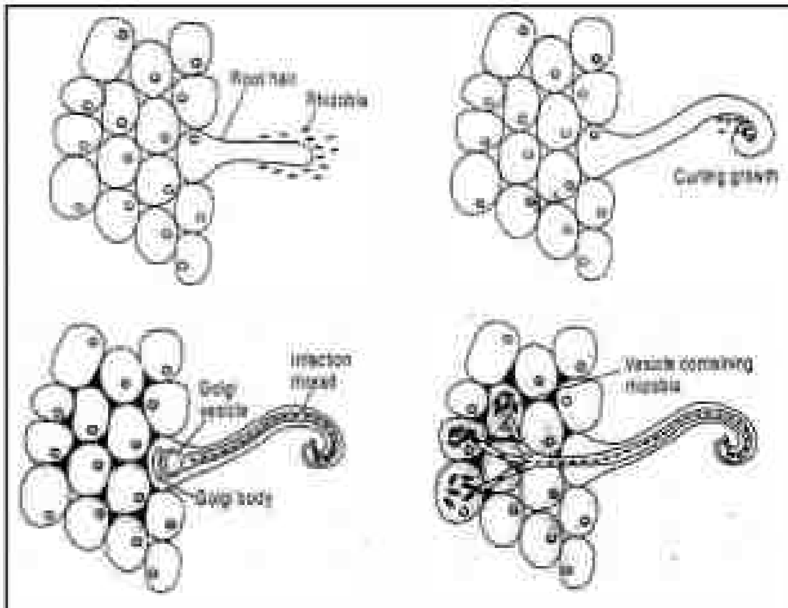


Fig.11.3 : Formation of infection thread and root nodule.

Neither organism alone is able to fix nitrogen. In the initial stage, host cells recognise the correct strain of symbiotic bacteria. The roots of leguminous plants secrete some growth factors. As a result the bacteria accumulate in the vicinity of plant roots (Fig. 11.3). The bacteria, then, either penetrate the relatively soft root hair tip or invade damaged or broken root hairs and progress in as an infection thread. The infection thread intrudes, settles and liberates its contents in a cortical cell.The *Rhizobia* are liberated either individually or in small groups enclosed by a membrane bound vesicles and enter the plant cell. The vesicles are termed as *symbiosomes.* The bacterial cells induce the cortical cells to divide which ultimately result in the formation of nodules. The bacterial cell divides and attain enlargement to fix nitrogen in this area. At this stage the bacteria are called *endosymbionts orbacteriods.* The nodules grow rapidly, pushing its way to the surface of the root (Fig. 11.4). The nodule contains a red pigment *leghemoglobin.* The enzyme nitrogenase is sensitive to O_2. Leghemoglobin combines with O_2 and prevent it reaching out nitrogenase. The development of leghaemoglobin and nitrogen fixing capacity are outcome of symbiotic interaction. The mature nodules remain connected with the root via vascular tissues through which exchange of fixed nitrogen of the bacteriods and the nutrients of host takes place.

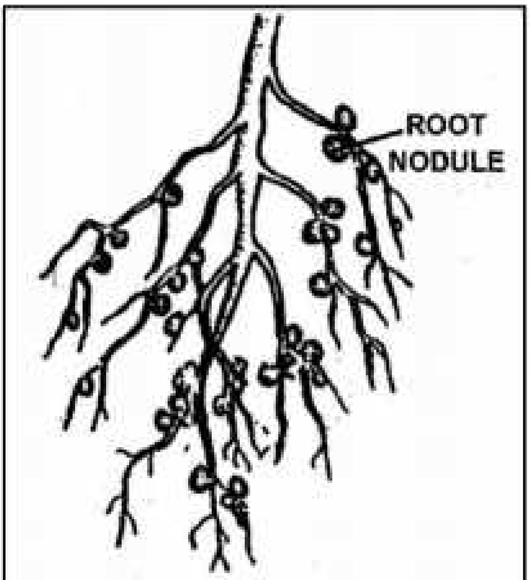


Fig.11.4 : Pea plant showing root nodules.

Mechanism of Symbiotic Nitrogen Fixation

The root nodules of leguminous plant have a red pigment called leghemoglobin. It is a reddish pigment found in cytoplasm of host cells. Leghemoglobin by combinig with O_2 not only protects the nitrogenase from damage by O_2 but also maintains steady supply of O_2 to nitrogen fixing bacteria for respiration. The ATP generated in the process of respiration of bacteria is used for nitrogen fixation. The bacteroids contain the enzyme nitrogenase. The free atmospheric nitrogen is first bound to the enzyme surface and is not released until it is completely reduced to ammonia. The nitrogenase enzyme complex is composed of two proteins (i) iron protein (Fe protein) and (ii) iron molybdenum protein (MoFe protein). Fe protein has a reductase activity while MoFe protein has nitrogenase activity. Photosynthates are transported to the nodule tissue, where it is metabolized and ultimately reduces ferredoxin. Reduced ferredoxin transfers electron to Fe protein which gets reduced. ATP hydrolysis within the Fe protein efficiently transfers electron to MoFe protein. Reduced MoFe protein which has nitrogenase activity reduces N_2 to NH_3. (Fig. 11.5).

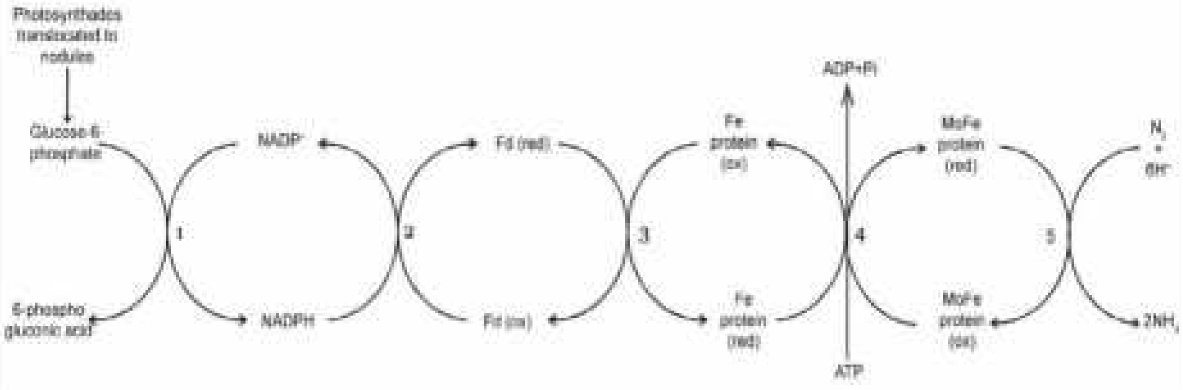


Fig. 11.5 : Symbiotic nitrogen fixation in root nodules of legumes. 1. glucose-6-P dehydrogenase; 2. NADPH-ferredoxin oxidoreductase; 3- ferredoxin transfers electron to Fe protein; 4. Reductase acitivity of nitrogenase complex; 5. Nitrogenase activity of nitrogenase complex. Reactions 2 to 5 are common for non-symbiotic nitrogen fixation by free living soil bacteria.

As started earlier, reduction of N_2 to NH_3 is a six electron transfer process. The ultimate source of electron and protons (H^+) is carbohydrate translocated from leaves to nodule tissue. The step-wise reduction of N_2 to NH_3 catalyzed by nitrogenase is shown below.

$$\underset{\text{Nitrogen (dinitrogen)}}{N \equiv N} \xrightarrow[2e^-]{2H^+} \underset{\text{Dimide}}{NH = NH} \xrightarrow[2e^-]{2H^+} \underset{\text{Hydrazine}}{NH_2\text{-}NH_2} \xrightarrow[2e^-]{2H^+} \underset{\text{Ammonia}}{2NH_3}$$

11.3.1.3. Nitrification

The organisms, either free-living or in symbiotic associations,which carry out biological nitrogen fixation to form NH_3 from N_2, utilize the NH_3 to produce their own cell's nitrogen components. The excess NH3 fixed may be excreted into the soil.However very little NH3 is found in the soil. Infact in the soil NH_3 is rapidly oxidized to nitrate ion (NO^-_3) and this NO^-_3 is the main source of nitrogen for non-nitrogen fixing plants.

Two groups of soil-living bactria known as nitrifying bacteria,carry out the oxidation of $NH_3$to NO_3^-. One group, *Nitrosomonas* oxidizes $NH_3$to NO_2^-while the other group, *Nitrobacter,* oxidizes NO_2^- to NO_3^-.

$$NH_3 + 1/2\ O_2 \xrightarrow{\textit{Nitrosomonas}} NO_2^- + H_2O + H^+ \qquad NO_2^- + 1/2\ O_2 \xrightarrow{\textit{Nitrobacter}} NO_3^-$$

11.3.1.4. Nitrate and Ammonia Assimilation

Both NO_3^- and NH_4^+ (protonated form of NH_3) are the sources of nitrogen for higher plants, although the plants have a preferance for NO_3^-. NO_3^- is absorbed by the roots of plants and is assimilated both in roots and shoots. NO_{3-} is first reduced to NO_2"by the enzyme nitrate reductase (NR) which is then reduced to NH_4^+ by the enzyme nitrite reductase (NiR) as per following reactions:

NO_3- + NAD(P)H + IT + 2e- $\xrightarrow{NR}$ NO_2" + $NAD(P)^+$ + H_2O

NO/ + 6 Fd(red) + $8H^+$ + 6e~ $\xrightarrow{NiR}$ NH_4^+ + 6 Fd(ox) + $2H_2O$

NH_4^+ is toxic and does not accumulate in the tissue. NH_4^+ formed this way or by biological nitrogen fixation is converted into amino acid and then into other nitrogenous compounds inside the plant cells.

11.3.1.5. Denitrification

Some anaerobic soil bacteria, such as *Pseudomonas* and *Denitrobacillus,* convert nitrate (NO/) to N_2 and other gaseous nitrogen species (e.g., NO and N_2O) by a process known as denitrification. Denitrification occurs when these soil bacteria use NO/ as electron acceptor instead of O_2 during respiration. Denitrification proceeds through the following reaction sequence by the soil denitrifying bacteria:

NO_3- -> NO_2- -> NO —> N_2O -> N_2

Nitrate Nitrite Nitric oxide Nitrous oxide Nitrogen

In this process the fixed nitrogen in the soil returns back into the atmosphere in the gaseous forms of nitrogen (NO, N_2O, N_2).

11.4. NITROGEN CYCLE

Nitrogen exists in our environment in several forms as N_2, NH_3, NO/, NO/, NO, N_2O and as organic nitrogen. The continuous inter-conversion of these forms of nitrogen by physical and biological processes is known as **nitrogen cycle.** The major steps in the nitrogen cycle are described below.

Nitrogen fixation -It is the conversion of atmospheric nitrogen gas (N_2) to form biologically usable nitrogen compound. This can takes place by physical and biological processes. Electrochemical and photochemical fixation by lightening forms NO/ by the oxidation of N_2 by O_2 or O_3. In the industrial fixation, N_2 is converted to ammonia and nitrate salts and are used as fertilizers. Biological N_2 fixation forms NH_4^+ (protonated form of NH_3) as has already been described.

Nitrification - In this process NH_3 is oxidized to NO/ and then to NO/ by nitrifying bacteria as discussed earlier.

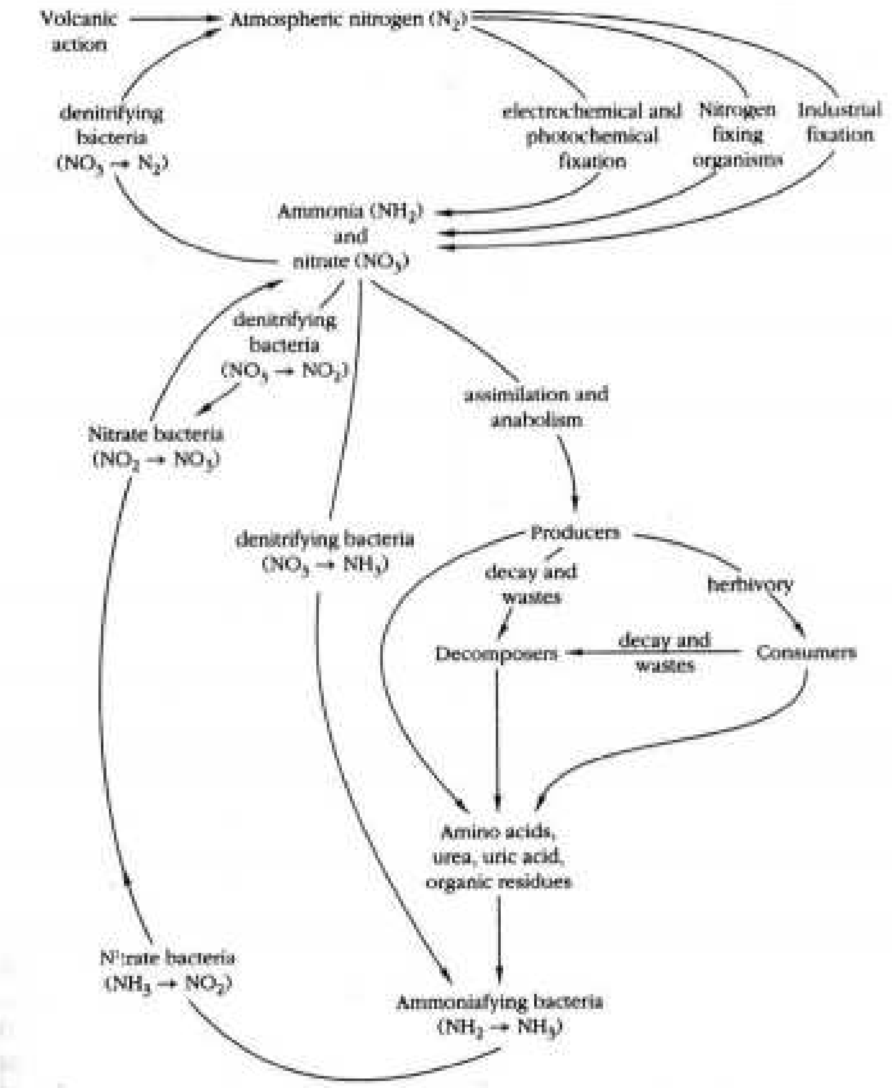


Fig.11.6 : The nitrogen cycle.

Assimilation - In this process NO_3^-, NO_2^- and NH_4^+ are absorbed by the plants and are utilized for the formation nitrogenous compounds such as amino acids, proteins, nucleic acids, chlorophyll etc.

Ammoniafixation - This is a decaying process of dead organisms or their parts carried out by decomposers like bacteria and fungi. The organic nitrogen compounds are converted to NH_3SO that it can re-enter into the cycle.

Denitrification - This is a process by which NO_3^- is reduced by soil bacteria to form gaseous nitrogen species, generally N_2 or N_2O, which are then escape into the atmosphere to complete the cycle.

The steps of nitrogen cycle described above are shown in Fig. 11.6.

SAMPLE QUESTIONS

A. Choose the correction answer:

1. Most of the plants absorb nitrogen from soil in the form of.
   (a) free N_2 (b) Nitrites
   (c) Nitrates (d) HNO_3
2. Choose the micro-nutrient
   (a) Sulphur (b) Manganese
   (c) Calcium (d) Nitrogen
3. Choose the macronutrient
   (a) Manganese (b) Phosphorus
   (c) Zinc (d) Molybdanum
4. Symbiotic nitrogen fixation is done by
   (a) *Rhizobium* (b) Clostridium
   (c) *Nostoc* (d) Azotobacter
5. The enzyme responsible for nitrogen fixation requires.
   (a) Fe and Mo (b) Mo and Ca
   (c) Zn and Cu (d) Zn and Mn
6. Micro-organisms affect fertility of soil by
   (a) Nitrogen fixation (b) Production of toxins
   (c) Destroying harmful bacteria. (d) Retaining moisture
7. Maintenance of soil fertility without addition of nutrients is due to
   (a) Activity of micro-organisms (b) Floods
   (c) Favourable temperature (d) Standing crops
8. The root nodules formed in the leguminous plant have a red pigment called
   (a) Hemoglobin (b) Phycocyanin
   (c) Leghemoglobin (d) Chlorophyll
9. The process of conversion of ammonia into nitrate is called.
   (a) Nitrification (b) Ammonification
   (c) Transcription (d) Translation
10. The enzyme responsible for fixing nitrogen is called.
    (a) Nitrate reductase (b) Nitrite reductase
    (c) Nitrogenase (d) Aminoacid synthetase.

B. Write short notes on :

1. Essential elements
2. Hydroponics
3. Biological nitrogen fixation
4. Macronutrients
5. Micronutrients.
6. Asymbiotic nitrogen fixation.
7. Symbiotic nitrogen fixation.
8. Leghemoglobin

C. Differentiate between.

1. Macro-elements and micro elements.
2. Symbiotic and asymbiotic nitrogen fixation.

PHTOSYNTHESIS

CHAPTER 12

All forms of life in this earth depend on plants, directly or indirectly, for their food requirements. Plants prepare their own food and serve other organisms. Heterotrophs depend on plants for food which provide them both organic carbon and energy for growth and development. Plants are unique in carrying out photosynthesis, the process in which carbon dioxide with the help of water is reduced to carbohydrate by input solar energy. Photosynthesis is the process through which solar energy is routed to the living world. It is most important for two reasons, as the source of food for all and the oxygen released to the atmosphere makes aerobic respiration possible. The coal deposits, the petroleum products, food, fuel, fibre, forage, every biomass we talk about is the product of photosynthesis.

12.1. EARLY HISTORY:

In 1771, Joseph Priestley, an English chemist, performed experiments showing that plants release a type of air that allows a candle to burn. He demonstrated this by putting a sprig of mint into a transparent closed vessel with a burning candle until the flame went out. After several days he extinguished candle again and it burned perfectly well in the air that previously would not support it. In another experiment, conducted in 1772, Priestley observed that a mouse kept in a transparent jar of air collapsed while a mouse kept with a plant in the same transparent jar survived. These observations led Priestley to offer an interesting hypothesis that plants restore to the air whatever breathing animals or burning candles remove. He named this as “dephlogisticated air” which was later named as ‘oxygen’. Priestley’s work thus showed that plants release oxygen into the atmosphere. Jan Ingenhousz, a Dutch physician, took Priestley’s work further and demonstrated in 1779 that sunlight was necessary for photosynthesis and that only the green parts of plants could release oxygen. During this period Jean Senebier, a Swiss botanist and naturalist, discovered that CO_2 is required for photosynthesis. Nicolas Theodore de Saussure, a Swiss chemist and plant physiologist, showed that water is also required for photosynthesis. Julius Robert von Mayer, a German physician and physicist, in 1845 proposed that photosynthetic organisms convert light energy into chemical free energy.

By the end of the nineteenth century the key features of plant photosynthesis were known. Plants could use light energy to make carbohydrates from $CO_2$and water. Glucose, a six carbon sugar, is often considered as an intermediate product of photosynthesis, the net equation of photosynthesis is frequently written as:

$$6CO_2 + 12H_2O + \text{Light Energy} \longrightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Early scientists studying photosynthesis concluded that the O_2 released by plants came from CO_2, which was thought to be split by light energy. In the 1930s, V. B. van Niel was aware that some photosynthetic bacteria could use hydrogen sulfide (H_2S) instead of water for photosynthesis and that these organisms released sulfur instead of oxygen. Van Niel, among others, concluded that photosynthesis is a redox (reduction-oxidation) process depending on electron donor and acceptor reactions and that the O_2 released during photosynthesis comes from the photooxidation of water. The generalized equation for photosynthesis, thus, can be written as :

$$6CO_2 + 12H_2A + \text{Light Energy} \longrightarrow C_6H_{12}O_6 + 12A + 6H_2O$$

In oxygenic photosynthesis, 12A is $6O_2$, whereas in anoxygenic photosynthesis, which occurs in some photosynthetic bacteria, the electron donor can be an inorganic hydrogen donor, such as H_2S (in which case A is elemental sulfur) or an organic hydrogen donor such as succinate (in which case, A is fumarate). Experimental evidence that molecular oxygen came from water and not from CO_2 was provided by Robert Hill in 1937. He demonstrated light-dependent O_2 evolution in the absence of CO_2 in isolated chloroplast thylakoids using artificial electron acceptors such as iron salts. This has since been known as **Hill reaction** and the artificial electron acceptors as **Hill oxidants.** Hill reaction, with iron salt as Hill oxidant, is usually written as:

$$4\,Fe^{3+} + 2H_2O \xrightarrow[\text{light energy}]{\text{isolated chloroplast thylakoid}} 4\,Fe^{2+} + O_2 + 4\,H^+$$

More direct evidence for the evolution of molecular oxygen from water during photosynthesis was provided by Ruben et al (1941) who used $^{18}O_2$ enriched water for their study on photosynthesis and demonstrated the evolution of $^{18}O_2$.

12.2. PHOTOSYNTHETIC ORGANISMS :

The organisms capable of synthesizing carbohydrate from carbon dioxide and other inorganic raw materials using energy are termed as **autotrophs.** In contrast, animals and human beings lack the ability to do so and are termed as **heterotrophs.**

Depending upon the source of energy utilized by the autotrophs for their organic synthesis, these are further divided into **photosynthetic autotrophs** (or **photoautotrophs)** and **chemosynthetic autotrophs** (or **chemoautotrophs).** Photoautotrophs use solar energy as the primary energy source. They convert solar energy into chemical or bond energy of carbohydrates through photosynthesis. Cyanobacteria, algae, bryophytes and all vascular plants use water as the source of electron to reduce carbon dioxide and release oxygen to the environment making it aerobic. This type of photosynthesis is known as **oxygenic** (/.e., **oxygen-evolving) photosynthesis** and the organisms doing so are known as **oxygenic photosynthetic organisms.** Green bacteria and Green Sulfur Bacteria use light energy to extract electrons and protons from molecules other than H_2O and use those for the reduction of CO_2. Since H_2O is not used as the reductant, no O_2 is evolved during photosynthesis. This type of photosynthesis is known as **anoxygenic** (/.e., **non-oxygen-evolving) photosynthesis.** The photosynthetic bacteria are, therefore, also known as **anoxygenic photosynthetic organisms.**

Chemoautotrophs (none of which contain chlorophyll) obtain their energy for carbohydrate synthesis from variety of inorganic compounds containing hydrogen, iron, sulfur and nitrogen. In most cases these compounds combine with oxygen in the cells resulting in the production of energy. Two groups of bacteria, called nitrifying bacteria, are well studied examples of chemoautotrophs. One group, *Nitrosomonas,* converts ammonia to nitrite with O_2 as the oxidizing agent.

NH_3 + $^1/_2$ O_2 -> NO; + H_2O + H^+ + Energy

The other group, *Nitrobacter,* oxidizes nitrite to nitrate.

NO/ + % O_2 —> NO/ + Energy

The energy released during the oxidation of NH_3 and NO/ is used for the reduction of CO_2 to carbohydrates and other carbon compounds.

12.3. PHOTOSYNTHETIC PIGMENTS :

Chlorophylls and carotenoids are the main photosynthetic pigments in plants. Both chlorophyll-a and chlorophyll-^) are present in plants and green algae. As chlorophyll-a takes part in photo-reaction and present in all oxygenic photoautotrophs, it is called the universal pigment. Chlorophyll-b and carotenoids transfer their energy absorbed to the reaction center (chl-a) for use in photosynthesis. For this reason, these are considered as accessory pigments. Phycobiliproteins, namely phycoerythrin and phycocyanin, are the photosynthetic pigments in red algae and cyanobacteria (blue-green algae) in addition to chlorophyll.

Carotenoids are broadly two types - carotenes and xanthophylls, p-carotene is the abundant carotene present in all photosynthetic organisms while a-carotene is present only in higher plants, lower vascular plants and bryophytes. The xanthophylls, such as lutein, violoxanthine and neoxanthine, are present in higher plants. In other groups of photosynthetic organisms, different other forms of xanthophylls are also present.

The structural formulae of some of the photosynthetic pigments are shown in Figure 1. The basic structure of chlolorophyll is a porphyrin head and a long phytol tail. The porphyrin is a cyclic tetrapyrrole formed by four pyrroles arranged in a cyclic fashion. $Mg^{++}$is chelated in the centre being covalently bonded to two N-atoms and coordinately bound to other two N-atoms of

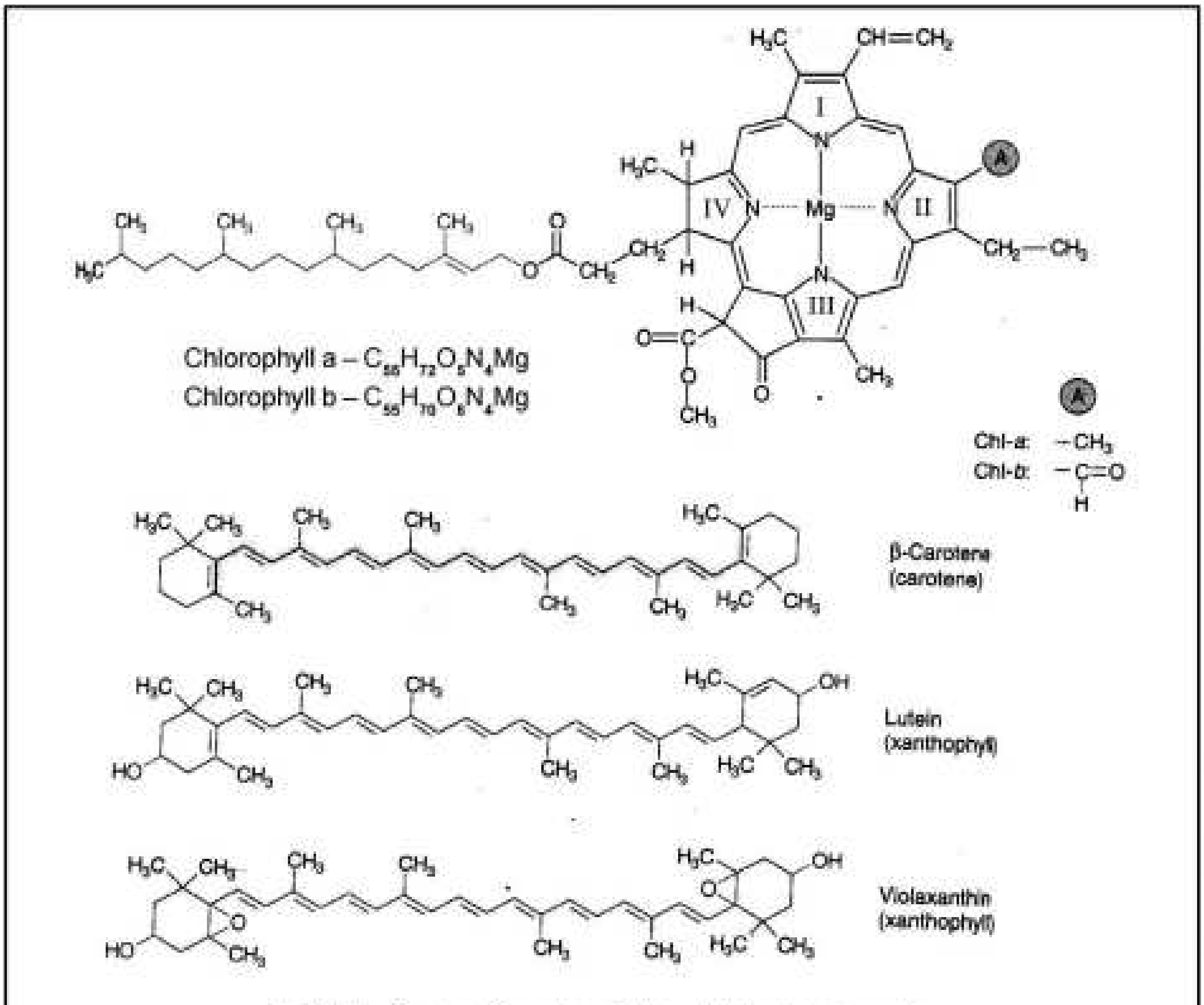


Fig.12.1 : Structural formulae of chlorophylls and carotenoids.

the tetrapyrrole ring. The phytol tail is attached to the ring IV. In chlorophyll-a there is a methyl residue ($-CH_3$) in the ring II which is replaced by a formyl group (-CHO) in chlorophyll-/?. Chlorophylls with their tail put themselves in thylakoid membrane. The carotenoids molecules have ring structures at both the ends joined by similar type of central segment (Fig. 12.1). The different carotenoids vary only in the structure of the rings.

12.4. PROCESS OF PHOTOSYNTHESIS - AN OVERVIEW :

The process of photosynthesis in plants and algae occurs in small organelles, known as **chloroplasts,** which are located inside cells. The basic equation of photosynthesis appears extremely simple. Water and carbon dioxide combine to form carbohydrates and molecular oxygen, and this reaction is driven by light energy:

$$6CO_2 + 6H_2O \xrightarrow{\text{light energy}} C_6H_{12}O_6 + 6O_2$$

However, the process of photosynthesis is not as simple as it appears. It is carried out by a complex series of reactions with high overall efficiency.

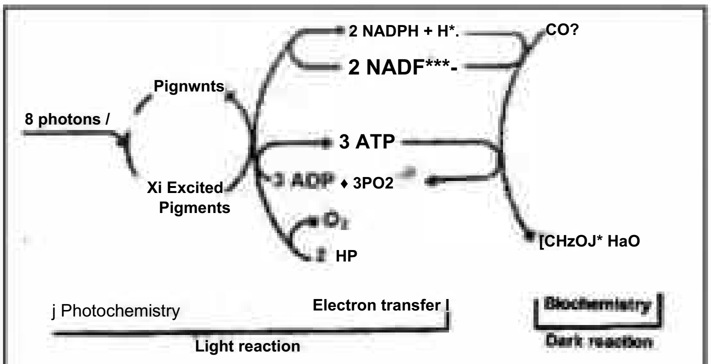


Fig.12.2 : Schematic presentation of light & dark reactions of photosynthesis

Photosynthesis begins with the absorption of light energy by photosynthetic green pigments, called **chlorophyll,** located in membranous structures, the thylakoids, in chloroplasts. Light energy absorbed by accessory pigments is transferred to chlorophyll molecules for use in photosynthesis. The absorbed light energy is used to oxidize water thereby releasing oxygen. The resultant electrons and protons pass through a series of electron transport molecules leading to the production of NADPH and ATP. These NADPH and ATP formed by action of absorbed light then reduce carbon dioxide and convert it ultimately into carbohydrate by a series of biochemical reactions taking place in the stroma of chloroplasts. These reaction steps of photosynthesis, schematically shown in Figure 12.2, are traditionally divided into two types of reactions for convenience of discussion: (1) **Light reactions** (also called **light-dependent reactions);** and (2) **Dark reactions** (also called **light-independent reactions).**

12.5. LIGHT REACTIONS :

12.5.1.Light absorption :

Photosynthesis in plants is initiated by the absorption of light in the visible range (wavelength 400 to 700 nm) by pigment molecules, mainly chlorophylls and carotenoids. Not all wavelengths of light in the visible range are effective in photosynthesis. **Absorption spectrum** (see Box I) of chlorophyll (Figure 12.3) indicates that light is mainly absorbed in the red and blue parts of the spectrum. Therefore, light in the blue and red parts of spectrum are effective in photosynthesis. Light moves in discrete particles, called as **photons.** The energy content of a photon is called a **quantum.** The energy content of a photon varies with its wavelength; the energy of photon is higher when its wavelength is shorter and vice versa. When a chlorophyll molecule in its lowest energy or ground state absorbs a photon (represented by *hv),* the energy of the photon is transferred to one of the electrons in the outermost orbit of chlorophyll molecule. This electron, having higher energy level, is elevated to a higher orbit equivalent to its energy level. The chlorophyll molecule is then said to be in a higher energy, or **excited state** as shown below:

Chi +	*hv*	—>	Chi*
ground state	photon		excited
chlorophyll	(quantum)		chlorophyll

Absorption of blue light excites the chlorophyll molecule to a higher energy state (called as the **second excited singlet state)** than the absorption of red light because, as stated above, the energy of a photon is higher when its wavelength is shorter. In the second excited singlet state, the chlorophyll molecule is extremely unstable having the half-life of 10^{-12}s. It very rapidly gives up some of its energy to its surroundings as heat and comes to the **first excited singlet state.** The chlorophyll molecule can directly enters into the first excited singlet state by the absorption of a photon of red light. The first excited singlet state is much more stable than the second excited singlet state; its half life is 10^{-9}s. The excited chlorophyll in this state has the inherent tendency of returning back to the ground state after dissipating the excess energy in different ways (Figure.12.4).

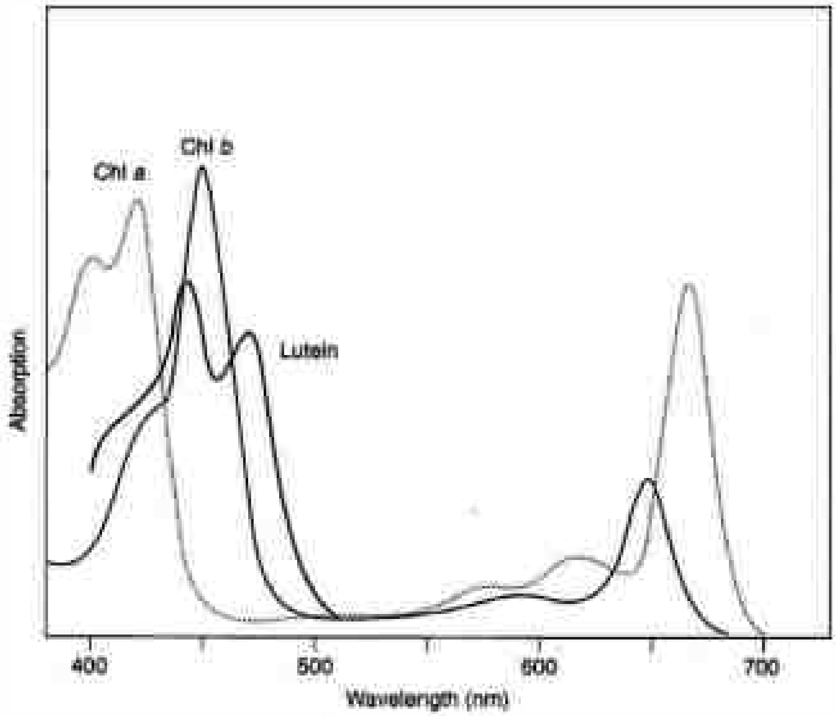


Fig.12.3 : Absorption spectrum of chlorophyll-a, chlorophyll-b and lutein (a carotenoid)

1. The excited chlorophyll can return to its ground state by directly converting its excitation energy into **heat** with no emission of a photon (called as **radiation- less transition).** The heat is lost to the environment.
2. The excited chlorophyll can return to its ground state by releasing the excitation energy in the form of light. This emission of light is called **fluorescence.** The wavelength of fluorescent light is slightly longer (and, therefore, has lower energy) than the wavelength

of absorbed light which is required for attaining the first excited singlet state. This is because part of the excitation energy is usually lost as heat before the fluorescent photon is emitted. Therefore, *chlorophyll fluoresces always in the red region of the spectrum irrespective of whether blue or red light is absorbed.* Chlorophyll fluoresces during energy transition from first excited singlet state to ground state.

3. By releasing part of the excitation energy in the form of heat, the chlorophyll molecule can attain an excitation state of lower energy, called as the **triplet state.** Triplet state can

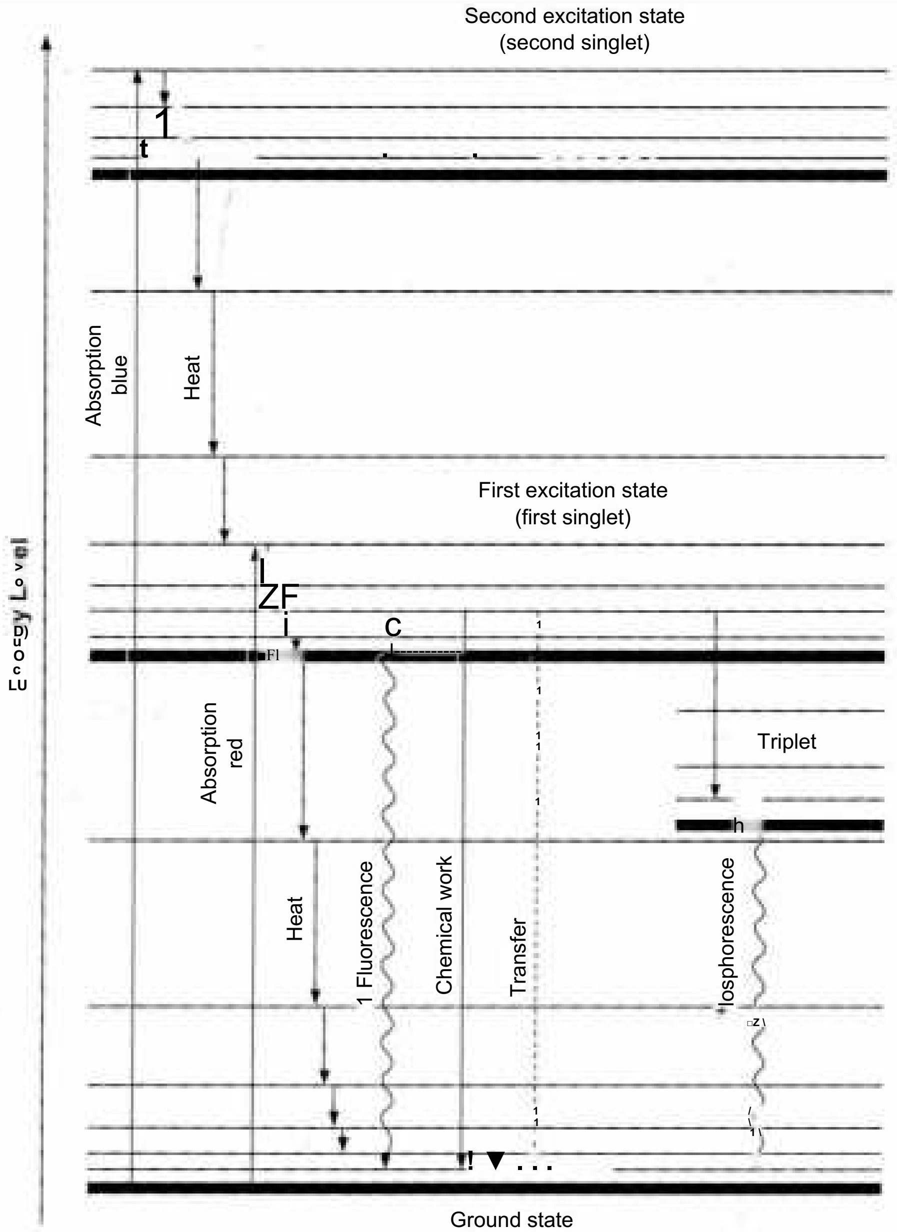


Fig. 12.4 : Excitation of chlorophyll and subsequent dissipation of excitation energy

not be reached directly from ground state by excitation. In the triplet state, spin of the excited electron is reversed. The transition from singlet state to triplet state is, therefore, called as the **inter system crossing.** As the probability of spin reversal is low, the triplet state does not occur frequently. By emitting excitation energy in the form of light (called as **phosphorescence),** or by heat loss, the chlorophyll molecule can return from the triplet state to the ground state.

4. Chlorophyll in the first excited singlet state can return to the ground state by transferring the excitation energy to a neighbouring molecule which requires lesser energy for excitation. This **energy transfer** is very important during photosynthesis.

5. The fifth process is **photochemistry** in which the energy of excited chlorophyll is utilized for chemical reactions. The chlorophyll molecule transfers the excited electron from the first excited singlet state to an electron accepter. The electron accepter is reduced leaving behind positively charged chlorophyll radical. This step is also known as **charge separation** which constitute the most important step in photosynthesis.

$$Chi^* + A \text{ ---------------------------- } > Chl^+ + A$$

BOX-I

Absorption and Action Spectrum

Light must first be absorbed in order to interact with matter and only light that is absorbed can be active in a photochemical process. Absorption of the amount of light by a molecule or substance in a nonabsorbing solvent is measured as relative absorbance. This is done with the help of an instrument named as the **spectrophotometer.** A molecule or substance absorbs different wavelength of light to different extent. *An* ***absorption spectrum*** *is a graph that shows the relative absorption of light by a molecule or substance plotted as a function of wavelength.* To explain this in a very simpler way, an absorption spectrum is a graph that shows which wavelength of light is absorbed how much by a particular molecule or substance. Every light-absorbing molecule has a characteristic absorption spectrum that is often used as a key for its identification. The important photosynthetic pigments, chlorophylls and carotenoids, have characteristic absorption spectra *(Figure 12.3).* Chlorophylls absorb light in the visible range at wavelengths below 480 nm and between

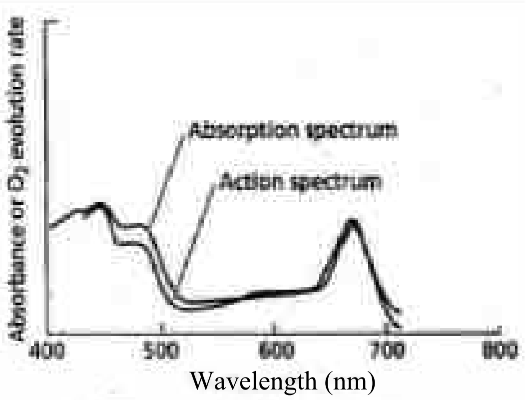


Fig.BLir Absorption spectrum of photosynthetic pigments -and action spectrum of photosynthesis

550 and 700 nm but green light with wavelengths between 480 and 550 nm are not absorbed. Plant chlorophylls and leaves appear green to our eyes because they absorb light in the blue and red parts of the spectrum but green light is not absorbed and is reflected into our eyes. Carotenoids absorb light between 400 to 500 nm regions of the spectrum which give carotenoids their characteristic orange colour.

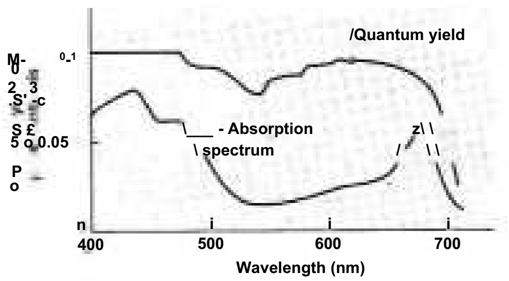


Fig.BI.2. Phenomenon of red drop.

Light must be absorbed in order to be effective in a photo process. Different wavelengths of light are effective in a photo process to different extent. *An **action spectrum** is a graph that shows the effectiveness of light in inducing a particular process plotted as a function of wavelength.* To explain this in a very simpler way; an action spectrum is a graph that shows which wavelength of light is effective how much in inducing a photo process. Normally, the action spectrum for a light-dependent process closely resembles the absorption spectrum of the molecule or substance which acts as the mediator for the photo process. With reference to photosynthesis, the graph showing the effectiveness of different wavelengths of light on the rate of photosynthesis is known as the action spectrum of photosynthesis (Figure BI-1). The rate of photosynthesis is usually measured as the amount of CO_2 taken up or as the amount of O_2 evolved. The action spectrum of photosynthesis has pronounced peaks in the blue and red regions of the spectrum which correspond with the absorption peaks for chlorophyll.

The action spectrum of photosynthesis in *Figure BI-1* does not tell anything about the efficacy of the absorbed photons of different wavelengths of light on the rate of photosynthesis. This can be determined by expressing the photosynthesis rate as the number of molecules O_2 evolved or CO_2 taken up per photon of light absorbed. This is known as the **quantum yield** of photosynthesis. Quantum yield is a very important parameter of the light reactions of photosynthesis and is defined as follows:

$$\text{Quantum yield} = \frac{\text{Number molecules of } O_2 \text{ evolved or } CO_2 \text{ taken up}}{\text{Total number of photons absorbed}}$$

The action spectrum of photosynthesis drawn by plotting quantum yield as the function of different wavelengths of light (Figure BI-2) indicates that quantum yield is more or less constant at different wavelengths of light. In other words, any photon absorbed by chlorophyll is more or less equally effective in driving photosynthesis. However, there is a sudden drop in the quantum yield of photosynthesis at wavelengths greater than 680 nm (far-red light) even though light is still absorbed in that range of the spectrum. This drop in the quantum yield of photosynthesis is known as the **red drop.** The phenomenon of red drop was shown for the first time by R. Emerson and C.M. Lewis in 1943 in the green alga *Ch lore I la.*

12.5.2. Electron transport:

Photo-induced charge separation, which results in the reduction of an acceptor molecule leaves behind an oxidized reaction centre chlorophyll molecule. It is the beginning of flow of electron in the photosynthetic electron transport chain. The energy of one photon causes the release of one electron from the excited chlorophyll molecule. This charge separation effectively stores light energy as redox energy and represents the actual conversion of light energy to chemical energy. The chlorophyll molecule involved in the primary photochemical redox reaction is called as the **reaction centre chlorophyll.**

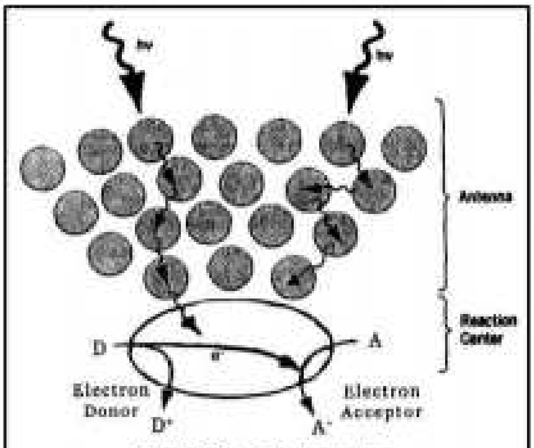


Fig.12.5 : Photosystem

Each reaction centre chlorophyll is associated with some 200 - 300 chlorophyll molecules and accessory pigments such as carotenoids and xanthophylls. These pigment molecules together form a broad surface to efficiently capture various wavelengths of light and the excitation energy then pass from one pigment molecule to another until it eventually arrives at the reaction centre chlorophyll. These associated pigment molecules are called as **antenna.** The antenna along with the reaction centre chlorophyll molecule is known as **photosystem** (Figure 12.5). The photosynthetic electron transport chain has two such photosystems (see Box II) known as **photosystem I** (PS-I) and **photosystem II** (PS-II). The reaction centre chlorophyll of PS-I is called **P700** while that of PS-II is known as **P680.** These reaction centre chlorophylls absorb maximally at 700 nm and 680 nm respectively.

BOX-II

Red Drop and Enhancement Effect

The phenomenon of **red drop** shown by Emerson and Lewis (see Box-I) was quite puzzling. This is not due to decrease in light absorption because the quantum yield measures only light that has actually been absorbed. This only indicates that light of wavelengths greater than 680 nm is much less efficient than light of shorter wavelengths. In subsequent experiments, Emerson and his colleagues measured photosynthesis using red and far-red light after adjusting their fluence rates to give equal rates of photosynthesis. They observed that the quantum yield obtained using both red and far-red light simultaneously was much higher than the sum of the yields obtained with red and far-red light separately (Figure BII-1). This phenomenon is known as **Emerson enhancement effect** or often as **Emerson effect.**

These puzzling phenomena of red drop and enhancement effect led to the conclusion that two different reaction centers or photochemical events are involved in photosynthesis. One event is driven by red light (= 680 nm) and the other driven by far-red light (>680 nm). Optimal photosynthesis occurs when both events are driven simultaneously or in rapid succession. These two photochemical events are now known as **Photosystem II** and **Photosystem I** and they operate in series to carry out photosynthesis optimally. Photosystem II absorbs red light of 680 nm well and is driven very poorly by far-red light. On the other hand Photosystem I absorbs preferentially far-red light of wavelengths greater than 680 nm.

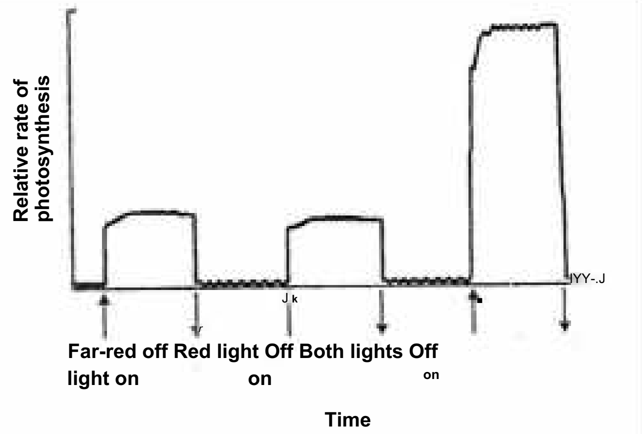


Fig.BII.i. Emerson's enhancement effect

PS-1 and PS-II operate in series in the photosynthetic electron transport chain. The reaction centre chlorophylls of PS-1 and PS-II are special pairs of chlorophyll-a molecules. Electron transport actually begins with arrival of excitation energy at the PS-II reaction centre chlorophyll, **P680.** The excited P680 (written as **P680*)** passes an electron to the **pheophytin (Pheo),** which is considered as the **primary electron acceptor** of PS-II. **(Pheo** is a form of chlorophyll-a in which the magnesium has been replaced by two hydrogen atoms). The result of this photo-oxidation event is the formation of P680$^+$and Pheo$^-$ (due to charge separation). The electron flows from **Pheo** through **plastoquinone** (PQ) to another multiprotein complex, **cytochrome b$_6$/f complex.** From this complex the electrons are picked up by a copper-binding protein, **plastocyanin** (PC).

P680$^+$, formed by initial charge separation, is very strong oxidant and is able to extract electrons from water. The electron that reduces P680$^+$ is supplied by Yz which is called as the **first electron donor of PS-II. Yz** is a tyrosine residue in the D$_1$ protein of PS-II, which in turn receives the electron from a cluster of four manganese ions bound to a small complex of proteins called the **oxygen-evolving complex (OEC).** This complex is responsible for the splitting (oxidation) of water by drawing electrons from water with the evolution of molecular oxygen and the formation of H$^+$. Photolysis of water takes place as per the following equation:

$$2H_2O \text{--------------------------}> O_2 + 4H^+ + 4e^-$$

Light-driven charge separation similar to that involving PS-II reaction centre (P680) also takes place in the reaction centre of PS-I. The PS-I reaction centre chlorophyll, **P700,** is first excited to **P700*,** then photo-oxidized to P700$^+$. The **primary electron acceptor in PS-I** is **special chlorophyll-a molecule (A$_o$)** which then passes the electron to **ferredoxin.** Ferredoxin

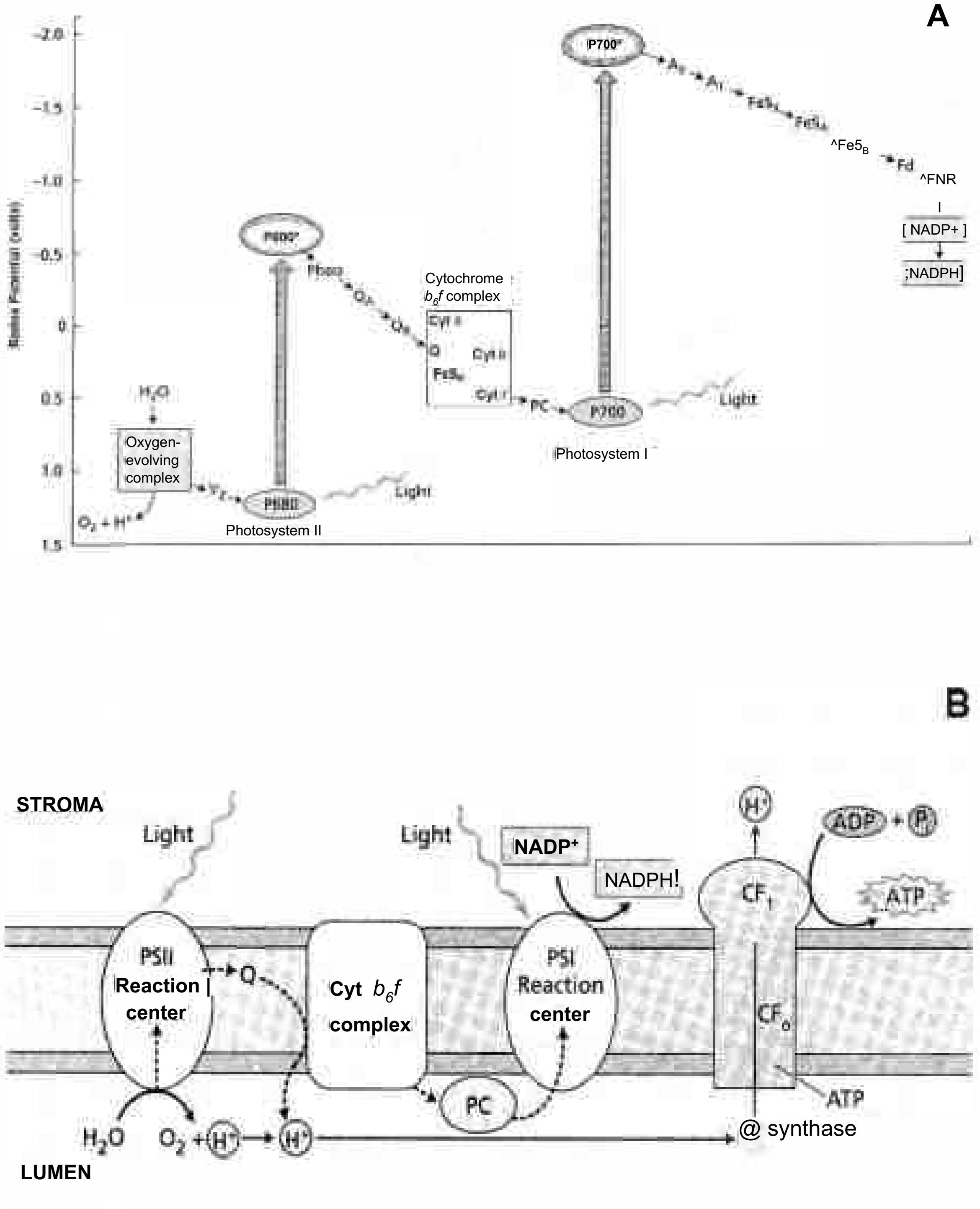


Figure 12.6 : Photosynthetic electron transport in chloroplast thylakoid membrane. A - The Z-Scheme and B - Topographic arrangement of electron transport chain components in the thylakoid membrane.

in turn reduces $NADP^+$ to NADPH, a reaction mediated by the enzyme **ferredoxin-$NADP^+$-oxidoreductase.** The oxidized **$P700^+$** is reduced by withdrawing an electron from reduced **plastocyanin.**

The complete **photosynthetic electron transport chain** in which there is a continuous flow of electrons starting from water to $NADP^+$, passing through the two different photosystems and cytochrome b_6/f complex is shown schematically in Figure 4.6. The scheme, in which the components of the photosynthetic electron transport chain are arranged as per their redox potential, is named as the **Z-scheme** because of its characteristic shape. (Figure 12.6 A) The topographic arrangement of photosynthetic electron transport chain components in the thylakoid membrane is shown in Figure 12.6 B.

12.5.3. Photophosphorylation and ATP synthesis :

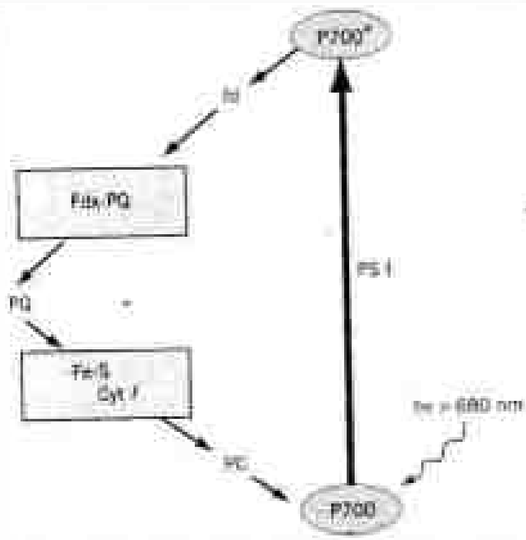


Fig.12.7 : Cyclic electron transport.

NADPH is one of the main products of the light reactions of photosynthesis. The other important product is ATP. *The formation of ATP molecules coupled to the light-driven transfer of electrons through the thylakoidal electron transfer chain in the chloroplast is known as **photophosphorylation.*** When electron transport takes place continuously from water to NADPH, as shown in Figure 4.6, it is known as **non-cyclic or linear electron transport.** The formation of ATP in association with non-cyclic electron transport is known as **non-cyclic photophosphorylation.** The PS-I may transport electrons independent of PS-II, a process known as the **cyclic electron transport.** In this case ferredoxin transfers the electrons back to plastoquinone. The electron then returns to $P700\pm$ passing through cytochrome b_6/f complex and plastocyanin (Figure 12.7). This cyclic electron transport supports ATP synthesis, a process known as **cyclic photophosphorylation.** This is thought to be an additional source of ATP to support chloroplast activities. Cyclic photophosphorylation does not generate NADPH.

The molecular mechanism of ATP synthesis during photosynthesis in the thylakoid membrane of chloroplasts can be explained through the **chemiosmotic hypothesis.** The detail of this hypothesis is described in the chapter on respiration. The light-driven electron transport creates a proton motive force across the thylakoid membrane. This proton motive force drives the synthesis of ATP when the protons force their way into the stroma through an integral thylakoid protein complex known as *ATP synthase.* This complex is also described in many text books under the name CF_0-CF_1 particle (C for chloroplast) or coupling factor. It is estimated that for 4 protons transported through *ATP synthase,* one ATP is synthesized. Because 12 protons are transported for two pairs of electrons (derived from the splitting of two molecules of H_2O) transferred trough the photosynthetic electron transport chain, a total of 3 ATP molecules are synthesized for the photooxidation of two molecules of H_2O. For the splitting of one molecule of H_2O, one pair of electrons is transported and 1.5 ATP molecules are synthesized.

12.6. DARK REACTIONS :

The products of light reactions of photosynthesis, ATP and NADPH, are used for the reduction of CO_2 to carbohydrates by a series of enzyme catalyzed reactions in the stroma of chloroplast.These stroma reactions are long thought to be independent of light and, as a consequence, were referred to as the **dark reactions of photosynthesis.** However, it is now established without any doubt that some of the enzymes of the carbon reduction reactions are regulated by light. In darkness, about three enzymes including rubisco become inactivated and lose their capacity of catalysis. In light, these enzymes become active and catalyze the reactions. Therefore, CO_2 reduction reactions are not independent of light and naming this biosynthetic phase as **dark reaction** (or **dark phase)** is misleading. But for historical reasons and for ease of discussions of the steps of photosynthesis, the terms **dark reactions** and **light reactions** are still used in text books. *But we should remember here that some steps of 'light reactions' are independent of light while some steps of 'dark reactions' are dependent upon light.*

12.6.1. The C_3 Cycle:

Green plants and algae reduce CO_2 to carbohydrate in a series of reactions in a cyclic manner which is known as **Calvin cycle** (Figure 12.8). This cycle is named after **Melvin Calvin,** an American biochemist, who headed a research team to elucidate this pathway for which he was awarded with a Nobel Prize in 1961. Since many other scientists of Calvin's research team also contributed significantly for the same, it is often named as **Calvin-Benson cycle.** However, now people prefer to name this as **photosynthetic carbon reduction (PCR) cycle** or often as **reductive pentose phosphate (RPP) cycle.** Calvin cycle is now commonly referred to as the **C_3 cycle** because the first stable product of the CO_2 fixation reaction, 3-phosphoglyceric acid (3-PGA), is a three-carbon molecule. For ease of understanding, the Calvin cycle can be described under three reaction sequences: (a) **carboxylation,** (b) **reduction,** and (c) **regeneration.**

(a) Carboxylation Phase : The PCR cycle begins with the carboxylation reaction in which ribulose-1, 5-bisphosphate (RuBP) reacts with CO_2 to yield two molecules of 3-phosphoglyceric acid (3-PGA). This carboxylation reaction is catalyzed by the enzyme ribulose-1, 5-bisphosphate carboxylase-oxygenase **(rubisco).** *The first stable product of CO_2 fixation reaction in photosynthesis is 3-PGA.* As 3-PGA is a 3-carbon compound, Calvin cycle is also known as **C3-cycle.**

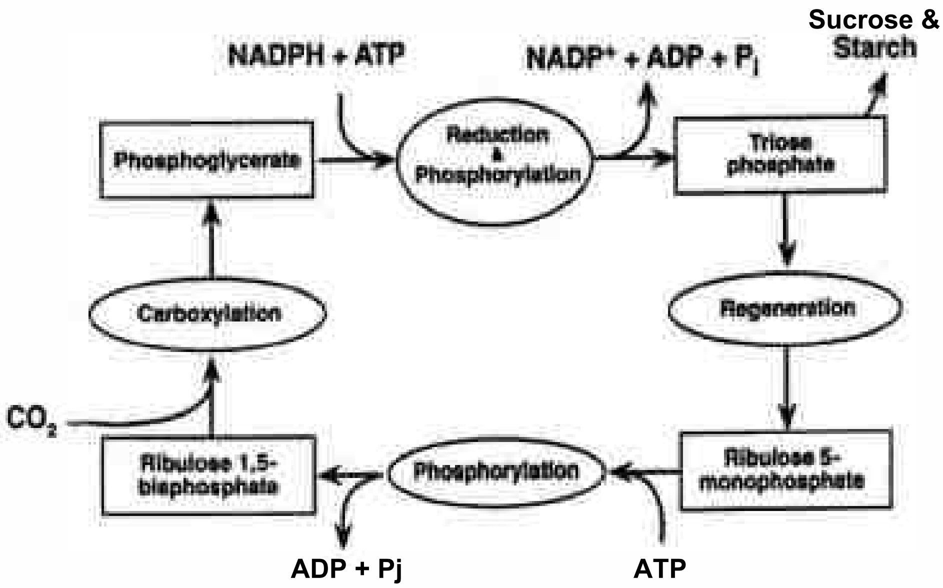


Fig.12.8 : Schematic presentation of of Calvin cycle

(b) Reduction Phase : In order for the Calvin cycle to operate continuously and reduce CO_2, the product of carboxylation reaction, 3-PGA, must be continuously removed and there should be a mechanism for continuous supply of CO_2 acceptor molecule, RuBP (Figure 12.8). The 3-PGA is removed by its conversion to a triosephosphate, glyceraldehydes-3-phosphate by a two step reaction. First 3-PGA is phosphorylated by reacting with ATP to form 1, 3-bisphosphoglyceric acid. This reaction is catalyzed by the enzyme phosphoglycerate kinase. In the second reaction, 1, 3-bisphosphoglyceric acid is reduced to glyceraldehyde-3-phosphate (G-3-P) by NADPH with the release of one molecule of inorganic phosphate (Pi). This reaction is catalyzed by the enzyme G-3-P dehydrogenase.

(c) Regeneration Phase : The product of reduction reaction, G-3-P, remains in equilibrium with its isomer dihydroxyacetone-3-phosphate (DHAP), an isomerization reaction catalyzed by the enzyme triosephosphate isomerase. *G-3-P and DHAP together are referred to as* ***triosephosphates.*** A portion of the triosephosphate molecules through a series of reactions are used to regenerate RuBP which is needed for the initial carboxylation reaction of Calvin cycle. *Regeneration of RuBP is crucial for the Calvin cycle to continue uninterrupted.* Rest of the triosephosphates is used through another series of reactions to form the final product of photosynthesis, sucrose and starch.

Overall, 13 enzymes are required to catalyze the reactions of Calvin cycle (Figure12.9). Each molecule of CO_2 reduced in Calvin cycle requires 2 molecules of NADPH and 3 molecules of ATP. To make one molecule of hexose-6-phosphate (H-6-P), the cycle has to reduce 6 molecules of CO_2 using 12 molecules of NADPH and 18 molecules of ATP. The overall reaction of Calvin cycle for the production of one molecule of hexose phosphate can be written as:

6CO2+ 11 H_2o+ 12 NADPH + 18 ATP —> Hexose-6-P + 12 $NADP^+$+ 6 H^++ 18 ADP + 17 Pi

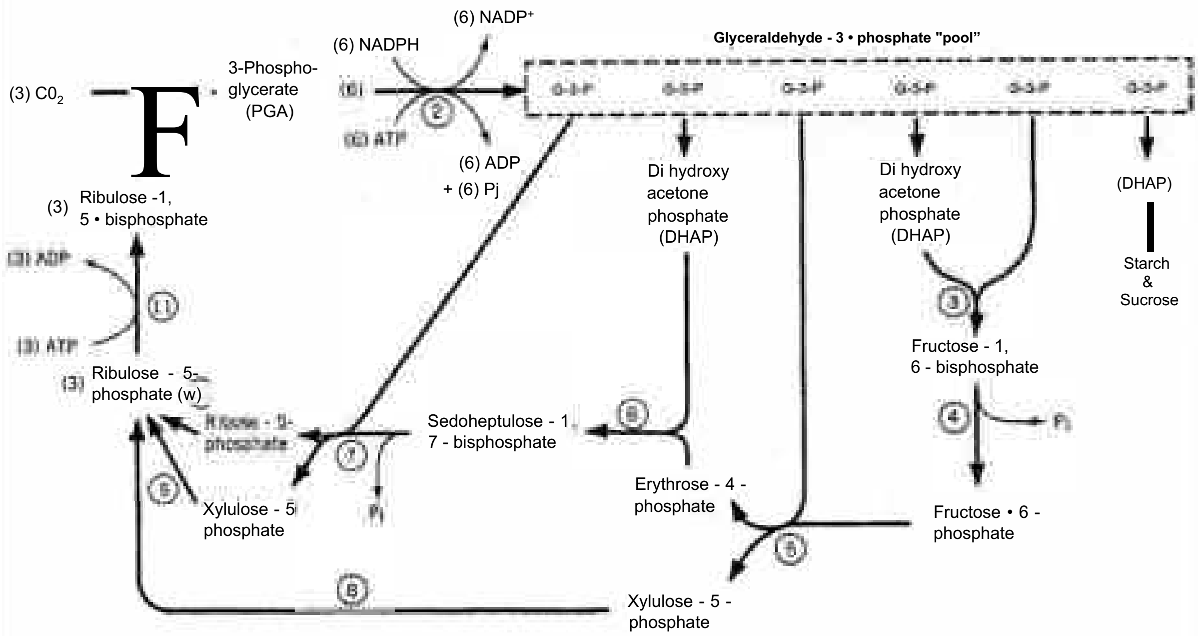


Fig.12.9 : The Calvin Cycle. The numbers in parentheses indicate the number of molecules taking part in the reaction. The numbers in the circles indicate the names of enzyms as follows -1: rubisco; **2:** 3-phosphoglycerate kinase and glyceraldehyde-3-phosphate dehydrogenase; **3:** aldolase; **4:** fructorse-1,6-bisphosphatase; **5:** transketolase; **6:** aldolase; **7:** sedoheptulose-1,7-bisphosphatase; 8&9: ribulose-5-phosphate epimerase; **10:** ribose-5-phosphate isomerase; **11:** ribulose-5-phosphate kinase.

12.6.2. The C4 Pathway :

Plants that assimilate CO_2 solely through the Calvin cycle are generally known as C_3 plants because the first stable product of photosynthetic CO_2 fixation reaction is a 3-carbon compound, 3-PGA. In certain tropical plants such as maize, sugarcane, sorghum, amaranths etc. the first stable product of photosynthetic CO_2 fixation reaction is oxaloacetic acid (OAA), a 4-carbon compound. These plants are known as **C_4 plants** and they assimilate CO_2 through a cycle of reactions known as **C_4 cycle.** Experiments initially conducted by H.P. Kortschack and subsequently by M.D. Hatch and C.R. Slack led to the elucidation of this cycle for which it was earlier known as **Hatch-Slack-Kortschack (HSK) cycle** or, in many texts, simply as **Hatch-Slack cycle.**

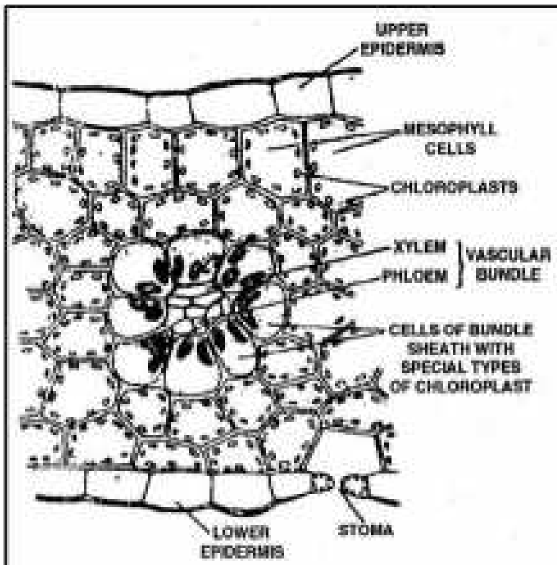


Fig.12.10 : Cross section of leaf showing 'kranz' anatomy.

C_4 plants exhibit a number of specific anatomical, physiological and biochemical characteristics not found in C_3 plants. Leaves of most of the C_4 plants have the presence of two distinct photosynthetic tissues. In the leaves, the vascular bundles are quite close together and each bundle is surrounded by a tightly fitted layer of cells called the **bundle sheath** (Figure 12.10). The **mesophyll** cells are loosely arranged between the vascular bundles. This type of distinction between the mesophyll and bundle sheath photosynthetic cells is known as **Kranz anatomy.**

The basic C_4 cycle (Figure 12.11) consists of four phases:

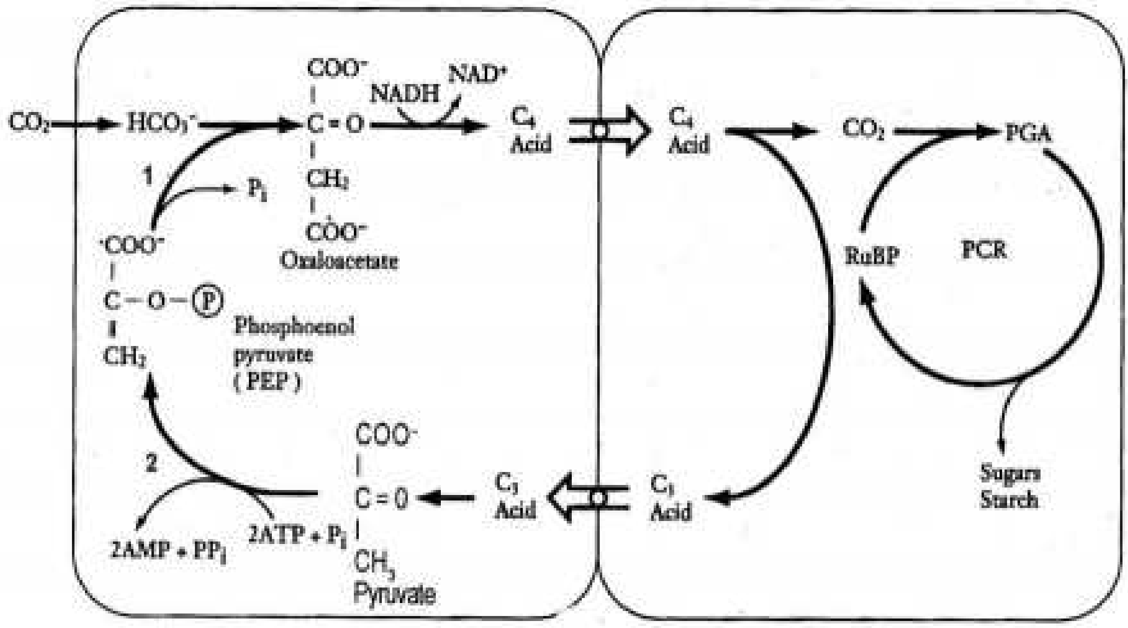


Fig.12.11 : Generalised scheme of C4 Cycle. 1. PEP carboxylase. 2. Pyruvate dikinase

(a) Carboxylation Phase : In the mesophyll cells, the fixation of CO_2(as HCO_3j takes place by the carboxylation of phosphoenolpyruvate (PEP) forming oxaloacetic acid (OAA), a 4-carbon compound. This carboxylation reaction is catalyzed by the enzyme PEP carboxylase.

(b) Transport Phase : OAA is converted into another 4-carbon compound (malic acid and/or aspartic acid, depending upon plant species) which is transported to bundle sheath cells.

(c) Decarboxylation Phase : The 4-carbon compound in the bundle sheath cells is decarboxylated to generate $CO_2$and a 3-carbon compound. The released CO_2 is then reduced to carbohydrate via the Calvin cycle which is operative in the bundle sheath cells but not in the mesophyll cells in C_4 plants.

(d) Transport and Regeneration Phase : The 3-carbon compound formed by the decarboxylation reaction in bundle sheath cells is transported to the mesophyll cells where it is converted back to PEP, the acceptor molecule of HCO_3; utilizing photosynthetically generated ATP.

The transport of metabolites between mesophyll and bundle sheath cells in stages (b) and (d) above is driven by diffusion gradient along the number of **plasmodesmata** present between these cells.

12.6.3. Crassulacean Acid Metabolism (CAM):

A third mechanism of CO2 fixation reactions is found in many plants growing in very dry and often hot habitats. In these plants, stomata remain closed during the day time to minimize water loss by transpiration which may, otherwise, be detrimental for the plants growing in dry habitats. The stomata, however, remain open during the night time when air is cool and air humidity is comparalively high . Through the open stomata during the night, not only CO_2 enter the leaves, the plants are also able to take some amount of water vapours from the atmosphere, which are not possible during the day time. In order to adopt to such situation, these plants developed a mechanism of fixing CO_2, entering the leaves through diffusion, to form an organic acid in the night time. During the following day, the organic acid is decarboxylated to release CO_2 which is then refixed by the normal photosynthetic process by the Calvin cycle to form carbohydrates. This mechanism of photosynthetic CO_2 fixation pathway was first elucidated in plants belonging to the family Crassulaceae. Therefore, this pathway has been named as Crassulacean Acid Metabolism (CAM) and also often described in many text books as CAM pathway or CAM photosynthesis . However, CAM is not restricted to the family Crassulaceae (Succulent plants like Kalanchoe, Opuntia, Bryophyllum etc.) but also found in pineapple, *Agave,* vanilla and many other plants. The basic CAM pathway consists of four phases :

(a) Carboxylation phase (in the night): During the night, when the weather is cool and humid, CO2 enters the leaves through the open stomata and is then taken up by phosphoenolpyruvate (PEP) to from oxaloacetate. This carboxylation reaction is catalyzed by the enzyme phosphoenolpyruvate carboxylase in the same way as in C4 metabolism. PEP is formed from triose phosphates in the cytoplasm which are in turn formed from the metabolic products of starch hydrolysis in the chloroplasts.

(b) Acidification phase (in the night): The oxaloacetate formed by the carboxylation reaction is reduced to malate by malate dehydrogenase using NADH. Malate then enters the vacuole and accumulate there as malic acid making the vacuolar content very acidic (pH about 3). This causes the nocturnal acidification of leaves.

(c) Decarboxylation and deacidification phase (in the following day): In the following day, stomata close preventing loss of water and uptake of CO_2. Leaf deacidification takes place when vacuolar reserves of malic acid enters the chloroplast as malate and is decarboxylated by

$NADP^+$- malic enzyme forming pyruvate and CO_2. Pyruvate is further metabolized in the chloroplast to form starch.

(d) Carboxylation phase (in the following day) : The released CO_2 fails to escape from the leaves due to closed stomata. This CO_2 is fixed by the enzyme rubisco to form 3-PGA which is then further metabolized to form sugars by the Calvin cycle, as described earlier, and finally stored as starch.

These phases of CAM are shown in Fig. 12.12.

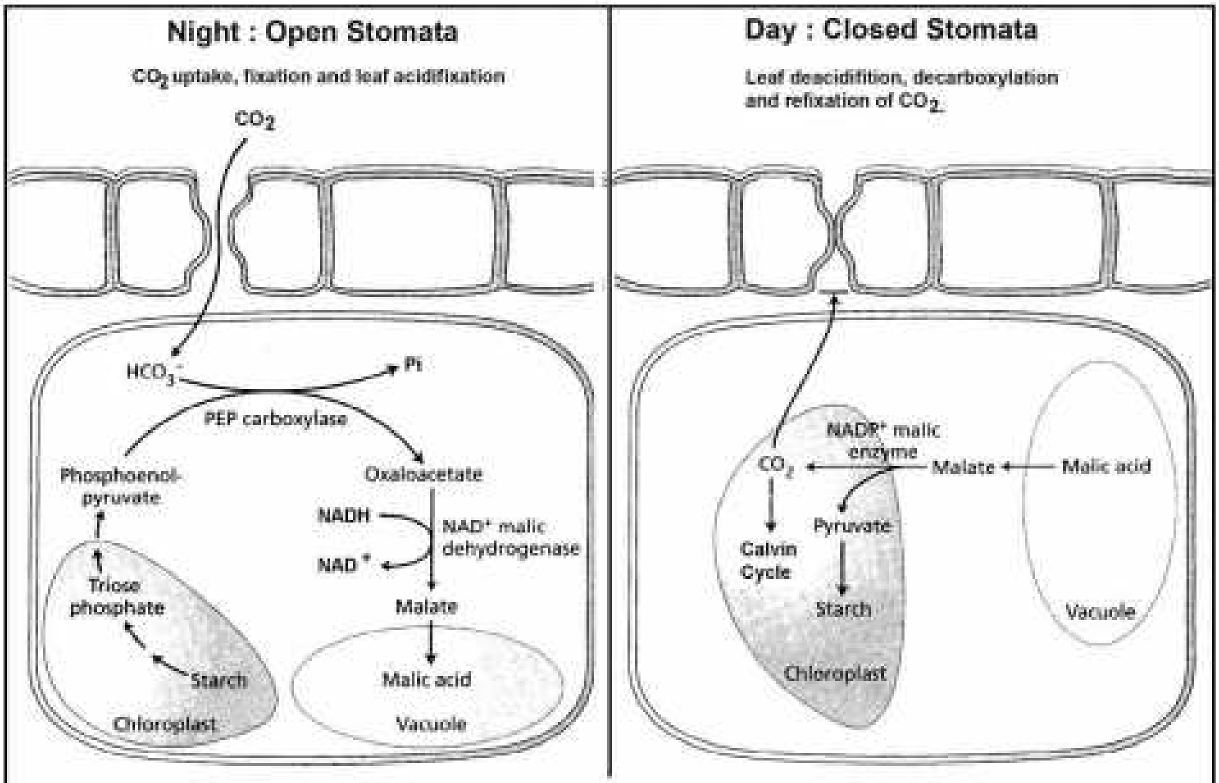


Fig 12.12 : Crassulacean acid metabolism in succulents.

12.7. PHOTORESPIRATION :

The first enzyme of Calvin cycle, **rubisco,** as the name indicates, has both **carboxylase** and **oxygenase** activity. It means that rubisco catalyzes the fixation of both CO_2 and O_2. When CO_2 is fixed by the carboxylation reaction with RuBP, the product is 2 molecules of 3-PGA. But when O_2 is fixed by the oxygenation reaction with RuBP, one molecule of 3-PGA and one molecule of phosphoglycolic acid are produced. Whether rubisco performs as carboxylation or oxygenation reaction depends upon the ratio of CO_2/O_2. High ratio of CO_2/O_2 fixes CO_2 while low ratio fixes O_2. Under normal atmospheric conditions of $CO_2$and O_2, some amount of O_2 is always fixed by rubisco reaction producing phosphoglycolic acid in the chloroplast. Phosphoglycolic acid is subsequently metabolized in a series of reactions in the peroxisome and mitochondrion that result in the release of CO_2 and recovery of the remaining carbon of phosphoglycolic acid by the Calvin cycle. Thus during active photosynthesis in light, apart from fixing CO_2 by the Calvin cycle, the leaves also consume O_2 and release CO_2 similar to that happens during cellular respiration. This light-dependent CO_2 evolution and O_2 consumption is termed as **photorespiration.** The conventional respiration (cellular respiration), in order to distinguish it from photorespiration, is often named as the **dark respiration,** even though it takes place both in light and in darkness. Unlike dark respiration, which takes place in the cytoplasm and mitochondrion, photorespiratory metabolism is carried out involving three organelles such as chloroplast, peroxisome and mitochondrion (Figure 12.13) . Photorespiration is prevalent in C_3 plants and by releasing CO_2 it decreases the net fixation of CO_2 in light during photosynthesis. Therefore, photorespiration is considered as a wasteful process in C_3 plants.

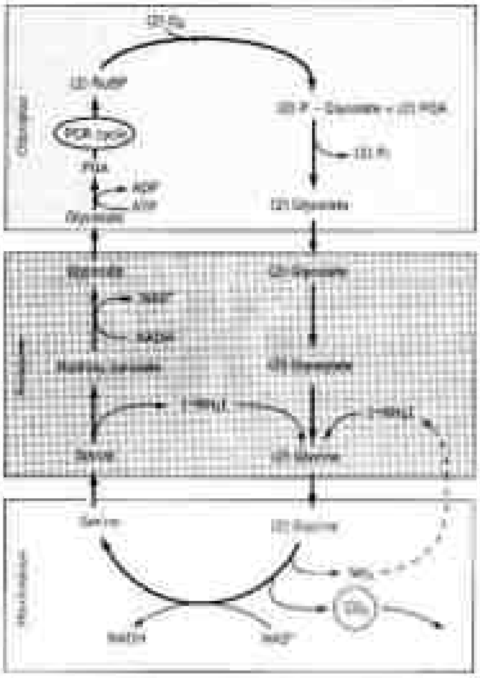


Fig.12.13 : Photorespiratory pathway

It can be recalled here that in C_4 plants the product of carboxylation reaction in mesophyll cells is transported to bundle sheath cells where it is decarboxylated releasing CO_2. These reactions serve as a CO_2 concentrating mechanism in bundle sheath cells. Since rubisco is present only in the bundle sheath cells, high CO_2 concentration in these cells ensure that rubisco functions as a carboxylase minimizing oxygenase activity. Thus in C_4 plants photorespiration does not occur or is suppressed. For this reason, the productivity of C_4 plants is higher than the C_3 plants.

12.8. FACTORS AFFECTING PHOTOSYNTHESIS :

The environmental factors affecting the process of photosynthesis follow the ***law of limiting factor*** as hypothesized by the British plant physiologist F. F. Blackman in 1905. According to Blackman, when a process is influenced by a number of factors, the rate of the process is limited by the slowest factor. For example, photosynthesis can be influenced by both CO_2 concentration and light intensity. By increasing the CO_2 concentration at a fixed intensity of light, the rate of photosynthesis can be increased up to a particular concentration of CO_2 after which no further increase can be noticed. At this point by increasing the light intensity to another fixed level, the rate of photosynthesis can be increased with increase in CO_2 concentration. In this example the intensity of light is the limiting factor for the rate of photosynthesis (Figure 12.14) . The implication of this hypothesis is that at any given time, photosynthesis can be limited either by light intensity or by CO_2 concentration, but not by both the factors.

There are several factors which affect the rate of photosynthesis as described below:

12.8.1. Light intensity :

The intensity of light influences the rate of photosynthesis. When other factors are not limiting, the rate of photosynthesis increases almost linearly with increase in light intensity (Figure 12.15). With further increase in light intensity, the rate of photosynthesis starts to level off and reaches saturation indicating that factors other than light intensity (CO_2 in Figure 12.15) have become limiting to photosynthesis. At extremely high light intensity, when leaves are unable to utilize all the absorbed light, the rate of photosynthesis declines by a phenomenon called **photoinhibition.** Photoinhibition is caused by the absorption of too much light which inactivates and damages reaction centre of PSI I.

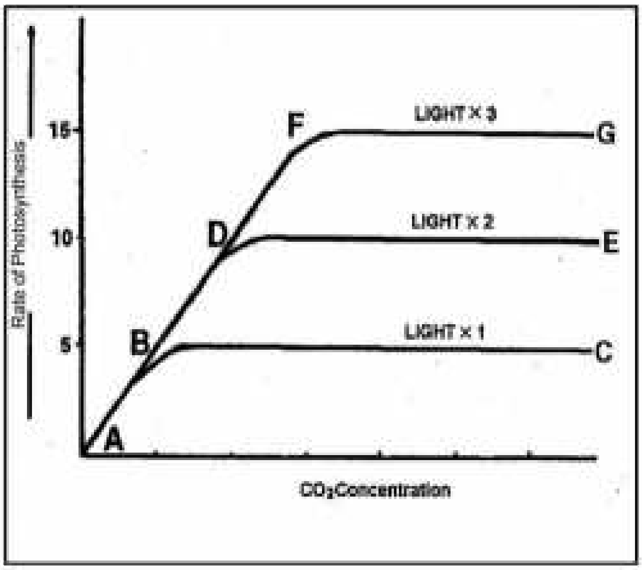


Fig.12.14 : Blackman's concepts of limiting factors

In the dark there is no photosynthetic CO_2 fixation (i.e. CO_2 uptake) taking place by the leaves; rather CO_2 is given off by the plant because of respiration. By convention, photosynthetic carbon assimilation is considered as negative at this situation (Fig. 12.15). As the light intensity increases, photosynthetic CO_2 fixation increases until it equals CO_2 release by respiration. *The light intensity at which the rate of photosynthetic* CO_2 *uptake equals the rate of respiratory CO_2 release is known as the light compensation point* (Figure 12.15) . Plants do not survive below the light compensation point.

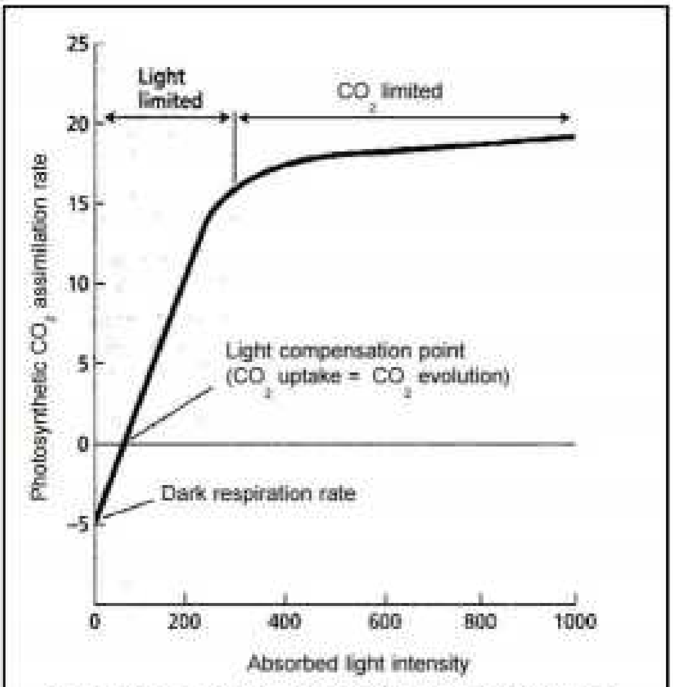


Fig.12.15 : Effect of light intensity on photosynthesis

12.8.2. Light quality :

Photosynthesis occurs only in the visible spectrum of light, the wavelength of which ranges from about 400 nm to 750 nm. Different wavelengths of light, (i.e., different qualities of light) are not equally effective in photosynthesis (see Box-I). Different plants show different rate of photosynthesis under different quality of light.

12.8.3. Carbon dioxide :

Carbon dioxide is the key inorganic molecule required for photosynthesis. Photosynthesis occurs at a very wide range of CO_2 concentration. At very low CO_2 concentration, photosynthesis is strongly limited by the low CO_2, while respiratory rate is unaffected. As a result, CO_2 fixed by photosynthesis is lower than the CO_2 released by respiration. So there is a net efflux of CO_2 from the plants. With the increase in CO_2 concentration, the rate of photosynthesis increases provided other factors are not limiting. *The CO_2 concentration at which the rate of CO_2 fixation by photosynthesis equals the rate of* CO_2 *release by respiration is known as CO_2* ***compensation point*** (Figure 4.16). In C_3 plants, increasing CO_2 concentration above the compensation point stimulates photosynthesis over a wide concentration range. On the other hand, photosynthesis in C_4 plants level off and reach saturation at a lower CO_2 concentration when compared with that of C_3 plants (Figure 12.16).

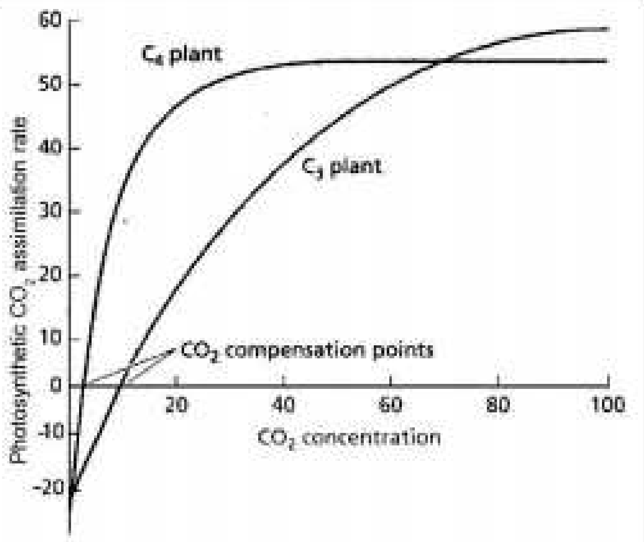


Fig.12.16 : Effect of CO_2 concentration on photosynthesis in C3 and C4 plants

12.8.4. Water

Water is one of the raw materials used in photosynthesis. The amount of water utilized in photosynthetic reactions is quite small. Therefore, water rarely becomes a limiting factor for photosynthesis. However, water deficit stress reduces the rate of photosynthesis by affecting the process indirectly. One of the indirect effects is the stomata closure which reduces the entry of CO_2 in the leaf cells.

SAMPLE QUESTIONS

A. Multiple-choice questions :

1. Oxygenic photosynthesis does not occurs in :
   (a) Plants
   (b) Green sulfur bacteria
   (c) Bryophytes
   (d) Cyanobacteria

2. Cyclic electron transfer around PS I results in the formation of:
   (a) ATP (b) NADPH
   (c) ATP and NADPH (d) ATP, NADPH and O2

3. In higher plant chloroplasts, the chlorophylls are located in :
   (a) stroma (b) lumen of grana
   (c) outer membrane (d) thylakid membrane

4. All algae generally have :
   (a) Chlorophyll-a and chlorophyll-b
   (b) Chlorophyll-a and 0-carotene
   (c) Chlorophyll-b and 0-carotene
   (d) Phycoerythrin and 0-carotene

5. In C-4 plants, the first stable product of CO2 fixation in mesophyll cells is :
   (a) 3-Phosphoglycerate (b) Dihydroxyacetonephosphate
   (c) Oxaloacetate (d) Phosphoenol pyruvate

6. During light absorption and emission by chlorophyll molecule, the length of fluroscent light is :
   (a) Longer than that of absorbed light
   (b) Shorter than that of absorbed light
   (c) Equal to that absorbed light
   (d) Equal to that of phosphorescent light.

7. Electron donor to PSI is
   (a) Cyt-b (b) Cyt-b_6
   (c) Ferredoxin (d) Plastocyanin

8. The reaction centre of PS II is :
   (a) P_{600} (b) P_{680}
   (c) P_{700} (d) P_{750}

9. The ions essential for photolysis of water during photosynthesis are :

(a) Mn^{++}, Ca^{++} and Cl^{-} (b) Mg^{++}, Ca^{++} and Cl^{-}

(c) Cu^{++}, Ca^{++} and Mg^{++} (d) Fe^{++}, Ca^{++} and Mn^{++}

10. The first reaction of photosynthesis is :

(a) Excitation of chlorophyll (b) Photolysis of water

(c) ATP formation (d) CO2 fixation.

B. Fill in the blanks :

(a) The graph showing the effectiveness of different wave lengths of light on the photosynthetic activity of leaves is known as.

(b) In higher plants the reaction centre chlorophyll of PS I is.

(c) In C-4 plants rubisco is present in the chloroplasts ofcells.

(d) The accepter of CO2 during photosynthesis in bundle sheath cells of C-4 plants is

(e) Kranz type of leaf anatomy is seen inplants.

C. Short answer:

1. Absorption spectrum
2. Photosystem
3. Photolysis of water
4. Photophosphorylation
5. Photorespiration.
6. CAM Plants

D. Long answers :

1. Describe the light reaction of photosynthesis.
2. Explain different phases of Calvin cycle.
3. Explain different phases of C4-pathway.
4. What is photorespiration ? Give a brief idea about photorespiration.
5. Give an account of different factors affecting photosynthesis.

❑ ❑ ❑

RESPIRATION

CHAPTER 13

The essential feature of photosynthesis, as discussed in the previous chapter, is the conversion of solar energy into potential chemical energy which is stored in carbohydrates and other carbon compounds. These carbon compounds are broken down inside the cell in a controlled manner to release the stored chemical energy for utilization in various cellular functions. This process is known as **respiration** or, more specifically, **cellular respiration.** Cellular respiration is an oxidation process where the energy released is conserved as the high energy terminal bonds of ATP that can be readily utilized by the cell to do work (Figure 13.1). The step by step reactions of respiration also modify the carbohydrates to form the carbon skeletons that make up the basic building blocks of cell structure.

Reactions releasing energy Intermediate energy-transfer Reactions consuming energy compounds

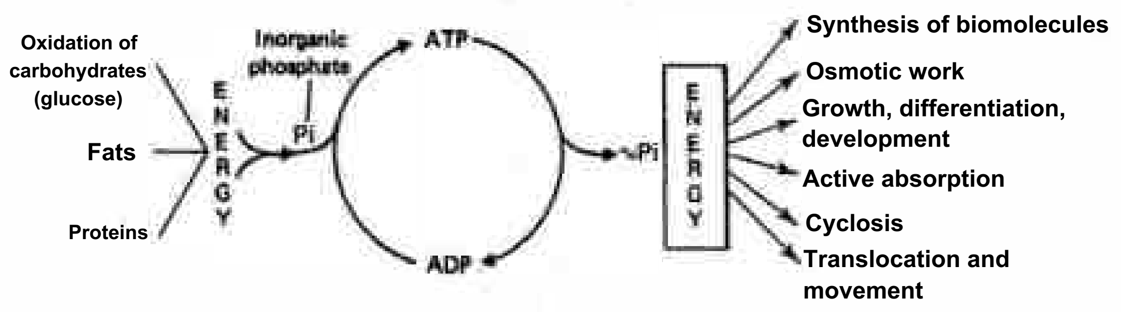


Fig. 13.1 : The ATP cycle

The overall process of respiration and photosynthesis appears as reverse metabolic processes and certain commonalities do exist between these processes. A comparative account of some aspects of photosynthesis and respiration are given in Box I.

13.1. PROCESS OF RESPIRATION :

Respiration is the process of complete oxidation of carbon compounds to CO_2 and H_2O, using molecular oxygen as the final electron acceptor, and the energy released being conserved as the high energy terminal bonds of ATP. This process is also known as **aerobic respiration,** since O_2 is used as the final electron acceptor. Nearly all eukaryotic organisms including plants and animals respire aerobically. In the absence of O_2, yeasts, some bacteria, and even green plants resort to incomplete oxidation of carbon compounds producing ethanol or lactic acid and

BOX-I **Comparison of some important aspects of the processes of photosynthesis and respiration**	
Photosynthesis	Respiration
1. Takes place only in chlorophyll-containing cells of plants	1. Takes place in all plant and animal cells
2. Takes place only in the presence of light	2. Takes place continuously both in light and in dark
3. The raw materials for this process are CO_2 and H_2O	3. The raw materials for this process are sugars and O_2 (Other carbohydrates as well as fats and proteins are used as raw materials when soluble sugars are depleted)
4. The products of this process are sugars, water and O_2(Soluble sugars are then used to produce other carbohydrates and provide carbon skeleton for the production of fats and proteins)	4. The products of this process are CO_2 and H_2O
5. Synthesizes food materials	5. Oxidizes food materials
6. Converts light energy to chemical energy (ATP) and stores the energy in C-C bonds	6. Releases energy from C-C bonds in usable form (ATP)
7. Results in an increase in dry mater	7. Results in a decrease in dry mater

much less amount of ATP than is produced during aerobic respiration. This process is termed as **fermentation.** There are relatively a few other types of bacteria which respire in the absence of O_2, an inorganic compound being the terminal electron acceptor; this process is called **anaerobic respiration.** ***Fermentation*** *is also often referred to as* ***anaerobic respiration.***

Aerobic respiration is the most common type of respiration in nearly all eukaryotic organisms. From a chemical standpoint, the overall process of aerobic respiration may be stated as per the following general equation with glucose as the substrate:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \text{ ---------->} \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{ATP}}{\text{ENERGY}}$$

It may be noted here that this equation is written as a reversal of the equation for photosynthesis. As in the case of photosynthesis, this equation is a mere representation of the raw materials, necessary conditions, and the products of the respiratory reaction. It in no way accounts for the large number of intermediate chemical reactions that actually occur during cellular respiration. Direct oxidation of glucose by molecular oxygen, as shown in the equation above, would release a large quantity of energy, all at once that would be sufficient to incinerate the cell structure. Instead, during aerobic respiration the cell releases the large amount of free energy from the oxidation of glucose in a series of step by step reactions in a controlled manner in order to conserve this energy in metabolically useful forms (for example, ATP). These reactions can be grouped into three major phases such as **glycolysis, citric acid cycle,** and **respiratory electron transport chain.** The cellular site for glycolysis is the cytoplasm, whereas citric acid cycle and respiratory electron transport chain occur in the mitochondrion.

Out of the three distinct phases of respiration, glycolysis is common to both aerobic and anaerobic respiration. The product of glycolysis is pyruvate which is reduced to ethanol or lactic acid in anaerobic respiration but is completely oxidized to CO_2 and H_2O through the citric acid cycle and electron transport chain in aerobic respiration.

13.1.1. Glycolysis :

Glycolysis (Greek: *glycos* meaning *sugar,* and *lysis* meaning *splitting)* literally means the splitting up of sugar. It represents a set of reactions in which glucose molecule is partially oxidized into two molecules of pyruvates. The reactions of glycolysis occur in all living organisms - both prokaryotes and eukaryotes. These reactions take place in the cytoplasm of cells and do not require oxygen. The glycolytic pathway is also called the Embden-Meyerhoff pathway. These biochemists charactrised the steps of glycolsis in the early 20th century.

Glycolysis is conveniently considered in two major groups of reactions. The first group is a set of reactions by which glucose and fructose derived from storage carbohydrates are converted to triosephosphates via fructose-1, 6-bisphosphate. This first group of reactions is regarded as the **preparatory (or investment) phase** since energy in the form of ATP is consumed during this phase. In the second set of reactions triosephosphates are converted to pyruvate, which is the end product of glycolysis. This second set of reactions is known as **pay-off (or energy-conserving) phase,** which is characterized by net gain of energy-rich molecules, such as ATP and NADH. The reactions of glycolysis are shown in Figure 13.2.

The **preparatory phase** of glycolysis begins with the conversion of glucose to glucose 6-phosphate by the activity of the enzyme *hexokinase (glucokinase).* This phosphorylation reaction, catalyzed by *hexokinase,* requires ATP and Mg^{++}. Glucose 6-phosphate then isomerizes to form fructose 6-phosphate being catalyzed by the enzyme *hexosephosphate isomerase.* When fructose is the substrate, it is phosphorylated to fructose 6-phosphate by the enzyme *hexokinase (fructokinase)* which requires ATP and Mg^{++} for its activity. The enzyme *phosphofructokinase*, which also requires ATP and Mg^{++} for its activity, catalyzes the phosphorylation of fructose 6-phosphate to form fructose-1,6-bisphosphate. This reaction is essentially irreversible. In plants, an additional cytosolic enzyme, *pyrophosphate (PPi)-dependent phosphofructokinase* is present which catalyzes the reversible inter conversion of fructose 6-phosphate and fructose-1,6-bisphosphate. In the next step, *fructose-1, 6-bisphosphate aldolase* catalyzes the conversion of fructose-1, 6-bisphosphate into two triosephosphate molecules. One is glyceraldehyde 3-phosphate, which will proceed further through glycolysis. Another is dihydroxyacetone phosphate, which unless otherwise used up, is converted to glyceraldehyde 3-phosphate to proceed through glycolysis. Glyceraldehyde

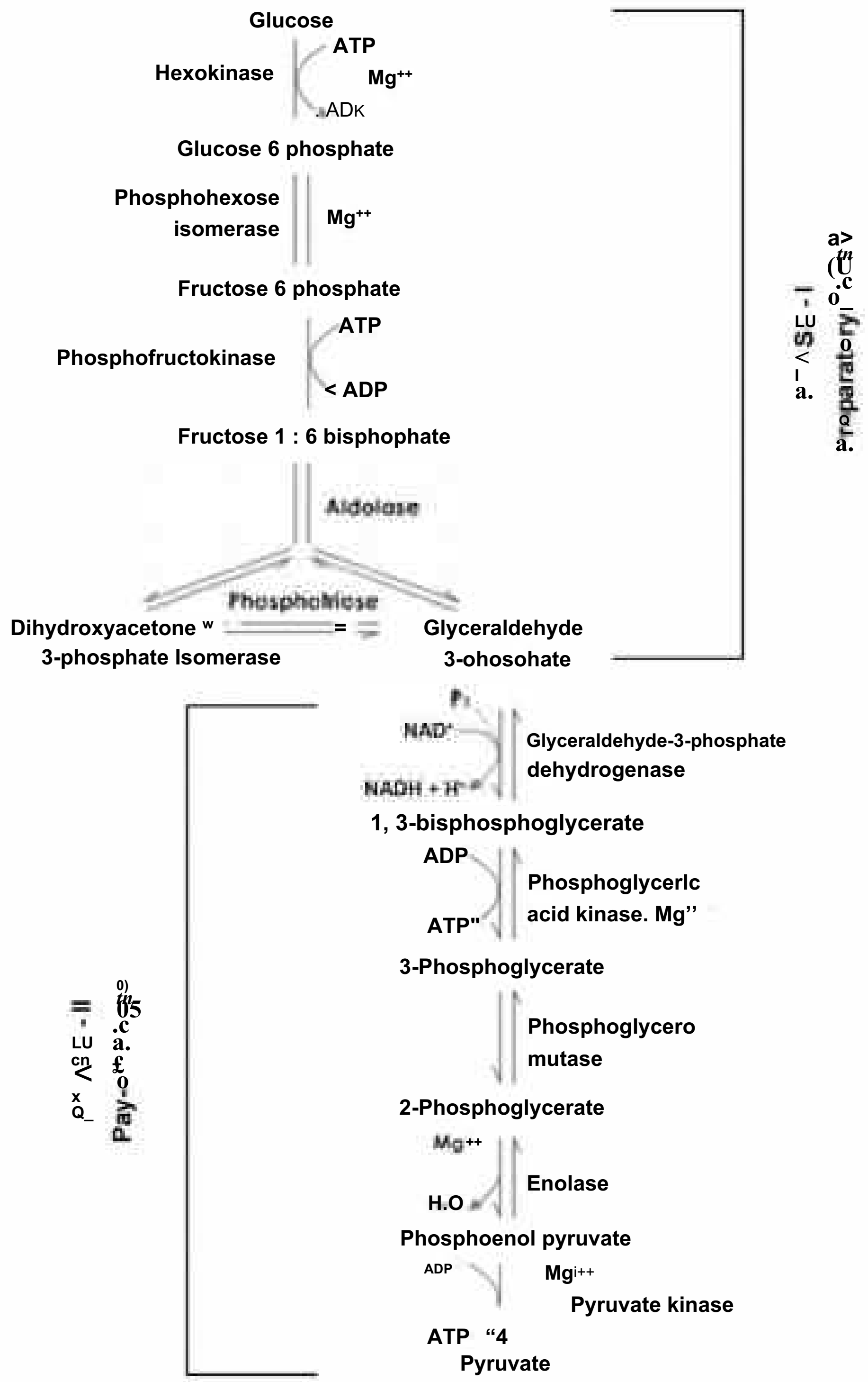


Fig. 13.2 : Two phases of glycolysis

3-phosphate and dihydroxyacetone phosphate are inter-convertible, an equilibrium reaction catalyzed by the enzyme *triosephosphate isomerase.*

In the **pay-off phase** of glycolysis, *glyceraldehyde 3-phosphate dehydrogenase* catalyzes the oxidation of glyceraldehyde 3-phosphate to produce 1,3-bisphosphoglycerate with the integration of one inorganic phosphate molecule. In this reaction NAD^+ removes two ITfrom glyceraldehydes 3-phosphate forming NADH + $H^+$and sufficient free energy is released to allow the phosphorylation (using inorganic phosphate) of glyceraldehyde 3-phosphate to produce 1, 3-bisphosphoglycerate. In the next step, 1, 3-bisphosphoglycerate transfers the phosphate on its carbon-1 to a molecule of ADP, yielding ATP and 3-phosphoglycerate. This reaction is catalyzed by the enzyme *phosphoglycerate kinase.* This type of ATP synthesis, involving the direct transfer of phosphate group from a substrate molecule to ADP to form ATP, is traditionally referred to as **substrate-level phosphorylation.** The enzyme *phosphoglyceratemutase* catalyzes the conversion of 3-phosphoglycerate to 2-phosphoglycerate and then the enzyme *enolase* catalyzes the removal of water from 2-phosphoglycerate forming phosphoenolpyruvate. The enolphosphate in phosphoenolpyruvate has the properties of a high-energy bond. *Pyruvate kinase* irreversibly catalyzes the transfer of phosphate group from phosphoenolpyruvate to ADP forming ATP and pyruvate.

Each glyceraldehyde 3-phosphate molecule, on being converted to pyruvate by a series of reactions during the pay-off phase, produces 2 molecules of ATP and 1 molecule of NADH + H^+. So one glucose molecule when converted to pyruvate by glycolysis can produce 4 molecules of ATP and 2 molecules of NADH + H^+. During the preparatory phase, activation of glucose (or fructose) to form fructose-1, 6-bisphosphate uses 2 molecules of ATP. *Hence, there is a net gain of 2 molecules of ATP and 2 molecules of NADH + H^+ when 1 molecule of glucose (or fructose) is converted to 2 molecules of pyruvate during glycolysis.*

13.1.2. Metabolic Fate of Pyruvate :

Pyruvate is the end product of glycolysis. The sequence of reactions leading to the formation of pyruvate from glucose is the common pathway occurring during anaerobic and aerobic respiration. Depending upon the absence or presence of molecular oxygen and the cellular metabolic need, pyruvate takes up different routes for its metabolism (Figure 13.3).

In the absence of molecular oxygen, respiratory electron transport chain and oxidative phosphorylation can not function in the mitochondrion because molecular oxygen is the terminal electron acceptor for these two highly coordinated processes (see later in the chapter). As a result the oxidation of NADH to form NAD^+ does not take place. There are limited amount of NAD^+ available in the cell. Once all the NAD^+ becomes tied up in the reduced state (NADH), the reaction catalyzed by *NAD^+-dependent glyceraldehyde 3-phosphate dehydrogenase* and, therefore, glycolysis can not continue to operate. Under the situation of unavailability of molecular oxygen, glycolysis is the main source of chemical energy (ATP) necessary for cell survival.

Consequently, NAD^+ must be regenerated for glycolysis to proceed. To overcome this problem, different organisms and different cell types metabolize pyruvate by **fermentation pathways,** which are localized in the cytosol, to regenerate NAD^+. Two fermentation pathways are of prime importance: **alcohol fermentation** and **lactic acid fermentation.**

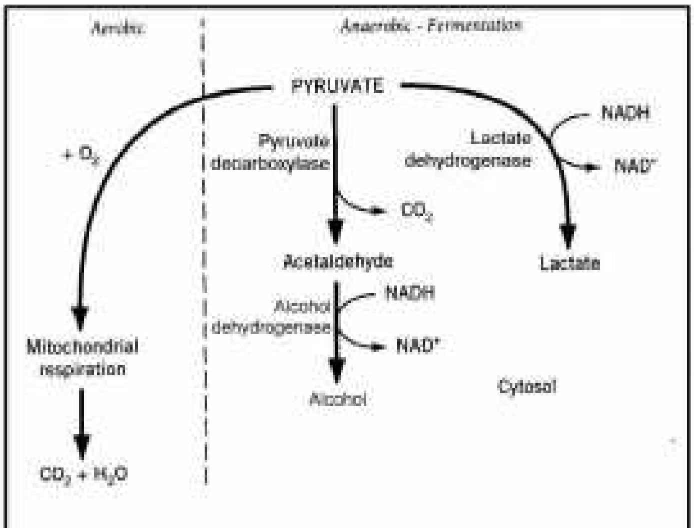


Fig.13.3 : Metabolic fate of pyruvate under aerobic and anaerobic conditions

Under anaerobic conditions, yeast and several other microorganisms produce ethanol from pyruvate by fermentation pathways. The first step is the decarboxylation of pyruvate to produce acetaldehyde. This reaction is catalyzed by the enzyme *pyruvate decarboxylase.* In the second step *alcohol dehydrogenase* catalyzes the reduction of acetaldehyde to ethanol by NADH and regenerates NAD^+. Higher plant tissues or organs are often subjected to anaerobic conditions, for example, plant roots under flooded soil, and produce ethanol from pyruvate. A variety of microorganisms reduce pyruvate to lactate by a process called lactic acid fermentation. This reaction also takes place under anaerobic conditions in some plant tissues and under oxygen limiting conditions in animal muscles. The reduction of pyruvate by NADH to form lactate and regenerate NAD+ is catalyzed by the enzyme *lactate dehydrogenase.*

Under aerobic conditions, pyruvate enters the mitochondrial matrix where it is decarboxylated, oxidized, and the resultant acetyl group is transferred to coenzyme A (CoA) to form acetyl CoA. In this oxidative decarboxylation reaction, catalyzed by *pyruvate dehydrogenase* complex, NAD^+ is reduced to NADH and CO_2 is released.

Pyruvate + NAD^+ + CoA —> Acetyl CoA+ CO_2 + NADH + H^+

The acetyl group of acetyl CoA then enters the citric acid cycle where it is completely oxidized to release more energy than that is possible under anaerobic respiration. Thus the reaction catalyzed by *pyruvate dehydrogenase complex* is the link between glycolysis and citric acid cycle.

13.1.3. Citric Acid Cycle :

The German-born British biochemist **Hans A. Krebs** in 1937 discovered the **citric acid cycle** (so named because citric acid is the early intermediate of the cycle) that usually occurs in the mitochondria and oxidizes pyruvate to CO_2 and H_2O. The citric acid cycle is also known as the **tricarboxylic acid (TCA) cycle** (because tricarboxylic acids, such citric acid and isocitric

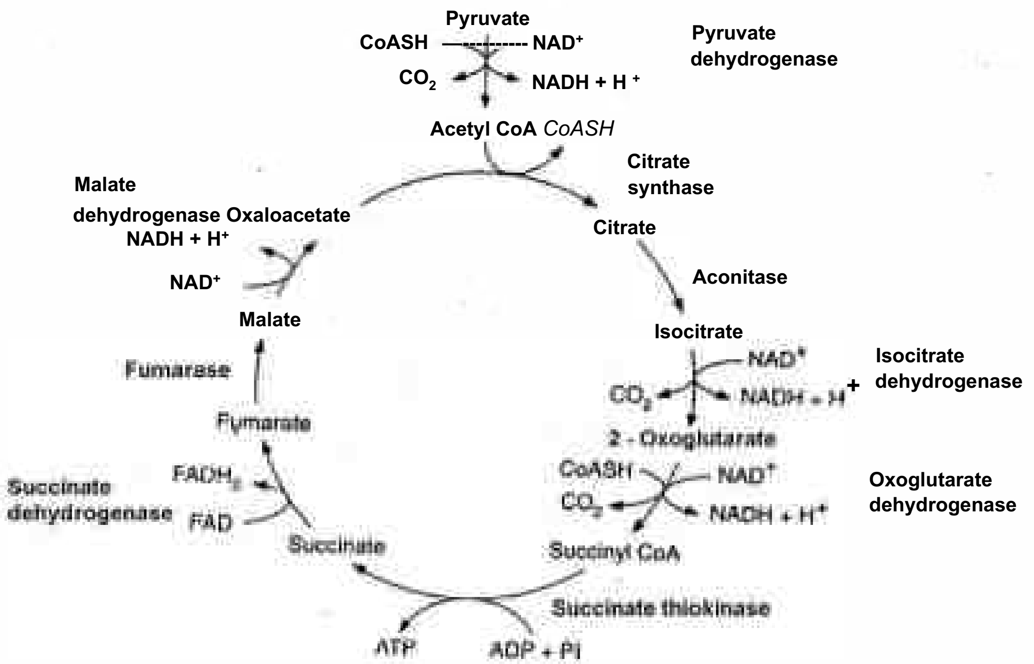


Fig.13.4 : Critic Acid Cycle (Krebs Cycle)

acid, are the early intermediates of the cycle) or the **Krebs cycle,** in honour of its discoverer. Hans Krebs was awarded the Nobel Prize in physiology and medicine in 1953 for his discovery of the citric acid cycle. The reactions of citric acid cycle are presented in Figure 13.4.

The citric acid cycle begins with the condensation of two-carbon acetyl group from acetyl CoA with the four-carbon oxaloacetate to form the six-carbon citrate and CoA is released. This irreversible reaction is catalyzed by the enzyme *citrate synthase.* Citrate is then isomerized to isocitrate by the enzyme *aconitase.* The next two successive oxidative decarboxylation reactions, each of which reduces one molecule of NAD^+ to NADH and releases one molecule of CO_2, are catalyzed by *isocitrate dehydrogenase* and *2-oxoglutarate dehydrogenase complex,* respectively, yielding succinyl CoA. The latter reaction is similar to the one catalyzed by *pyruvate dehydrogenase complex* in which 2-oxoglutarate is decarboxylated, oxidized and the resultant succinate group is transferred to CoA to form succinyl CoA. The thioester bond of succinyl CoA is rich in energy. This free energy is conserved in the terminal phosphoester bond of ATP (in plants) or GTP (in animals, which can then be converted to ATP enzymatically, if required) by substrate-level phosphorylation in a coupled reaction catalyzed by *succinate thiokinase* (also known as *succinyl CoA synthetase).* The succinate formed is oxidized to fumarate by *succinate dehydrogenase,* the only enzyme of Krebs cycle bound to inner mitochondrial membrane and a component of mitochondrial electron transport chain. The FAD (flavin adenine dinucleotide) is reduced to $FADH_2$ is covalently bound to the active site of *succinate dehydrogenase.* In the next reaction, catalyzed by *fumarase,* fumarate reacts with water to form L-malate. Malate is then oxidized to regenerate oxaloacetate and NADH is formed from NAD^+. This reaction is catalyzed by the *malate dehydrogenase.* The oxaloacetate regenarated can now condense with another molecule of acetyl CoA to continue the cycling of citric acid cycle.

In summary, stepwise oxidation of one molecule of acetyl CoA through the citric acid cycle releases 2 molecules of CO_2. The free energy released during the oxidation reactions is conserved in the form of 3 molecules of NADH and 1 molecule of $FADH_2$. One molecule of ATP is also produced by the substrate-level phosphorylation. Two molecules of water are consumed during the operation of the cycle. Although formation of acetyl CoA from pyruvate is not part of the citric acid cycle, one should be reminded here that during this reaction 1 molecule of CO_2 is released and one molecule of NADH is produced. Therefore, *oxidation of one molecule of pyruvate inside the mitochondrion produces, in total, 4 molecules of NADH, 1 molecule of $FADH_2$ and 1 molecule of ATP, and 3 molecules of CO_2 are also released.*

13.1.4. Electron transport chain :

The transfer of electrons from NADH and $FADH_2$ to oxygen involves a sequence of electron carriers arranged in an **electron transport chain** (Figure 13.5). The electron carriers with their associated enzymes making up the electron transport chain are organized predominantly into four large multimolecular complexes, numbered as *complex Ito IV,* and two mobile carriers located in the inner mitochondrial membrane. Electrons from NADH enter the electron transport chain through *complex I,* known as *NADH-ubiquinone oxidoreductase.* This complex has a tightly bound flavin mononucleotide (FMN). This complex transfers the electron received from NADH to ubiquinone. Ubiquinone also receives electrons from *complex II (succinate dehydrogenase). Succinate dehydrogenase* oxidizes succinate to fumerate and the

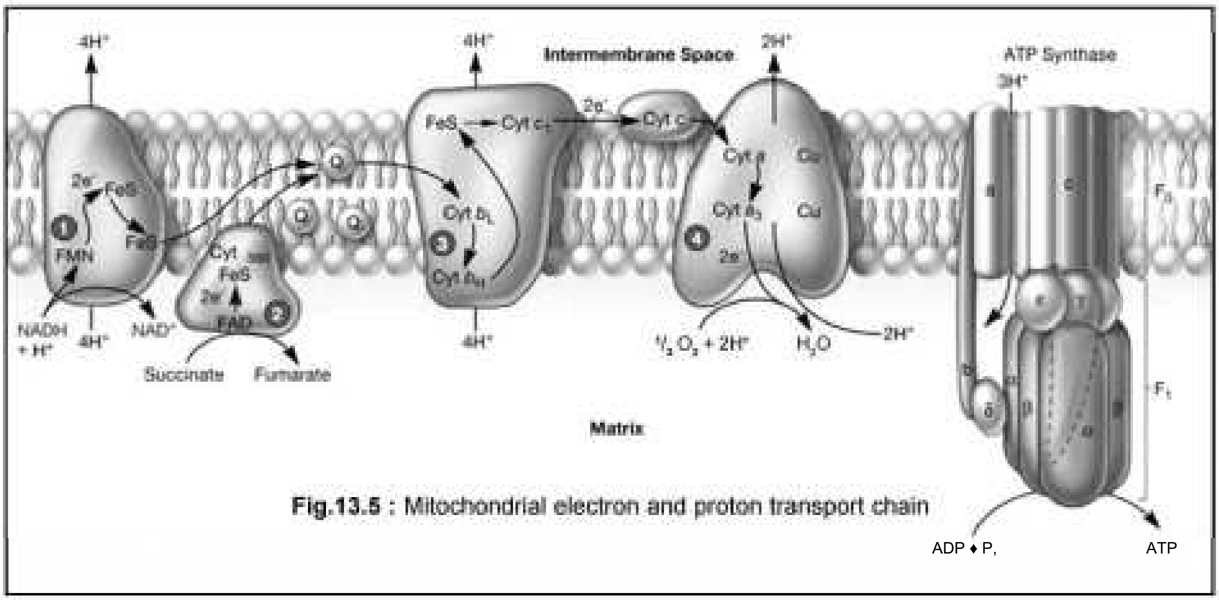


Fig.13.5 : Mitochondrial electron and proton transport chain

reducing equivalents are transferred to ubiquinone via $FADH_2$ which is bound to *complex II.* Ubiquinone is a mobile carrier highly soluble in lipid and diffuses freely in the hydrophobic interior of the membrane. Upon receiving 2 electrons from NADH and 2 protons from the matrix side of the membrane, ubiquinone is reduced to ubiquinol. Ubiquinol (the fully reduced form of ubiquinone) then transfers the electrons to *complex III* and the protons (H^+) are released into the intermembrane space of the mitochondrion. *Complex III* is known as *cytochrome c (cyt-c) reductase* and contains of cyt-b and cyt-c, and iron-sulphur protein. *Complex III* then passes the electrons to cyt-c, which is a mobile electron carrier located on the outer surface (i.e., facing the intermembrane space) of the inner mitochondrial membrane. Cyt-c, in turn, transfers the electrons to *complex IV,* also known as *cyt-c oxidase,* which contains copper ion, and cyt-a and cyt-a_3. Electrons are transferred from cyt-c to cyt-a, then to cyt-a_3 and finally to molecular oxygen which is the terminal electron accepter in mitochondrial electron transport chain. As electrons are transferred via complex IV, protons are simultaneously transferred from the matrix side of the inner mitochondrial membrane to the intermembrane space of the mitochondrion.

13.1.5. Oxidative phosphorylation and ATP synthesis :

Passage of an electron pair down the electron transport chain releases free energy which is used to phosphorylate ADP molecules with inorganic phosphate (Pi) and thus forms ATP. *The formation of ATP molecules coupled to the transfer of electrons, derived from the oxidation of organic compounds, through the mitochondrial electron transport chain is called as* ***oxidative phosphorylation.*** The molecular mechanism of this ATP synthesis is best explained through the **chemiosmotic hypothesis** proposed by Peter Mitchell in 1961. For this revolutionary hypothesis, Peter Mitchell was awarded the Nobel Prize in chemistry in 1978. The essential feature of this hypothesis is that during electron transport, a proton gradient is formed across the membrane which results in the generation of a **proton motive force.** It is the proton motive force of the gradient which drives the synthesis of ATP when protons force their way through an integral membrane protein complex known as the coupling factor (Fig. 13.5).

Figure 13.5 shows the vectorial transfer of protons from the matrix side of the inner mitochondrial membrane to the intermitochondrial space when electrons are transferred through *complexes I, III* and *IV.* A total of 10 protons are transferred when two electrons are transported from NADH to oxygen molecule via the components of the electron transport chain. For the transport of electrons coming from succinate via $FADH_2$ which bypasses complex I, 6 protons are transported per two electrons transferred. This establishes a proton motive force across the inner mitochondrial membrane. This proton motive force drives the synthesis of ATP when the protons force their way into the matrix through an integral membrane protein complex known as *ATP synthase.* This complexis also described in many text books under the name F_o-F_1 particle or coupling factor. It is estimated that for 3 protons transported through *ATP synthase,* one ATP is synthesized. Because 10 protons are transported for each pair of electrons transferred trough the chain, a total of approximately 3 ATP molecules are synthesized for each molecule of NADH oxidized in the mitochondrial electron transport chain. For the oxidation of each molecule of NADH formed in the cytoplasm during glycolysis and $FADH_2$ formed inside mitochondria during citric acid cycle, 2 molecules of ATP are formed since complex I is bypassed. A balance sheet of total ATP formed for each molecule of glucose oxidized during cellular aerobic respiration is shown in Table 13.1.

13.2. AMPHIBOLIC PATHWAY :

We have discussed in the previous pages that during respiratory metabolism, glucose molecule is oxidized step-wise and the released energy is used by the organism for various work including synthesis of biomolecules (see Fig. 13.1). Although glucose is the most favoured substrate for respiration, other carbohydrates also used as respiratory substrates. Different types of carbohydrates such as disaccharides (e.g., sucrose) and polysaccharides (e.g., starch in plants and glycogen in animals) are enzymatically hydrolyzed to form the simplest form of carbohydrate, the monosaccharides. The monosaccharides produced by hydrolysis of starch (plant) or glycogen (animal) are glucose. Glucose-1-phosphate is also produced by the phosphorolytic degradation of starch and maltose. Hydrolysis of sucrose produces the mixture of glucose and fructose. Glucose, fructose and glucose-1-phosphate enter the first common phase respiration known as glycolysis.

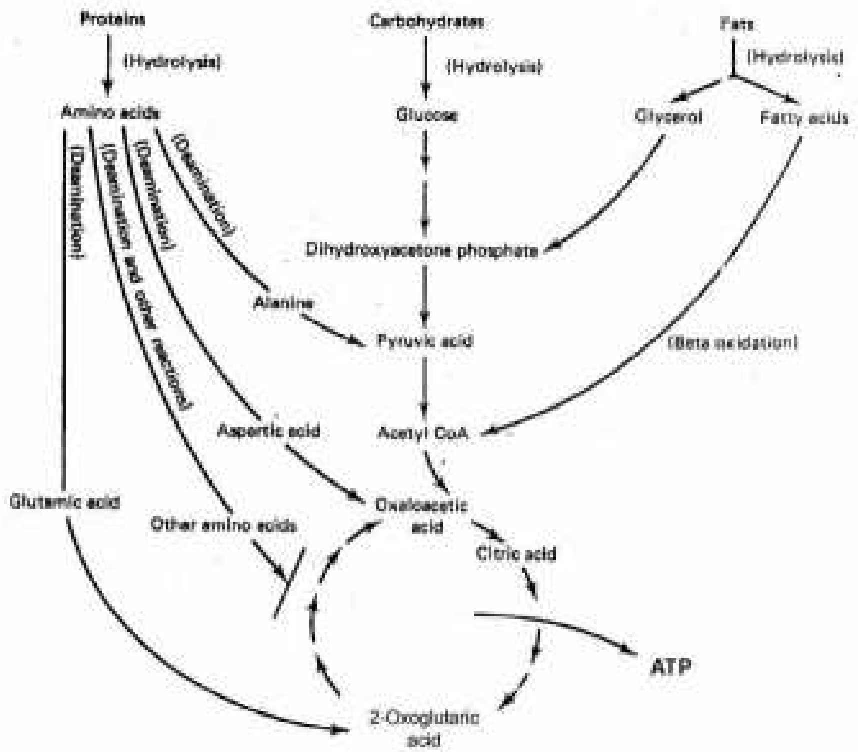


Fig.13.6 : Catabolic role of Krebs cycle (citric acid cycle).

Fats are generally used as respiratory substrate after the exhaustion of carbohydrate reserve. Fatty acids are oxidized to give acetyl CoA, which enters the respiratory metabolism through the citric acid cycle. Proteins are used as respiratory substrates only when carbohydrate and fat reserves are exhausted. Proteins are hydrolyzed to form amino acids which are then deaminated to form ketoacids before entering into the citric acid cycle. The entry points of different substrates of respiration into the respiratory metabolic pathways are shown in Fig. 13.6. Because carbohydrates, lipids and proteins are degraded during cellular respiration, traditionally, respiratory metabolism is considered as *catabolic* process.

However, citric acid cycle has *anabolic* role as well. When required by the cell, the intermediates of respiratory metabolism are diverted for the synthesis of various molecules including the ones degraded by this pathway. Oxaloacetate is removed from citric acid cycle for the synthesis of glucose when glucose is required by the cell and fats and proteins are available. Citrate provides the precursors for the biosynthesis of fatty acids and sterols. Oxaloacetate, phosphoenolpyruvate and 2-oxoglutarate provide the carbon skeletons for the synthesis of various amino acids. Succinyl-CoA is withdrawn from citric acid cycle for the synthesis of porphyrins, hemoglobin and chlorophyll. Purines and pyrimidines ultimately derived their carbon skeleton from 2-oxoglutarate and oxaloacetate. The *anabolic* role of citric acid cycle is shown in Fig. 13.7.

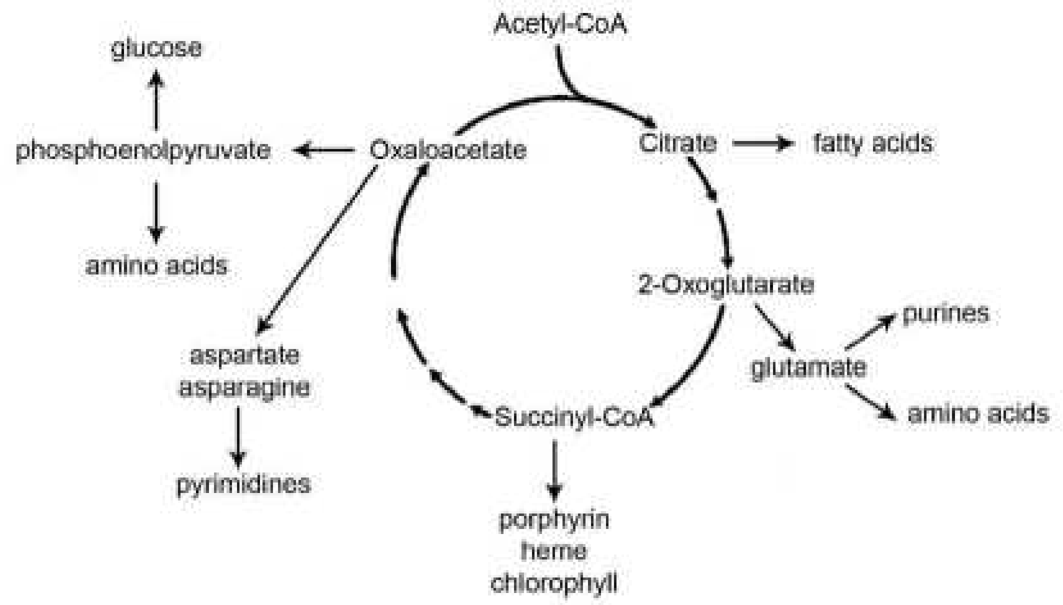


Fig.13.7 : Anabolic role of Krebs cycle (citric acid cycle).

Because the respiratory metabolic pathway has both *catabolic* and *anabolic* roles in cellular metabolism, this is called as *amphibolic* pathway. Citric acid cycle is a very good example of **amphibolic pathway.**

TABLE-13.1

Balance sheet of ATP formation for the complete oxidation of one molecule of glucose during aerobic respiration in plants.

Reaction	ATP formed	ATP consumed	Net gain
Glycolysis			
1. Glucose —> Glucose-6-P	-	1 ATP	
2. Fructose 6-P—>Fructose-1,6-BisP	-	1 ATP	
3. 1,3-Bisphospoglyceraldehyde > — 1,3-Bisphosphoglycerate	2 NADH x 2 ATP = 4 ATP		
4. 1,3-Bisphosphoglycerate—> 3- Phosphoglycerate	2 ATP		
5. Phosphoenolpyruvate—> Pyruvate	2 ATP		
Total for Glycolysis	**8 ATP**	**2 ATP**	**6 ATP**
6. Pyruvate —> Acetyl CoA	2 NADH x 3 ATP= **6 ATP**	-	**6 ATP**
Krebs cycle			
7. Isocitrate—> 2-Oxoglutarate	2 NADH x 3 ATP = 6 ATP		
8. 2-Oxoglutarate—>Succinyl CoA	2 NADH x 3 ATP = 6 ATP		
9. Succinyl CoA—>Succinate	2 ATP		
10. Succinates* Fumerate	2 $FADH_2$ x 2 ATP = 4 ATP		
11. Malates*Oxaloacetate	2 NADH x 3 ATP = 6 ATP		
Total for Krebs cycle	**24 ATP**	-	**24 ATP**
Grand Total	**38 ATP**	**2 ATP**	**36 ATP**

13.3. RESPIRATORY QUOTIENT :

During aerobic respiration, O_2 is consumed and CO_2 is released. The ratio of the amount of CO_2 evolved to the amount of O_2 consumed in respiration is called the **respiratory quotient** (RQ).

$$RQ = \frac{\text{amount of } CO_2 \text{ evolved}}{\text{amount of } O_2 \text{ consumed}}$$

The value of the RQ depends upon the type of substrate used for respiration. Generally carbohydrates are used as the substrates for respiration. Complete oxidation of carbohydrates during aerobic respiration consumes O_2 and releases CO_2 in equal amounts as per the following equation:

$C_6H_{12}O_6 + 6O_2$ -----> $6CO_2 + 6H_2O$ + ENERGY

Therefore, for carbohydrates the RQ is 1.

The chemical composition for fats differs from that of carbohydrates in that fats contain considerably fewer oxygen atoms in proportion to atoms of carbon and hydrogen. The fatty acids, which are formed by the hydrolysis of fats, are used as respiratory substrates. The overall equation for the complete oxidation of a common fatty acid such as palmitic acid during aerobic respiration is given below.

$C_{16}H_{32}O_2 + 23\ O_2$--------> $16\ CO_2 + 16\ H_2O$

The RQ of palmitic acid is $16\ CO_2 / 23\ O_2 = 0.696$ (~0.7)

Proteins are composed of amino acids which in turn are composed of carbon, hydrogen, oxygen, nitrogen and also sulfur. The respiratory quotient for protein varies from 0.8 to 0.9.

The value of RQ usually ranges from 1.0 (for pure carbohydrate oxidation) to ~0.7 (for pure fat oxidation), the RQ value for proteins being 0.8 to 0.9.

SAMPLE QUESTIONS

A. Multiple-choice questions :

1. The first reaction step in glycolysis, that produces ATP, is catalyzed by the enzyme,
   (a) Hexaokinase (b) Pyruvate kinase
   (c) Phosphoglycerate kinase (d) Phosphofructokinase
2. The reaction which links glycolysis with Krebs cycle is catalyzed by :
   (a) Glutamate dehydrogenase (b) Pyruvate dehydrogenase complex
   (c) Citralilyase (d) Pyruvate kinase
3. Which of the following respiratory substrates produces per mole the highest number of ATP molecules
   (a) Glucose (b) Sucrose
   (c) Strach (d) Fatty acid
4. The enzyme which splits 6-C compound to 3-C compound during glucolysis is :
   (a) Fumarase (b) Aldolase
   (c) Ligase (d) Carboxylase.
5. Glycolysis takes place in
   (a) Nucleus (b) Vacuole
   (c) Cytoplasm (d) Mitochondria
6. The respiratory quotient, when carbohydrates are used as respiratory substrate, is:
   (a) 1.0 (b) 0.7
   (c) 0.9 (d) 0.3

B. Fill in the blanks :

1. Anaerobic respiration is often known as.
2. The synthesis of ATP involving the direct transfer of phosphate group from a substrate molecule to ADP is called as.
3. The formation of ethanol from pyrurate is catalyzed by the enzymesand alcohol dehydrogenase.
4. The reactions of Krebs cycle takes place inside.

C. Short answer type questions :

1. Alcoholic fermentation.
2. Lactic acid fermentation
3. Substrate level phosphorylation
4. Chemiosmotic hypothesis
5. Respiratory Quotient
6. Oxidative phosphorylation.

D. Long answer type questions :

1. Describe the reaction steps of glycolysis.
2. Describe the metabolic fates of pyruvate.
3. Describe the reaction steps of Krebs cycle.
4. Describe the respiratory electron transport chain and explain the mechanism of ATP synthesis.

PLANT GROWTH AND DEVELOPMENT

CHAPTER 14

14.1. SEED GERMINATION :

Germination is the process by which the dormant embryo wakes up. In all mature angiospermic seeds, the embryo lies in a dormant state after fertilization and consequent developments. During this period, the embryo exists at its minimal physiological activity. As soon as the necessary conditions are created, the dormancy is broken and the phenomenan of germination begins. Like all growth processes, the process of germination is irreversible. The process of germination include all changes that take place from the time when the dry seed is placed under suitable conditions to the time when the seedling becomes established in the soil or any other substratum.

Generally, the radicle grows out first during germination and forms root. It is followed by growth of plumule to form shoot. There are 3 different types of seed germination, (i) epigeal, (ii) hypogeal, (iii) viviparous

(i) Epigeal germination

In this, the cotyledons are raised out of the soil and generally become green and photosynthetic. In dicots, they are pushed up by rapid extension of hypocotyl before growth of the epicotyl. Epigeal germination occurs in bean, caster, mustard, tamarind, sunflower etc. (Fig.14.1)

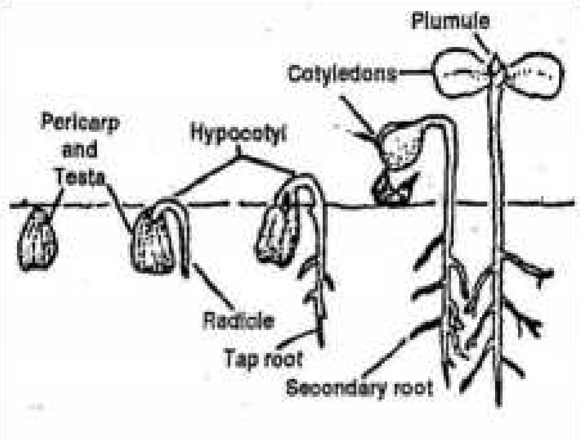


Fig.14.1 : Stages in the epigeal germination of sunflower seed.

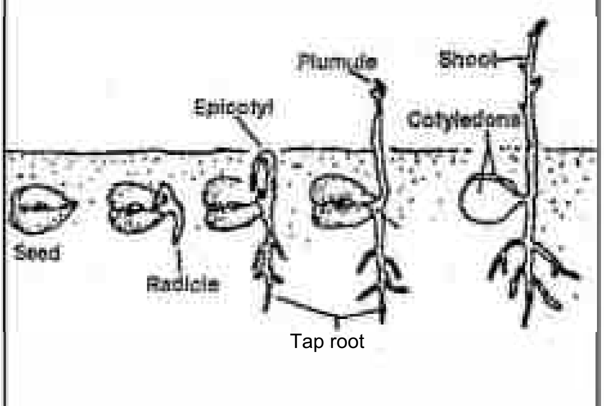


Fig.14.2 : Stages of hypogeal germination of gram seed.

(ii) Hypogeal germination

In this type of genmination, the cotyledons remain underground. Hypocotyl growth is restricted. The epicotyl grows to raise the first leaves out of the soil. Hypogeal germination occurs in dicotyledenous seeds of gram, pea, mango, ground nut etc and in monocotyledons like rice, maize, wheat etc. (Fig. 14.2)

(iii) Viviparous germination

Generally seen in mangrove plants like *Rhizophora, Sonneratia.* These plants generally grow in salty areas, sea coasts and deltas. Seeds cannot germinate in such habitats due to excessive salt and deficiency of oxygen. In this type, seeds germinate while still attached to the parent plant. The seed does not undergo dormancy. The embryo emerges out of the fruit with a massive radicel pointing downwards. As the weight increases the seedling separates and falls down into the mud. The lateral roots then develop from radicel to help anchorage of the seedling (Fig. 14.3).

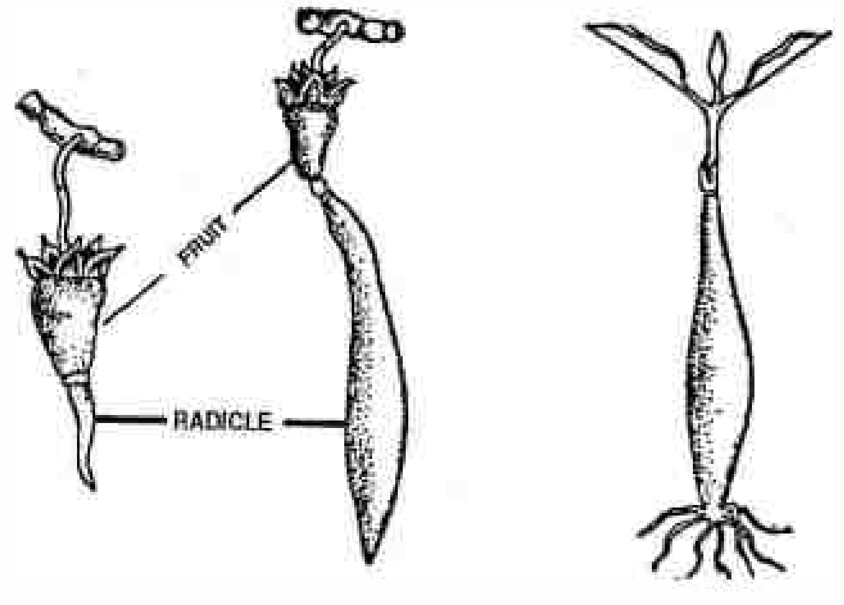


Fig. 14.3 : Stages of Viviparous germination.

Factors affecting seed germination :

For germination of any viable seed, the following conditions are necessary.

Water: Water is very essential for germination. No seed can germinate unless it gets ample amount of water. As soon as the seed is soaked in water, it absorbs water to swell. When the moisture content of the cells is increased, their physiological activities are accelerated. The reserve food materials present either in the endosperm or the cotyledens of the seed are hydrolysed to simpler forms and are made available to the embryo to initiate growth.

Oxygen : The availability of oxygen in sufficient quantity is also another important facter in the germination. It is essential for respiration and all physiological activities. When a seed absorbs water and becomes activated, the rate of aerobic respiration increases manifold and a lot of oxygen is consumed.

Temperature : Like all other physiological activities, germination is affected by temperature. There is minimum and a maximum temperature beyond which germination cannot take place. Within this range, there is a certain optimum temperature where conditions for germination is most congenial. This range varies from plant to plant. Seeds are not usually expected to germinate below 0°C and above 50°C and the optimum temperature is 25-30°C.

Light: Light is not considered as an essential factor since germination takes place even without light. Light affects the germination of different seeds in different ways. Generally, seeds are categorised under three groups based on their response to light.

Positively photoblastic - These seeds would not germinate in the absence of light, e.g., lettuce.

Negatively photoblastic - These seeds germinate under the conditions of total darkness. If kept under lighted conditions, they do not germinate, e.g., pumpkin.

Photoblastic neutral - These seeds germinate equally well under darkness as well as in light conditions, e.g., cucumber, tomato.

Mechanism of germination :

When all factors necessary for germination(water, oxygen, temperature, light) are available, then germination takes place. Take for example, cereal grains such as grain of maize. Water penetrates the permeable seed coat and get into the seed, even into the embryo within the seed. The embryo, then, becomes active and synthesizes mRNA which in turn synthesizes various enzyme proteins. Gibberellic acid is discharged into the aleurone. In the aleurone, gibberellic acid induces synthesis of a number of hydrolases which mobilize reserve materials. For example, a-amylase is one of such enzymes which degrades starch. They also comprise nucleases and proteases which breakdown nucleic acids and proteins, respectively. As a result of the activity of nucleases, cytokinins contained in the nucleic acids are set free. The proteases release amino acids including tryptophan from which IAA is formed.

Cytokinins and IAA now act on the embryo. The cytokinins induce cell division and IAA cell elongation. The embryo so induced starts to grow and bursts its seed coat. It is helped also by pectinases and cellulases. First the radicles appear out of the seed, then, the coleoptile. As a result of gravity, IAA migrates underside of both the organs. This, in turn, leads to reactions which are geotropically different owing to the different sensitivity of coleoptile and radicle. The root turns downwards and is positively geotropic, the coleoptile turns upwards and is negatively

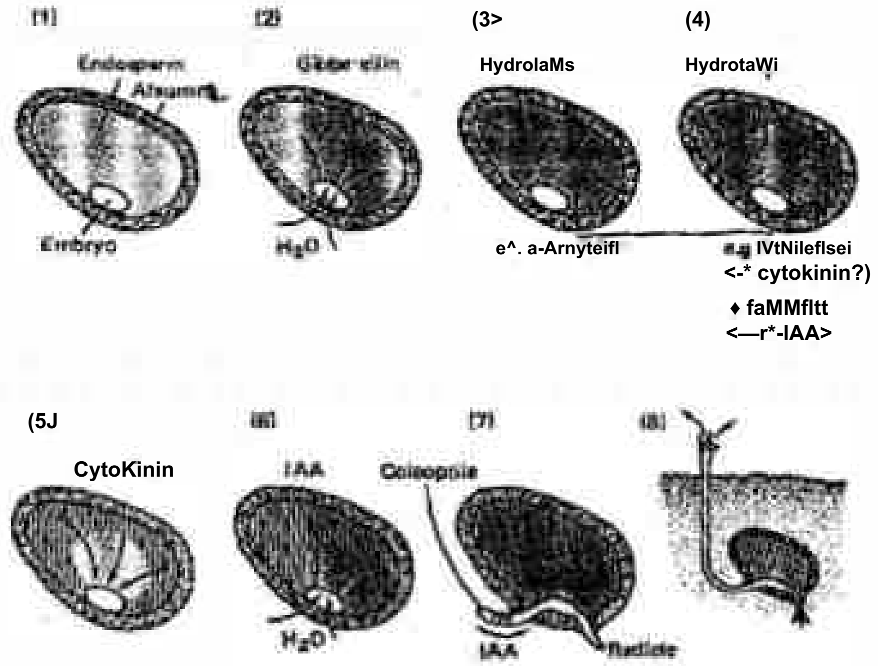


Fig.14.4 : Stimulation of embryo to cell division, cell elongation and seedling formation

geotropic. As soon as the coleoptile has broken through the soil, its photosynthetic apparatus differentiates. This marks the completion of the seedling stage (Fig-14.4)

14.2. GROWTH :

Growth is a typical characteristic of all living organisms. It is a permanent and irreversible change in size, length or volume and dry weight of an organ or its parts or even of an individual cell. Generally, growth is associated with high degree of metabolic activities which include both anabolic and catabolic reactions. During growth the rate of anabolism is more than catabolism.

Growth is unique in plants because the plants have the capacity for unlimited growth throughout their life. In plants growth is restricted to different meristems located in specific positions. Meristematic cells are having the power of active division which help the plant to grow. Thus plants have the capacity for *indeterminate growth;* that is, they grow more or less indefinitely. In some plants, such as corn and sunflower after flowering vegetative growth seases. Such plants exhibit *determinate growth.*

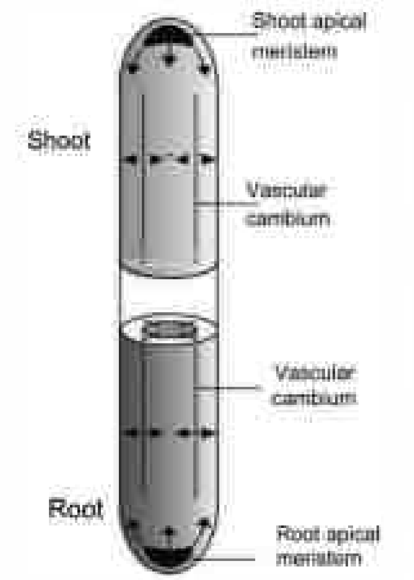


Fig. 14.5 : Locations of root epical meristem, shoot apical meristem and vascular cambium. Arrows indicate the direction of growth.

The meristems present in the apical positions of the root or shoot are responsible for the increase in length, which attributes to the **primary growth** of the plant. In dicot plants, some meristems appear later called lateral meristems (cambium) which also help in growth known as **secondary growth.** This type of growth helps in increase in the girth of the plant (Fig. 14.5).

Measurement of Growth :

Rate of growth can be measured by various ways. Any one of the following measures can be suitably applied in determining growth rate and total growth of the individual organs of a plant or the entire plant.

(a) Increase in weight; (b) Increase in volume; (c) Increase in height; (d) Increase in the number of cells produced; (e) Increase in surface area.

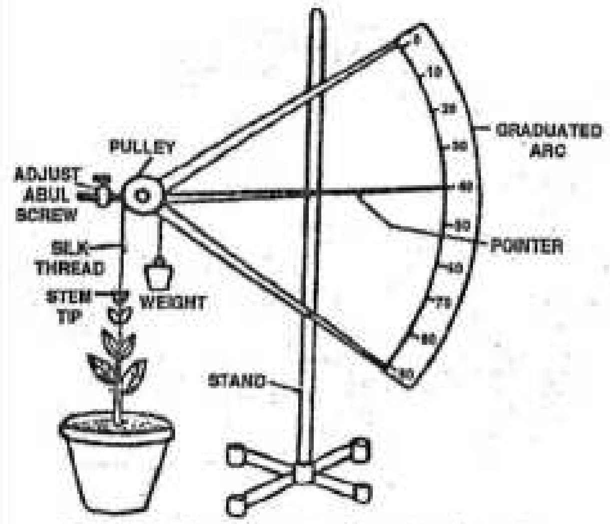


Fig.14.6 : Measurement of growth of stem by Auxanometer

The standard instruments like auxanometer can be conviniently used to measure (Fig. 14.6) the rate of growth. The criterion used by this instrument is to measure the growth by increase in length. The increase in size per unit time is referred to as relative growth rate or RGR. It can be calculated from the growth curve. The increase in length may not always be accompanied by an increase in weight or cell number. It may occur only due to cell elongation. Therefore, RGR is commonly measured in terms of increase in dry weight.

Phases of Plant Growth :

The plant growth takes place in three different phases i.e. meristematic (phase of cell division), elongation (phase of elongation) and maturation (phase of differentiation).

The meristematic phase is observed in the shoot and root tips of the plants where meristems divide constantly. Due to this, it is also called phase of cell division. The cells formed in this phase show dense protoplasm, prominent nucleus, thin cell walls with plasmodesmata and high respiration rates.

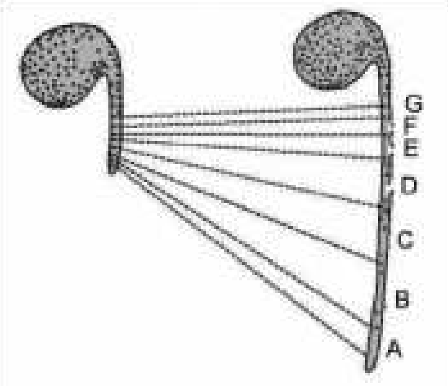


Fig. 14.7 : Detection of zones of elongation by the parallel line method. The A,B,C,D zones below the apex elongated most.

The elongation phase is situated just next to the meristematic zone (Fig. 14.7). The cells of this phase are marked with the increase in number and size of vacuoles, cell enlargement and new cell wall deposition.

The maturation phase is present next to the zone of elongation. In this phase the enlarged cells undergo structural and physiological changes to differentiate into a particular or special type of cell. During this phase the cells attain their maximum size in terms of wall thickening and protoplasmic differentiations. After differentiation, the cells so formed remain unchanged till the end of life.

Plant Growth Rates :

The organisms or the parts of an organism can produce more cells in a variety of ways. The increase in growth per unit time is defined as the growth rate. This growth rate can be defined mathematically i.e either arithmetical or geometrical (Fig. 14.8).

(a) Arithmetic growth : In this type the growth occurs at a constant rate from the beginning and progresses arithmetically. After mitotic cell division only one of the daughter cells divides continuously whereas other cell undergoes differentiation and becomes mature. If we plot a graph to study the growth pattern in root elongation by taking length of the organ of plant at Y axis against the time at X axis, a linear curve is obtained.

(b) Geometric growth : In this type every cell divides with all the daughters growing and dividing again. The examples of plants and microorganisms can be considered to study the pattern of geometrical growth.

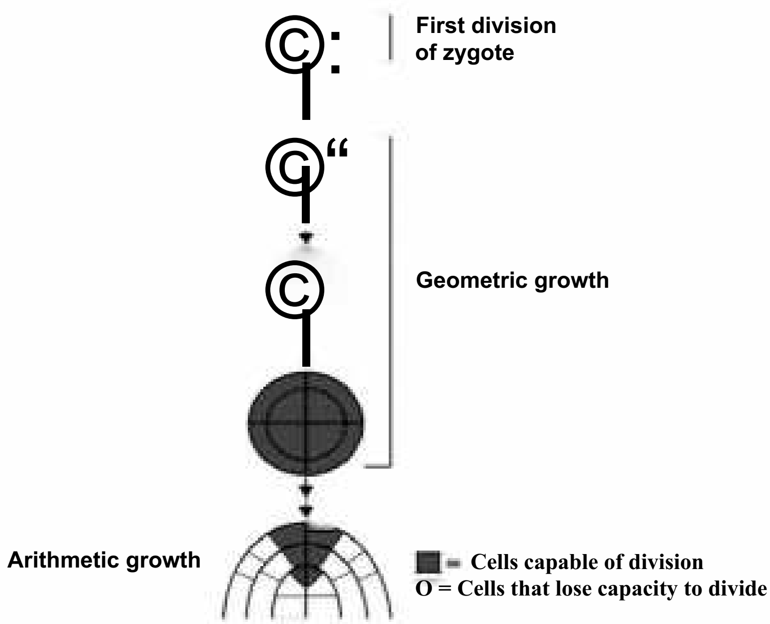


Fig 14.8 : Stages of embryonic development showing geometric and arithmetic growth phases.

Growth of a plant in early stage is slow, which gradually increases to a maximum and then rapidly decreases which ultimately stops. This can be studied under three phases: (Fig. 14.9)

(i) Lag phase or initial slow phase of growth rate.

(ii) Log phase or exponential phase where growth rate becomes very rapid. This period of rapid growth is called the grand period of growth. However, such a growth cannot be sustained for long and growth reaches to the next phase.

(iii) Stationary phase or steady state growth where the rate of growth remains almost static due to some limiting factors such as space, food, accumulation of toxins, etc.

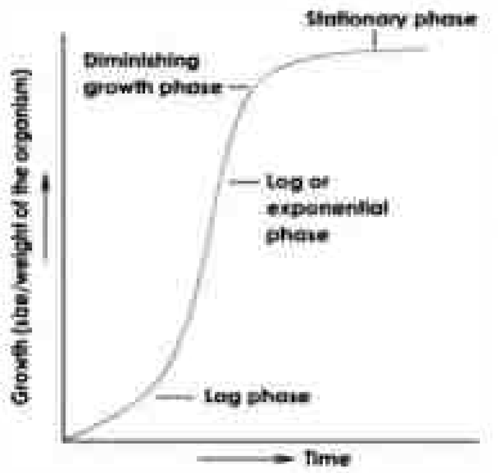


Fig.14.9 : A Sigmoid curve to describe the general growth pattern of higher plants and plant organs.

If a graph will be plotted by taking these three phases, 'S' shaped curve or Sigmoid growth curve will be resulted. But, a tree showing seasonal activities does not show a typical S-shaped curve. In this, the curve will show small steps indicating stoppage and resumption of growth every year.

One can compare quantitatively the growth of living system by two ways.

(i) **Absolute growth rate :** This is the measurement and comparison of total growth per unit time.

(ii) **Relative Growth Rate :** The growth of the given system per unit time expressed per unit initial parameter is called relative growth.

$$\text{Relative Growth Rate} = \frac{\text{Growth per unit time}}{\text{Initial size}} \times 100$$

Conditions of Growth :

There are many factors which affects the plant growth include:

(a) Nutrient supply : Green plants require several mineral ions and other essential elements for normal growth and development. These nutrients come from the soil for manufacturing of food. Growth ceases when the nutrient supply becomes limiting.

(b) Water: Water is a medium for all chemical reactions and physiological processes. Water is essential for photosynthesis. Early growth which is due to the turgid conditions of the cells require plenty of water. Under conditions of water scarcity, plant growth is severely impaired. On the other hand, excess of water in the soil may cause waterlogging, resulting anaerobic conditions in the roots Thus, growth is severely affected.

(c) Oxygen : Oxygen is necessary for cellular respiration in the plants. Food materials are broken down in the process of respiration and energy is released in the form of ATP molecules. This is the utilizable form of energy for the living cells. This energy is used for various activities of the cell and directly take part in the growth processes.

(d) Temperature : Temperature of 25-30°C is optimum for the proper growth of most of the plants. If there is any deviation from this range, there could be detrimental consequences on the growth of the plant. For example: temperature above 45°C hinders plant growth due to excessive transpiration, denaturation of enzymes and coagulation of protoplasm.

(e) Light: Light influences many physiological and growth processes of plants. Plants which can grow well under bright, direct sunlight and grow poorly in shady conditions are called photophilic plants. On the other hand, the plants capable of growing best under low light conditions are photophobic plants.

Light has great morphological effect on the leaves and stems of the plants. Plants growing in darkness are characterzied by long, succulent weak stems. The leaves become underdeveloped, pale, yellowish, chorophyll deficient. This is called etiolation. Variations in the intensity, quality and duration of light variously affect seed germination and flowering in different plants. The effect of light on reproductive growth is called photoperiodism.

(f) Plant Growth Hormones : It has been established that the growth of the plant is controlled by some organic compounds present in exceedingly minute quantity. These compounds are called phytohormones or growth promoting substances.

14.3. DIFFERENTIATION, DEDIFFERENTIATION, REDIFFERENTIATION

This is a phenomenon where a cell changing from one cell type to another. During plant cell development cells become specialized fora particular function. This process is called plant cell **differentiation.** For example, *tracheary element* is formed by way of differentiation where cells elongate and loose their protoplasm to form tracheids. The lignocellulosic secondary cell wall develop which allows the tracheid to withstand tension and to carry water a long distance. *Chlorenchyma* is a specialized form of tissue to perform photosynthesis which is developed due to the formation of chloroplast in the living cells.

A differentiated cell can regain its capacity for cell division under certain conditions. This phenomenon is called **dedifferentiation.** Formation of interfascicular cambium and cork cambium from fully differentiated parenchyma cells is an example of dedifferentiation. A dedifferentiated plant cell once again loses its capacity to divide and becomes mature (permanent) to perform a specific function. This phenomenon is called **redifferentiation.**

14.4. DEVELOPMENT :

Development involves a sequence of events in the life of a cell, organ or organism. For example: During the life of a plant, zygote develops to embryo, embryo to seedlings then juvenile stage, maturation, flowering, seed formation and senescence. The conversion of each phase into next involves development. The appearance of chloroplast in the cells when exposed to the sunlight is also a type of development. Development ultimately leads to senescence and death of the organism.

The sequence of developmental process in a higher plant cell is given in Fig. 14.10. Mitotic cell division is followed by plasmatic growth, expansion (elongation), differentiation, maturation, senescence and death. There is no clear cut demarcation as to where one process ends and other begins. These processes are overlapping. After plasmatic growth and cell expansion, one or both of the daughter cell s may undergo cell division again instead of undergoing the developmental process.

Cell Division

SENESCENCE

Death

Plasmatic growth

Differentiation

MERISTEMATIC CELL

MATURE CELL

Expansion (Elongation)

Maturation

Fig 14.10 : Sequence of developmental process in a plant cell

If we consider the general pattern of development in the life of a plant, this takes the following route :

Seed germination -> Vegetative Phase Maturation Reproductive phase →
Senescence Death

Always the process of development is not straight rather plants also show plasticity. Due to this plasticity plants can deviate and follow different pathways to produce various structures in response to the environment. Phenotypic plasticity is considered one of the major means by which plants can cope with environmental factor variability. Example of plasticity is heterophylly in plants. It means the appearance of different forms of leaves on the same plant like cotton, coriander etc. These type of plants show variation in leaf shape in the juvenile stage and in mature stage. Similarly, the difference in shapes of leaves can be observed in buttercup plant growing in air and water (Fig. 14.11).

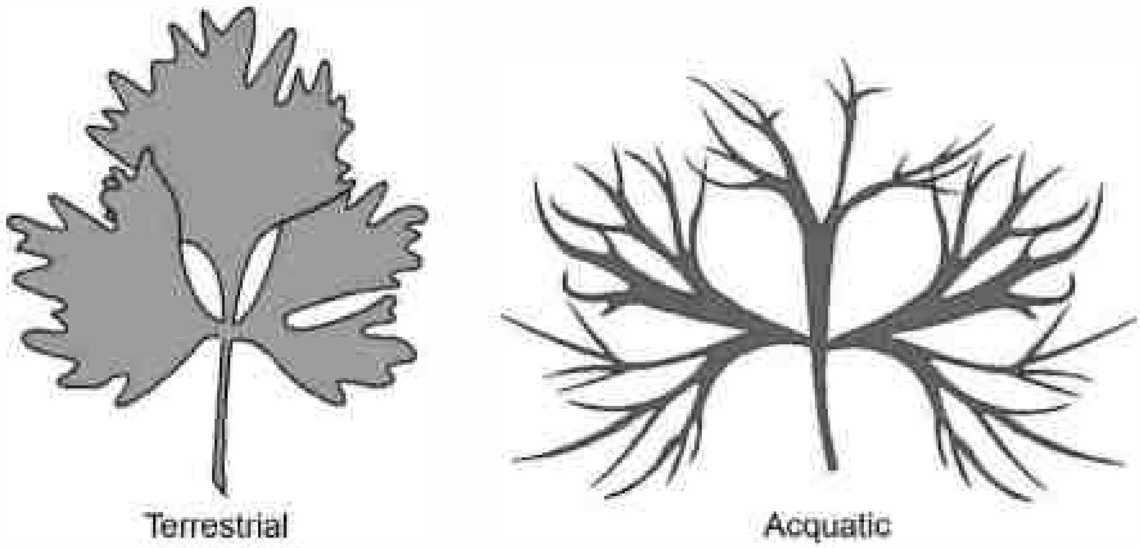


Fig 14.11 : Heterophylly in a. larkspur and b. buttercup

It is very clear now that the growth, differentiation and development are closely interrelated in the life of a plant. However, development includes the growth and differentiation. There are many intrinsic and extrinsic factors that influence the developmental stages of a plant. The intrinsic factors include genetic (intracellular) and chemical substances like plant growth regulators (intercellular). The extrinsic factors include, oxygen, CO_2, temperature, nutrition, etc. These factors very much influence the different sequence of events, such as, dormancy, seed germination, flowering, plant movements, etc. during the development of plant.

14.6. GROWTH REGULATORS :

Growth regulators are the organic compounds synthesized in plants naturally and required in very minute quantities. These compounds regulate one or more physiological activities at the same site or away from its site of synthesis. These substances affect physiological activities of plants which lead to promotion, inhibition and modification of growth. Hence, these are also called plant growth regulators or phytohormones.

Basing on the action of these compounds on the plant system, the plant growth regulators have been classified into the following:

(a) Growth Promoters : The chemicals which help in promoting the plant growth by causing the cell division, cell enlargement, flowering, fruiting and seed formation e.g. Auxin, Gibberellins and Cytokinin.

(b) Growth Inhibitors : The chemicals which help in inhibition of growth such as dormancy and abscission, e.g. Abscisic Acid(ABA)

Another phytohormone ethylene does not fit into the above categories but as this is an inhibitor of growth activities, this is popularly known as a plant growth inhibitor.

14.6.1. Auxin :

These were the first of the major plant hormones to be discovered. Auxins are a group of phytohormones produced in the shoot and root apices and they migrate from the apex to the zone of elongation. Auxin promote the growth along the longitudinal axis of the plant and hence the name (auxein meaning to grow). The term, auxin was introduced by Kogi and Haagen-Smith (1931). Went (1928) isolated auxin from the Avena coleoptile tips by a method called Avena coleoptile or curvature test and concluded that no growth can occur without auxin.

Auxin was first isolated from the human urine sample. They occur in the growing apices of the stems and roots from where they migrate to the site of action. The transportation of auxin is predominantly polar. The auxins produced naturally in the plants include Indole -3-Acetic Acid(IAA) and Indole-3-Butyric Acid(IBA). However, there are some synthetic auxins produced artificially e.g. Napthalene Acetic Acid(NAA), 2.4-Dichloro phenoxy acetic acid (2,4-D), 2,4,5-Tricholro phenoxy acetic acid (2,4,5-T).

Physiological effects and applications of auxin :

(i) **Cell division and elongation :** The primary physiological effects of auxin are cell division and cell elongation in the shoots. It is important in the secondary growth of stem and differentiation of xylem elements.

(ii) **Apical Dominance :** In many plants, if the terminal bud is intact and growing, the growth of lateral buds just below it remains suppressed. Removal of the apical bud results in the rapid growth of lateral buds. This phenomenon in which the apical bud dominates over the lateral buds and does not allow the lateral buds to grow is known as *apical dominance.*

Skoog and Thimmann (1948) pointed out that the apical dominance might be under the control of auxin produced at the terminal bud and which is transported downward through the stem to the lateral buds and prevents the growth. They removed the apical bud and replaced it with *agar* block. This resulted in rapid growth of lateral buds. But when they replaced the apical bud with agar block containing auxin, the lateral buds remained suppressed and did not grow.

(iii) **Abscission :** Auxins prevent the formation of abscission layer which may otherwise result in the abscission (premature fall) of leaves, flowers and fruits.

(iv) **Root initiation** : Auxin stimulates root initiation on stem cuttings. This is used as arooting hormone in tissue culture. The commonly used rooting hormones are NAA and IBA.

(v) Parthenocarpy : Auxin can induce the formation of parthenocarpic fruits (fruit formation without pollination and fertilization). In parthenocarpic fruits, the concentration of auxin in the ovaries is higher than in the ovaries of plants which produce fruits by way of fertilization.

(vi) Weedicide : Some synthetic auxins are very useful for eradication of weeds from the farmer's fields. 2,4-D, 2,4,5-T are such auxins used as the weedicides at higher concentrations.

14.6.2. Gibberellins :

A Japanese scientist Kurosawa found that the rice seedlings infected by the fungus *Gibberella fujikuroi* grow taller and turned very thin and pale. These are the symptoms of bakanae disease of rice. An active substance was isolated from the infected seedlings and named as Gibberellin or gibberellic acid. It is now known that there are over 100 different gibberellins have been isolated and chemically characterized. They all share gibbane ring structures and are acidic in nature. They are denoted as GA_r GA_2, GA_3 and so on. Among all available gibberellins, GA3 is one of the first to be discovered and thoroughly the most intensively studied form. No plant appears to possess all of the gibberellins, some have only been found in fungi and some only in higher plants. Gibberellins are found in all parts of higher plants including shoots, roots, leaves, flower, petals, anthers and seeds.

Physiological effects and applications of gibberellins :

(i) Seed germination: Certain light sensitive seeds e.g. Lettuce and tobacco show poor germination in dark. Germination starts vigorously if these seeds are exposed to light or red light. This requirement of light is overcome if the seeds are treated with gibberellic acid in dark.

(ii) Stem and leaf growth: Gibberellins stimulate stem elongation and other aerial parts. Therefore, these increase the size of stem and fruits.

(iii) Bolting : Gibberellins induce stem elongation in rossette plants like cabbage, beet. In rossette plants, intermodal growth gets reduced and leaves develop profusely. In these plants, just prior to the reproductive phase the internodes elongate profusely causing a marked increase in stem height. This is called bolting. The bolting can also be induced by the application of gibberellins.

(iv) Parthenocarpy : The growth of the fruit and the formation of parthenocarpic fruits can be induced by gibberellin treatment. In many cases, e.g. pome and stone fruits where auxins have failed to induce parthenocarpy, the gibberellins have proven to be successful. Seedless and fleshy tomatoes and large sized seedless grapes are produced by gibberellin treatments on commercial scale.

(v) Seed Germination : Gibberellins are known to break the seed dormancy. Seeds which are light dependent for their germination, can be made to germinate by the application of gibberellins in dark.

(vi) Bud dormancy : Application of gibberellins help in breaking the bud dormancy though the external environmental conditions are not favourable.

(vii) Elongation of internodes : Gibberellins help in the elongation of internodes thus help in overcoming genetic dwarfism e.g. dwarf maize, dwarf pea.

Carbohydrate in the form of sugar is deposited in sugarcane. The internode length of the stem increases with the application of gibberellins, thus the sugar deposition content increases in the crop.

14.6.3. Cytokinin :

Miller and his group (1955) isolated kinetin from the herring sperm DNA which had a power of promoting cytokinesis. Because of its specific effect on cytokinesis (cell division), it was called as **cytokinins** or **kinetin.** Kinetin (6-furfurylaminopurine) is a synthetic product and does not occur naturally in plants. The term cytokinin was proposed by Letham (1963).

The first natural cytokinin was isolated from unripe maize grains or kernels known as **zeatin.** It can also be isolated from coconut milk. After the discovery of zeatin, several naturally occurring cytokinins and some synthetic compounds with the capacity to promote cell divison have been identified. These are found to occur in the area where cell division occur like root apex, shoot buds, young fruits, etc.Chemically these are modified purines, derived from tRNA e.g., zeatin (Benzyl amino purine or BAP), di hydrozeatin, Isopentenyl adenine(IPA).

Physiological effects and applications of cytokinin:

(i) Cell Division : The most important biological effect of kinetin on plants is to induce cell division. Cytokinin with a mild dose of Auxin can bring about cell division in permanent cells.

(ii) Apical Dominance : The cytokinin are known to counteract the apical dominance. This can initiate the lateral bud formation even in presence of apical buds.

(iii) Delay in Senescence (Richmond Lang effect) : Senescence is accompanied by the loss of chlorophyll and active breakdown of proteins from the plant parts. Application of cytokinin on the leaves and other organs delay the senescence by controlling protein synthesis and nutrient mobilization. Commercially florists use this for increasing the shelf life of the flowers.

(iv) Breaking Dormancy : Like gibberellins, the dormancy of certain light sensitive seeds such as lettuce and tobacco can also be broken by kinetin treatment.

Besides, the cytokinin is very much useful in Plant Tissue Culture for inducing morphogenesis and organogenesis.

14.6.4. Ethylene :

H.H.Cousins first observed that the unripe bananas kept near the ripe oranges made to ripe because of some volatile substance emission. R. Gane (1934) clearly established that ethylene is a natural product for ripening of fruits and responsible for first ripening of fruit. Ethylene is a gas and is produced in very minute quantities in plant tissues. It is synthesized in almost all plant parts like roots, leaves, flowers, fruits, tubers, seeds, etc. it is synthesized in the plants from the amino acid **methionine.** It affects some physiological activities of the plants.

(i) It is more known as a fruit ripening hormone. Fruits such as apple, banana, tomato, etc. when in contact with ethylene results in respiration climacteric (sudden sharp rise in rate of respiration) and fruits ripen. Such fruits are climacteric fruits.

(ii) It is a very good feminizing agent i.e. it increases the number of female flowers and fruits in some plants e.g. Cucumber.

(iii) This is known to inhibit flowering in plants. But in mango and pineapple, it is known to induce flowering. Ethylene is commercially used to synchronize flowering and fruit set in pineapple.

(iv) It is known to promote senescence of plant parts such as leaves, flowers.

(v) It is responsible for the abscission of leaves, flowers and fruits.

(vi) It inhibits longitudinal growth but stimulates transverse growth of seedlings.

(vii) It is helpful in breaking the dormancy of seeds in peanuts, barley and some cereals,

(viii) It induces the development of lateral roots and growth of root hairs.

(ix) It induces epinasty and geotropic movements in plants.

14.6.5. Abscissic acid :

F.T. Addicott (1963) first noticed an antagonistic substance to growth of young cotton fruits, which was named later as Abscissic Acid(ABA). This is also called **dormin,** a naturally occurring growth regulator found in a wide variety of plants. These are mostly found in dormant buds and seeds. The known precursor of ABA is **violaxanthin.** This has the following physiological role on the plants:

(i) The role of ABA in the closure of stomata in water stressed plants is established. More befittingly this is called a stress hormone. It has also been suggested that ABA causes closing of stomata by inhibiting ATP mediated H^+/ K^+ ion exchange pumps in guard cells.

(ii) It acts as a growth inhibitor and induces dormancy of buds and seeds. It is called dormin because of its nature to induce dormancy.

(iii) This promotes senescence by inhibiting the protein, RNA synthesis and causing destruction of chlorophyll.

(iv) It inhibits gibberellins induced growth in various plants and is known to be a powerful gibberellins antagoniser.

(v) It is known to inhibit the germination of seeds.

(vi) It regulates growth and ripening of fruits.

14.7. SEED DORMANCY :

Many angiospermic seeds cannot germinate immediately after their formation. They have to undergo a period of dormancy or resting period. The period of dormancy is not constant in all the plants. Most cereals are capable of germination immediately after harvesting but some other seeds do not germinate until one year. Some plants do not need any resting period while, in some plants, seeds fail to germinate even under suitable conditions of germination. This state of inactivation of seeds may be due to some internal factors that inhibit the process of germination. This is known as seed dermancy. The causes of seed dormancy and its release mechanism vary in different seeds, being species specific.

Dormancy due to seed coat: The seed coat testa of many seeds is extremely hard and tough. It offers mechanical resistance to germination. It is impermeable to water and oxygen. Such seeds can germinate only if the seed coat is artificially removed either by chemical treatment or by mechanical means. The mechanical method of removal of seed coat is called **scarification.**

Dormancy due to the condition of the embryo : Dispersal of some seeds takes place when their embryos are not mature. It may take sometime to mature and this is the cause of dormancy. In some seeds, like those of rose, the embryo though fully developed is physiologically immature at dispersal. The seeds germinate after a period of rest. Such seeds can be induced to germinate early if they are stored in moist, well aerated and low temperature conditions - a process called **stratification.**

Dormancy due to chemicals and growth regulators : Presence of some chemical substances such as coumarin, phenolic acid, para ascorbic acid etc and hormones like abscissic acid in the embryo, endosperm and seed coat induce dormancy and seeds do not germinate as long as their concentation is high. Concentration of such inhibitors can be reduced by various treatments such as exposure to fluctuating temperature, chilling, light, keeping under running water, treatment of hydrated seeds with hormones like gibberellin and cytokinin or with certain chemicals like potassium nitrate, thiourea etc.

14.8. VERNALIZATION :

In many plants, flowering is influenced also by temperature. In annuals, the flowering is primarily affected by photoperiod. The effect of temperature is secondary to light. A biennial plant, on the other hand, grows only vegetatively during the first season and will not initiate