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hand **book**

KEY NOTES | TERMS
DEFINITIONS | FLOW CHARTS

Biology

Highly Useful for Class XI & XII Students,
Medical Entrances and Other Competitions

A Multi-Purpose
Quick Revision Resource

handbook

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Biology

Highly Useful for Class XI & XII Students,
Medical Entrances and Other Competitions

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Arihant Prakashan (Series), Meerut

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Sales & Support Offices
Agra, Ahmedabad, Bengaluru, Bareilly, Chennai, Delhi, Guwahati, Hyderabad, Jaipur, Jhansi, Kolkata, Lucknow, Meerut, Nagpur & Pune

ISBN : 978-93-13196-51-8

Published by Arihant Publications (India) Ltd.

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PREFACE

Handbook means reference book listing brief facts on a subject. So, to facilitate the students in this we have released this **Handbook of Biology.** This book has been prepared to serve the special purpose of the students, to rectify any query or any concern point of a particular subject.

This book will be of highly use whether students are looking for a quick revision before the board exams or just before other Medical Entrances.

This handbook can even be used for revision of a subject in the time between two shift of the exams, even this handbook can be used while travelling to Examination Centre or whenever you have time, less sufficient or more.

The format of this handbook has been developed particularly so that it can be carried around by the students conveniently.

The objectives of publishing this handbook are :

- To support students in their revision of a subject just before an examination.
- To provide a focus to students to clear up their doubts about particular concepts which were not clear to them earlier.
- To give confidence to the students just before they attempt important examinations.

However, we have put our best efforts in preparing this book, but if any error or what so ever has been skipped out, we will by heart welcome your suggestions. Apart from all those who helped in the compilation of this book, a special note of thanks goes to Miss Akansha Tomar of Arihant Publications.

Authors

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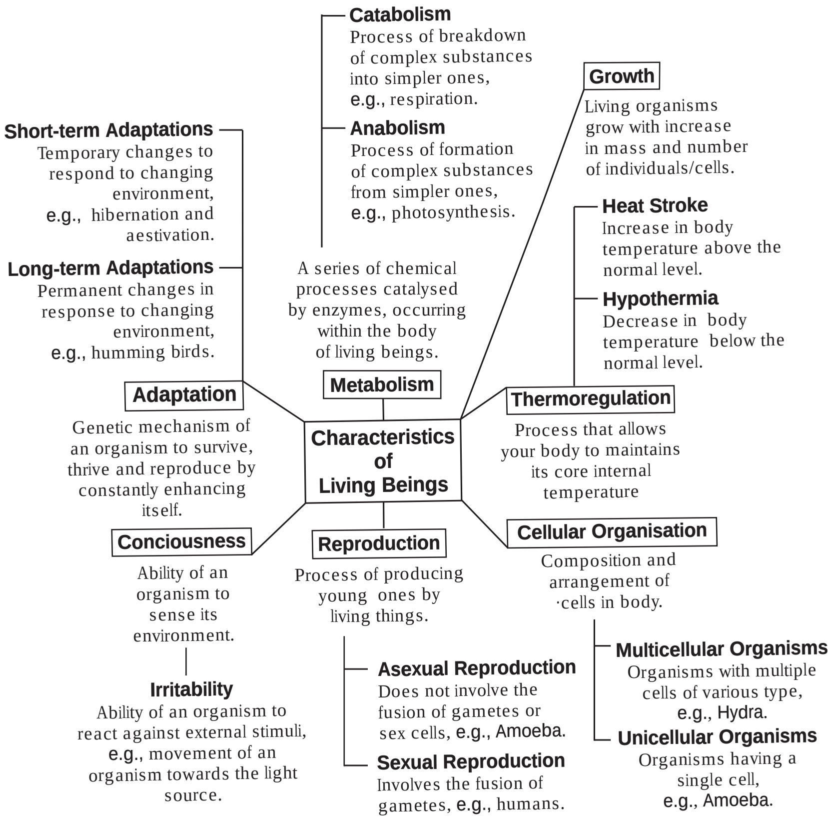
1

The Living World

Life is a characteristic quality that differentiates inanimate (non-living) objects from the animate (living) forms.

Characteristics of Living Beings



Biodiversity

It is the degree of variability among living organisms. It includes all the varieties of plants and animals. It encompasses all the ecological complexes (in which the diversity occurs), ecosystem, community diversity, species diversity and genetic diversity. It comprises all the millions of species and the genetic differences between them.

Systematics

It is the study of the biodiversity. It attempts to classify the diversity of organisms on the basis of following four fields **viz**, identification, classification, nomenclature.

1. Identification

It aims to identify the correct name and position of an organism in the already established classification system. It is done with the help of keys. **Key** is a list of alternate characters found in organisms. An organism can be identified easily by selecting and eliminating the characters present in the key.

2. Classification

It involves the scientific grouping of identified organisms into convenient categories or taxa based on some easily observable and fundamental characters. The various categories which show hierarchical arrangement in decreasing order are

Kingdom → Phylum → Class → Order → Family → Genus → Species

3. Nomenclature

After classification, organisms are subjected to a format of two-word naming system called **binomial nomenclature**. It consists of two components, **i.e.,** generic name and specific epithet. For example, in **Mangifera indica**, '**Mangifera**' is the generic name and **'indica'** is the specific name of mango. This system was proposed by **C Linnaeus** (a Swedish Botanist) in (1753) in his book **Species Plantarum**.

Polynomial system of nomenclature is a type of naming system containing more than two words. Trinomial system is a component of polynomial system and contains three words. Third word represents the sub-species and first two-words remain the same as in binomial system.

Codes of Biological Nomenclature

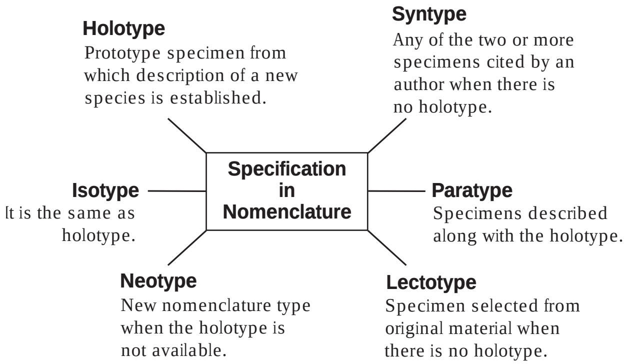
There are five codes of nomenclature which help to avoid errors, duplication and ambiguity in scientific names.

These codes are as follows

ICBN	International Code of Botanical Nomenclature
ICZN	International Code of Zoological Nomenclature
ICVN	International Code of Viral Nomenclature
ICNB	International Code for Nomenclature of Bacteria
ICNCP	International Code for Nomenclature for Cultivated Plants

Types of Specification in Nomenclature

The ICBN recognises following several types are given below



Taxonomy

It deals with the principles and procedures of identification, nomenclature and classification of organisms. It reflects the natural and phylogenetic relationships among organisms. It also provides the details of external and internal structures, cellular structure and ecological information of organisms. The term taxonomy was coined by AP de Candolle, 1813.

Various Branches of Taxonomy

Taxonomic Field	Basis
Alpha (α) Taxonomy	Morphological traits
Artificial Taxonomy	Habit and habitat of organisms
Natural Taxonomy	Natural similarities among organisms
Chemotaxonomy	Presence or absence of chemicals in cells or tissues
Cytotaxonomy	Cytological studies
Numerical or Phenetic Taxonomy	Number of shared characters of various organisms
Phylogenetic or Omega (ω) Taxonomy	Based on phylogenetic relationships

Classical Taxonomy

It is also known as old taxonomy. In classical taxonomy, species is the basic unit and it can be described on the basis of one or few preserved specimens. Organisms are classified on the basis of some limited features.

Modern Taxonomy/New Systematics

The concept of modern taxonomy was given by **Julian Huxley** (1940). According to it, species are dynamic and ever-changing entity. Studies of organisms are done on a huge number of variations. It includes cytotaxonomy, numerical taxonomy, chemotaxonomy, etc.

Taxonomic Categories

Classification is not a single step process. It involves hierarchy of steps in which each step represents a rank or category. Since, the category is a part of overall taxonomic arrangement, it is called the **taxonomic category**.

The taxonomic categories, which are always used in hierarchical classification of organisms are called **obligate categories**.

The sub-categories like sub-species, sub-class, sub-family, etc., which facilitate more sound and scientific placement of various taxa are called **intermediate categories**.

Arrangement of taxonomic categories in a descending order during the classification of an organism is called **taxonomic hierarchy**. It was first introduced by **Linnaeus** (1751) and hence, it is also known as **Linnaean Hierarchy**.

Taxonomic Categories

For Plants	**For Animals**
Kingdom	Kingdom
↑	↑
Division	Phylum
↑	↑
Class	Class
↑	↑
Order	Order
↑	↑
Family	Family
↑	↑
Genus	Genus
↑	↑
Species	Species

Taxonomic categories showing hierarchical arrangement in ascending order

Taxon represents the rank of each category and referred to as a unit of classification. The term 'Taxon' was first introduced by ICBN during 1956. According to **Mayr** (1964), taxon is a group of any rank that is sufficiently distinct to be worthy of being assigned a definite category. In simple words, taxon refers to a group of similar, genetically related individuals having certain characters distinct from those of other groups.

(i) **Kingdom** It is the highest category in taxonomy. A kingdom includes all the organisms which share a set of distinguished characters.

(ii) **Phylum or Division** (Cuvier, Eichler) It is a taxonomic category higher than class and lower in rank to kingdom. The term 'Phylum' is used for animals, while 'Division' is commonly employed for plants. It consists of more than one classes having some similar correlated characters.

(iii) **Class** (Linnaeus) It is a major category, which includes related orders.

(iv) **Order** (Linnaeus) It is a group of one or more related families that possess some similar correlated characters, which are lesser in number as compared to a family or genera.

(v) **Family** (John Ray) It is a group of related genera with less number of similarities as compared to genus and species. All the genera of a family have some common or correlated features. They are separable from genera of a related family by important differences in both vegetative and reproductive features.

(vi) **Genus** (Term given by John Ray) It comprises a group of related species, which has more characters common in comparison to species of other genera. In other words, genera are the aggregates of closely related species.

(vii) **Species** Taxonomic studies consider a group of individual organisms with fundamental similarities as a species (John Ray). It is the lowest or basic taxonomic category, which consists of one or more individuals of a population.

Taxonomical Aids

They include techniques, procedures and stored information that are useful in identification and classification of organisms.

Some of the taxonomical aids are as follows

Taxonomical Aids

Herbarium
Storehouse of collected plant specimens that are dried, pressed and preserved on sheets.

Manuals and Catalogues
Provide information for identification of names of species found in an area.

Museums
Place for the collection of preserved plants and animal specimens.

Monographs
Contain information on any one taxon.

Keys
Used for identification of plants and animals based on their similarities and dissimilarities.

Botanical and Zoological Parks
Contain the living collection of plants and animals in the conditions similar to their natural habitat.

Importance of Taxonomical Aids

- These aids help to store and preserve the information as well as the specimens. The collection of actual specimens of plant and animal species is essential and is the prime source of taxonomic studies.
- These are also essential for training in systematics which is used for the classification of an organism. Hence, taxonomic aids facilitate identification, naming and classification of organisms using actual specimens collected from the fields and preserved as referrals in the form of herbaria, museums, etc.

2

Biological Classification

Biology : Nature and Scope

Biology (L. **bios** – life; **logos** – knowledge) is the branch of science, which deals with the study of living organisms and their life processes. **Aristotle** is called the Father of Biology, but the term 'Biology' was first coined by **Lamarck** and **Treviranus** in 1802. It has two main branches, **i.e.**, Botany (study of plants) and Zoology (study of animals).

- **Father of Botany Theophrastus**
- **Father of Zoology Aristotle**

Classification of Living Organisms

Classification is an arrangement of living organisms according to their common characteristics and placing the group within taxonomic hierarchy.

The branch of science which deals with description, nomenclature, identification and classification of organisms is called taxonomy. **Some major branches of taxonomy are**

(i) **Numerical taxonomy** It is based on all observable characteristics. Number and codes are assigned to characters and data is processed through computers.

(ii) **Cytotaxonomy** In this taxonomy, the detailed cytological information is used to categorise organisms.

(iii) **Chemotaxonomy** The chemical constituents are taken as the basis for classification of organisms.

On the basis of reference criteria, the classification of living organisms can be of three types

Artificial or Prior Classification	Natural or Phenetic Classification	Phylogenetic or Cladistic Classification

1. Artificial or Prior Classification

In this system of classification one or very few characters are considered as the key feature of classification. This classification system never throws light on affinities or relationships between the organisms.

2. Natural or Phenetic Classification

The classification system in which organisms are classified on the basis of their permanent vegetative characters. In this classification system, the grouping of heterogenous groups (unrelated) of organisms is avoided.

3. Cladistic or Phylogenetic Classification

This classification may be monophyletic (**i.e.**, one ancestry), polyphyletic (**i.e.** the organism derived from two ancestors) and paraphyletic (**i.e.**, the organism does not include all the descendents of common ancestor).

Cladistics is a method of classification of organisms based upon their genetic and ancestral relationships, which are more scientific and natural.

The most accepted, five kingdom system of classification of living organisms was proposed by **RH Whittaker**. These five kingdoms are **Monera, Protista, Fungi, Animalia** and **Plantae**.

Other Classification Systems

- Two kingdom system–**Carolus Linnaeus** (Animalia and Plantae).

  Merits Photosynthetic organisms were included into plant kingdom and non-photosynthetic organisms were included into animal kingdom.

  Demerits Some organisms do not fall naturally either into plant or animal kingdom or share characteristics of both.

- Three kingdom system–**Ernst Haeckel** (Protista, Animalia and Plantae).

  Merits Created a third kingdom which includes unicellular eukaryotic microorganisms and some multicellular organisms.

  Demerits Monerans were not placed correctly.

- Four kingdom system–**Copeland** (Monera, Protista, Animalia and Plantae).

  Merits Monerans were placed separately along with other kingdoms.

  Demerits Monerans were not subdivided in Archaebacteria and Eubacteria.
- Six kingdom system–**Carl Woese** (Archaebacteria, Eubacteria, Protista, Fungi, Animalia and Plantae).

  Merits Archaebacteria and Eubacteria were separately placed.

A. Kingdom–Monera (Prokaryotic, Unicellular Organisms)

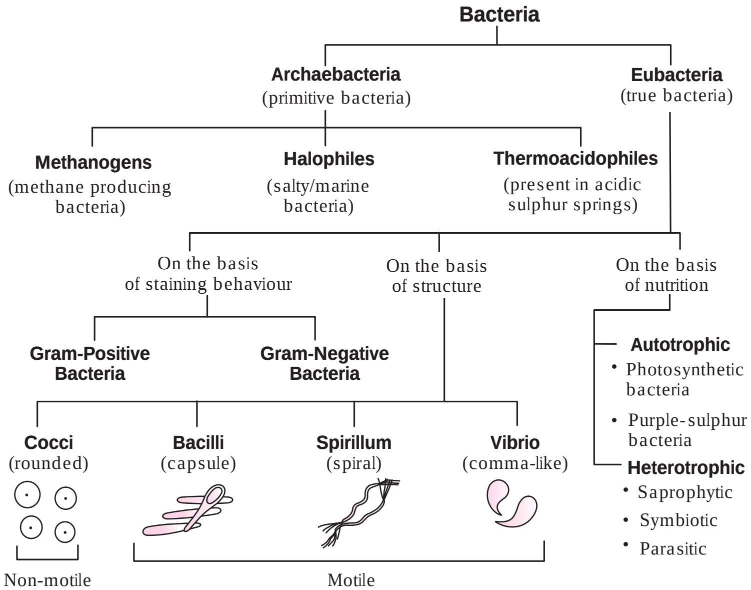
It includes all prokaryotes such as bacteria, archaebacteria, mycoplasma, actinomycetes, cyanobacteria and rickettsia.

1. Bacteria

These unicellular, prokaryotic organisms contain cell wall (feature of plant cells only). These are approximately 4000 species of bacteria, with cosmopolitan occurrence. Bacteria can be regarded both friends and foes on the basis of interaction with human beings.

An average weight human (~ 70 kg) has about 2.5 kg of bacteria in the form of gut microflora to supplement the proper digestion and other metabolic functions.

Details to bacteria can be visualised in a nutshell as



(I) Archaebacteria

These are the group of most primitive prokaryotes. They have a cell wall, made up of protein and non-cellulosic polysaccharides. The presence of 16 **sr**RNA, makes them unique and helps in placing in a separate domain called **archaea** between bacteria and eukarya.

Archaebacteria can live under extreme hostile conditions like salt pans, salt marshes and hot sulphur springs. They are also known as **living fossils**, because they represent the earliest form of life on earth.

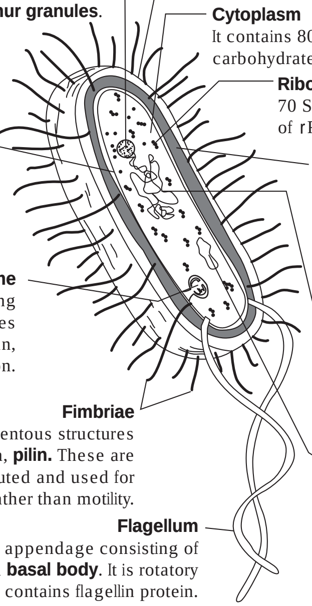
Archaebacteria can be used for

(a) Experimentation for absorption of solar radiation.
(b) Production of gobar gas from dung and sewage.
(c) Fermentation of cellulose in ruminants.

(II) Eubacteria

Eubacteria are 'true bacteria' which lack nucleus and membrane bound organalles like mitochondria, chloroplasts, etc. Eubacteria are usually divided into five phylums– Spirochetes, Chlamydias, Gram- positive bacteria, Cyanobacteria and Proteobacteria.

The structural detail of a typical eubacterial cell is given as follows



Detailed structure of a bacterium

Nutrition in Bacteria

The process of acquiring energy and nutrients., is called nutrition. On the basis of mode of nutrition, bacteria are of two types– **autotrophic** and **heterotrophic**. About 1% bacteria show autotrophic mode of nutrition and the rest are of heterotrophic habit. Chemosynthetic bacteria oxidise various inorganic substances such as nitrates, nitrites and ammonia and use the released energy for their ATP production.

Autotrophic (**i.e.,** photosynthetic) **bacteria** and **heterotrophic bacteria** with their related details are mentioned in following tables.

Some Photosynthetic Bacteria

Group	Main Habitats	Cell Wall	Representatives
Prochlorobacteria	Live in tissues of marine invertebrates.	Gram-negative	**Prochloron**
Purple or green bacteria	Generally anaerobic and reside on sediments of lakes and ponds.	Gram-negative	**Rhodospirillum** and **Chlorobium**

Some Heterotrophic Bacteria

Group	Main Habitats	Cell Wall	Representatives
Spirochetes	Aquatic habitats, parasites of animals	Gram-negative	**Spirochaeta** and **Treponema.**
Aerobic rods and cocci	Soil, aquatic habitats, parasites of animals and plants	Gram-negative	**Pseudomonas, Neisseria, Nitrobacter, Azotobacter** and **Agrobacterium**
Facultative anaerobic rods (enterobacteria)	Soil, plants, animal gut	Gram-negative	**Salmonella, Shigella, Proteus, Escherichia** and **Photobacterium**
Sulphur and sulphate reducing bacteria	Anaerobic muds, sediments (as in bogs, marshes)	Gram-negative	**Desulfovibrio**
Myxobacteria	Decaying plant and animal matter, bark of living trees	Gram-negative	**Myxococcus** and **Chondromyces**

Group	Main Habitats	Cell Wall	Representatives
Mycoplasmas	Parasites of plants and animals	Cell wall absent	**Mycoplasma**
Gram-positive cocci	Soil, skin and mucous membranes of animals	Gram-positive	**Staphylococcus** and **Streptococcus**
Endospore-forming rods and cocci	Soil; animal gut	Gram-positive	**Bacillus** and **Clostridium**
Non-sporulating rods	Fermenting plant and animal material, human oral cavity, gut, vaginal tract	Gram-positive	**Lactobacillus** and **Listeria**
Chemoautotrophes	Soil, aquatic habitat	Gram-negative	**Halothiobacillus** and **Acidothiobacillus**

Respiration in Bacteria

Respiration occurs in the plasma membrane of bacteria. Glucose is broken down into carbon dioxide and water using oxygen in aerobic cellular respiration and other molecules such as nitrate (NO_3) in anaerobic cellular respiration.

Reproduction in Bacteria

Bacteria reproduce **asexually** and **sexually** both.

Asexual Methods

Asexually, bacteria reproduce by following methods

- **Fission** Bacteria divide both laterally and longitudinally.
- **Budding** Vegetative outgrowths result into new organisms after maturity.
- **Spore formation** Non-motile spores like **conidia, oidia** and **endospores** are formed.

Sexual Methods

Although sexes are not differentiated in bacteria, following methods of genetic recombination are categorised under sexual reproduction in bacteria.

- **Transformation** F Griffith (1928), Genetic material of one bacteria is transferred to other through **conjugation tube**.

- **Conjugation** Lederberg and Tatum (1946), Transfer of genetic material occurs through **sex pili**.
- **Transduction** Zinder and Lederberg (1952), Transfer of genetic material occurs by **bacteriophage**.

Economic Importance of Bacteria

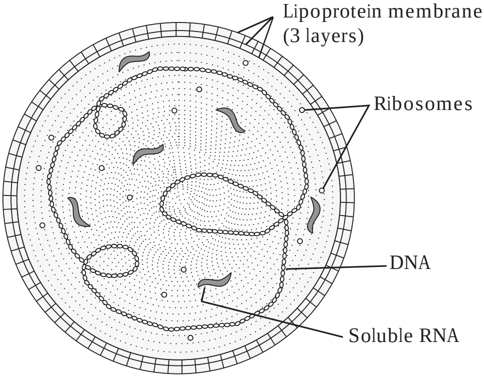
Economically, some bacteria are useful in producing various useful substances like curd, cheese, antibiotics and vinegar, etc. While other bacteria cause several chronic diseases in humans, plants and other animals, etc.

Other Monerans

These are as follows

1. Mycoplasma

- It was discovered by **Nocard** and **Roux** in 1898. These are cell wall less, aerobic and non-motile organisms. Due to the absence of cell wall and pleomorphic nature, they are commonly called as **jokers of living world**.
- The mycoplasmas are also known as **Pleuro Pneumonia Like Organisms** (PPLO). These are the smallest living cells, yet discovered, can survive without oxygen and are typically about 0.1 μm in diameter.



Structure of Mycoplasma

2. Actinomycetes

- The members of a heterogeneous group of Gram-positive, are generally anaerobic bacteria noted for a filamentous and branching growth pattern. It results in most forms in an extensive colony or **mycelium.**

- Morphologically, they resemble fungi because of their elongated cells that branch into filaments or hyphae. During the process of composting, mainly thermophilic and thermotolerent **Actinomyces** are responsible for the decomposition of the organic matter at elevated temperature.
- Generally, Actinomycetes grow on fresh substrates more slowly than other bacteria and fungi. During the composting process, the Actinomycetes degrade natural substances such as chitin or cellulose.
- Natural habitats of thermophilic Actinomycetes are silos, corn mills, air conditioning systems and closed stables. Some Actinomycetes are found responsible for allergic symptoms in the respiratory tract, **e.g.,** Extrinsic Allergic Alveolitis (EAA).

3. Cyanobacteria/Blue-Green Algae (BGA)

- They are Gram-negative photosynthetic prokaryotes which perform oxygenic photosynthesis. These can live in both freshwater and marine habitats and are responsible for 'blooms' in polluted water (eutrophication).
- They have photosynthetic pigments, **chlorophyll-**a, **carotenoids** and **phycobilins** and food is stored in the form of cyanophycean starch, lipid globule and protein granules.
- Cyanobacteria have cell wall formed of peptidoglycan, naked DNA, 70S ribosomes and the absence of membrane bound organelles like endoplasmic reticulum, mitochondria, Golgi bodies, etc.
- The red sea is named after the colouration provided by red coloured cyanobacteria **i.e., Trichodesmium erythraeum.**
- Cyanobacteria can fix atmospheric nitrogen through a specific structure called **heterocyst**. These are modified cells in which photosystem-II is absent hence, non-cyclic photophosphorylation does not take place. Nitrogen-fixation is performed through enzyme nitrogenase, present in it.

4. Rickettsia

- These are small, aerobic and Gram-negative bacteria. They belong to phylum–Proteobacteria, which are capable of growing in low level of nutrients and have long generation time relative to other Gram-negative bacteria.
- Rocky Mountain Spotted Fever (RMSF) is a tick borne human disease caused by **Rickettsia rickettsii**, an obligate, intracellular bacteria.

B. Kingdom–Protista (Eukaryotic, Unicellular Organisms)

It includes three broad groups, explained in the following flow chart

Kingdom–Protista
- **Plant-like Protists** (photosynthetic protists)
  - Subphyla
    - **Pyrophyta** (dinoflagellates)
    - **Chrysophyta** (diatoms)
    - **Euglenophyta** (euglenoids flagellates)
- **Fungi-like Protists** (slime moulds)
  - **Subphyla**
    - **Myxomycota** (acellular slime moulds)
    - **Acrasiomycota** (cellular slime moulds)
- **Animal-like Protists** (protozoans)
  - Subphyla
    - **Amoeboid Protozoans**
    - **Flagellated Protozoans**
    - **Sporozoans**
    - **Ciliated Protozoans**

In the view of evolution, the **kingdom–Protista** acts as a connecting link between the prokaryotic kingdom–Monera and multicellular kingdoms like Fungi, Plantae and Animalia. The term 'Protista' was given by German biologist, **Ernst Haeckel** in 1866.

The group Protista shows following characteristics in common

(i) These are mostly aquatic.

(ii) Eukaryotic cell of protists possess well-defined nucleus.

(iii) Membrane bound organelles present.

(iv) Protists reproduce both asexually and sexually by a process involving cell fusion and zygote formation.

(v) They may be autotrophic and heterotrophic (**i.e.,** parasitic).

The detailed descriptions of protistan groups are as follows

Plant-like Protists (Photosynthetic)

These can be

1. Dinoflagellates

The group of 1000 species of photosynthetic protists, belongs to the division–**Pyrophyta** and class–**Dinophyceae.** They are unicellular, motile and biflagellate, golden-brown coloured protists. They form the important components of phytoplanktons.

Their macronuclei possess condensed chromosomes, even in interphase, called as **mesokaryon** (Dodge; 1966). Sometimes they exhibit the phenomenon of bioluminescence.

2. Chrysophytes

These include **diatoms** and **desmids.** Diatoms are mostly aquatic and sometimes present in moist terrestrial habitat. They are very **good pollution indicator**.

The diatoms do not decay easily as their body is covered by **siliceous shell.** They pile up at the bottom of water body and form **diatomite** or **diatomaceous earth** (can be used as fuel after mining).

3. Euglenoids

These are **Euglena** like unicellular flagellates found mostly in stagnant freshwater. Instead of a cell wall, they have a protein rich layer called **pellicle**, which makes their body flexible.

They have two types of flagella

(i) **Long** Whiplash

(ii) **Short** Tinsel

The food is stored in proteinaceous granules called **pyrenoids**. Photosynthetic euglenoids, behave like heterotrophs in dark, this mode of nutrition is called **mixotrophic.**

The chief member of this group, **i.e., Euglena** is regarded as connecting link between animals and plants.

Fungi-Like Protists (Slime Moulds)

They possess the characters of both animals and fungi therefore, combinedly called as **fungus-animals.** They show saprophytic food habit and consume organic matter. Under suitable conditions, they form **Plasmodium**. **On the basis of occurrence of Plasmodium, these are of two types**

(i) **Acellular/Plasmodial slime moulds**, **e.g., Physarum**, **Fuligo septica,** etc.

(ii) **Cellular slime moulds**, **e.g., Dictyostelium, Polysphondylium,** etc**.**

Animal-Like Protists (Protozoans)

The most primitive relatives of animals, protozoans are heterotrophic (predator or parasitic) organisms, **divided into four major groups**

(i) **Amoeboid protozoans** They live in freshwater, moist soil and salt water as parasite. They move with the help of **pseudopodia** as in **Amoeba.**

Other members of this group are

Entamoeba histolytica and **E. gingivalis** cause various digestive and oral diseases when engulfed through polluted water.

(ii) **Flagellated protozoans** They are either free-living or parasitic in nature. **Chief members are**

(a) **Trypanosoma** sp.–carried by **tse-tse fly** and causes **African sleeping sickness**.

(b) **Leishmania** sp. carried by **sand fly** and causes **kala-azar** or **dum-dum fever**.

(c) **Giardia** sp. causes **giardiasis**.

(d) **Trichomonas vaginalis** causes **leucorrhoea**.

(iii) **Ciliated protozoans** They are aquatic and move actively due to the presence of cilia. They show nuclear dimorphism (macro and micronucleus), **e.g., Paramecium**, etc.

(a) **Macronucleus/Vegetative nucleus** Controls metabolic activities and growth.

(b) **Micronucleus/Reproductivenucleus** Controls reproduction.

(iv) **Sporozoans** They have an infectious, spore-like stage in their life cycle. All are endoparasites. Locomotory organs are cilia, flagella and pseudopodia, **e.g., Plasmodium**, **Monocystis**, etc.

C. Kingdom–Fungi (Eukaryotic, Heterotrophic Organisms)

Fungi are a group of eukaryotic, achlorophyllous, non-photosynthetic and heterotrophic organisms.

The basic features of fungi include

(i) Fungi lack chlorophyll, hence they are heterotrophic.

(ii) They cannot ingest solid food, but absorb it after digestion. The digestive enzymes are secreted on food, then they (fungi) absorb it.

(iii) On the basis of food sources, they may be saprophyte or parasites. Cell wall in fungi is made up of nitrogen containing polysaccharides, chitin. Reserved food material is glycogen or oil. Along with certain bacteria, saprotrophic fungi function as the main decomposers of organic remains.

With the exception of yeasts (unicellular, fungi and filamentous), fungi bodies consist of long, slender, thread-like structures called **hyphae.** Mycelium is the network of hyphae. Some are called coenocytic hyphae (continuous tubes filled with multinucleated cytoplasm) and others have cross walls (septae) in their hyphae. Cell walls of fungi are composed of chitin and polysaccharides.

Classification of Fungi (Martin; 1961)

Fungi

- **Myxomycetes** (body as amoeboid naked protoplast)
- **Eumycetes** (unicellular, multicellular, filamentous)
  - **Phycomycetes** (mycelium aseptate and multinucleate)
    - Members are found in aquatic habitats; decaying wood in damp places.
    - Reproduce asexually by zoospores or aplanospores.
    - e.g., *Allomyces* and *Puccinia*, etc.
  - **Ascomycetes** (mycelium septate)
    - Known as sac fungi, mostly multicellular (*Penicillium*) or rarely unicellular (yeast).
    - Asexual spores are conidia produced on conidiophores.
    - Sexual spores are ascospores produced on asci.
    - e.g., *Albugo*, etc.
  - **Deuteromycetes** (mycelium septate)
    - Known as imperfect fungi.
    - Deuteromycetes reproduce only by asexual spores, conidia.
    - e.g., *Synchytrium*, *Aspergillus*, etc.
  - **Basidiomycetes** (septate)
    - Grow in soil, on logs and in living plant bodies.
    - Reproduce vegetatively by fragmentation, sex organs are absent.
    - e.g., *Agaricus*, etc

Reproduction in Fungi

Three types of reproduction occur in fungi

Reproduction

Vegetative

When a vegetative structure after separation produces new individual, it is called vegetative reproduction.
It occurs by following processes

- Fragmentation
- Budding
- Fission
- Sclerotia
- Rhizomorphs

Asexual

During asexual reproduction, several mononucleate and binucleate spores are produced which later germinate into new individuals.
It occurs by following methods

- Zoospore
- Sporangiospore (Phycomycetes)
- Chlamydospore
- Oidia
- Conidia
- Ascospore (Ascomycetes)
- Basidiospore (Basidiomycetes)
- Binucleate spore

Sexual

In sexual reproduction, the fusion of compatible nuclei takes place. It involves three steps, plasmogamy, karyogamy and meiosis.
It occurs by following methods

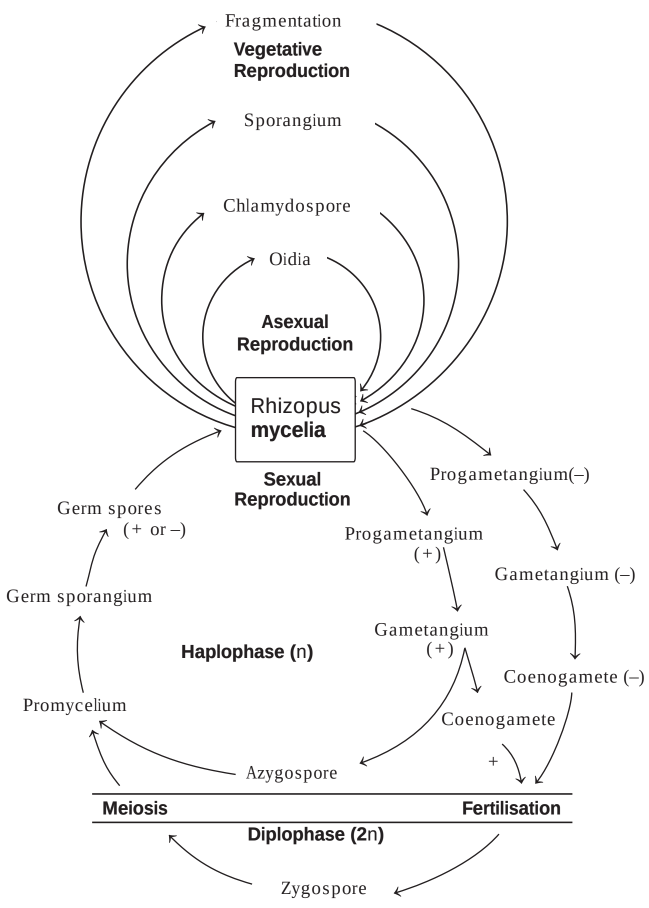
- Planogametic copulation
- Gametangial contact
- Gametangial copulation
- Spermatogamy
- Somatogamy

Life Cycles of Some Fungi

These can be described as follows

(i) Life Cycle of *Rhizopus*

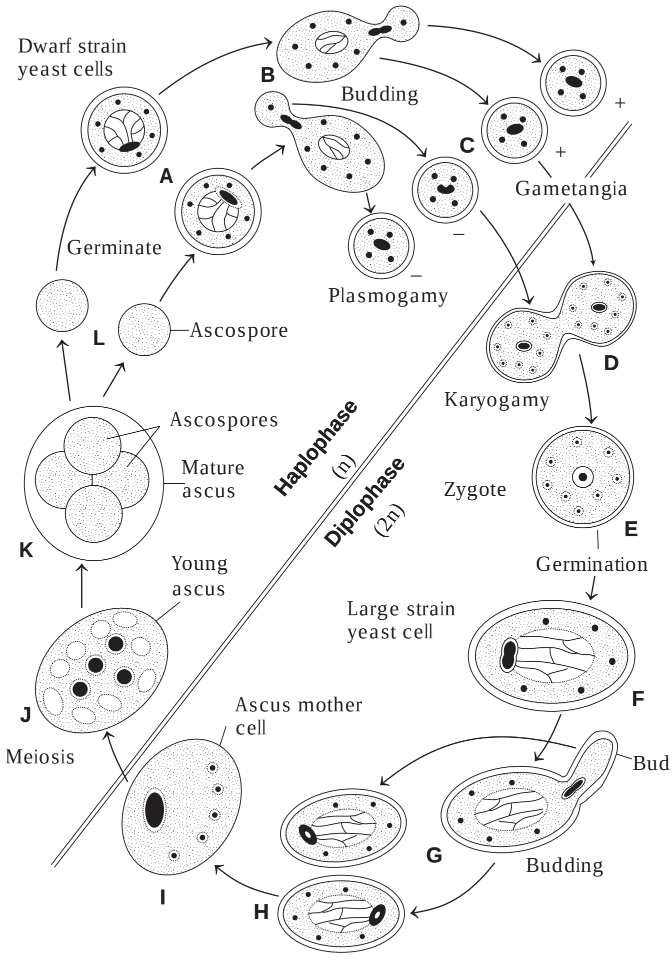
The structural representation (sexual and asexual) of life cycle of Rhizopus is as follows



Life cycle of Rhizopus

(ii) Life Cycle of Yeast

The diagrammatic representation of sexual cycle of Saccharomyces cerevisiae is as follows



Life cycle of Saccharomyces cerevisiae

Heterothallism

The phenomenon of having two genetically different and compatible sexual strains in two different thalli is called heterothallism. It was discovered by **Blakeslee** in **Mucor.**

Mushroom and Fairy Rings

Agaricus compestris is an edible mushroom. It is also called **white button mushroom**. The fruiting body of **Agaricus**, arises in concentric rings (called fairy rings or fungal flowers) from the mycelium present in the soil.

Lichens

They have composite structure and consist of two dissimilar organisms forming a symbiotic relationship between them.

Lichens are formed by

- Algal Part — Phycobiont — Provide food to fungi
- Fungal part — Mycobiont — Provide shelter to algae

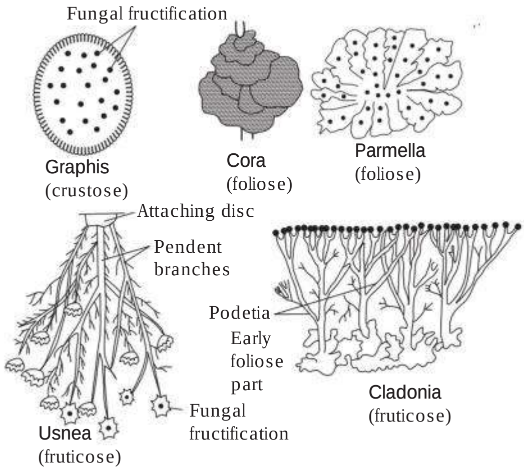
Lichens are of three types on the basis of their structure

(i) **Crustose lichens** These are point-like, flat lichens, **e.g., Caloplaca.**

(ii) **Foliose lichens** These lichens have leafy structure, **e.g., Hypogymnia physodes**.

(iii) **Fruticose lichens** These are branched lichen, form filamentous branching, **e.g., Cladonia evansii**, **Usnea australis**, etc.

Various forms of lichens are given below



Forms of lichens

Mycorrhiza

It is a symbiotic association between a fungus and a plant. Plants prepare organic food and supply them to fungus and in return, fungus supplies water and mineral nutrients to plants.

D. Kingdom–Plantae (Eukaryotic, Chlorophyllous Organisms)

These are chlorophyllous and embryo forming organisms. Mostly non-motile and function as the producers in **ecosystem** as they can fix solar energy into chemical energy through the process of photosynthesis. The cell wall in plants is cellulosic and stored food material is in the form of starch.

A detailed account of plant kingdom is given in chapter 6.

E. Kingdom–Animalia (Multicellular, Eukaryotic Organisms)

The heterotrophic, eukaryotic organisms which are multicellular and lack cell wall, present in this kingdom. Animals have advanced level of tissue organisation, in which the division of labour is highly specific. The two main groups among animals are Non-chordata and Chordata, divided on the basis of the presence of notochord in them.

A detailed account of animal kingdom is given in chapter 7.

Viruses and Viroids

1. Viruses

The term 'Virus' means **poisonous fluid**. The word was coined by **Louis Pasteur**. Viruses are very small (0.05-0.2 μm), infective, nucleoprotein particles, which can be called as **living** because of the presence of nucleic acid as genetic material and ability to produce their own copy-viruses. They show only some properties of living beings, otherwise they behave like non-livings. Hence, these are referred to as the **connecting link between living and non-living**.

On the basis of nature of genetic material, the viruses are of two types

(i) **Adenovirus** DNA containing, **e.g.,** HIV, etc.
(ii) **Retrovirus** RNA containing, **e.g.,** Rous sarcoma virus, etc.

On the basis of their host, the viruses can be categorised as

(i) **Animal virus** (Zoophagineae), **e.g.,** HIV, sarcoma, etc.
(ii) **Plant virus** (Phytophagineae), **e.g.,** TMV, etc.
(iii) **Bacterial viruses** (Phagineae), **e.g.,** T_4 phage, etc.

Characteristics of Viruses

Characteristics of viruses are as follows

Living

- They can replicate.
- In host body, they can synthesise protein.
- They cause diseases like other living organisms.
- Similar gene mutation as living organism.

Non-living

- Do not have protoplasm, and do not perform metabolism.
- These can be crystallised.
- They do not respire.
- **In vitro** culture is not possible.

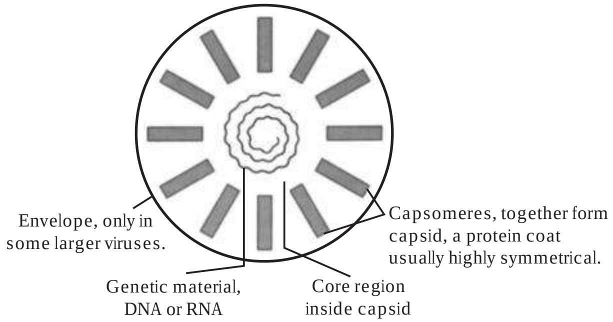
Structure of Viruses

(i) Viruses are non-cellular and ultramicroscopic.

(ii) **Virus has two components**

(a) A core of nucleic acid called **nucleoid**.

(b) A protein coat called **capsid**.



Structure of a virus (generalised)

2. **Viroids** (RNA without a Capsid)

TO Diener (1917) introduced the term as 'Subviral pathogens'. Viroids are 100 times smaller than smallest virus. They are known to be infectious for plants only (no animal), **e.g.,** potato spindle tuber caused by viroids.

Virion

An intact, inert, complete virus particle capable of infecting the host lying outside the host cell in cell free environment is called **virion.**

Virusoids

These are like viroids, but located inside the protein coat of a true virus. Virusoid RNA can be circular or linear. These are non-infectious as they are replicated only in their host.

Prions/Slow Virus

The prions are smallest, proteinaceous infectious particles, **i.e.,** disease causing agents that can be transmitted from one animal to another.

3

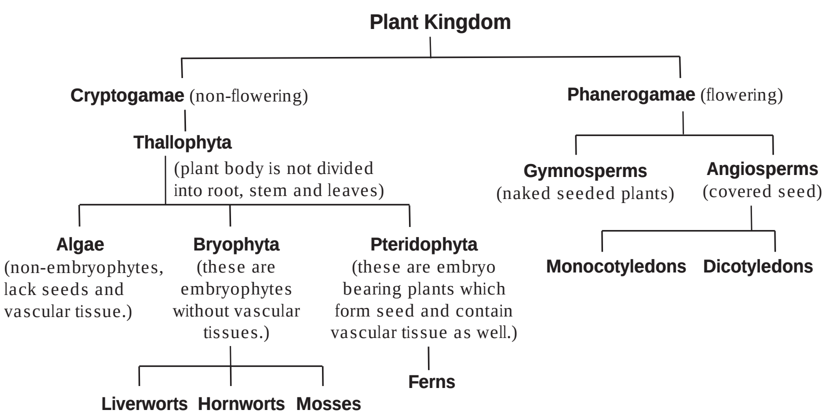
Plant Kingdom

Plants : Producers of the Ecosystem

Plants are multicellular, photoautotrophic and embryo forming (excluding algae) organisms placed in kingdom–Plantae. They have cell wall, which is made up of cellulose and reserve food material in the form of starch (sometimes fat as in seeds).

Plants are referred to as producers, because they have unique ability to fix solar energy in the form of chemical energy, through the process of **photosynthesis**. They supply the energy in ecosystem to other living organisms, hence they are referred to as producers.

The plant kingdom is classified as



Algae (L. Alga–sea weeds)

These are eukaryotic, autotrophic (holophytic), chlorophyll containing, non-vascular thallophytes. These are characterised by the absence of embryonic stage and presence of non-jacketed gametangia. Mostly, they are of aquatic habitat (both freshwater and marine).

The branch of Botany which deals with the study of algae is termed as 'Algology or Phycology'. **FE Fritsch** is known as 'Father of Algology'. (Prof. MOP Iyengar is regarded as Father of Indian Algology).

Classification of Algae (FE Fritsch; 1935)

Chlorophyceae	Grass green	Starch	**Chlamydomonas** and **Spirogyra**.
Xanthophyceae	Yellow-green	Fat	**Microspora** and **Botrydium.**
Chrysophyceae	Yellow-green and golden-brown	Carbohydrate and leucosin	**Amphipleura** and **Chrysosphaera**.
Bacillariophyceae	Brown and green	Fat and volutin	**Pinnularia** and **Melosira**.
Cryptophyceae	Red and green-blue	Carbohydrate and starch	**Cryptomonas**.
Dinophyceae	Dark yellow, brown-red	Starch and oil	**Peridinium** and **Glenodinium.**
Chloromonadineae	Bright green	Fatty compounds	**Vaucheria** and **Trentonia.**
Euglenophyceae	Grass green	Paramylum	**Euglena** and **Phacus.**
Phaeophyceae	Brown coloured	Laminarin and mannitol	**Laminaria** and **Fucus.**
Rhodophyceae	Red coloured	Floridean starch	**Polysiphonia** and **Batrachospermum.**
Myxophyceae	Blue-green	Protein granules	**Nostoc** and **Anabaena.**

Characteristics of Algae

Important characteristics of algae are given below

Structure

Algae may be unicellular and multicellular.

1. **Unicellular**

It is of two types

(i) **Motile**, **e.g., Chlamydomonas**, etc.
(ii) **Non-motile**, **e.g.**, **Chlorella**, etc.

2. **Multicellular**

It is of following types

(i) **Colonial**, **e.g., Volvox, Hydrodictyon,** etc.
(ii) **Aggregation**, **e.g., Tetraspora, Prasinocladus,** etc.
(iii) **Filamentous**, **e.g., Ulothrix, Cladophora,** etc.
(iv) **Pseudoparenchymatous**, **e.g., Nemalion,** etc.
(v) **Siphonous**, **e.g., Vaucheria,** etc.
(vi) **Parenchymatous**, **e.g., Ulva, Fritschiella,** etc.
(vii) **Well-developed thallus**, **e.g., Chara, Sargassum,** etc.

Nutrition

Mostly algae are autotrophic, due to the presence of chlorophyll. Some are parasitic, **e.g., Cephaleuros** that causes rust of tea.

Reproduction

Algae reproduce by

(i) Vegetative methods
(ii) Asexual methods
(iii) Sexual methods

Vegetative Reproduction

Algae reproduce vegetatively by two methods

(i) Fragmentation, **e.g., Fucus, Chara,** etc.
(ii) By hormogones, **e.g., Oscillatoria, Nostoc,** etc.

Asexual Reproduction

In this process, some cells form motile or non-motile spores. After release, these spores give rise to new plants. **Following spores are involved**

(i) By zoospore, **e.g., Ulothrix, Oedogonium,** etc.
(ii) By aplanospore, **e.g., Chlorella**, etc.
(iii) By hypnospore, **e.g., Vaucheria**, etc.
(iv) By palmella stage, **e.g., Chlamydomonas, Ulothrix,** etc.
(v) By endospore, **e.g., Anabaena, Nostoc**, etc.
(vi) By akinete, **e.g., Chara, Oedogonium,** etc.

Sexual Reproduction

On the basis of shape, size, morphology and behaviour of gametes, **the sexual reproduction is of following types**

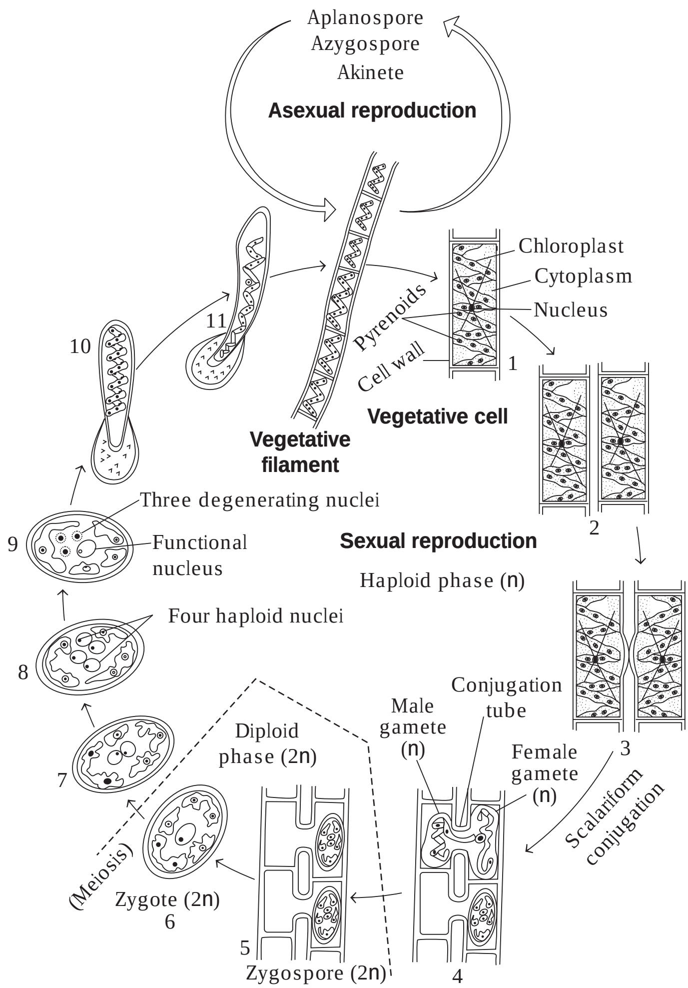
Sexual Reproduction

- **Isogamous** (similar gametes, morphologically), e.g., Spirogyra.
- **Anisogamous** (gametes are dissimilar morphologically), e.g., Chlamydomonas sp.
- **Oogamous** (gametes are different both morphologically and physiologically), e.g.,Volvox.

Life Cycle of Algae

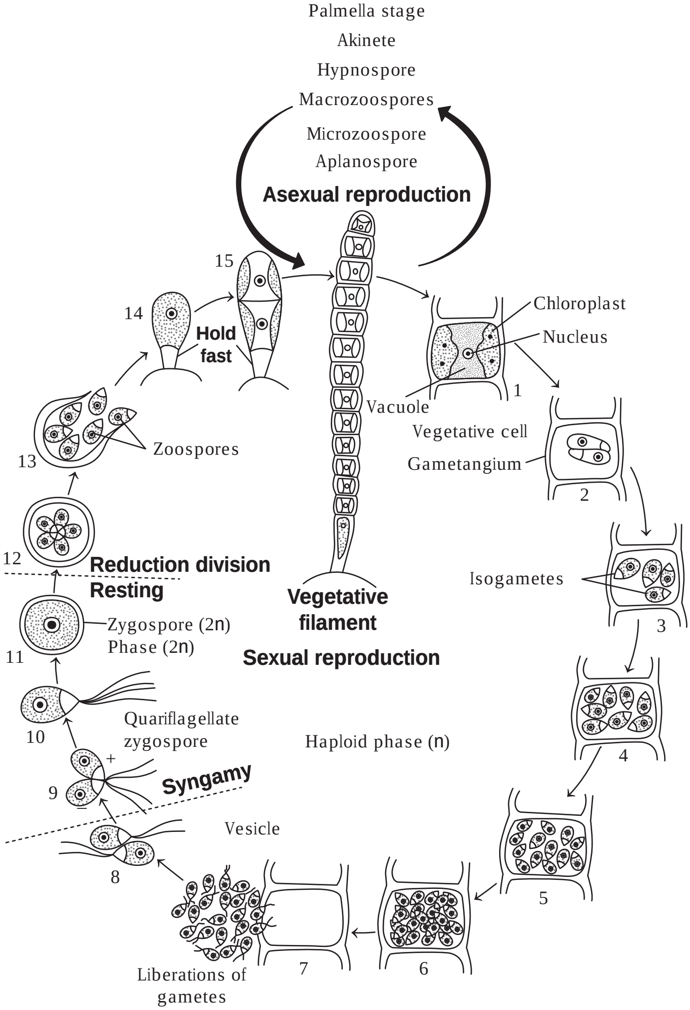
Various algae show different types of life cycles. Life cycles of **Spirogyra** and **Ulothrix** are discussed here.

Life cycle of *Spirogyra* It is a green alga of filamentous shape. **The detailed life cycle is given below.**



Life cycle of Spirogyra

Life cycle of Ulothrix The diagrammatic representation of life cycle of **Ulothrix** is given below.



Life cycle of Ulothrix

Economic Importance

Algae can be both useful and harmful. **Several useful algal species with their uses are mentioned here**

Algae

- **As Food** — Ulva, Sargassum, Laminaria, Porphyra, Nostoc and Laurencia.
- **As Medicine** — Chlorella gives chlorellin (antibiotic), Nitella is used as mosquito repellent.
- **In Industries** — Diatoms, Chondrus, Polysiphonia, Gracilaria are used in paints, cosmetics, etc.
- **Source of Minerals** — Laminaria, Polysiphonia and Ascophyllum are used in extraction of minerals.
- **In Agriculture** — Nostoc, Anabaena, help in nitrogen-fixation, hence used as biofertilisers.
- **In Biological Research** — Chlorella,Scenedesmus and Acetabularia are used as tools for biological research.
- **Ecological Significance** — Algae like planktons are used as food by others and stabilise the ecosystem.

Useful applications of algae

Algin, Carrageenan and Agar

- **Algin,** used as **artificial fibre** to control blood flow in surgery and in production of non-inflammable films, is extracted from **marine brown algae**.
- **Carrageenan,** extracted from seaweeds is used in **cosmetics**, **boot polish**, **ice cream**, **paints**, etc.
- **Agar**, extracted from **Gelidium** and **Gracilaria** is used in culture medium, **biscuits for diabetic patients**, etc.
  - **Sargassum** is used as **food** and **fodder**.
  - **Laminaria**, **Fucus** are used in extraction of **iodine**, **bromine** and **potash**.

Harmful Algae

Group of algae like **Microcystis**, **Oscillatoria** and **Anabaena** cause water blooms (eutrophication) and death and reduction of aquatic organisms.

Bryophyta (L. Bryon–leaf-like; phyton–plant body)

It is the simplest and primitive group of land plants. They are also known as **amphibians of plant kingdom** because of their habitat adaptability in both aquatic and terrestrial environment. They are the **connecting link between algae and pteridophytes**. Bryophytes are autotrophic, non-seeded, **cryptogamic** plants. The plant body is gametophytic and may be differentiated into stem, leaves and rhizoids.

- Bryophytes do not have true vascular tissue (xylem and phloem), but some of them have **hydroids** (similar to xylem) and **leptoids** (similar to phloem) which help in the conduction of water and food, respectively.
- The sex organs in bryophytes are multicellular, male sex organ is called **antheridium** and female sex organ is called **archegonium**. Sexual reproduction in bryophytes is mainly **oogamous type**.

Classification of Bryophyta

Bryophyta (sub-division)

Classes

Hepaticopsida (Liverworts)

- Plant body is thalloid or foliose.
- Cells have chloroplast without pyrenoids.
- Sporophyte simple or differentiated into foot, seta and capsule.

Orders

- **Sphaerocarpales** e.g.,Sphaerocarpus.
- **Marchantiales** e.g., Marchantia and Riccia.
- **Jungermaniales** e.g., Porella
- **Calobryales** e.g., Calobryum.

Anthocerotopsida (Hornworts)

- Plant body is thalloid and dorsiventrally flattened.
- Sex organs embedded in the thallus tissue.
- Cells bear large chloroplast with a conspicuous pyrenoid.

Order

Anthocerotales e.g., Anthoceros

Bryopsida (Mosses)

- Primary gametophyte consists of prostate or thalloid protonema.
- Adult gametophyte consists of stem, spirally arranged leaves.
- Sex organs develop from superficial cells.

Orders

- **Bryales** e.g., Funaria and Polytrichum.
- **Sphagnales** e.g.,Sphagnum.

Reproduction in Bryophytes

Bryophytes reproduce by both vegetative and sexual methods of reproduction.

Vegetative Reproduction

Following methods of vegetative reproduction are reported in bryophytes

(i) **By fragmentation** The two fragments resulted by progressive death and decay of thallus, produce new thallus, **e.g., Riccia.**

(ii) **By adventitious branches** Special adventitious branches arise from the mid-ventral surface of the thallus, **e.g., Riccia fluitans**.

(iii) **By tubers** Some species form perennating tubers at the apices of thallus, **e.g., Riccia, Marchantia,** etc.

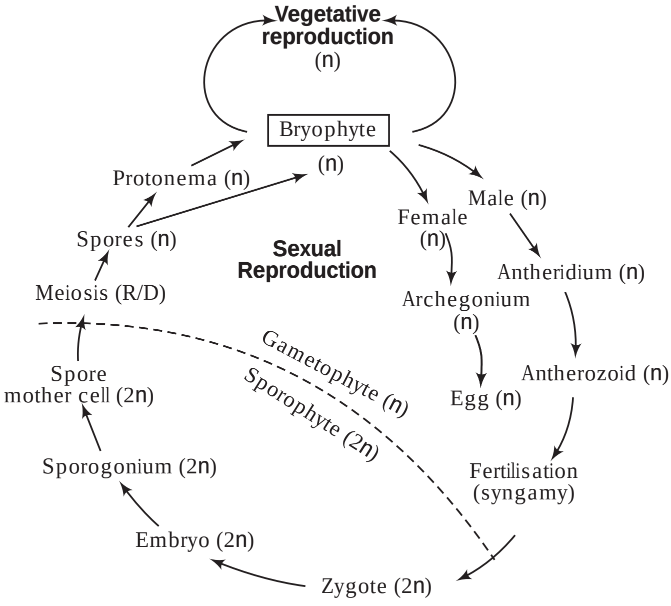
(iv) **By persistent apices** The underground part of thallus in soil remains living and grows into plant, **e.g., Riccia, Pellia,** etc.

Sexual Reproduction

The sex organs are highly differentiated and well-developed in bryophytes. The **antherozoids** or **sperms** (minute, slender, curved body, having two whiplash flagella) are released from antheridium and reach to archegonium through neck canal cells. The antherozoid fuses with **egg cell** to produce sporophytic generation.

Life Cycle of Bryophytes

A typical bryophyte shows following type of life cycle



Graphic representation of the life cycle of bryophyte
(R/D refers to reductional division)

Economic Importance

Bryophytes have limited economic importance, **they can be used in following ways**

(i) They help in **soil formation** (pedogenesis) and act as agent for biological succession.

(ii) Peat from **Sphagnum** can be used as fuel and in preparation of ethyl alcohol.

(iii) They help in protecting soil from erosion.

(iv) Some bryophytes are used as **fodder** for cattle.

(v) Due to high water retention capacity, **Sphagnum** can be used in preserving living materials and used in **grafting of plants**.

Pteridophyta (L. pteron–feather; phyton–plant)

Pteridophytes are seedless, vascular cryptogams. They reproduce by means of spores and can reach to the tree-like heights (30-40 feets).

General Characteristics

(i) The plant body is differentiated into **root**, **stem** and **leaves**.

(ii) The stem may be aerial or underground and is generally herbaceous, rarely solid and stout.

(iii) Vascular tissues consist of **xylem** (without vessels) and **phloem** (without companion cells).

(iv) **Alternation of generations** is found here, gametophyte is autotrophic and independent.

(v) Sporangia containing leaves are called **sporophylls**.

(vi) Antherozoids (flagellated male gametes) are formed in **antheridia**.

(vii) Reproduction is of both vegetative and sexual types.

(viii) On the basis of development of sporangia, **they are of two types**

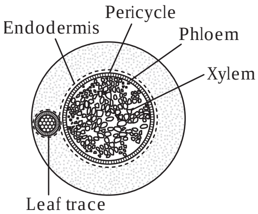
(a) **Eusporangiate** From a group of superficial initial cells.

(b) **Leptosporangiate** From a single superficial initial cell.

Stelar System in Pteridophytes

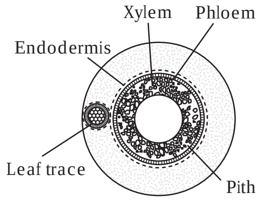
Stele is central vascular tissue surrounded by cortex. **It is of two types**

Protostele

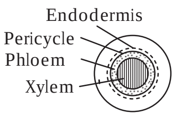


Xylem in centre is surrounded by phlem e.g., Selaginella.

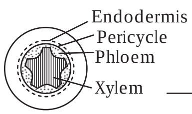
Siphonostele



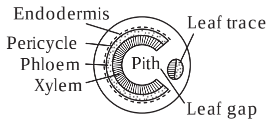
Xylem surrounds the central pith.
Phloem is outside to xylem, e.g., Pteridium.



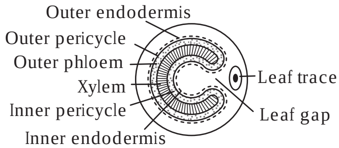
Haplostele
Central xylem core surrounded by phloem e.g., Rhynia



Actinostele
Central xylem core is star-shaped phloem is patchy outer to xylem, e.g., Lycopodium.



Ectophloic Solenostele
Xylem is like hollow cylinder surrounded by phloem e.g., Equisetum



Amphiphloic Solenostele
Hollow xylem cylinder has phloem on both outer and inner side of xylem, e.g., Marsilea

Classification of Pteridophyta

(Smith; 1955, Bold; 1955-57, Benson; 1957)

Division–Pteridophyta

Sub-division

- **Psilophyta** (rootless sporophytes).
- **Lycophyta or Lepidophyta** (differentiated sporophytes contain strobili).
- **Sphenophyta or Arthrophyta** (foliage leaves are borne in transverse whorls, e.g., horse tails).
- **Filicophyta or Pterophyta** (sporophyll contains sori e.g., ferns).

Reproduction

Pteridophytes reproduce by vegetative, asexual and sexual methods.

Vegetative Reproduction

It takes place by two methods

(i) Death and decay of older tissues lead to separation of new branches, which can grow into new plants.

(ii) Adventitious buds develop from petiole and later on rooting takes place and get separated.

Asexual Reproduction

It occurs by meiospores

When pteridophytic plants get mature, the special spore bearing structures develop under the surface of pinnules.

These structures are

(i) **Sporangium** These are differentiated into capsule and the stalk. Capsule has a single layer of thick wall, which consists of specialised cell along with the normal wall cells.

(ii) **Spores** These are minute, bilateral bodies of brown colour. The spore coat is two layered, **i.e.,** thick exine and thin intine.

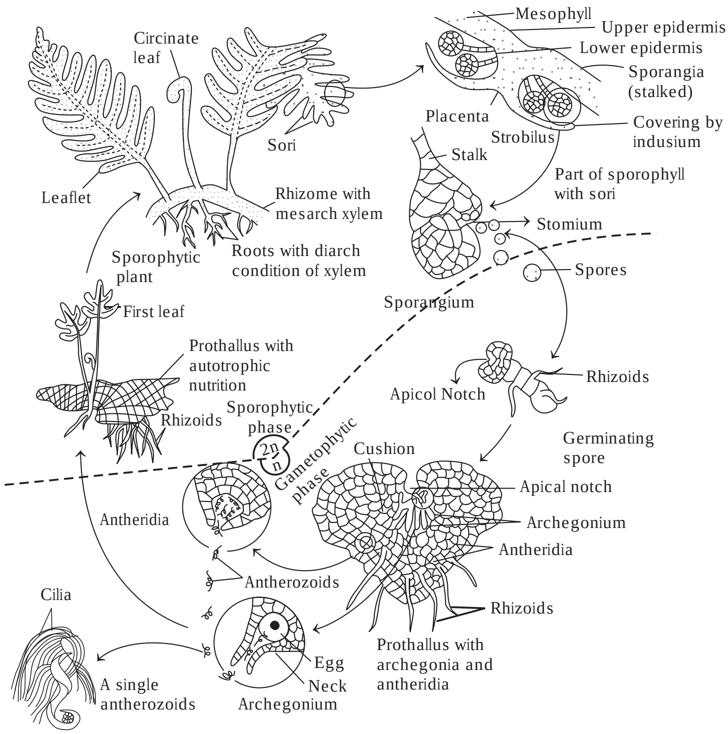
Sexual Reproduction

It is of advanced type, in which the multicellular sex organs (**i.e.,** antheridia and archegonia) are borne on the underside of prothallus. The mucilaginous substance oozes out from archegonia, which contains **malic acid**. After diffusing into water, it attracts antherozoids through **chemotaxis**. The male nucleus fuses with the egg nucleus and forms zygote.

Life Cycle of Pteridophytes

Most pteridophytic plants show similar type of life cycle.

Which is diagrammatically represented below.



Life cycle of Dryopteris

Heterospory in Pteridophytes

In heterosporous plants, a sporophyte produces two types of **sporangia–micro** and **megasporangia**. Microsporangia contain Microspore Mother Cell (MMC) each of which undergoes meiosis and produces **microspores**. Megasporangia contain **megaspore mother cell**, which after going through meiosis, produces **megaspores**.

$$\text{Microspore} \xrightarrow{\text{germinate}} \underset{\text{(possess antheridia)}}{\text{Microgametophyte}}$$

$$\text{Megaspore} \xrightarrow{\text{germinate}} \underset{\text{(possess archegonia)}}{\text{Megagametophyte}}$$

The differentiation between male and female gametophytes ensures cross fertilisation. This set of conditions occurs in **Marsiliaceae** and **Salviniaceae**.

Economic Importance

Pteridophytes are economically important group of plants.

Some of them are

(i) Pteridophytes are **used in horticulture**, since they resist wilting so can be used in cut flower arrangements.

(ii) Some ferns are used in **handicrafts and basketery**.

(iii) **Pteridium** leaves are used in making **green dyes**.

(iv) Club mosses are used for making **industrial lubricant** since their spores contain non-volatile oils. These spores are also used as fingerprint powder in forensic investigation.

(v) Some pteridophytes are used as **biofertiliser** (**Azolla**) due to their nitrogen-fixing ability.

(vi) Some pteridophytes are **eaten as food**.

Gymnospermae (L. gymnos – naked; sperma – seed)

Gymnosperms are naked seeded plants, which evolved earlier than the flowering plants. They have their seeds exposed on the megasporophylls, **i.e.,** carpels. Probably, they are the first surviving seed plants (evolved during Jurassic period).

General Characteristics

(i) Plants are sporophytic, differentiated into root, stem and leaves.

(ii) Always **heterosporous**, **i.e.,** contains two types of spores (one spore (microspore) produces male gametophyte and other (megaspore) produces female gametophyte after germination).

(iii) Root system is well-developed, **i.e., tap root system**, some have **coralloid** roots (**e.g., Cycas**).

(iv) Form various structures through symbiotic relationships, **i.e.,** coralloid root (with algae) and **mycorrhizae** (with fungi).

(v) **Leaves are dimorphic. They are of two types**

(a) **Foliage leaves** Green, simple, needle-shaped and pinnately compound.

(b) **Scaly leaves** Minute and deciduous.

(vi) Flowers are unisexual, simple, reduced and naked, **i.e.,** without perianth (except **Gnetum**).

Classification of Gymnospermae

Classification of gymnosperms was described by **A Arnold** (1948) and modified by **Pilger** and **Melchior** (1954).

Division–Gymnospermae

Cycadopsida	**Coniferopsida**	**Gnetopsida**
[monoxylic wood, large frond (a type of leaf) and bipinnately compound leaves] e.g., Cycas and Zamia.	(large tree of sporophytic nature, produce cones in reproductive phase) e.g., Pinus and Cordaites.	(include both extinct and extant genera) e.g., Gnetum and Ephedra.

Reproduction

Gymnosperms reproduce by both vegetative and sexual methods.

Vegetative Reproduction

This is done by **bulbils**, which commonly arise on trunk. These bulbils get separated from plants and germinate into new plants.

Sexual Reproduction

The life cycle of gymnosperms is also characterised by alternation of generations. The green leafy part of the plant is the sporophyte while, the cones contain the male and female gametophytes.

Upon landing on the female cone, the tube cell of the pollen forms the pollen tube, through which the generative cells migrate towards the female gametophyte.

The generative cells split into two sperm nuclei, one of which fuses with the egg, while the other degenerates. After fertilisation of the egg, the diploid zygote is formed, which divides by mitosis to form embryo.

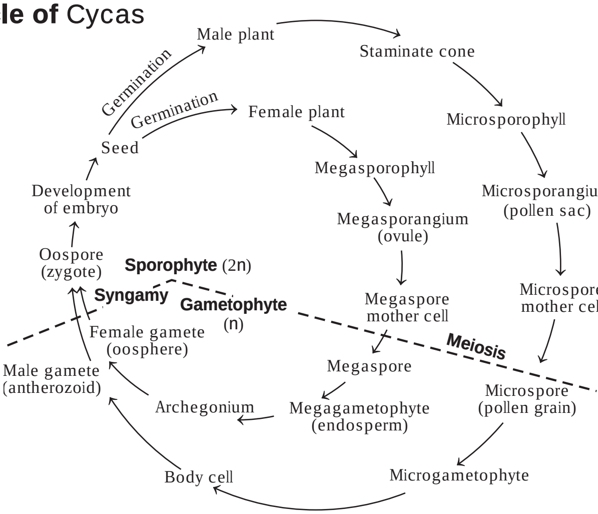
The seed is covered by a seed coat, which is derived from the female sporophyte. No fruit formation takes place as gymnosperms do not have true seed covering.

Life Cycle of Gymnosperms

The gymnosperms are higher plants with advanced life cycle.

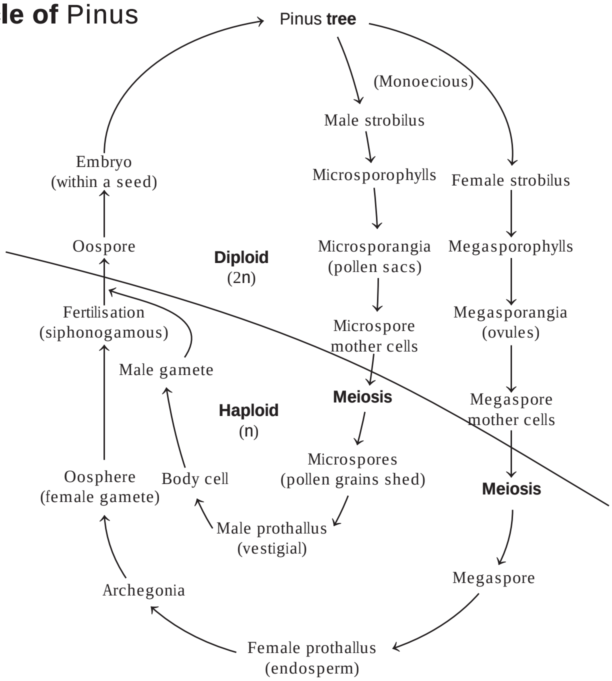
The descriptive account of life cycle of both Cycas and Pinus are as follows

Life Cycle of *Cycas*



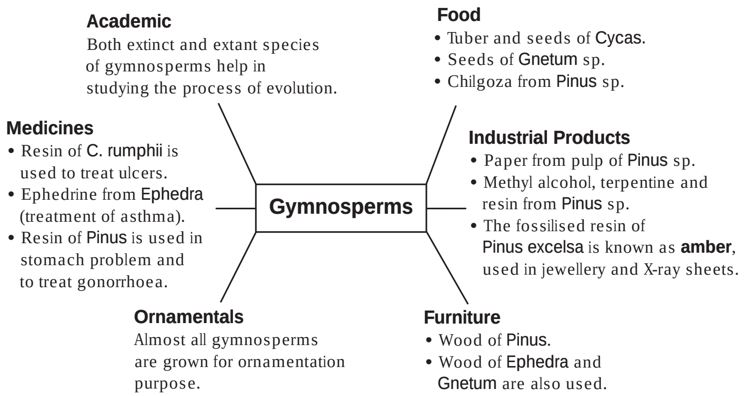
Cycas : Topographical representation of life cycle

Life Cycle of *Pinus*



Pinus : Topographical representation of life cycle

Economic Importance



Angiospermae

(Gk. Angion–vessel; sperma–seed)

Angiosperms constitute a distinct group of flowering plants, which form covered seeds. With about 2,50,000 species, it can be regarded as the most successful group of plants. They arose in middle of Cretaceous period.

General Characteristics

(i) Angiosperms range from microscopic **Wolffia** to the largest tree such as **Eucalyptus.**

(ii) The pollen grains and ovules develop in their flowers and the seeds are formed within the fruits.

(iii) Nutritionally, they may be **autotrophic** (wheat, corn, etc.), **parasitic** (**Cuscuta, Santalum,** etc.), **saprophytic** (**Monotrapa**, etc.) and **insectivorous** (**Drosera, Utricularia,** etc.).

(iv) They may be herb, shrub and trees.

(v) Their lifetimes may be **ephemeral**, **annual**, **biennial** and **perennial**.

(vi) Angiosperms are adapted to various habitats, as they may be hydrophytes, xerophytes and mesophytes.

(vii) A flower is a modified shoot comprising of four whorls, **i.e.**, **sepal**, **petal**, **androecium** and **gynoecium**.

Classification of Angiosperms

A natural system of classification was given by **George Bentham** and **JD Hooker** in 1862-63 in his book **Genera Plantarum** (3 volumes) in Latin.

The outline of the above mentioned classification is as follows

Phanerogamia
(seed plants in which sex organs are evident)

Classes
- **Dicotyledonae**
  - Sub-classes
    - **Polypetalae**
    - **Gamopetalae**
    - **Monochlamydeae**
- **Gymnospermae**
  - Sub-classes
    - **Cycadaceae**
    - **Coniferae**
    - **Gnetaceae**
- **Monocotyledonae**

Some important plant families with their representative genera are as follows

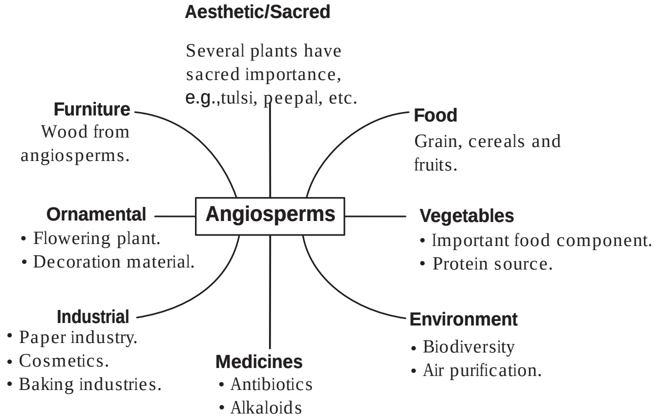
Ranunculaceae, **Brassicaceae** (**e.g.,** mustard), **Malvaceae** (**e.g.**, gurhal), **Asteraceae** (**e.g.,** sunflower), **Lamiaceae** (**e.g.,** tulsi), **Solanaceae** (**e.g.,** potato), **Leguminosae** (**e.g.,** pea), **Cucurbitaceae**, **Euphorbiaceae**, **Orchidaceae**, **Palmae** (**e.g.,** cashewnut), **Poaceae** (**e.g.,** paddy) and **Liliaceae** (**e.g.,** onion), etc.

Reproduction in Angiosperms

Angiosperms are plants that bear fruits and flowers. These flowers are plant's reproductive structures. Reproduction in angiosperms (mostly sexual type) occurs when the pollen from an anther is transferred to stigma.

When the ovules get fertilised, they will develop into seeds. Non-reproductive structures like petals, sepals etc. of the flowers fall off leaving only the ovary behind, which will develop into a fruit.

Economic Importance



Useful applications of angiosperms

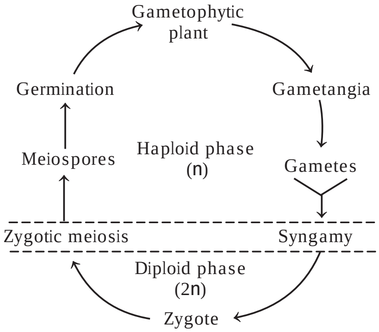
Alternation of Generations

It can also be termed as 'Patterns of life cycle'. Plants divide mostly through mitotic divisions and form different plant bodies (these may be haploid or diploid).

The interconversion of the haploid and diploid plant body in alternate manner is called **alternation of generations**. **Generally, it is of three types**

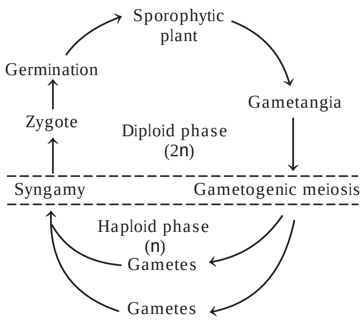
Plant Life Cycles

(i) **Haplontic** Sporophytic generation is not prominent, **e.g.,** algae, etc.



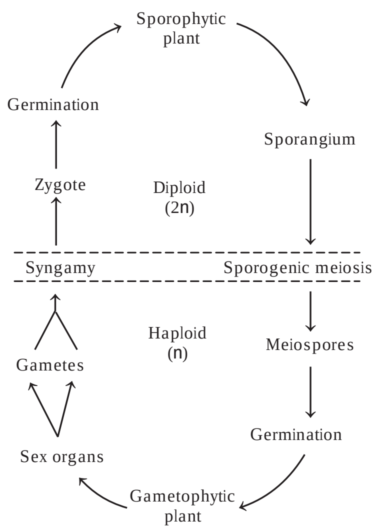
Diagrammatic outline of a haplontic life cycle

(ii) **Diplontic** Gametophytic generation is of very short duration,



Diagrammatic outline of a diplontic life cycle

(iii) **Haplo-Diplontic** Both gametophytic (**n**) and sporophytic (2**n**) are free-living, independent and multicellular phases, **e.g.,** bryophytes, pteridophytes, etc.



Diagrammatic outline of a haplo-diplontic life cycle

Types of Meiosis Seen in Different Life Cycles

- **Sporic Meiosis** (in diplo-haplontic life cycle), e.g., Ectocarpus, Laminaria, etc.
- **Zygotic Meiosis** (in haplontic life cycle), e.g., Volvox, Spirogyra.
- **Gametic Meiosis** (in diplontic life cycle), e.g., Diatoms, Sargassum, etc.

4

Animal Kingdom

Kingdom Animalia is characterised by multicellular, eukaryotic animal forms. It is also known as **Metazoa**. It includes around 1.2 million species of animals from sponges to mammals (other than protozoans).

Metazoa

Infra kingdoms or branches

Mesozoa
Worm-like bilateral symmetry, parasitic on cephalopods and other invertebrates, e.g., Phylum–Mesozoa.

Parazoa
Cells loosely organised, no organs, no digestive cavity, e.g., Phylum–Porifera.

Enterozoa
True tissues present, a digestive cavity present also called Eumetazoa.

Divisions

Radiata
Radial or biradial symmetry no organs, diploblastic, e.g., Phylum–Coelenterata and Ctenophora.

Bilateria
Bilateral symmetry, organ systems present, triploblastic, digestive tract complete.

Sub-divisions

Protostomia
Mouth from blastopore, cleavage spiral and determinate.

Deuterostomia
Mouth not from blastopore mesoderm develops from archenteron, e.g., Phylum–Echinodermata, Hemichordata and Chordata.

Sections

Acoelomata
Contains no coelom, e.g., Phylum–Platyhelminthes.

Pseudocoelomata
Contains pseudocoelom, e.g., Phylum–Nematoda.

Eucoelomata (Schizocoela)
Contains true coelom, e.g., Phylum–Annelida, Arthropoda and Mollusca, along with Sipuncula, Onychophora, etc. (minor phyla).

Classification of Metazoa

Phylum–Chordata
(True coelomates with enterocoelic type of coelom)

Three sub-phyla

Urochordata (Tunicates)
- Notochord is restricted in the posterior part of the body (tail region).
- Notochord is present in larval stage only.
- Body is unsegmented, e.g., Herdmania.

Cephalochordata
- Notochord is extended in the head region.
- Notochord is present throughout the life.
- Body is segmented, e.g., Amphioxus.

Vertebrata (Craniata)
- Notochord is replaced by vertebral column.
- Notochord is present in embryonic stage only.
- Body is either segmented or unsegmented.

Two divisions

Agnatha (Jawless)
- Mouth does not possess jaws.
- Notochord persists throughout life.
- Paired appendages are absent.
- Single nostril is present.
- Internal ear has two or one semicircular canals.
- 8-10 pairs of cranial nerves, are present.

Gnathostomata (Bear jaws)
- Mouth bears jaws.
- Embryonic notochord is replaced in adults by a vertebral column.
- Paired appendages (fins or limbs) are present.
- Nostrils are paired.
- Internal ear has three semicircular canals.
- There are 10-12 pairs of cranial nerves.

Two classes

Ostracodermi
- Extinct class, e.g., Pteraspis,

Cyclostomata
- Contains 1-16 pairs of gill slits.
- Head and brain are poorly developed.
- Endoskeleton is cartilaginous.
- Two-chambered heart.
- Fertilisation is external and development is indirect, e.g., Petromyzon (lamprey), Myxine (hagfish).

Two super-classes

Pisces
- Fins are present.
- Respire by gills.
- Do not have internal nares (except lungfish).
- Heart is two or three-chambered.
- They have internal ears.

Tetrapoda
- Limbs are present.
- Respire by lungs, gills and skin.
- They have internal nares.
- Heart is three or four-chambered.
- They have internal, middle and external ears (except snakes).

Three classes

Chondrichthyes (Cartilaginous fishes)
Placodermi (Extinct)
Osteichthyes (Bony fishes)

Four classes

Amphibia
Reptilia
Aves
Mammalia

Classification of Phylum Chordata

Basis of Classification

There are few fundamental common features to various animal groups, which form the basis of classification. **These features are as follows**

1. Level of Organisation

Though, all the members of kingdom–Animalia are multicellular, yet all of them do not exhibit the same pattern of cellular organisation.

Different levels of organisation are discussed below

Levels of Organisation

Acellular or Protoplasmic Level Body consists of mass of protoplasm. All activities are performed by different cell organelles and confined within the limit of plasma membrane, e.g., Protozoa.

Cellular Level Body consists of many cells which either forms an aggregate or a colony. It is of two types

(i) **Cellular aggregate** Porifera (sponges), where cells are not organised into tissue.

(ii) **Cellular colony** Protists and some algae.

Tissue Level Group of similar cells forms tissues which serves specific functions, e.g., coelenterates.

Organ Level Some tissues join and function as a unit of a organ, e.g., Stomach (one of digestive organs) contains all tissues, e.g., Platyhelminthes.

Organ-System Level Group of organs working together to forms organ system, e.g., Organs such as stomach, intestine, etc., aid in digestion and constitute digestive system, e.g., Nemathelminthes to chordates.

2. Symmetry

It refers to the correspondence of body parts in all major respect like size, shape, position, etc., with the parts on opposite side when divided from the central axis.

Types of symmetry found in animals are

(i) **Radial symmetry** In radial symmetry, the animal gets divided into two '**identical halves**' when any plane passes through the central axis, **e.g.,** coelenterates, echinoderms.

(ii) **Bilateral symmetry** In bilateral symmetry, body is divided into two '**identical halves**' only when a plane passes through the median longitudinal axis, **e.g.,** annelids, arthropods, etc.

3. Germ Layers

These are the groups of cells behaving as a unit during early stages of embryonic development. On the basis of number of germ layers, animals are placed in two groups, **i.e.,** diploblastic and triploblastic. These groups are divided at the gastrulation stage.

(i) Diploblastic

Embryo is two-layered consisting an outer ectoderm and inner endoderm, **e.g., Hydra,** jellyfish, etc.

(ii) Triploblastic

Embryo is three-layered consisting of an outer ectoderm, middle mesoderm and inner endoderm, **e.g.,** humans.

4. Coelom

It is a large fluid-filled space or cavity lying between the outer body wall and inner digestive tube.

Types of Coelom

Internal body cavity separates digestive tract from outer body wall

Acoelom

There is no body cavity. Region between the ectodermal epidermis and the endodermal digestive tract is completely filled with mesoderm in the form of a spongy mass of space filling cells called **parenchyma.** e.g., Porifera, Coelenterata, Ctenophora and Platyhelminthes.

Pseudocoelom

The presence of false coelom or perivisceral cavity. Coelom is not lined by mesoderm and directly connected to archenteron. Developmentally, pseudocoelom is the persistent blastocoel of blastula stage, e.g., Rotifera, Aschelminthes and Nematoda.

Eucoelom or True Coelom

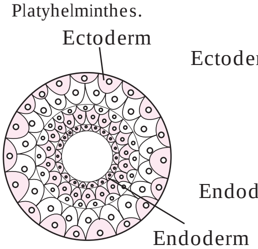
True body cavity develops entirely lined with the mesoderm, e.g.,higher invertebrates (Annelida, Echinodermata and Chordata).

Schizocoel

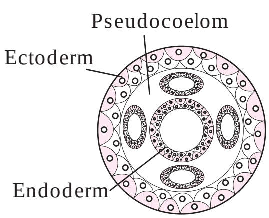
Developed as a split in the mesoderm sheet, e.g., Annelida to Arthropoda. Protostomes are schizocoelous.

Enterocoel

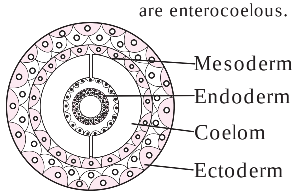
Formed from the pouches of the archenteron or primitive gut. e.g., Echinodermata and chordata. Deuterostomes are enterocoelous.



Acoelomate



Pseudocoelomate



Coelomate

Digrammatic sectional view of coelom

5. Segmentation

It is the serial repetition of similar parts along the length of an animal.

It is of two types

(i) **Pseudosegmented** (strobilisation) Body is divided into number of pseudosegments (proglottids) which are independent of each other, **e.g.,** tapeworms.

(ii) **Metameric** Linear repetition of body parts (somites), **e.g.,** annelids, arthropods and chordates.

6. Notochord

It is a rod-like structure present on the dorsal side of the animal body. It is derived from the embryonic mesoderm. Based on its presence and absence, animals are non-chordates (phylum–Porifera to Echinodermata) and chordates (phylum–Chordata).

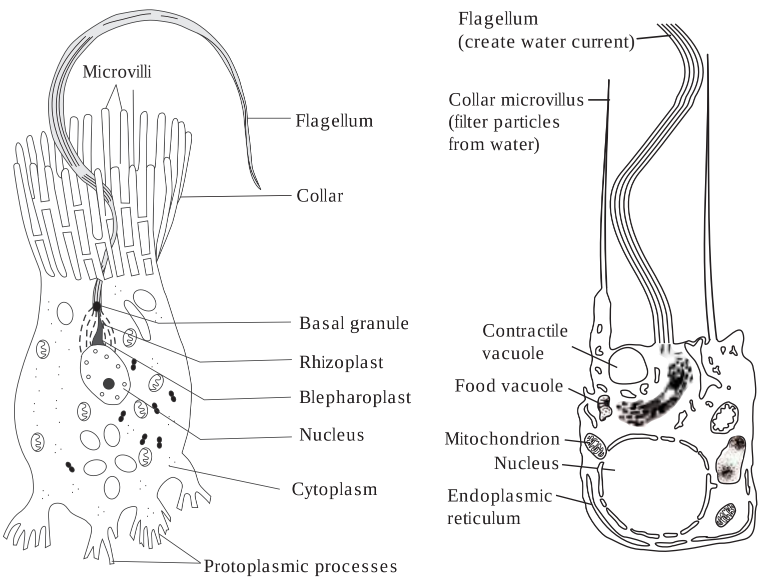
Major differences between Chordata and Non-Chordata are as follows

Chordata	Non-Chordata
Bilaterally symmetrical.	Asymmetrical, radially symmetrical or bilaterally symmetrical.
True metamerism.	Non-segmented, false segmented or true metamerically segmented.
True coelomates.	Acoelomate, pseudocoelomate or true coelomates.
Post-anal tail usually present.	It is usually absent.
Triploblastic animals.	Cellular, diploblastic or triploblastic animals.
Alimentary canal is always ventrally placed to nerve cord. Heart is ventrally placed.	It is always dorsally placed to the nerve cord. Heart is dorsal or absent.
Central nervous system is hollow, dorsal and single.	Central nervous system is ventral, solid and double.
Pharynx is perforated by gill slits.	Gill slits are absent.

Phylum–Porifera

Poriferans bear numerous minute pores called **ostia** on the body wall, which leads into a central cavity called **spongocoel** or **paragastric cavity**. The spongocoel opens to outside by **osculum**.

Majority of poriferans (sponges) are marine and sedantry. They are diploblastic animals and contain an outer dermal layer of pinacocytes and inner gastral layer of choanocytes.



Choanocyte : (a) Light microscopic view
(b) Electron microscopic view

Canal System (Aquiferous system)

It is a system of interconnected canals through which water circulates and helps in a number of metabolic activities of a sedentary sponge. In sponges, canal system is of three types, **i.e.**, asconoid, syconoid and leuconoid.

Different Types of Canal System

Asconoid Canal System	Syconoid Canal System	Leuconoid Canal System
Simplest type with thin walls.	Complex type with thick walls.	Much complex type with highly folded thick walls.
Spongocoel is large and spacious.	Spongocoel is narrow.	Spongocoel is either reduced or absent.

Asconoid Canal System	Syconoid Canal System	Leuconoid Canal System
Choanocytes form the gastral layer and lines the whole spongocoel.	Choanocytes are restricted in radial canals only.	Choanocytes are confined in the flagellated chambers which are formed by the evagination of radial canals.
Route of water is Outside water $\xrightarrow{\text{Dermal Ostia}}$ Spongocoel $\xrightarrow{\text{Osculum}}$ Outside e. g., **Leucosolenia.**	Route of water is Outside water $\xrightarrow{\text{Dermal Ostia}}$ Incurrent canal $\xrightarrow{\text{Prosopyle}}$ Radial canal $\xrightarrow{\text{Apopyle}}$ Excurrent canal $\xrightarrow{\text{Gastral Ostia}}$ Spongocoel $\xrightarrow{\text{Osculum}}$ Outside e.g., **Grantia.**	Route of water is Outside water $\xrightarrow{\text{Dermal Ostia}}$ Hypodermal spaces $\rightarrow$ Incurrent canals $\xrightarrow{\text{Prosopyle}}$ Flagellated chambers $\xrightarrow{\text{Apopyle}}$ Excurrent canal $\rightarrow$ Excurrent spaces $\xrightarrow{\text{Osculum}}$ Outside, e. g., **Plakina.**

Reproduction

In sponges, reproduction occurs by both asexual and sexual means.

(i) **Asexual reproduction** Mainly occurs by budding and gemmules.

(ii) **Sexual reproduction** Occurs with the help of amoebocyte or archeocytes or sometimes through choanocytes.

Classification of Porifera

Phylum–Porifera

Three classes

Calcispongiae or Calcarea
- Skeleton of calcareous spicules.
- Large choanocytes.
- Small-sized species.

Hyalospongiae or Hexactinellida
- Skeleton of siliceous spicules.
- Small choanocytes.
- Moderately-sized species.

Demospongiae
- Skeleton of spongin fibres or may be absent.
- Very small choanocytes.
- Large-sized species.

Common and Scientific Names of Some Members of Porifera

Common Species of Porifera	Scientific Name	Common Species of Porifera	Scientific Name
Glass rope sponge	**Hyalonema**	Venus flower basket	**Euplectella**
Bath sponge	**Euspongia**	Bowl sponge	**Pheronema**
Freshwater sponge	**Spongilla**	Dead man's finger sponge	**Chalina**
Urn sponge	**Scypha**	Boring sponge	**Cliona**

Economic Importance

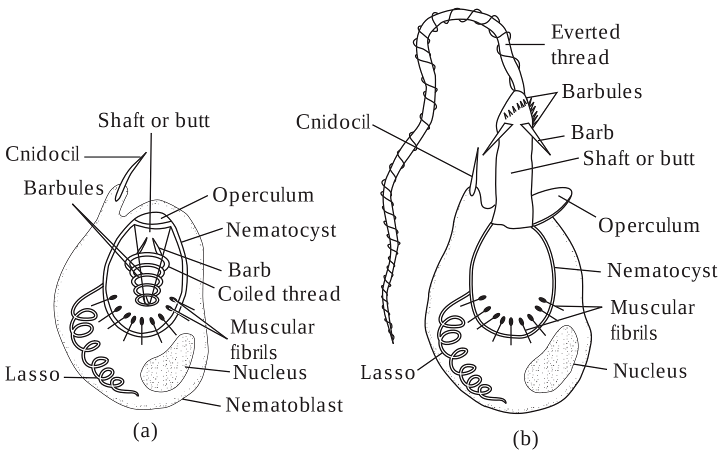
- They are used commercially for bathing/cleaning sponges.
- They help to clean-up the ocean floor by boring into dead shells and corals releasing chemicals to break them down.

Phylum–Coelenterata (Cnidaria)

Coelenterates are the animals bearing a special body cavity called **coelenteron** (gastrovascular cavity). They exhibit dimorphism and display two major forms namely polyp (sedentary) and medusa (swimming). They also exhibit trimorphism (**e.g., Siphonophora**) and polymorphism (**e.g., Porpita**).

Body Wall

They are diploblastic animals and their body wall contains several types of cells, **e.g., stinging cells** (cnidoblast/nematocyst), **interstitial cells** (totipotent cells), **sensory cells, nerve cells,** etc.



Cnidoblast Cells : (a) Undischarged (b) Discharged

Skeleton

In coelenterates, skeleton may be endoskeleton, exoskeleton or absent.

- **Endoskeleton e.g.**, **Alcyonium** (fleshy mesogloea), **Pennatula** (axial rod of calcified horn).
- **Exoskeleton e.g.**, **Millipore** (coenosteum), **Gorgonia** (gorgorin), **Madrepora** (corallum).
- **Absent e.g.**, sea anemones.

Metagenesis

It is like the alternation of generations between the sexual (medusa) and asexual (polyp) forms. In contrast to alternation of generation in metagenesis, it is difficult to distinguish between asexual and sexual forms as both individuals are diploid.

Reproduction

It occurs both by sexual and asexual means.

(i) **Asexual reproduction** By external budding.

(ii) **Sexual reproduction** By sexual medusae. The development is usually indirect which occurs through ephyra, planula and hydrula larvae.

Classification of Coelenterata

Phylum–Coelenterata

Three classes

Hydrozoa
- Both polyp and medusa present. Polyp stage dominant, medusa stage reduced or absent.
- Velum is present.
- Gonads are epidermal in origin.
- Larva hydrula, planula,

Scyphozoa
- Medusa form is dominant. Polyp represented as scyphistoma stage.
- Pseudovelum is present.
- Gonads are endodermal in origin.
- Larva ephyra.

Anthozoa (Actinozoa)
- Medusa form is absent.
- Velum is absent.
- Gonads, if present are endodermal in origin.
- Corals and sea anemone.

Common and Scientific Names of Some Coelenterates

Common Names of Coelenterates	Scientific Name	Common Names of Coelenterates	Scientific Name
Sail-by-wind	**Valella**	Organ-pipe coral	**Tubipora**
Portuguese man of war	**Physalia**	Stag horn coral	**Madrepora**
Stinging coral	**Millipora**	Mushroom coral	**Fungia**
Sea anemone	**Metridium**	Star coral	**Astraea**
Dead's man finger coral	**Alcyonium**		

Economic Importance

- They take part in the formation of coral reefs, **e.g.**, **Millipora** (stinging coral).
- Their skeleton has medicinal value, **e.g., Tubipora** (organ-pipe coral).
- They have ornamental value, **e.g.**, **Astraea** (star coral).

Phylum–Ctenophora

The members of this phylum are generally marine, solitary, free-swimming or pelagic. They are diploblastic animals and acoelomates.

Peculiar Characteristics

A gelatinous mesoglea is present between epidermal and gastrodermal tissue layers. They are also called **comb plates. Colloblast cells** are the sensory and adhesive cells.

Reproduction

Sexes are not separate. All are hermaphrodites. Gonads develop from endosperm. Fertilisation is internal. Development is indirect through **cydippid** larva.

Classification of Ctenophora

Phylum–Ctenophora

Two classes

Tentaculata
- Possesses tentacles
- Contains two long aboral tentacles
- e.g., Ctenoplana, Velamen, etc.

Nuda
- Does not possess tentacles.
- Have a highly branched gastrovascular cavity.
- e.g., Beroe, etc.

Common and Scientific Names of Some Ctenophores

Common Name of Ctenophores	Scientific Name
Venus Girdle	**Velamen**
Sea walnut	Pleurobrachia
Swimming eye of cat	Beroe

Economic Importance

- They reproduce quickly and are good predators.
- They can bring down an ecosystem.

Phylum–Platyhelminthes

They are dorsoventrally flat animals having either unsegmented and leaf-like (**e.g.**, flukes) or segmented and ribbon-like (**Taenia**) body. They are the first animals to have bilateral symmetry and to undergo **cephalisation**.

Habitat

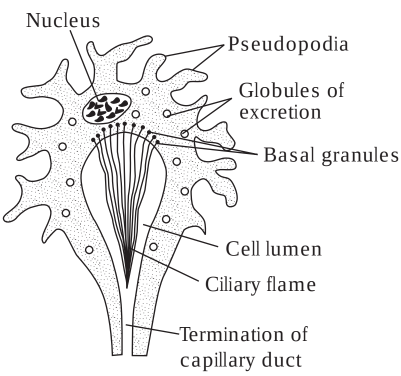
They are mostly found as free-living forms, but few of them are parasitic in their habitat.

Platyhelminthes

- **Free-living forms**
  - **Freshwater** (e.g., Dugesia and Planaria)
  - **Marine** (e.g., Convoluta and Thysanozoon)
  - **Terrestrial** (e.g., Bipalium and Geoplana)
- **Parasitic forms**
  - **Ectoparasites** (e.g., Diplozoon and Gyrodactylus)
  - **Endoparasites** (e.g., Echinococcus and Taenia)

Peculiar Features

These are the first animals with **triploblastic layers** in body wall and **organ system organisation**. They are **acoelomates** due to the presence of a mesodermal connective tissue, **parenchyma**, in between the visceral organs. These animals have ladder-type nervous system and peculiar cells called **flame cells or protonephridia for excretion**. These cells are modified mesenchymal cells.



Flame cell (Solenocyte)

Reproduction

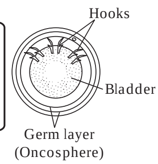
These animals are generally bisexual. **Cross- fertilisation** occurs in trematodes, while **self-fertilisation** occurs in cestodes. Fertilisation is always internal. Turbellarians reproduce by **transverse fission.**

Life Cycle of *Taenia solium*

Adult tapeworm in human gut

Fertilised ova (zygotes) in the mature proglottids capsules containing zygotes in gravid proglottids.

Onchosphere (larvae) in the gravid proglottids. It contains all embryonic membranes along with a hexacanth (structure with 6 hooks).

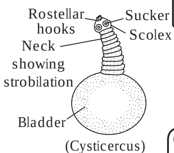


Onchospheres in human faeces (outside the body). Faeces containing onchospheres is eaten by pig.

Hexacanth
It is the six-hooked larval stage containing a pair of penetration glands.

Cysticercus
Hexacanth reaches heart *via* liver and finally muscles tongue, shoulder, neck, thigh and settles to develop into next larval stage called cysticercus or bladder worm within 10 days of infection of the secondary host.
It is the infective stage of human when they feed infected meat.

Each cysticercus develops into young tapeworm in the human gut.



The graphical representation of life cycle of Taenia solium depicting different larval stages and adult form in the primary and secondary hosts

Life Cycle of Fasciola hepatica

Adult Fasciola in the liver of sheep

Metacercaria This is the encysted infective stage of the Fasciola and now infects vertebrate host (sheep).

Large number of eggs in faecal matter of sheep. Development of egg into next larval stage miracidium.

Miracidium First larval stage freely swim in water with the help of cilia present all over body. Penetrate secondary host snail reaches to salivary gland and forms second larval stage sporocysts.

Cercaria It escapes from the secondary host through pulmonary sac. Its tail help in swimming of the larvae in water. After 2-3 days, it loses its tail and becomes incepted on grass or aquatic plant and is now called letacercaria.

Sporocyst It is the second larvae of Fasciola living in pulmonary tissues of snail and obtaining nutrition from it and develops into 5-8 rediae.

Rediae It is the most important larval stage and it bears an anterior end with a ring of collar, a birth pore and pair of projections (lappets or procruscula).

During Winter Every rediae produces, 14-20 cercaria (next larval stage).

During Summer It replicates giving rise to the same form, i.e., daughter rediae.

Graphical representation of life cycle of Fasciola hepatica depicting polyembryony along with different larval stages

Classification of Plathelminthes

Phylum–Platyhelminthes

Three classes

Turbellaria

- Mostly non-parasitic and free-living.
- Unsegmented and flat leaf-like. Body wall contains
- syncytial epidermis with rod-shaped rhabditis, e.g., Planaria.

Trematoda

- Ecto or endoparasites.
- Unsegmented and flat leaf-like.
- Body wall contains cuticular spines, e.g., Fasciola.

Cestoda

- Exclusively endoparasites
- Segmented and ribbon-like.
- Body wall is lined by microvilli. e.g., Taenia.

Common and Scientific Names of Some Platyhelminthes

Common Names of Platyhelminthes	Scientific Name	Common Names of Platyhelminthes	Scientific Name
Liver fluke	**Fasciola hepatica**	Pork tapeworm	**Taenia solium**
Planarian	**Dugesia**	Hydatid worm or dog tapeworm	**Echinococcus granulosus**

Economic Importance

- **Fasciola** causes **fascioliosis** or **liver rot** which is characterised by hepatitis.
- **Echinococcus** causes hydatid disease which is characterised by enlargement of liver.

Phylum–Aschelminthes

They are long, cylindrical, unsegmented and thread-like animals with no lateral appendages, so these are commonly called **roundworms**, **bagworms** or **threadworms.**

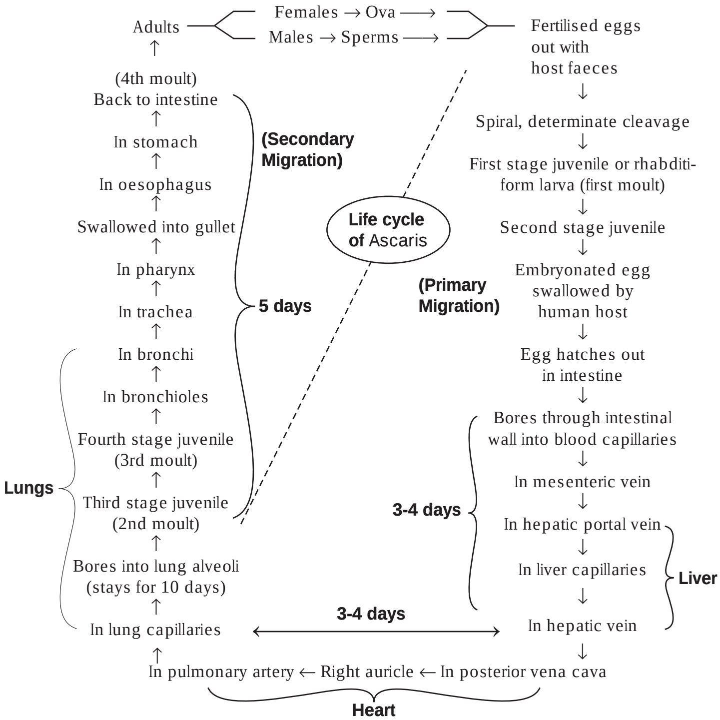
Peculiar Features

Body wall of these pseudocoelomate animals is composed of complex cuticle, syncytial epidermis and only longitudinal muscles. They have **tube-within-tube plan of digestive system**.

They have fixed number of cells in every organ of the body (eutylic condition). Excretory system is H-shaped and contains **rennete cells**.

Reproduction

Sexual dimorphism is present and males are smaller than females. Fertilisation is internal and it may be direct or indirect.



A graphical representation of life cycle of Ascaris

Classification of Aschelminthes

Phylum–Aschelminthes

Nematoda
- Body wall have cuticle, epidermis and longitudinal muscles.
- Excretory system is formed of renette cells.

Nematophora
- Cuticle is highly thickened and formed of collagen fibres.
- Excretory system absent.

Rotifera
- Cuticle is formed of plates (lorica) and body wall contains both circular and longitudinal muscles.
- Formed of two protonephridia.

Gastrotricha
- Cuticle is produced into short spines.
- Formed of two protonephridia.

Kinorhyncha
- Cuticle is spiny, but without cilia.

Aphasmida
Without phasmids, *i.e.*, the caudal sensory organs. Usually free-living, *e.g.*, *Trichinella* and *Trichuris*, etc.

Phasmida
Phasmids, *i.e.*, caudal sensory organs are present, *e.g.*, *Anguina*, *Ancylostoma*, *Ascaris*, *Enterobius*, *Dracunculus*, *Wuchereria*, *Loa loa*, etc.

Common and Scientific Names of Some Aschelminthes

Common Names of Aschelminthes	Scientific Name	Common Names of Aschelminthes	Scientific Name
Roundworm	***Ascaris lumbricoides***	Guinea worm	***Dracunculus medinesis***
Root-knot eel worm	***Meloidogyne marioni***	Pinworm	***Enterobius vermicularis***
Filarial worm	***Wuchereria bancrofti***	Whipworm	***Trichuris trichiura***
Eye worm	***Loa loa***		

Economic Importance

- ***Ascaris*** causes ascariasis in humans.
- ***Meloidogyne*** is a harmful phytoparasitic nematode.

Phylum–Annelida

Annelids are segmented worms with an elongated body possessing triploblastic layers. Their musculature is formed of only smooth muscle fibres of two types, ***i.e.,*** longitudinal (inner) and circular (outer) muscles.

Peculiar Features

- These animals show **metameric segmentation**, **i.e.**, the external division of the body by annuli corresponds to internal division of coelom by septa.
- These are the first animals to have circulatory system.
- Locomotory organs are minute rod-like chitinous **setae** or **suckers** which are embedded over **parapodia**.
- A characteristic **circumoesophageal ring** is present in the anterior part of CNS.
- Special structures called **nephridia** are present for excretion.

Reproduction

Asexual reproduction By fragmentation is seen in some polychaetes.

Sexual reproduction Sexes are either united (**e.g.,** oligochaetes) or separate (**e.g.,** polychaetes). Fertilisation is internal (**e.g., Hirudinaria**) or external (**e.g.,** earthworm). Development is direct in monoecious form and indirect in dioecious form involving a free-swimming **trochophore** larva.

Classification of Annelida

Phylum–Annelida

Three classes

Polychaeta
- Marine, fossorial or tubicolous.
- Distinct head bearing tentacles, palps and eyes.
- Bristle-like setae and parapodia for locomotion
- Clitellum is absent.
- Unisexual, e.g., Aphrodite and Chaetopterus.

Oligochaeta
- Terrestrial, freshwater
- Distinct head with eyes (palps and tentacles are absent).
- Locomotion by peristalsis, parapodia is absent.
- Permanent clitellum is present.
- Bisexual, e.g., Pheretima and Tubifex.

Hirudinea
- Mostly freshwater, few marine.
- No cephalisation
- Locomotion by anterior and posterior suckers.
- Clitellum appears during breeding season.
- Bisexual, e.g., Hirudinaria and Acanthobdella.

Common and Scientific Names of Some Annelids

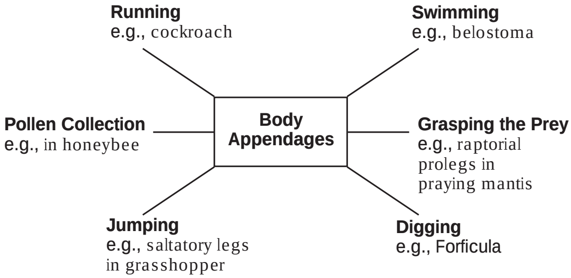
Common Names of Annelids	Scientific Names	Common Names of Annelids	Scientific Names
Earthworm	**Pheretima posthuma**	Paddle worm	**Chaetopterus**
Clam worm	**Nereis**	Blood worm	**Glycera**
Polalo worm	**Eunice**	Skate sucker	**Pontobdella**
Sea mouse	**Aphrodite**	Lung worm	**Arenicola**

Economic Importance

- Earthworms are used as fish-baits and for improving the soil fertility.
- **Polynoe** shows bioluminescence and this phenomenon is used in self-defence.
- **Tubifex** has putrefaction ability and is grown in filtre beds of sewage disposal plants.
- **Pontobdella** causes huge food loss to man when present in large number.

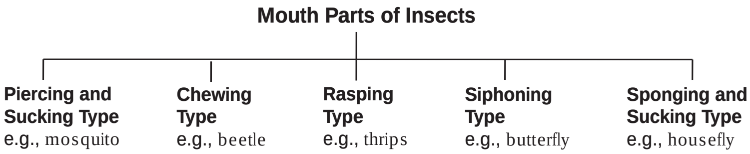
Phylum–Arthropoda

It is the largest phylum of Animalia which includes insects with jointed legs and sclerotised exoskeleton. Their body is divided into three parts or tegmata, **i.e., head**, **thorax** and **abdomen**. They are haemocoelomates, **i.e.,** true coelom is replaced by haemocoel (pseudocoel with blood). The body appendages are variedly modified in different arthropods to perform various functions.



Peculiar Features

- They are the first animals to have an **endoskeleton** and **voluntary muscles** in their body wall.
- They have well-developed sensory organs which include antennae, sensory hair, simple or compound eyes, auditory organs and statocyst.
- They have well-developed **endocrine system** containing glands like corpora cardiaca, corpora allata, etc.
- Mouth is always surrounded by mouth parts of different types in different animals.



Arthropods have special respiratory and excretory structures as follows

Respiratory Structures

- **Trachea** e.g., insects and some spiders.
- **Book Lungs** e.g., scorpions.
- **Gills** e.g.,prawns and crabs.
- **Book Gills** e.g., king crab.

Excretory Structures

- **Antennary or green glands** e.g.; crustaceans
- **Malpighian tubules** e.g.; insects
- **Coxal glands** e.g.; scorpions and most spiders

- Their nervous system possesses all the three types, **i.e., central**, **peripheral** and **autonomic**.

Reproduction

Sexes are separate and fertilisation is internal. These animals are generally oviparous or ovoviviparous.

Development may be direct (**e.g.,** cockroach) or indirect. Some arthropods undergo parthenogenesis, **e.g.,** drones of honeybee.

Classification of Arthopoda

Phylum–Arthropoda

Three sub-phyla

Chelicerata
- Body is divided into cephalothorax (prosoma) and abdomen (opisthosoma), cephalothorax is covered by a carapace. Antennae are absent.
- Mandible absents.

Trilobitomorpha
- Extinct group

Mandibulata
- Body is divided into cephalothorax and abdomen.
- One or two pairs of antennae present.
- One pair of mandible presents.

Three classes (of Chelicerata)

Mesostomata
- Aquatic (marine)
- Abdomen ends into a spike-like telson, e.g., Limulus and Eurypterus.

Arachnida
- Mostly terrestrial, some parasitic.
- Abdomen lacks locomotory appandages. e.g., Aranaea, Palamnaeus

Pycnogonida
- Marine
- Abdomen is reduced, e.g., Pycnogonum.

Four classes (of Mandibulata)

Crustacea
- Mostly aquatic, few are terrestrial or parasitic.
- Body is divisible into two parts, i.e., cephalothorax and abdomen.
- Exoskeleton is calcified.
- Excretion by green glands, e.g., Cyclops and Sacculina.

Chilopoda
- Terrestrial
- Body is divisible into two part, i.e., head and trunk.
- Exoskeleton is uncalcified.
- One pair of Malpighian tubule is present, e.g., Scolopendra and Lithobius.

Diplopoda
- Terrestrial
- Body is divisible into three parts, i.e., head, thorax and abdomen.
- Calcified
- Two pairs of Malpighian tubules present, e.g., Julus and Glomeris.

Insecta
- Found in all habitats.
- Body is divisible into three parts, i.e.,head, thorax and abdomen.
- Uncalcified
- Two to many pairs of Malpighian tubules are present, e.g., Mantis and Lepisma.

Common and Scientific Names of Some Arthropods

Common Names of Arthropods	Scientific Name	Common Names of Arthropods	Scientific Name
Walking worm	**Peripatus**	Grasshopper	**Poecilocercus**
Prawn	**Palaemon**	House cricket	**Gryllus**
Spiny lobster	**Palinurus**	Praying mantis	**Mantis religiosa**
Brown crab	**Cancer**	Earwig	Forficula
Root-headed barnacle	**Sacculina**	Dragon fly	**Sympetrum**
Hermit crab	**Eupagurus**	Silkmoth	**Bombyx mori**
Goose-barnacle	**Lepas**	Yellow wasp	**Polistes**
Rock barnacle	**Balanus**	Honeybee	**Apis indica**
Silverfish	**Lepisma**	Millipede	**Thyroglutus**
Cockroach	**Periplaneta**	Centipede	**Scolopendra**
Desert locust	**Schistocerca**	Horseshoe crab	**Limulus**

Economic Importance

- **Limulus** is a living fossil.
- Honeybee produces wax and honey.
- **Peripatus** acts as a connecting link between Arthropoda and Annelida.
- Prawn and lobster are used as food in many countries.
- **Microtreme** (white ant-termite) causes loss to furniture and other wooden articles.

Phylum–Mollusca

Phylum–Mollusca is the second most abundant phylum which contains soft-bodied animals usually protected by a calcareous shell and a ventral muscular foot. The study of molluscs is called **Malacology**, while study of molluscan shell is called **Concology**.

Peculiar Features

- They generally have an exoskeleton of calcareous shell which may be internal or absent.
- Body is divisible into three parts, **i.e.,** head, foot and mantle cavity.
- A glandular fold called **mantle** or **pallium** is present in the body wall.
- A rasping organ called **radula** is present in buccal cavity of most of molluscs.
- A peculiar sense organ called **osphradium** check the quality of water.

Respiration occurs by the following structures

Respiratory Structures

- Gills/Ctenidia, e.g., Pila, Patella
- Pulmonary sac e.g., Limax.
- Gills + Pulmonary sac, e.g., Pila.

Excretion occurs by 1 or 2 pairs of metanephridial tubules called **kidneys** or **organs of Bojanus**. Pelecypods also have a large, reddish-brown **Keber's organ** in front of pericardium for excretion. Nervous system is formed of 3-paired ganglia, **i.e.,** cerebral, pedal and visceral ganglia.

Reproduction

Sexes are usually dioecious, but some are hermaphrodite, **e.g., Doris, Limax**, etc. Most forms are oviparous, but only a few are viviparous (**e.g., Pecten**). Fertilisation is external (**e.g., Patella**) or internal (**e.g., Pila**).

Development is either direct (**e.g.,** all pulmonates and cephalopods) or indirect including **trochophore**, (**e.g., Chiton**) or **glochidium** (**e.g., Unio**) or **velliger** (**e.g., Dentalium**) larvae.

Classification of Mollusca

Phylum–Mollusca

Scaphopoda
- Tusk-like shell opens at both sides.
- Head is absent.
- Radula is present.
- Foot is conical-shaped for digging.

e.g., Dentalium.

Monoplacophora
- Limpet-shaped shell formed of single value.
- Head bears tentacles, but eyes are absent.
- Radula is present.
- Foot is broad and flat and has 8 pairs of pedal retractor muscles,

e.g., Neopilina.

Pelecypoda (Bivalvia)
- Two-valved shell.
- Head is absent.
- Radula is absent.
- Foot is wedge-shaped and muscular for creeping or burrowing.
- Absent in sedentary forms.

e.g., Pecten.

Amphineura
- Shell is formed of 8 plates.
- Head is reduced and lacks tentancles and eyes.
- Radula is usually present.
- Foot is large, flat and muscular.
- Absent in some forms,

e.g., Chiton.

Gastropoda
- Spirally coiled shell, but absent in pulmonates.
- Head bears both eyes and tentancles.
- Radula is present.
- Foot is large and flat for creeping and attachment,

e.g., Pila.

Cephalopoda (Siphonopoda)
- Externally spiral shell.
- Well-developed, internal or absent.
- Head bears a pair of large complex eyes.
- Radula is present.
- Foot is partially modified into 8-10 suckers and partially into siphon or funnel.

e.g., Octopus.

Common and Scientific Names of Some Molluscs

Common Names of Molluscans	Scientific Name	Common Names of Molluscans	Scientific Name
Sea mussel	**Mytilus**	Sea lemon	**Doris**
Edible oyster	**Ostrea**	Grey slug	**Limax**
Cockle	**Cardium**	Squid	**Loligo**
Rock-borer	**Pholas**	Cuttlefish	**Sepia**
Razor clam	**Solen**	Devil fish	**Octopus**
Scallop	**Pecten**	Pearly nautilus	**Nautilus**
Ear shell	**Haliotis**	Tusk shell	**Dentalium**
True limpet	**Patella**	Coat of mail shell	**Chiton**
Sea hare	**Aplysia**		

Economic Importance

- Molluscans like oyster, squid and cuttlefish are used as food in many countries.
- Shell of many molluscans is of ornamental value.
- **Dentalium** is used as decorative piece.
- **Sepia** ink has medicinal value.

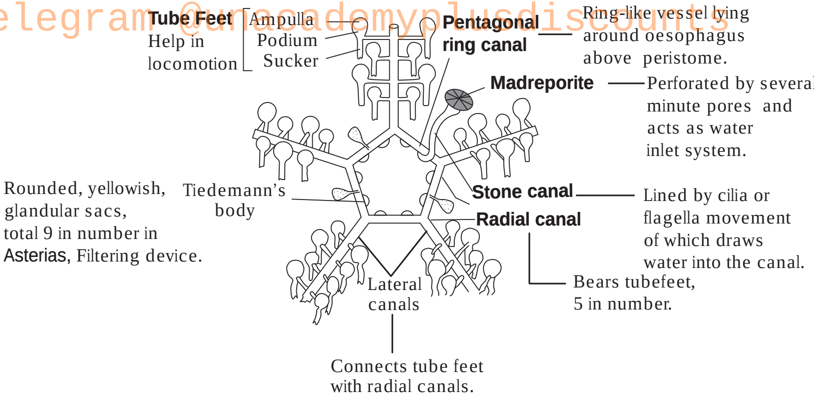
Phylum–Echinodermata

It is a group of exclusively marine, spiny-skinned animals. These triploblastic animals form the only phyla (except Chordata) which contains true endoskeleton (mesodermal origin).

Peculiar Features

- Adults with pentamerous radial symmetry, while larval forms with bilateral symmetry.
- Great power of **autotomy** and **regeneration**.
- Body surface of five symmetrical radiating areas or ambulacra and alternating between interambulacra. Ambulacra have tube feet for locomotion, respiration, etc.

- The presence of water vascular system of coelomic origin.



Water vascular system in Asterias

Degenerate Characters

- Head, respiratory pigment and excretory organs are absent.
- Sense organs are poorly developed.
- Nervous system is formed of nerve plexi.
- Circulatory system is of open type.

Classification of Echinodermata

Phylum–Echinodermata

Five classes

Asteroidea
- Star-shaped body with pentagonal disc.
- 5-50 arms are present.
- Bipinnaria larva, e.g., Asterias.

Ophiuroidea
- Star-shaped body with rounded disc.
- 5-7 arms are present.
- Pluteus larva, e.g., Ophiothrix.

Echinoidea
- Spherical, oval or heart-shaped body.
- Arms are absent.
- Echinopluteus larva, e.g., Echinus.

Holothuroidea
- Elongated and cylindrical body.
- Arms are absent.
- Auricularia larva, e.g., Holothuria.

Crinoidea
- Contains mostly extinct forms, e.g., Antedon.

Common and Scientific Names of Some Echinoderms

Common Names of Echinoderms	Scientific Name	Common Names of Echinoderms	Scientific Name
Starfish	**Asterias**	Basket star	**Gorgonocephalus**
Sea urchin	**Echinus**	Feather star	**Antedon**
Brittle star	**Ophiothrix**		

Economic Importance

- **Antedon** is supposed to be a living fossil.
- Eggs of sea urchin are used for embryological studies.
- Sea cucumber is used as food in many countries.

Phylum–Hemichordata

It includes acorn worms or tongue worms. These are commonly called **half chordates** or **pre-chordates**. They are exclusively marine, mostly tubicolous, primitive chordates. They are bilaterally symmetrical, triploblastic and enterocoelic true coelomates.

Peculiar Features

- Body is divided into three regions, **i.e.,** proboscis, collar and trunk.
- Their foregut gives out a thick and stiff outgrowth called **stomochord** or **buccal diverticulum**.
- Excretion occurs by a proboscis gland or glomerulus present in the proboscis in front of heart.
- Nervous system is of primitive type containing sub-epidermal nerve plexus.

Reproduction

They mainly reproduce by sexual reproduction. Sexes are usually separate and number of gonads varies from one to several pairs.

Fertilisation is external. Development is direct or indirect with a free-swimming tornaria larva.

Economic Importance

They show affinities with annelids, echinoderms and chordates.

Phylum–Chordata

Animals belonging to phylum–Chordata are characterised by the presence of **notochord**, **dorsal tubular nerve cord**, **gill-clefts** and **post-anal tail**. These four structures are found in the embryological stages of all chordates.

Notochord

It serves as a primitive internal skeleton. It may persist throughout life, as in cephalochordata, cyclostomata and some fishes. It may be replaced partially or completely by a backbone or vertebral column.

Dorsal Tubular Nerve Cord

It lies above the notochord and persists throughout life in most chordates, but in a few it degenerates before maturity.

Gill Clefts

They appear during the development of every chordate, but in many aquatic forms, they are lined with vascular lamellae which form gill for respiration.

Post-anal Tail

An extension of the body that runs past the anal opening.

In terrestrial chordates which never breathe by gills, traces of gill clefts are present during early development, but disappear before adult life.

Classification of Chordata

The various sub-phyla and divisions are already explained in the chapter starting.

Major classes of Chordata are discussed below

Pisces

Three classes

Chondrichthyes

- Cartilaginous endoskeleton.
- Exoskeleton is of placoid scales (dermal origin).
- Mouth is placed ventrally.
- External nares are ventral to head.
- Caudal fin is heterocercal.
- 5-7 pairs of gills are present.
- Swim bladder is absent.
- Gills are not covered by operculum.
- Electric organs (e.g., Torpedo) and poison sting (e.g., Trygon) are present.
- Mostly viviparous, e.g., Scoliodon (dog fish), Pristis (saw fish), Trygon (sting ray), Carcharodon (great white shark), Chimaera (rabbit fish) and Rhinobatos.

Osteichthyes

- Bony endoskeleton.
- Exoskeleton comprises cycloid, ctenoid or ganoid scales (mesodermal origin).
- Mouth is terminal.
- External nares are dorsal to head.
- Caudal fin is homocercal.
- Four pairs of gills are present.
- Swim bladder is present.
- Gills are covered by operculum.
- Electric organs all absent
- Mostly oviparous, e.g., Labeo (rohu), Clarias (magur), Pterophyllum (angel fish),Betta (fighting fish), Catla and Exocoetus (flying fish).

Placodermi

- Includes earlier fossils
- Body is with an external protective armour of bony scales or plates
- Jaws are primitive with teeth, e.g., Climatius, Palaeospondylus.

Tetrapoda

Four classes

Amphibia

- Cold-blooded.
- Skin is smooth . and glandular.
- Heart is with two auricles and one ventricle.
- Respiration occurs by lungs, buccopharyngeal cavity, skin and gills.
- RBCs are nucleated.
- They have largest RBCs of animal kingdom.
- Two pairs of limbs, each with five-toes.
- Skull is dicondylic.
- Fertilisation is external, oviparous.

Reptilia

- Cold-blooded.
- Skin is cornified and covered with scales.
- Heart consists of two. auricles and partly divided ventricle.
- Respiration occurs by lungs.
- RBCs are nucleated.
- Two pairs of pentadactyl limbs, each with 5 digits bearing claws corneoscutes. In snakes, limbs are absent.
- Skull is monocondylic.
- Thecodont teeth.
- Fertilisation is internal, oviparous.

Aves

- Warm-blooded.
- Skin is covered by feathers,
- Heart contains two auricles and two ventricles.
- Respiration occurs by lungs provided by air sacs.
- RBCs are nucleated.
- Forelimbs are modified to wings and hindlimbs are modified for walking, swimming and pearching.
- Hindlimbs bear claws and scales.
- Skull is monocondylic.
- Teeth are absent and upper and lower jaws are modified into beak.
- Fertilisation is internal, oviparous.

Mammals

- Warm-blooded.
- Skin is covered by epidermal hairs.
- Heart contains two auricles and two ventricles.
- Respiration occurs by lungs.
- RBCs are enucleated.
- Quadruped limbs whose digit ends with claws or nails or hooves.
- In whales and dolphins, limbs are absent.
- Skull is dicondylic.
- Thecodont, heterodont and diphyodont teeth.
- Fertilisation is internal,both oviparous and viviparous.

Amphibia

Class-Amphibia consists of two sub-classes, **i.e.**, **Stegocephalia** (extinct) and **Lissamphibia** (modern living amphibians). In contrast to Stegocephalia whose skin bears scales and bony plates, Lissamphibians do not possess bony dermal skeleton.

Lissamphibia is further divided into three orders as follows

Lissamphibia

Three orders

Apoda/Gymnophiona/Caecillians

- Also called **limbless amphibians**.
- Long worm-like, burrowing, dermal scales present in skin.
- Tail short or absent, cloaca terminal.
- Skull compact, roofed with bone.
- Males have protrisible copulatory organ.
- Larva has 3 pairs of external gills, gills also present in adult stage.
- e.g., Ichthyophis (blindworm), Ureotyphus.

Anura/Salientia

- Also called tail-less amphibians.
- Commonly includes frogs and toads.
- Forelimbs shorter than hindlimbs.
- Adults without gills.
- Skin loosely fitting, scaleless, teeth present only on upper jaw or absent.
- Vertebral column very small of 5-9 procoelous.
- Vertebrae and a slender urostyle.
- Fertilisation always external.
- Full metamorphosis without neotenic forms e.g., Rana, Bufo, Hyla and Rhacophorus.

Urodela/Caudata

- Also called **tailed amphibians.** Lizard-like, limbs two pairs of weak and equal size.
- Commonly called newts and salamanders.
- Skin devoids of scales and tympanum.
- Possesses largest RBC.
- Gills permanant or lost in adults. (Necturus, Proteus, Siren and Axolotl larva have external gills). Fertilisation is internal.
- Larva aquatic, adult-like with teeth,
- e.g., Nectunes, Salotrandra and Ambystoma.

Reptilia

On the basis of the presence of **temporal fossae**, class–Reptilia is sub-divided into three sub-classes, **i.e.**, Anapsida, Parapsida and Diapsida.

These sub-classes are further divided into orders and sub-orders as follows

Class–Reptilia
(On the basis of temporal fossae)
Three sub-classes

Anapsida
Temporal fossae absent (extinct as well as living).

Parapsida
One temporal fossa presents (extinct only), e.g., Ichthyosaurus, Protosaurus and Opthalmosaurus.

Diapsida
Two temporal fossae present (extinct as well as living).

Anapsida — Two orders

Cotylosauria
e.g., Seymouria

Chelonia
Terrestrial, semiaquatic body covered with carapace. Cloacal aperture longitudinal one nasal aperture, oviparous, e.g., Chelone and Testudo.

Diapsida — Three classes

Rhynchocephalia
Lizard-like, nocturnal, carnivorous. Vertebra amphicoelous, transverse clocal aperture, no copulatory organ in males, e.g., Sphenodon.

Squamata
Living reptiles, movable quadrate, vertebrae procoelous, single-headed ribs, males possess paired copulatory organs (hemienis).

Crocodilia
Aquatic, large-sized, body covered with scales or body plates, ribs possess two heads, teeth thecodont, lungs in plural cavity, four-chambered, heart, diaphragm is also present.
e.g., Crocodilus, Gavialis and Aligator.

Squamata — Two sub-orders

Ophidia
Maxillae palatines, pterygoids movable, attached by ligaments, tympanum and nictitating membrane absent, tongue slender bifid, protrusible, all snakes, e.g., Naja, Crotalus, Python, Bungarus and Vipera.

Lacertilla
Terrestrial, arboreal or burrowing, two pairs of limbs, eyelids movable, all lizards are included in it, e.g., Calotes, Varanus, Chamaeleon and Hemidactylus.

Aves

Class–Aves possesses various peculiar characteristics which are not found in other animal groups. They possess long bones with air cavities, **i.e., pneumatic** bones which reduce their body weight and hence, helpful in flight. Their bones also lack bone marrow.

Their sternum is large and bears a keel for the attachment of flight muscles. They do not possess skin glands except the cutaneous oil glands or **green glands** (or uropygial glands) that are located at the root of the tail. These glands are absent in parrot and ostrich.

Class–Aves is further divided into sub-classes and orders as follows

Class–Aves

Two sub-classes

Archaeornithes

(Gk. archios–ancient;ornithes–bird)

Includes extinct (in Mesozoic era) birds, homodont (same type of teeth) teeth in both the jaw, long tapering tail, weak, vertebrae are amphicoelous, keeled sternum, non-pneumatic bones, hand with clawed fingers wings are primitive with little power of flight, e.g., Archaeopteryx lithographica (ancient or lizard bird) and Archaeornithes.

Neonithes

(Includes extinct as well as living birds)

Teeth absent except in some fossil birds, wings are well-developed and adapted for flight, tail short and reduced, fingers of the wings are without claw.

Four super-orders

Odontognathae

(Extinct cretaceous birds), jaw bears teeth for catching fish. e.g., Hesperornis, Ichthyornis.

Palaeognathae

(Flight less running birds)

- Wings vestigial or rudimentary, feathers without any interlocking mechanism.
- Oil gland is absent except in Tinamus and kiwi.
- Sternal keel is vestigial, flat or raft-like.
- Pygostyle is penis or reduced.
- Syrinx is absent.
- Male has a penis, e.g., Struthio camelus (African ostrich), Rhea americana (American ostrich), Dromaeus (emu), Casurarius (cassowary) Apteryx (kiwi), Tinamus (tinamou).

Impennae

- The super-order includes modern aquatic flightless birds with paddle-like wings or flippers.
- Feet are webbed.
- The skeleton is solid, air sacs are absent.
- The integument is a fatty insulating layer, e.g., Aptenodytes (emperor penguin), Eudyptes (rock hopper penguin).

Neognathae (Carinatar)

- Modern flying birds, with well-developed wings and feathers with interlocking mechanism.
- Sternum with developed keel.
- Males have no copulatory organ.
- Some important order of flying birds are **Gaviiformes,** e.g.,divers. **Procellariiformes,** e.g., albatross. **Anseriformes**, e.g.,swans, geese and ducks. **Falconiformes,** e.g.,vultures, eagles, hawks and falkons. **Gruiformes**. e.g., pheasants. **Columbiformes**, e.g., pigeons. **Psittaciformes**, e.g., parrots. **Cuculiformes**, e.g.,cuckoo. **Coraciiformes**, e.g., kingfishers. **Passeriformes**, e.g., crow and thrashers.

Flight Adaptation in Birds

In birds almost every system is modified to support flight as given under

- The feathers constitute very smooth covering over the body to reduce the friction of air. Due to non-conducting nature of these, body temperature is maintained. Feathers of tail (rectrices) form fan-like structure and steer the body during flight.
- Wings (remiges) act as main organ of flight with association of feathers. They are responsible for supporting the bird during the flight. Remiges are attached by ligament or directly to the bone.
- The bones are light, hollow and provide more space for the muscle attachment.

Types of Feathers

Body in birds is covered by feathers made up of keratin protein. An arrangement of feathers on the body of birds is called **pterylosis**. **An outline of these feathers are as follows**

1. **Contour feathers** These are small feathers that cover the body, wings and tail. Each contour feather has a central axis and a vane.
2. **Flight feathers or Quills These are useful in flights and can be of following types**
   (i) **Remiges These are large wing feathers and further categorised to**
      (a) **Primaries** which are attached to the bones of the hand.
      (b) **Secondaries** which are attached to the bones of the forearm.
      (c) **Tertiaries** which are attached to the humerus of upper arm bone.
   (ii) **Retrices** These are large tail feathers.
   (iii) **Coverts** These are found at the edge of remiges and rectrices.
3. **Filoplumes** These are hair-like feathers scattered over body surface and lie between the contour feathers. These act as sensory organs, registering pressure and vibration.
4. **Bristles** Modified filoplumes found in certain birds near nostrils and eyes. These are used as a touch sensor or funnel that makes the bird reflexively snap up food.
5. **Down feathers** Found only in the newly hatched birds. These form their first feathery covering, which provides insulation.

Mammalia

Class–Mammalia is considered to be superior of all animal groups. This class is further divided into two sub-classes.

The detailed classification of class–Mammalia is as follows

Class–Mammalia

Sub-classes

Prototheria

(Most primitive mammals)

- Oviparous
- No pinna
- No nipples
- No marsupial pouch
- Digestive and urinogenital tracts open into a cloaca, cloacal opens outside through cloacal aperture
- Corpus collosum is feebly developed or absent
- Testes abdominal, no scrotum.
- No placenta .

Order

Monotremata

(connecting link between reptile and mammals)

e.g., Ornithorhynchus (duck-billed platypus), Tachyglossus or Echidna (spiny anteater).

Theria

Infra-classes

Metatheria

(Australian mammals)

- Viviparous
- Pinna presents
- Nipples abdominal
- Marsupial or abdominal pouch often present.
- Anus and urinogenital aperture open into a shallow cloaca surrounded by a common sphincter.
- Corpus callosum is not developed or absent.
- Testes extra abdominal, scrotum lies anterior to penis.
- Placenta is less developed.

Order

Marsupialia

(pouched mammals)

e.g., Macropus (kangaroo), Phascolarctos (kolabear), Didelphys (opossum).

Eutheria

(Placental mammals)

- Viviparous
- Pinna usually presents
- Nipples abdominal or thoracic
- Marsupial pouch absent
- Digestive and urinogenital tracts open out be separate apertures.
- Corpus callosum is well - developed.
- It connects two hemisphere internally.
- Testis extra abdominal, scrotum lies below to penis.
- Placenta is less developed.

Comparative Analysis of Various Phyla of Animal Kingdom

Phylum	Porifera	Coelenterata	Ctenophora	Platyhelminthes	Aschelminthes
Organisation level	Cellular level	Tissue level	Tissue level	Organ and organ system level	Organ system level
Symmetry	No clear symmetry	Radial symmetry	Radial symmetry	Bilateral symmetry	Bilateral symmetry
Coelom	Absent	Absent	Absent	Absent	Pseudocoelomate
Segmentation	Absent	Absent	Absent	Absent	Absent
Digestive system	Absent	Incomplete	Incomplete	Incomplete	Complete
Circulatory system	Absent	Absent	Absent	Absent	Absent
Respiration	Absent	Absent	Absent	Absent	Absent
Distinctive feature	Pores and canal system	Cnidoblast cells	Comb plate for movement	Suckers, flat body and hooks.	Elongated worm-like
Example	**Sycon**, **Spongilla** and **Euspongia.**	**Physalia**, **Adamsia** and **Pennatula.**	**Ctenoplana** and **Pleurobrachia.**	**Taenia** and **Fasciola.**	**Ascaris**, **Wuchereria** and **Ancylostoma.**

Comparative Analysis of Various Phyla of Animal Kingdom

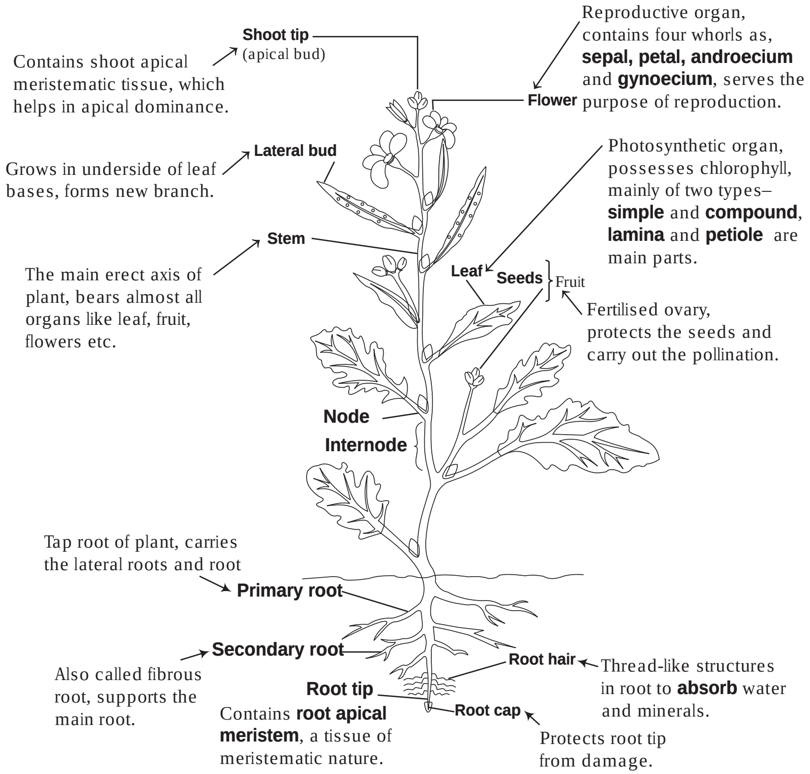
Annelida	Arthropoda	Mollusca	Echinodermata	Hemichordata	Chordata
Organ system level	Organ system level	Organ system level	Organ system level	Organ system level	Organ system level
Bilateral symmetry	Bilateral symmetry	Bilateral symmetry	Radial symmetry	Bilateral symmetry	Bilateral symmetry
Coelomate	Coelomate	Coelomate	Coelomate	Coelomate	Coelomate
Present	Present	Present	Absent	Absent	Present
Complete	Complete	Complete	Complete	Complete	Complete
Present	Present	Present	Present	Present	Present
Absent	Present	Present	Present	Present	Present
Segmented body	Joint appendage and exoskeleton	Shell present on body	Radial body with water vascular system	Worm-like body with proboscis, collar and trunk	Notochord, nerve cord, gills and lungs.
Nereis, Pheretima and **Hirudinaria.**	**Apis, Bombyx, Anopheles** and **Locusta.**	**Pila, Sepia** and **Octopus.**	**Asterias, Echinus, Cucumaria** and **Ophiura.**	**Balanoglossus** and **Saccoglossus.**	Fish, birds, amphibians, reptiles and mammals.

5

Morphology of Flowering Plants

Plant Morphology : An Overview

Flowering plants or angiosperms show large diversity in external structures or morphology. **A generalised morphology of these plants is as follows**



A typical flowering plant

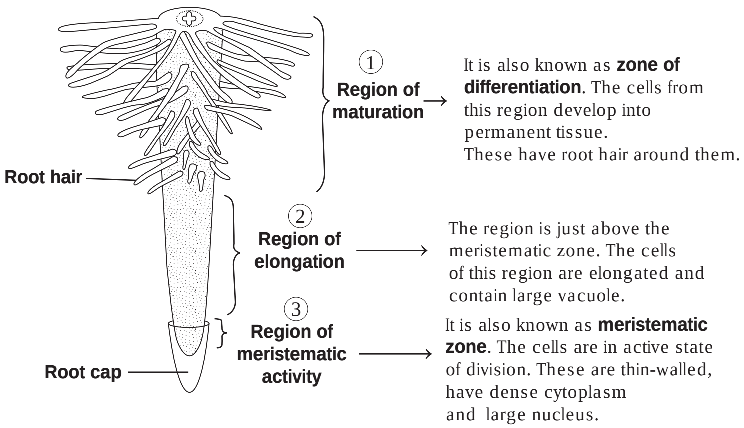
Various components of plant's morphology and their structures are discussed here.

Root

It is generally a non-green, underground, positively geotropic, positively hydrotropic and negatively phototropic, descending cylindrical axis of the plant body which develops from the radicle of the embryo. It is without node, internode, leaves, buds, flowers and fruits. Its main function includes anchorage to the plant along with water and mineral absorption.

Structure of Root

Generally, the root in plants is divided into three main regions. **These are**



The regions of the root-tip

Root cap A smooth cap-shaped structure to provide protection to the young apical cells against soil particles is called root cap.

Types of Root

There are two types of root

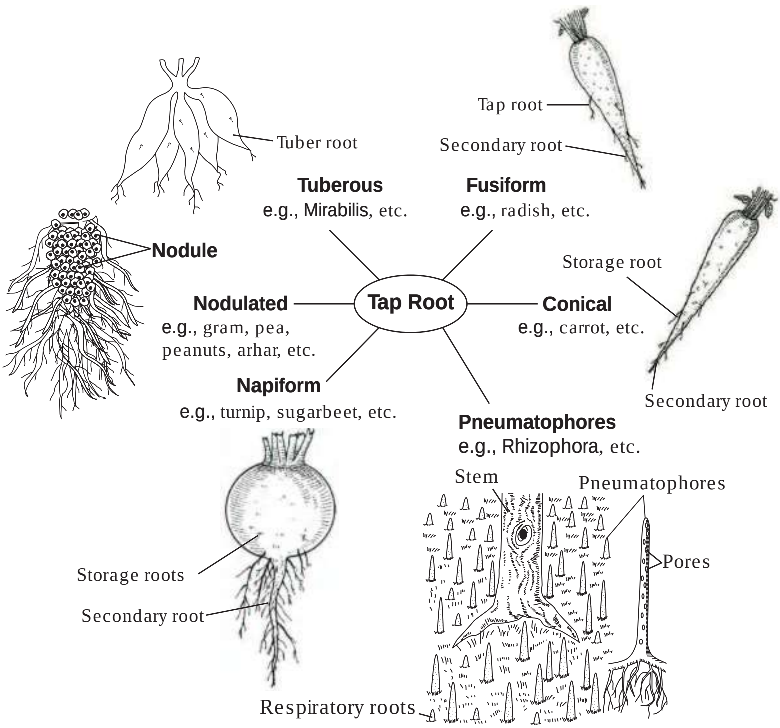
(i) **Tap root** Primary root further branches into secondary and tertiary roots, **e.g.,** dicotyledonous root.

(ii) **Adventitious root** In this, the radicle dies immediately after germination, hence these roots arise from different portions of the plant, **e.g.,** monocotyledonous root.

Modifications of Roots

Both, tap roots and fibrous roots are modified, according to their need.

1. Modifications of Tap Roots



Various modifications of tap root

- **Pneumatophores** are present in plants of coastal habitat. These roots absorb oxygen.
- **Nodulated roots** in leguminous plants form nodules after combining with nitrogen-fixing bacteria. They are meant for nitrogen-fixation.

2. Modifications of Adventitious Roots

(i) **Tuberous** From the nodes of the stem, **e.g.,** sweet potato.
(ii) **Fasciculated** Arise in bunches, **e.g., Asparagus**, **Dahlia**.
(iii) **Beaded root** Swell at different places, **e.g., Vitis**,. bitter gourd, etc.
(iv) **Nodulose** Apical portion swells up, **e.g., Curcuma**, maranta etc.

(v) **Annular** Ring structure formed, **e.g., Psychortia, cephaelis.**

(vi) **Prop roots** Roots hang from branches and penetrate into soil, **e.g.**, **Ficus**, banyan.

(vii) **Stilt Roots** They arise from stem and enter into soil, **e.g.**, maize, sugarcane, etc.

(viii) **Climbing roots** Arise from nodes, **e.g., Pothos**, piper bettle.

(ix) **Buttress roots** Arise from basal part of main stem, **e.g.**, **Bombax.**

(x) **Contractile roots** Underground and fleshy, **e.g.**, onion, etc.

(xi) **Sucking roots** In parasites, **e.g., Cuscuta**.

(xii) **Epiphytic roots** Found in epiphytes, **e.g.,** orchids.

(xiii) **Floating roots** Arise from nodes, help in floating, **e.g., Jussiaea**.

(xiv) **Photosynthetic roots** Have chlorophyll, **e.g., Trapa**, **Tinospora**.

(xv) **Reproductive roots** Develop vegetative buds, **e.g.**, **Trichosanthes dioica.**

(xvi) **Mycorrhizal roots** With fungal hyphae, **e.g., Pinus**.

(xvii) **Thorn roots** Serves as protective organ, **e.g.**, **Pothos**.

(xviii) **Clinging roots** Arise from node and pierce into host plant, **e.g.,** Orchid, **Ivy** etc.

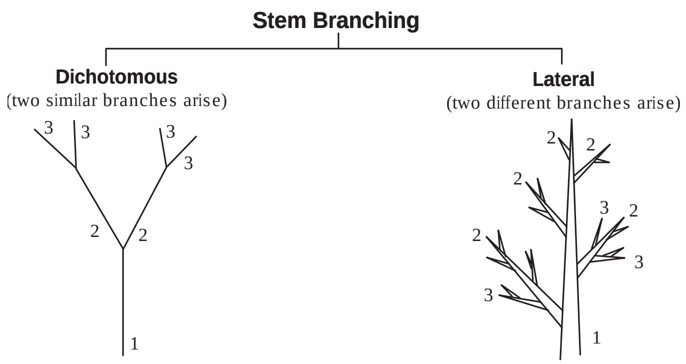
(xix) **Leaf roots** From margin of leaves, **e.g., Bryophyllum**.

Stem

It is the ascending cylindrical axis of plant body which develops from the plumule of the embryo and grows by means of terminal bud. This is usually negatively geotropic and positively phototropic. Its major function is to conduct water, minerals and photosynthates and to support the plant body.

Stem Branching

There are two types of branching



Branching patterns in stem

Types of Stem

Stems are of three types

1. Aerial 2. Sub-aerial 3. Underground

Different types of stems, actually are the modified stem. The modifications are to serve various purposes like **perennation**, **vegetative reproduction** and **storage of food**.

1. Aerial/Epiterranean Stem Modifications

These are of following types

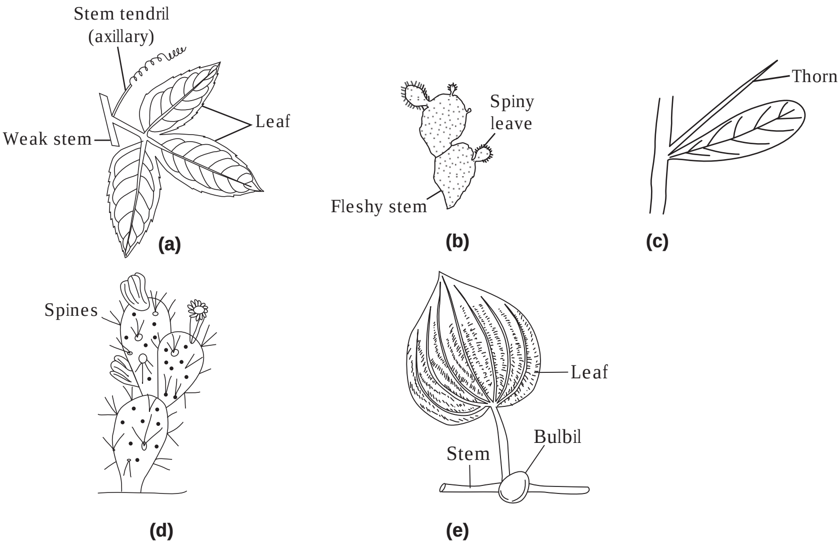
(i) **Stem tendril** In weak plants with weak stem, the apical bud is modified into tendril for climbing, **e.g., Vitis, Passiflora**, etc.

(ii) **Phylloclade** In this, the stem is modified into flat, fleshy and green leaf-like structure, **e.g., Opuntia**, **Cocoloba**, **Ruscus**, etc.

(iii) **Stem thorn** Axil of the leaf or apex of the branch is modified into pointed structure called thorn, **e.g., Citrus**, **Bougainvillea**, etc.

(iv) **Cladode** Stem is modified into leaf-like structure, **e.g., Asparagus**.

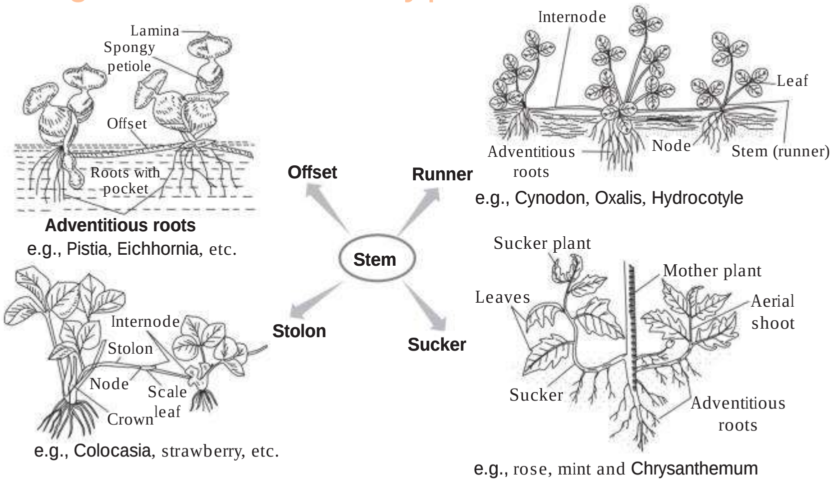
(v) **Bulbil** A multicellular structure functions as organ of vegetative reproduction, **e.g., Oxalis, Dioscorea**, etc.



Aerial stems : (a) Stem tendril in Vitis, (b) Phylloclade of Opuntia, (c) Stem thorn of Bougainvillea, (d) Cladode in Asparagus, (e) Bulbil in Dioscorea

2. Sub-Aerial/ Prostrate Stem

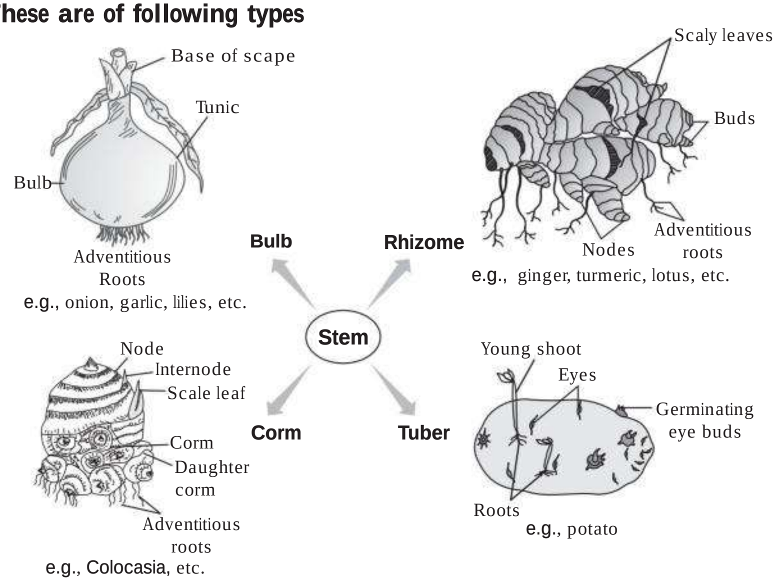
These are of following types



Sub-aerial modifications in stem

3. Underground/Subterrannean Stem

These are of following types



Underground modifications in stem

Leaf

It is an exogenous, lateral, generally flattened outgrowth that arises from the node of the stem and bears a bud in its axil. The leaves are the most important vegetative organs for photosynthesis and also perform gaseous exchange and transpiration.

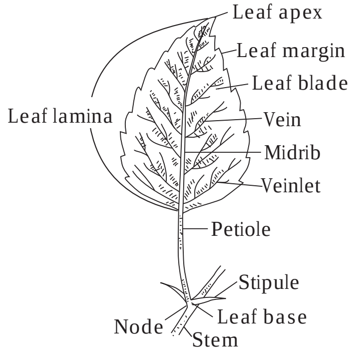
Parts of Leaves

A typical leaf has three main parts

(i) **Leaf base** Part of leaf attached to the stem by the leaf base.

(ii) **Petiole** Part of leaf that connects lamina to stem.

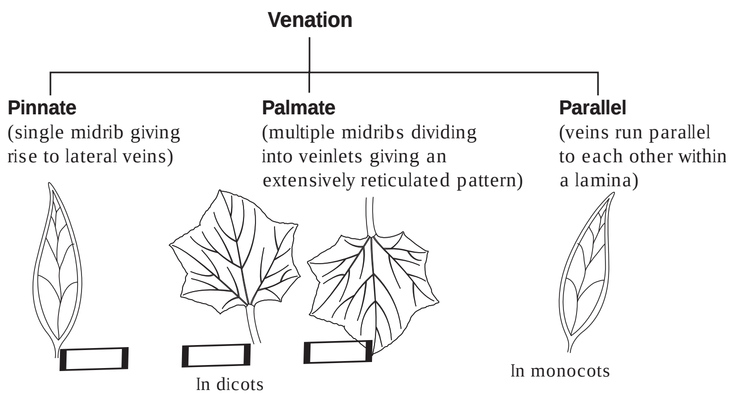
(iii) **Lamina or leaf blade** Flattened part of the leaves, which contains veins.



Typical leaf with its parts

Leaf Venation

The arrangement of veins in lamina is known as venation.



Different venation patterns in leaves

Types of Leaves

On the basis of incision of lamina, leaves may be of two types

1. Simple Leaves

In this, there is a single lamina, which is usually entire, **e.g.,** mango, guava, **Cucurbita**, etc. fig. (a).

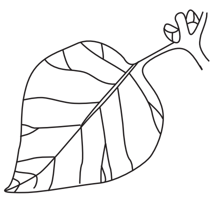
2. Compound Leaves

In this type of leaves, the incision of lamina, reaches up to midrib or petiole, **e.g.,** rose, neem, lemon, etc.

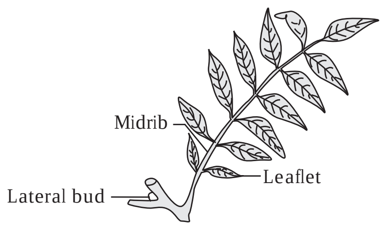
These are of two types

(i) Pinnately compound leaves (a number of leaflets present on rachis representing midrib of the leaf) fig. (b).

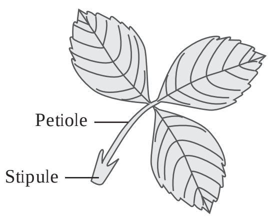
(ii) Palmately compound leaves (leaflets attached at a common point, **i.e.,** at the tip of petiole) fig. (c).



(a) Simple leaf of lilac



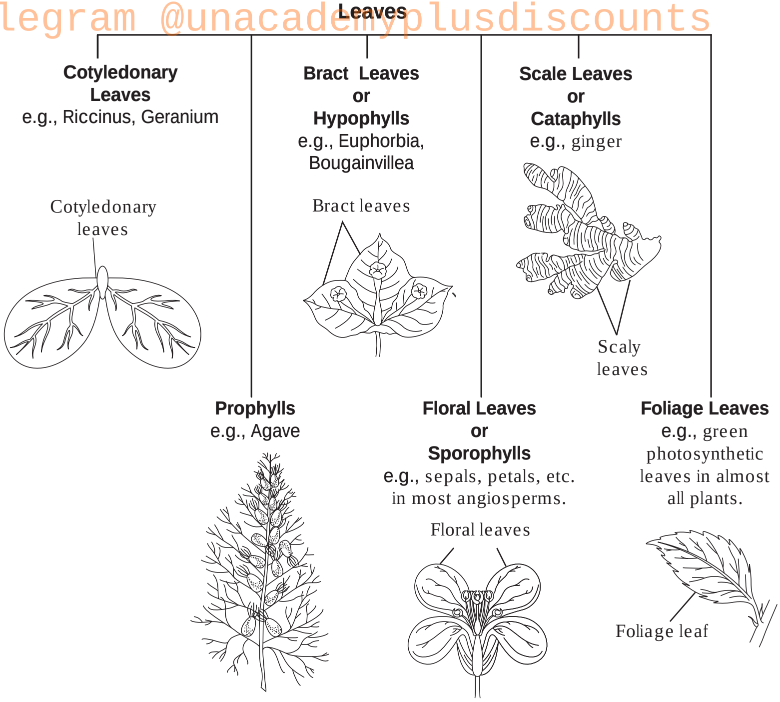
(b) Pinnately compound leaf of neem



(c) Palmately compound leaf of strawberry

Types of leaves

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

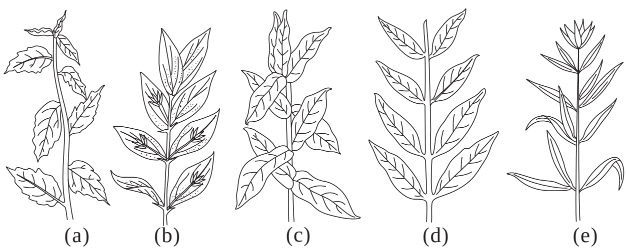


Types of different functional leaves

Phyllotaxy

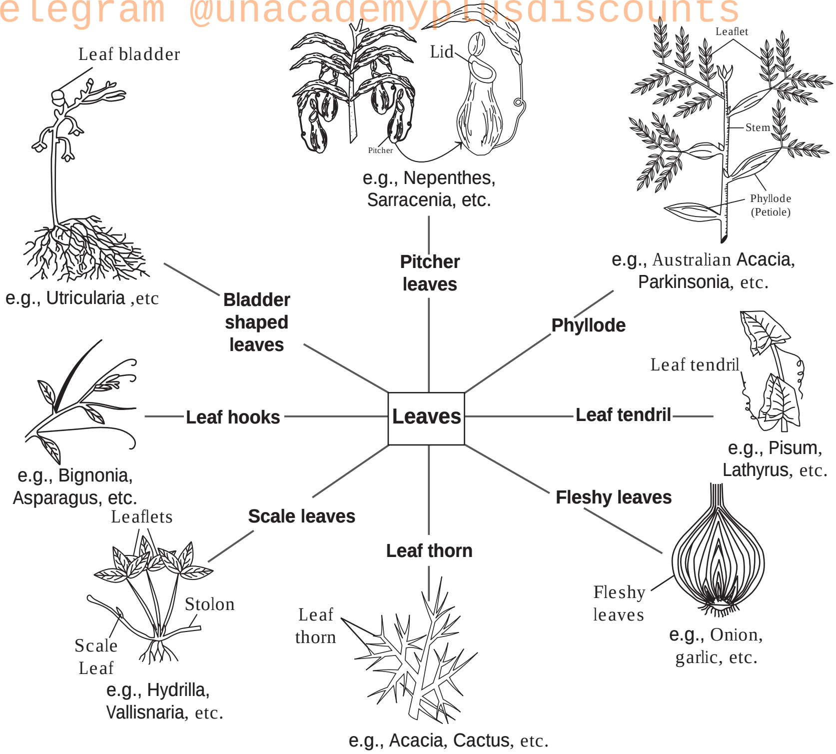
Arrangement of leaves on main stem or branches is known as phyllotaxy. There are 5 main types of phyllotaxies, reported in plants.

The various phyllotaxies can be understood through following figures



Types of phyllotaxy (a) Cyclic (b) Alternate (c) Opposite decussate, (d) Opposite superposed (e) Whorled or verticillate

Modifications of Leaves



Various leaf modifications

Inflorescence

The Shoot Apical Meristem (SAM) changes into floral meristem to form a flower and this flower bearing branch is called **peduncle**. The arrangement of flowers on floral axis is termed as **inflorescence**.

It can also be defined as 'system of branches bearing flower.'

Types of Inflorescence

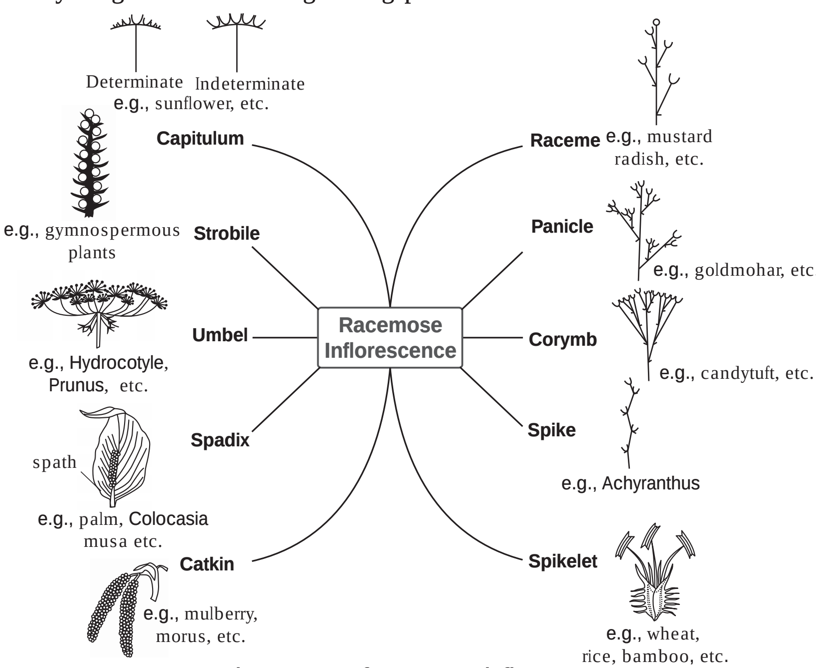
On the basis of the **mode of branching** and **modification of the peduncle, the inflorescence is of following types**

Types of Inflorescence

- **Recemose or indeterminate or indefinite**
  - Raceme (mustard)
  - Panicle (gold mohur)
  - Corymb (candytuft)
  - Spike (bottle brush)
  - Spikelet (wheat)
  - Catkin (mulberry)
  - Spadix (palm)
  - Umbel (coriander)
  - Capitulum or head (sunflower)
  - Strobile (hop)
- **Cymose or determinater or definite**
  - Uniparous or monochasial cyme (potato)
  - Biparous or dichasial cyme (night jasmine)
  - Polychasial or Multiparous cyme (Dianthus)
  - Cymose head (keekar)
  - Scapigerous
- **Compund**
  - Thyrus (grapevine)
  - Mixed spadix (banana)
  - Scorpigerus cyme umbel (onion)
  - Cymose corymb (Ixora)
  - Mixed panicle (Ligustrum)
- **Special type**
  - Cyathium (Euphorbia)
  - Verticillaster (Ocimum)
  - Hypanthodium (Peepal)
  - Coenanthium (Dorstenia)

Racemose/Indeterminate/Indefinite Inflorescence

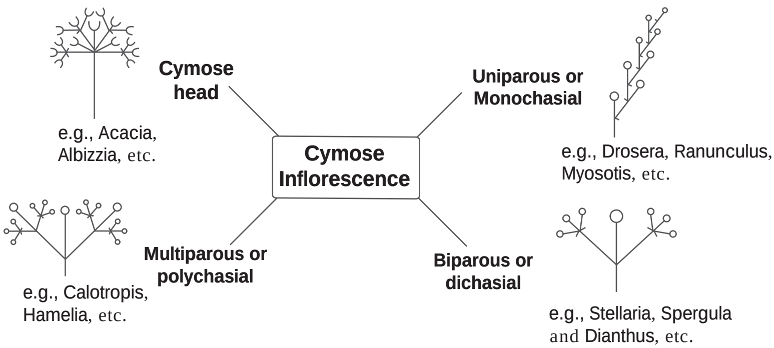
The peduncle continues to grow, forming new bracts and flowers in succession (acropetal manner). In this, the oldest flower is near to base and youngest is near the growing point.



Various types of racemose inflorescence

Cymose/Determinate/Definite Inflorescence

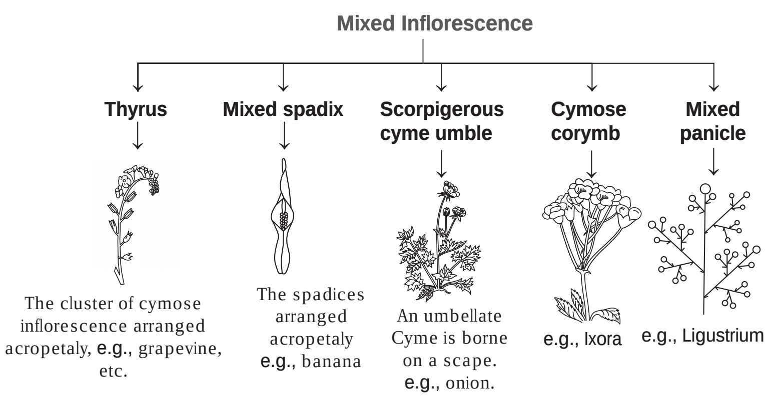
In this type of inflorescence, the apical meristem of peduncle produces the first flower while, the other flowers originate from lateral branches from the axis below. The oldest flower remains in centre and the youngest towards periphery, this arrangement is called centrifugal or basipetal sequence.



Various types of cymose inflorescences

Compound/Mixed Inflorescence

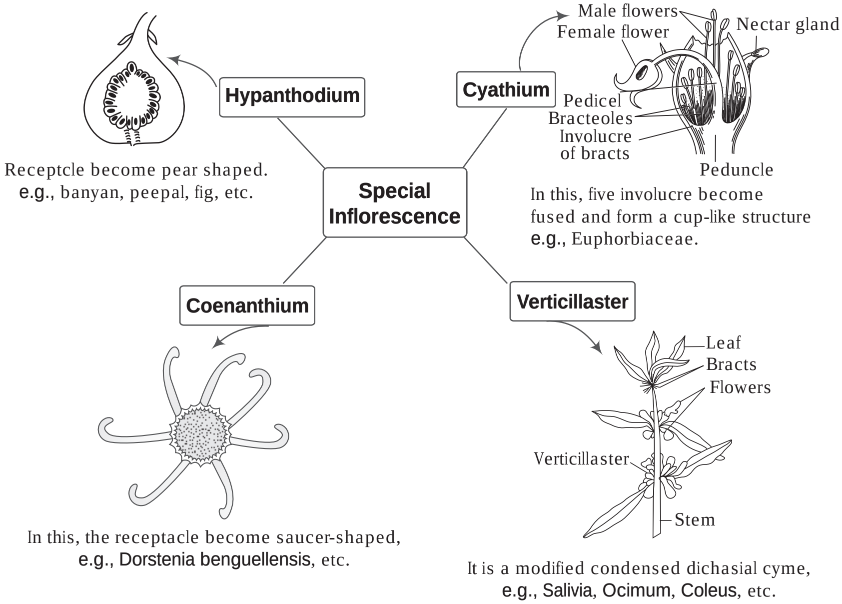
In this, the peduncle or main axis branches repeatedly once or twice in racemose or cymose manner.



Various types of compound inflorescences

Special Inflorescence

These are of unique type of inflorescences.



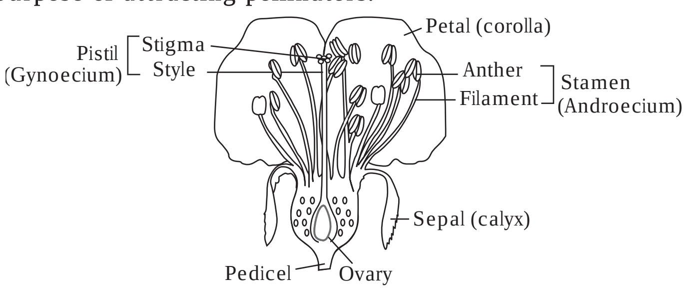
Various types of special inflorescences

Flower

It is the reproductive part of an angiospermic plant. It develops in the axis of a small leaf-like structure called **bract**.

Structure of a Flower

A complete flower is a modified condensed shoot, which is situated on receptacle (thalamus). It is a beautiful, reproductive organ that serves the purpose of attracting pollinators.



A flower showing detailed structure

Parts of a Typical Flower

Every flower normally has four floral whorls, **i.e, calyx, corolla, androecium** and **gynoecium**. All whorls are arranged on the swollen ends of the stalk, called **thalamus**.

The details of these parts are as follows

1. **Calyx** (Sepals)

It is the outermost whorl of floral leaves and the individual segment is called sepal. Mostly they are green in colour, but sometimes they are coloured like petals (petaloid).

- Sepals free from each other – Polysepalous
- Sepals fused with each other – Gamosepalous

Modifications of Sepals

Sepals undergo following modifications

(a) **Pappus** Hair-like modified sepals particularly for the dispersal of fruits, **e.g.,** sunflower, **Tagetes**, **Tridex**.

(b) **Spinous** Spine-like, **e.g., Trapa**.

(c) **Tubular** Tube-like, **e.g., Datura**.

(d) **Spurred** A tubular outgrowth called spur, arises at the base of one of the sepals, **e.g., Delphinium** (larkspur).

(e) **Campanulate** Bell-shaped, **e.g.,** China rose.

(f) **Leaf** One sepal becomes leaf-like, **e.g., Mussaenda**.

(g) **Hooded** One sepal becomes hood-like, **e.g., Aconitum**.

(h) **Cupulate** Cup-like, **e.g., Gossypium.**

(i) **Bilabiate** Like two lips of mouth, **e.g., Salvia, Ocimum**.

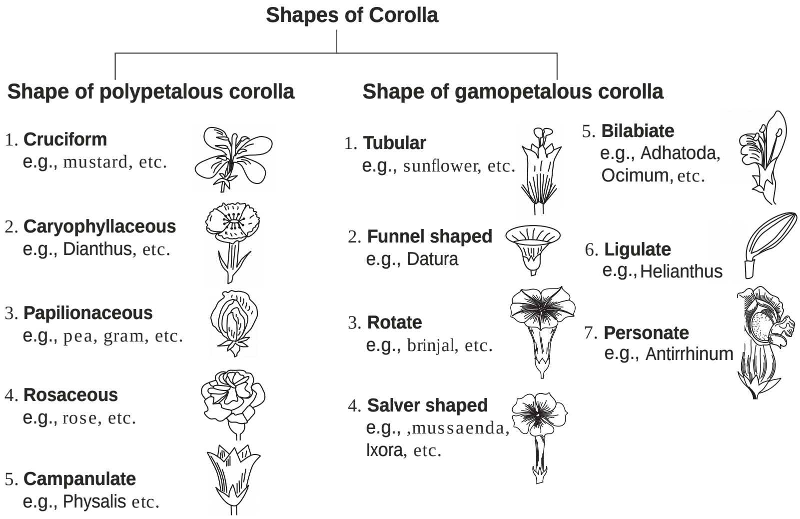
(j) **Infundibuliform** Like funnel-shapped, **e.g., Atropa**.

(k) Ureolate Urn-like, **e.g., Silene**.

2. **Corolla** (Petals)

This is the second whorl which arises inner to the calyx. The petal and sepal together form the floral envelope.

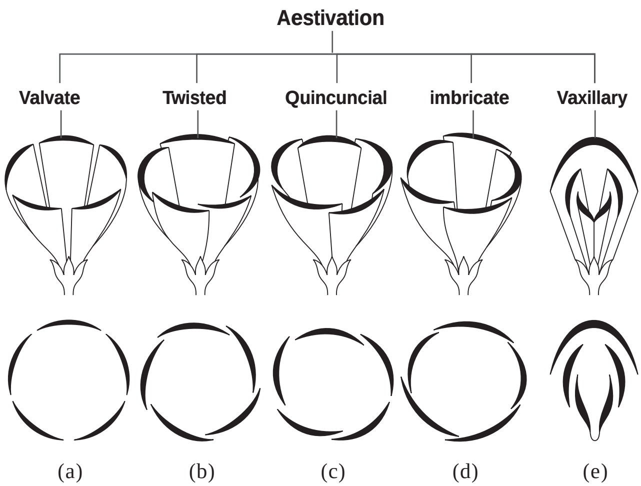
Note Both petals and sepals combinely called **perianth**. When petals and sepals are not differentiated clearly, it is called **tepal.**



Different shapes of corolla

Aestivation of Petals

The arrangement of petals or sepals on the thalamus is called aestivation. **On the basis of its arrangement/pattern, aestivation can be of following types**

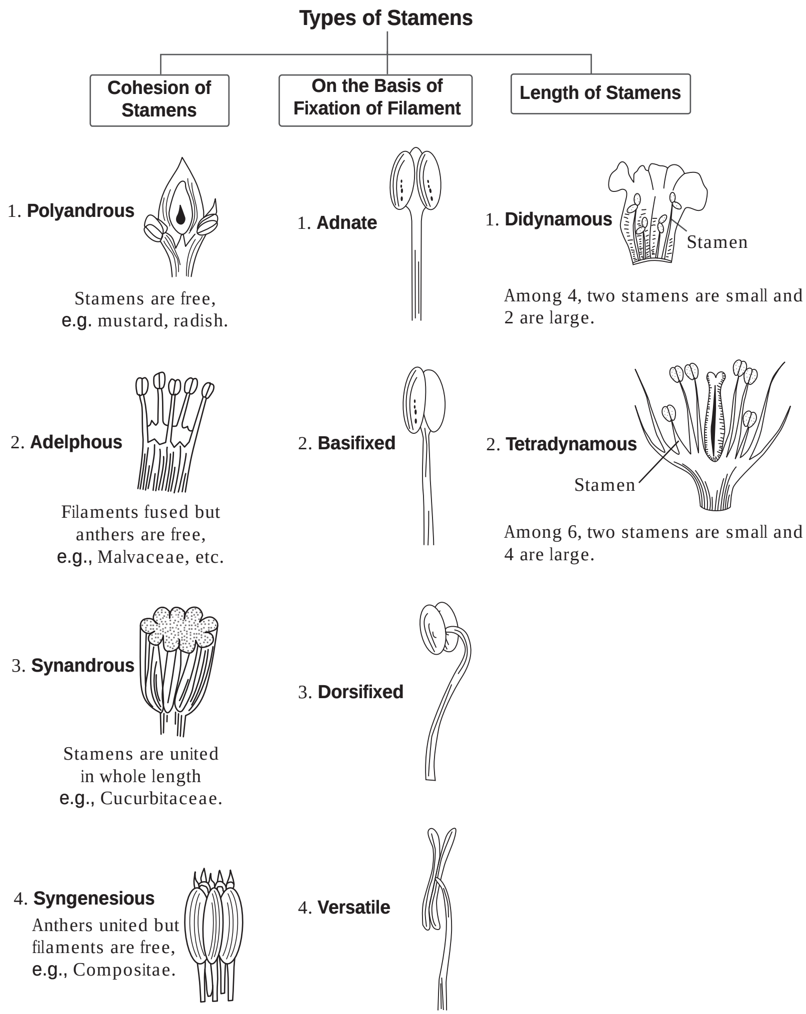


Various aestivations in flowering plants

3. **Androecium** (Male Reproductive Organ)

This is the third whorl of floral appendages, that arises inner to corolla. Individual appendage is called **stamen** which represents the male reproductive organ.

There are different types of stamens, on the basis of various criteria

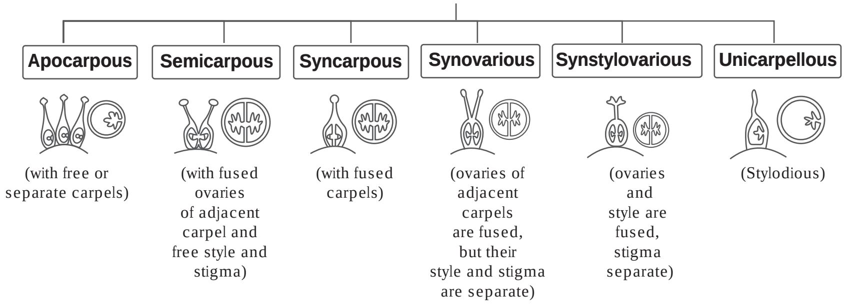


Various types of stamens

4. **Gynoecium** (Female Reproductive Organ)

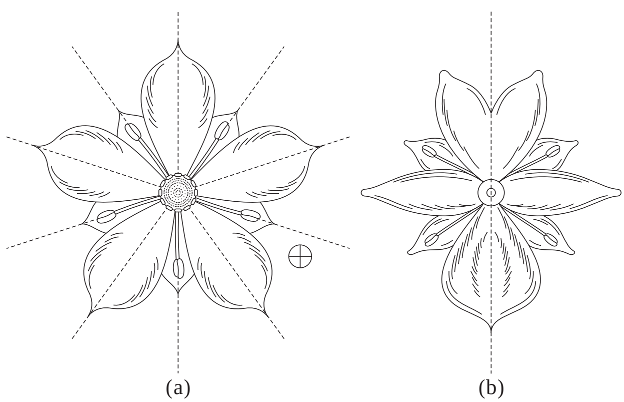
It is the innermost floral whorl which acts as female reproductive organ of the flower. On the basis of number of carpels and their arrangement, **the gynoecium is of following types**

Types of Gynoecium



Terms Related to Flower Structure

1. **Actinomorphic flower** When the flower is regular and radially symmetrical, it is termed as actinomorphic, **e.g.,** mustard (Cruciferae), onion (Liliaceae), brinjal (Solanaceae).
2. **Asymmetric flower** Flowers, which cannot be divided into two equal halves by any vertical division, **e.g., Canna**.
3. **Zygomorphic flower** When the flower is bilaterally symmetrical, **i.e.,** divisible into only two equal halves by a single vertical plane, it is termed as zygomorphic, **e.g., Adhatoda**, pea, larkspur, **Ocimum**.



Symmetries in flowers (a) Actinomorphic (b) Zygomorphic

4. **Hermaphrodite or intersexual or bisexual or monoclinous flower** A flower is called bisexual when it contains both male and female reproductive organs, **e.g.,** China rose, mustard, etc.
5. **Unisexual or dioecious flowers** A flower is called unisexual when it has only one essential floral whorl, either androecium (staminate or pistalloide) or gynoecium (pistillate or staminoide), **e.g., Morus alba**, papaya, **Cucurbita**, etc.
6. **Complete and incomplete flowers** A flower is called complete when it contains all the floral whorls, **i.e.,** calyx, corolla, androecium and gynoecium, **e.g., Solanum**, mustard. While the flower in the absence of any one of these four floral whorls, is called incomplete flower, **e.g., Cucurbita**.
7. **Regular and irregular flowers** When the flowers of a plant have same size, shape, colour and arrangement of various floral whorls/organs, then the flowers are called **regular**. If flower of a plant shows dissimilarity in any of its part or trait, then the flowers are called **irregular**.
8. **Cyclic and acyclic flowers** When the floral parts of a flower are arranged in a whorl, the flower is called **cyclic**, **e. g.**, **Solanum**. If the floral part of a flower are arranged spirally and not in whorls, the flower is called **acyclic**, **e.g., Ranunculus, Opuntia, Nymphaea.**
9. **Achlamydeous, monochlamydeous and dichlamydeous flowers** In achlamydeous flowers, the accessory floral whorls (calyx and corolla) are absent, **e.g., Piper** sp. (Piperaceae).

   When a flower contains only one accessory whorl (either calyx or corolla) or **perianth** (a collective term given to a group of undifferentiated calyx and corolla), it is called **monochlamydeous**, **e.g., Polygonum** (Polygonaceae), onion (Liliaceae).

   The condition **dichlamydeous** is used when both the accessory whorls (calyx and corolla) are present, **e.g.,** in most of the flowers.
10. **Isomerous and heteromerous flowers** When the parts of a floral whorl are found in a particular basic number or its multiple, the situation is called **isomery** and the flower is **isomerous**.

An isomerous flower may be **dimerous** (2 or multiple of 2), **g.**, poppy or **trimerous** (3 or multiple of it), **e.g., Argemone** or **tetramerous** (4 or multiple of 4), **e.g., Solanum**. A flower is called **heteromerous**, when different parts of different floral whorls have different basic number of its multiple.

11. **Hypogynous**, **perigynous and epigynous ovary** A flower is called **hypogynous,** when the innermost floral whorl (gynoecium) occupies the highest position (superior) while corolla and calyx successively arise below it (inferior). **e.g., Brassica**, China rose, **Papaver, Citrus, Solanum**, cotton, etc.

    In **perigynous** flower, all the floral whorls occurred at the same level of height on the thalamus so, they are called half superior or half inferior, **e.g.,** rose, peach, **Prunus.**

    In an **epigynous** flower, the innermost whorl, **i.e.,** gynoecium is covered by the elongated margins of thalamus.

    Thus, its position is inferior in relation to other floral whorls, which arise above the ovary and thus superior, **e.g.,** sunflower, **Cucurbita,** coriander, etc

12. **Bracteate and ebracteate flowers** Bract is a small leaf-like structure, whose axil bears a pedicel (flower stalk). A flower containing bract is called bracteate, **e.g., Adhatoda** and without bract it is called ebracteate, **e.g., Solanum.**

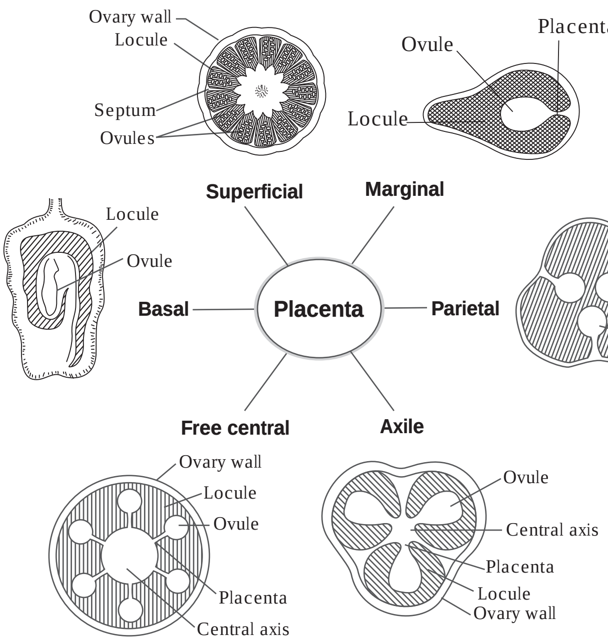
13. **Bracteolate and ebracteolate** A pedicel sometimes bears a pair of bracteoles, which are often green, sepal-like structures. A flower with bracteoles, is called **bracteolate** and without bracteoles, it is termed as **ebracteolate**.

14. **Epicalyx** It is an additional whorl of bracteole-like structures, which are found exterior to the sepals, **e.g.,** China rose, cotton (Malvaceae).

Placentation

The arrangement of ovules within the ovary is called placentation. The placenta is a tissue which develops along the inner wall of the ovary. The ovule remains attached to the placenta.

It is of following types



Types of placentations in flowering plants

Fruit

After fertilisation of ovary, ovule is changed into seed and ovary into fruit. The fruit is a characteristic feature of the flowering plants. A true fruit is a ripened ovary. At this stage, the perianth and stamens fall off, the gynoecium is rearranged and ovary becomes extended.

Generally the fruit consists of a **wall or pericarp** and **seeds. Sometimes this pericarp is differentiated into three layers**

1. Outer – Epicarp 2. Middle – Mesocarp 3. Inner – Endocarp

On the basis of their development, the fruits are of two types

1. **True Fruits** These fruits develop from the ovary of flower, **e.g.,** mango, orange, etc.
2. **False Fruits** The floral parts other than ovary develop into fruit, **e.g.,** apple and pears, etc.

A general classification of true fruits can be seen in following flow chart

- **True Fruits**
  - **Simple Fruit**
    - **Dry**
      - **Dehiscent** (capsular)
        - Legume or pod
        - Follicle
        - Siliqua
        - Silicula
        - Capsule
        - Pyxis
      - **Indehiscent** (achenial)
        - Achene
        - Nut
        - Samara
        - Cypsella
        - Caryopsis
      - **Schizocarpic** (splitting)
        - Lomentum
        - Cremocarp
        - Regma
        - Carcerulus
        - Double samara
    - **Succulent** (or fleshy)
      - Pome
      - Drupe (stony fruits)
      - Berry (bacca)
      - Pepo
      - Hesperidum
      - Balausta
      - Amphisarca
      - Hypanthium
  - **Aggregate Fruit** (etaerio)
    - Etaerio of follicles
    - Etaerio of achenes
    - Etaerio of berries
    - Etaerio of drupes
  - **Composite Fruits** (multiple)
    - Sorosis
    - Syconus

1. Simple Fruits

These develop from the monocarpellary or polycarpellary syncarpous ovary of a flower. These are divided into dry and succulent categories.

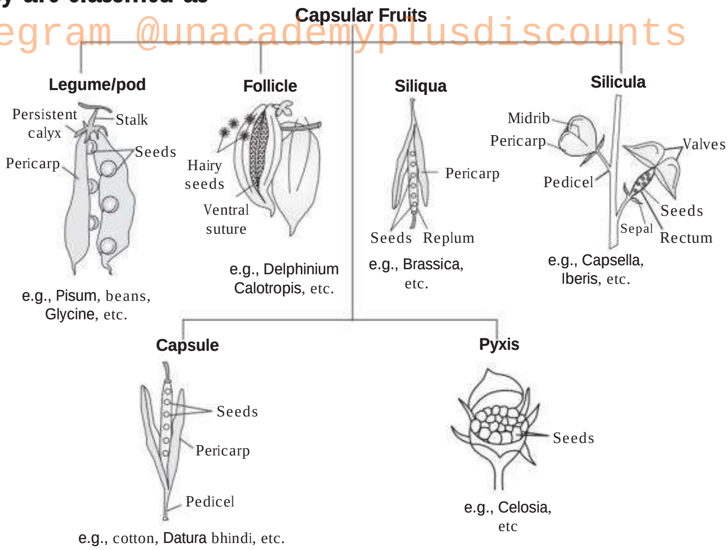
I. Dry Fruits

In dry fruits, the pericarp is dry and not differentiated into epicarp, mesocarp and endocarp. These are classified into three categories – capsular (dehiscent), achenial (indehiscent) and schizocarpic (splitting).

(i) Capsular (MULTISEEDED, DEHISCENT FRUITS)

In these, the pericarp splits open after ripening and seeds are exposed.

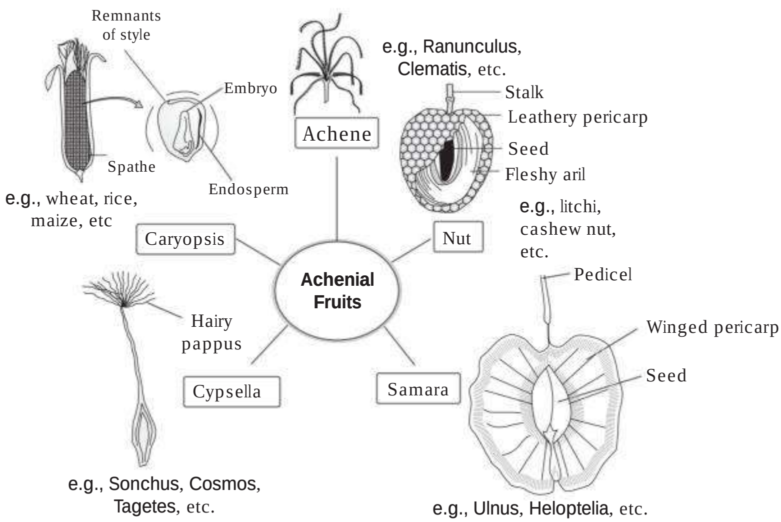
They are classified as



(II) **Achenial Fruits** (SINGLE-SEEDED, INDEHISCENT FRUITS)

They develop from single ovulated ovary having basal placentation. The seeds remain inside the pericarp after ripeneing.

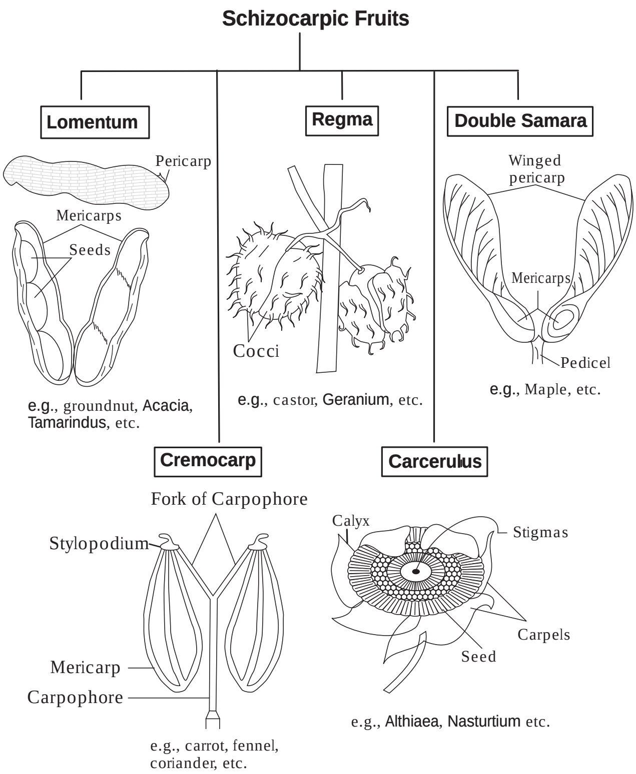
These are of following types



Achenial fruits and their types

(III) **Schizocarpic Fruits** (MULTIPLE SEEDED, SPLITTING FRUITS)

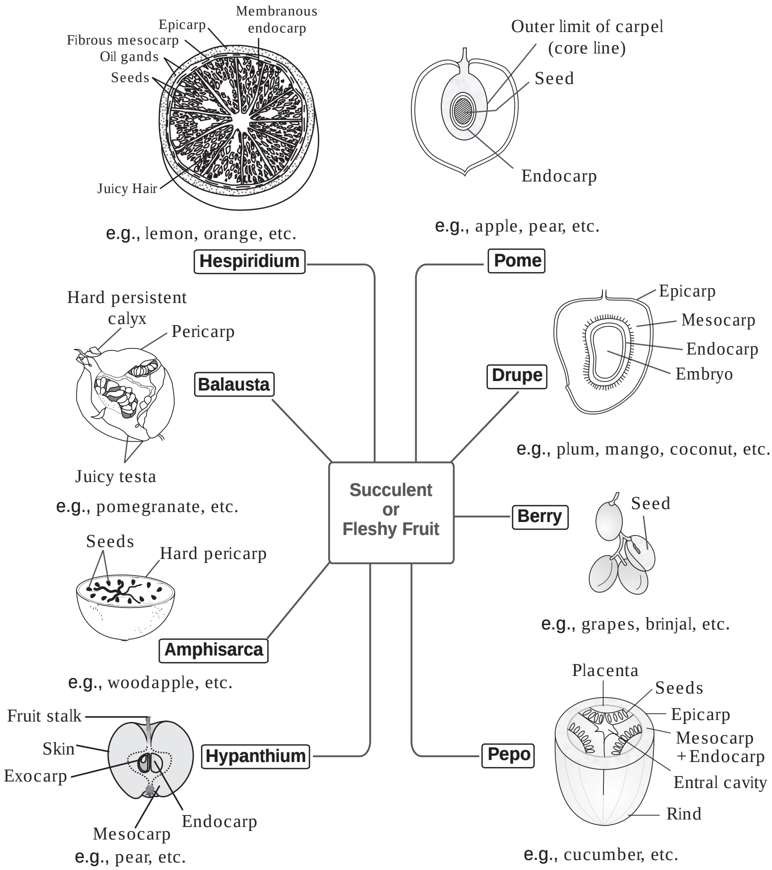
These are simple, dry fruits, which break up into single-seeded parts.



II. **Succulent Fruits** (Fleshy Fruits)

These have fleshy pericarp, which is divided into epicarp, mesocarp and endocarp.

They are of following types

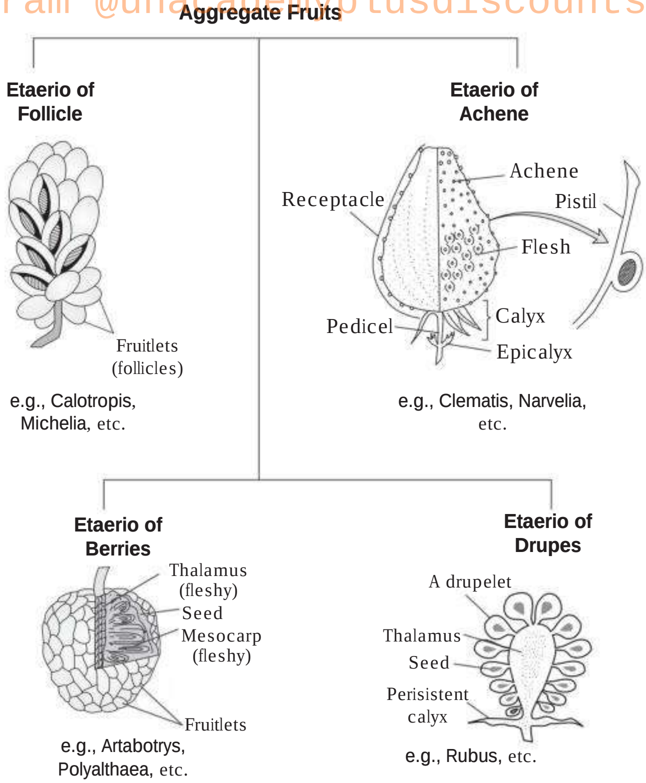


Different types of fleshy fruits

2. **Aggregate Fruits** (Etaerio)

Originally, these fruits are the group of fruitlets, which develop from the multicarpellary, apocarpous ovary. Individual carpel or pistil develops into fruitlet, but these mature in cluster on a single receptacle.

These can be categorised as

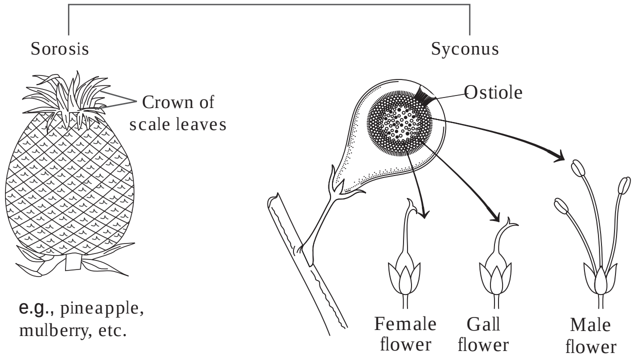


Various aggregate fruits

3. Composite or Multiple Fruits

These fruits develops from the whole inflorescence, hence they are also known as **infructescence**.

These are of following types



Multiple fruits
e.g., Anjir, peepal, banyan, etc.

Seed

It is a small embryo enclosed in a covering called seed coat, usually with some stored food. The formation of seed completes the process of reproduction in seed plants.

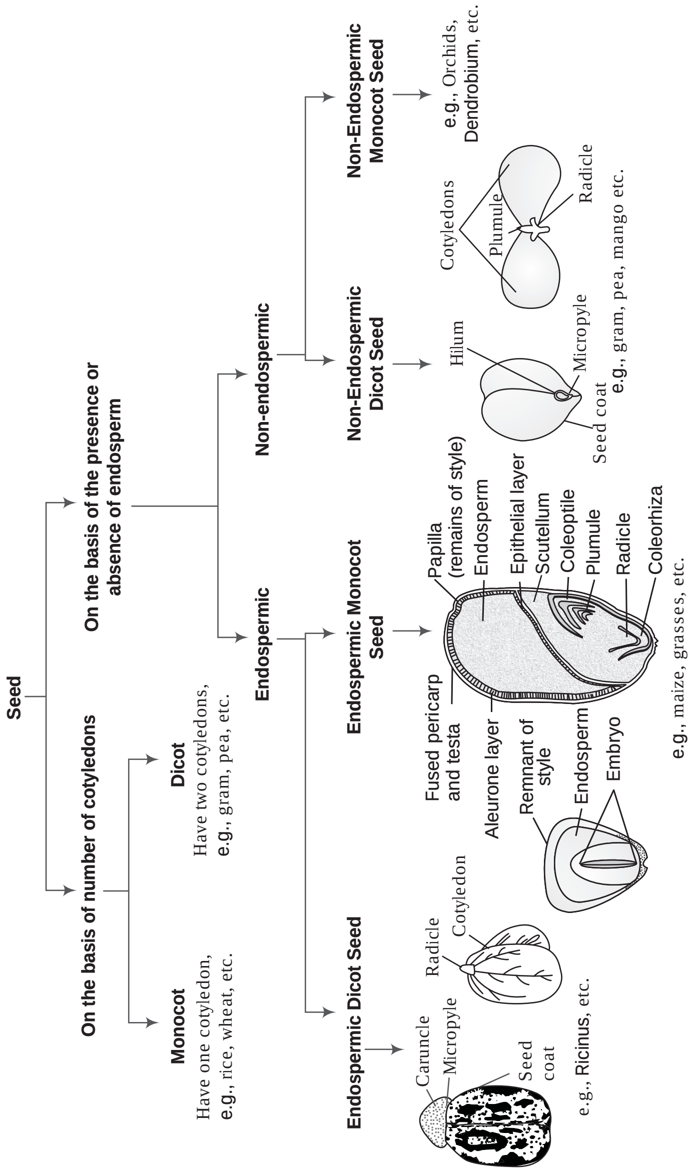
Parts of a Seed

A seed contains an embryo, an endosperm and a seed coat.

- **Embryo** It represents an embryonic plant. It consists of an axis called **tigellum** to which embryonic leaves or **cotyledons** are attached.
- **Endosperm** If present, acts as the food storage tissue of a seed.
- **Seed coat** It is a protective covering of the seed made up of one or two layers. The outer layer is called **testa** and inner is called **tegmen**. A minute opening called **micropyle** is present in seed coat.

Types of Seeds

Following flow chart provides the detailed account of different types of seed



Various types of seeds in plants

Viability of Seed

Germination power retaining ability of a seed is called the viability of seed, **i.e.,** a viable seed germinates during favourable condition.

Semi-technical Description of a Typical Flowering Plant

Various morphological features of a plant, need to be described in a scientific language. **Following table clearly explains almost every sign used in floral description**

Br	Bracteate	$\widehat{CA}$	Epipetalous stamens
Ebr	Ebracteate	$\widehat{PA}$	Epiphyllous stamens
Brl	Bracteolate	Std	Staminodes
Ebrl Epi	Ebracteolate Epicalyx	G_4	Tetracarpellary, free carpels, apocarpous
0 (zero)	Absence of a particular whorl	$G_{(\underline{4})}$	Tetracarpellary, syncarpous (superior)
∝	Indefinite number	$K_{(n)}$	Calyx united (gamosepalous)
⊕	Actinomorphic	G (4) –	Tetracarpellary, syncarpous (semi inferior)
%	Zygomorphic	$C_{(n)}$	Corolla united (gamopetalous)
♂	Male flower	$G(\bar{4})$	Tetracarpellary, syncarpous ovary inferior (epigynous)
♀	Female flower		
⚥	Bisexual flower or hermaphrodite condition	$G(\overline{\underline{4}})$	Tetracarpellary, syncarpous, ovary either superior or inferior
K_n	Calyx, where **n** = number of sepals	Pistd.	Pistillode
C_n	Corolla, where **n** = number of petals	$\widehat{AG}$	Androecium and gynoecium are united
P	Perianth	$\mathbf{A}_{(n)}$	Androecium with fused stamens
A_n	Androecium, where **n** = number of stamens	2+4	2 in one set and 4 in another
G_n	Gynoecium, where **n** = number of carpels	2–4	2 or 4
( )	Cohesion of floral parts in a whorl	X	Variable

Floral Formula

It represents the structure of as flower using numbers, letters and various symbols.

Floral Diagram

It represents the number of organs of a flower, their arrangement and fusion. It is useful for flower identification.

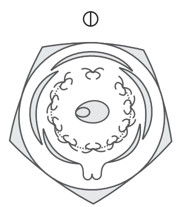
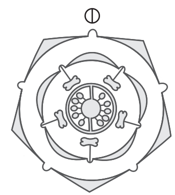
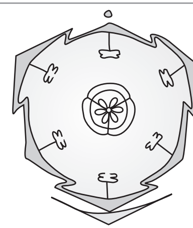
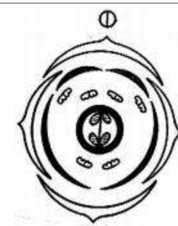
Description of Some Important Families

Various workers have divided both monocots and dicots into several families. For proper understanding of these families, the comparative account of 5 families is presented here.

Description of Some Important Families

Characteristics	Fabaceae	Solanaceae	Liliaceae	Cruciferae	Malvaceae
General Description	The family is also termed as pea family. It is distributed all over the world.	Commonly known as potato family. It is distributed in tropics and subtropics.	Commonly called as lily family. It is a representative of monocots.	It is known as mustard family or Brassicaceae. Mainly distributed in tropics.	Also known as mallow family. Present in tropic and subtropics.
Plant structure	Tree, shrub, herb.	Herb, shrub and small trees.	Perennial herb.	Annual, biennial and perennial herbs.	All herb, shrub and trees.
Root structure	Root with root nodules.	Taproot system.	Root with underground bulb, corm and rhizomes.	Taproot, fusiform and napiform.	Profusely branched taproot.
Stem structure	Erect or climber.	Herbaceous, rarely woody, hairy, hollow, underground (potato).	Stem may be underground partially.	Herbaceous stem with pungent watery fluid. Have stellate hairs.	Erect, branched sturdy with trichomes, sometimes decumbent.
Leaves	Alternate, pinnately compound or simple, venation reticulate.	Alternate, simple exstipulate, venation reticulate.	Mostly basal, alternate, linear, parallel venation.	Simple, alternate, rarely opposite, reticulate venation.	Simple, palmately lobed, reticulate venation.
Inflorescence	Racemose	Solitary, axillary or cymose.	Solitary/cymose often umbellate clusters.	Raceme or corymb.	Cymose or Raceme.
Flower	Bisexual, zygomorphic.	Bisexual, actinomorphic.	Bisexual, actinomorphic.	Bisexual, actinomorphic (may be zygomorphic).	Bisexual, actinomorphic, pentamerous.
Calyx	Five, gamosepalous, imbricate.	Five united, persistent, valvate.	6 tepals arranged in two whorls $(3+3)$. Free or rarely united valvate.	Four, polysepalous in two whorls.	Calyx-like whorl called epicalyx.
Corolla	Five, polypetalous, papilionacous.	Five united valvate.	—	Four, polypetalous cruciform.	5 petals, free but basally adnate.

Description of Some Important Families

Characteristics	Fabaceae	Solanaceae	Liliaceae	Cruciferae	Malvaceae
Androecium	Ten, diadelphous, anther dithecous.	Stamens five, epipetalous.	Stamen 6 (3 + 3)	6 stamens arranged in two whorls.	Numerous stamens, monoadelphous, reniform
Gynoecium	Ovary superior, monocarpellary, unilocular	Bicarpellary, syncarpous, superior.	Tricarpellary, syncarpous, superior.	Bicarpellary syncarpous, superior.	A compound pistil of 1 to many carpells.
Fruit	Legume	Berry or capsule.	Capsule, rarely berry.	Fruit siliqua or silicula.	Capsule or schizocarp.
Seed	One to many non – endospermic	Many, endospermous.	Endospermous.	Small, non – endospermic.	Seed with curved embryo and scanty endosperm.
Floral Formula	% ⚥ $K_{(5)}C_{1+2+(2)}A_{(9)+1}G_1$	⊕ ⚥ $K_{(5)}C_{(5)}\ A_5\underline{G}_{(2)}$	Br⊕ ⚥ $P_{3+3}A_{3+3}\underline{G}_{(3)}$	⊕ ⚥ $K_{2+2}C_4A_{2+4}\underline{G}_{(2)}$	⊕ ⚥ $Epik_{3\text{-}9 \text{ or } (3\text{-}9}$ $K_5C_5\ \ A_{(\alpha)}\underline{G}_{(2-5}$
Floral diagram					

6

Anatomy of Flowering Plants

Anatomy (Gk. **ana** – up; **tome** – cutting) is the study of internal structures of an organism. There is a large variety of plants having diverse structures both morphologically and anatomically.

Cell is the basic unit of organisation of all organisms and these are organised into tissues and above level of structure. The plant body is made up of various categories of tissues to comply the division of labour.

The Tissues

A group of cells having a common origin and cooperating with one another to perform a similar function is described as a tissue. The term 'tissue' was coined by **N Grew.**

The cells constituting a tissue are connected together by plasmodesmata for proper coordination among them. The study of tissues is called **histology**. On the basis of constitution of cells, the tissues are of two types, **i.e.,** simple and complex. A **simple tissue** is made up of similar cells, which carry out the same function, whereas the **complex tissue** is made up of two or more than two types of cells which carry out the similar functions. **Tissues can be conveniently grouped into two categories**

1. Meristematic tissues 2. Permanent tissues

Given flow chart shows the outlines of various tissues and their components in plants.

Tissues

- **Meristematic Tissue**
  - Based on origin and Development
    - Promeristem (Pri-mordial or Embryonic Meristem)
    - Primary Meristem
    - Secondary Meristem
  - Based on Position in Plant Body
    - Apical Meristem
    - Intercalary Meristem
    - Lateral Meristem
  - Based on Function
    - Protoderm
    - Ground Meristem
    - Pro-cambium
- **Permanent Tissue**
  - **Simple Tissue**
    - Parenchyma
    - Collenchyma
    - Sclerenchyma
      - Sclerenchy-matous fibres
      - Stone Cells
  - **Complex Tissue**
    - Xylem (wood)
      - Tracheids
      - Vessels (tracheae)
      - Xylem Fibres (xylem sclerenchyma)
      - Xylem Parenchyma
    - Pholem (bast)
      - Sieve Elements
      - Companion Cells
      - Phloem Fibres (phloem sclerenchyma)
      - Phloem Parenchyma
  - **Special Tissue**
    - **Glandular Tissue**
      - External Glands
        - Glandular Hairs
        - Digestive Glands (enzyme secreting glands)
        - Secreting Glands (nectaries)
      - Internal Glands
        - Oil Gland
        - Resin Gland
        - Water Secreting (hydathodes or water stomata)
    - **Laticiferous Tissue**
      - Latex Cells
      - Latex Vessels

1. Meristematic Tissues

A meristem or meristematic tissue (Gk. **meristos** – divided) is a simple tissue composed of 'a group of cells that are in continuous state of division resulting in new cells or retain their power of division'.

The term 'meristem' was coined by **C Nageli** (1858) to designate dividing cells.

The chief characteristics of these tissues are

(i) Rounded, oval, polygonal or rectangular immature cells of small size.

(ii) Intercellular spaces are absent between meristematic cells.

(iii) They do not store reserve food material and are in **active state of metabolism.**

(iv) They have abundant and dense cytoplasm with small endoplasmic reticulum and simple mitochondria.

(v) Plastids are present in proplastid stage.

(vi) Nucleus is large and conspicuous.

(vii) Vacuoles absent in protoplasm or if present, they are very small in size.

(viii) The cells of cambium are highly vacuolated and they are large in size.

(ix) Cell walls are thin, elastic and made up of cellulose.

The meristematic tissues can be classified on the basis of origin and development, functions and the position in plant body.

Classification on the Basis of Origin and Development

Meristem

Promeristem or Primordial Meristem

It is also known as **urmeristem** or **embryonic meristem**. It is situated at the apices of root and shoot.
It consists of thin-walled, isodiametric cells with dense cytoplasm and large nuclei.

Primary Meristem

It is the first derivative of promeristem and forms the fundamental parts of the plant. The cells of these tissues divide in all possible planes.

Secondary Meristem

It develops in the later stages of development and is **always lateral in position**.
This meristem develops either at emergency or to affect secondary growth or the formation of cork cells.

Classification on the Basis of Function

Meristem

Protoderm

It is the outermost meristematic layer of young growing region. It develops into **epidermis, stomata** and **root hairs**.

Procambium

It is composed of narrow elongated cells. It develops into primary vascular tissue.

Ground Meristem

It is the precursor of ground tissue system and has large and thin-walled cells.
These meristems develop into hypodermis, cortex, pericycle, pith and medullary rays.

Classification on the Basis of Location in Plant Body

Meristem

Apical Meristem

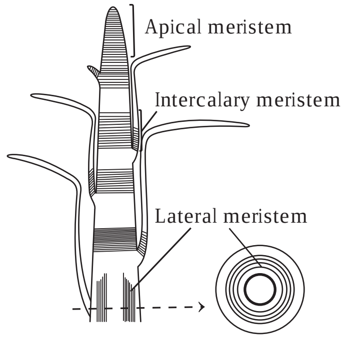
These meristems are present at the apices of primary and secondary shoots and roots of the plant. These meristems are responsible for the increasing plant length and all the primary tissues of plant body, originate from them.

Intercalary Meristem

These meristems lie between the regions of permanent tissues. They may be present either at **nodes** or at the **base** of **leaf**. These are also known as **detached meristem**, as they originate from the apical meristem.

Lateral Meristem

These meristems are present along the side of the organs. They divide only in radial direction. These meristems are responsible for the increasing girth of stem and roots.



(a) (b)

Position of meristems : (a) Longitudinal view (b) Cross-section

Various theories have been proposed to explain the organisation of both root and shoot apical meristems. (RAM and SAM) respectively. The important theories among these are discussed here.

Chief Theories related to SAM and RAM

Shoot Apical Meristem (SAM) Theories

Tunica-Corpus Theory
(Schmidt, 1924)
It states that there are two distinct zones present in shoot apices–tunica (outer) and corpus (inner).

Apical Cell Theory
(Hofmeister, 1857)
It states that a single apical cell is the structural and functional unit of apical meristems and it regulates the whole process of primary growth.

Histogen Theory
(Hanstein, 1870)
According to this, there are three distinct meristematic layers called as **dermatogen**, **periblem** and **plerome**

Root Apical Meristem (RAM) Theories

Quiescent Cell Theory (Frederick, 1953)
He observed cytogenerative centre which is the region of an apical meristem from which all future cells are derived. It is a group of cells, up to 1,000 in number, in the form of hemisphere, with the flat face toward the root tip.

Korper-Kappe Theory
(Schuepp, 1917)
According to this, the root apices divide in two planes. First a cell divides transversally then two daughter cells divide longitudinally. This sequence is termed as T-division.

Apical Cell Theory
(Nageli, 1858)
He observed a single tetrahedral apical cell in the root apices of a number of vascular cryptogams like algae, bryophytes, etc.

Histogen Theory
(Hanstein, 1870)
It is similar to histogen theory of SAM.
Each of the following three layers has a specific purpose
(a) Dermatogen—Epidermis
(b) Periblem—Cortex
(c) Plerome—Vascular cylinder

Note

Haberlandt (1914) proposed the name **protoderm, ground meristem** and **procambium** respectively to histogens.

2. Permanent Tissues

These tissues are formed as a result of division and differentiation in meristematic tissues. These have assumed a definite, shape, size and function and have temporarily or permanently lost the power of division. The cells of these tissues are either living or dead, thin-walled or thick-walled.

Permanent tissues are of following three types

(i) Simple tissues
(ii) Complex tissues
(iii) Special tissues

(i) Simple (Permanent) Tissue

A group of similar permanent cells that perform a common function is called simple permanent tissue. **These are classified as**

(a) Parenchyma
(b) Collenchyma
(c) Sclerenchyma

(a) Parenchyma

It (Gk. **para**–beside; **enchyma**–tissue) is the most abundant and common tissue of plants made up of thin-walled, usually living cells possessing distinct nucleus. Typically, the cells are isodiametric (all sides equal).

These may be oval, rounded or polygonal in outline. The cell wall is made up of cellulose. These cells may or may not have intercellular spaces. Parenchyma is morphologically or physiologically **unspecialised tissue** that forms the ground tissue in various parts of the plants.

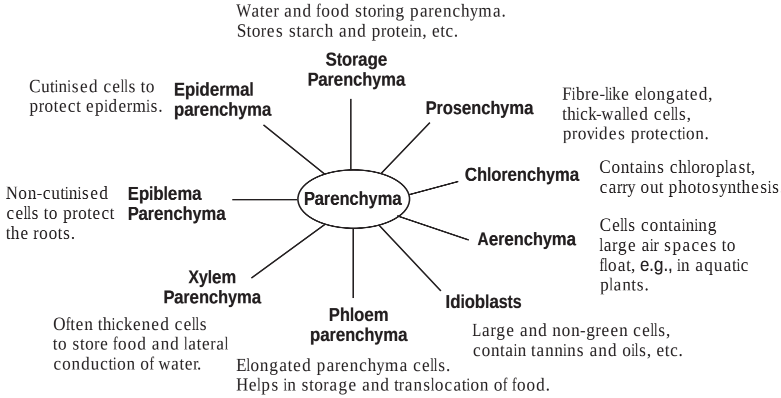
Note On the basis of their origin, the intercellular spaces are of two types

- **Schizogenous** formed by the splitting of middle lamella.
- **Lysogenous** by the breakdown of cells.

Types of Parenchyma

Parenchyma cells are modified to perform various functions.

These functions are mentioned in following figure



(b) **Collenchyma**

It (Gk. **kolla –** glue**; en, cheein–**to pour in) is a specialised, supporting, simple permanent tissue. These cells have uneven thickening of cellulose, pectin and hemicellulose on their walls. **Schleiden** (1839) discovered and coined the term 'collenchyma'. These cells are often elongated, circular, oval or angular in transverse section. Collenchyma is found below the epidermis in the petiole of leaves and stems.

Collenchyma provides both mechanical strength and elasticity to the plants, hence it is also known as **living mechanical tissue.**

Types of Collenchyma

Collenchyma is of three types on the basis of structure of wall thickenings

Collenchyma

Lamellar Collenchyma

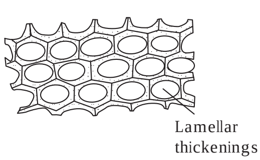
Deposition of heavy thickenings in tangential than in the radial cell walls. e.g., stem of Raphanus.

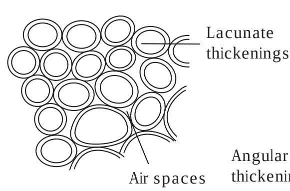
Lacunar Collenchyma

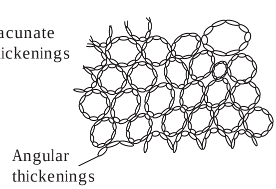
Deposition of thickenings are primarily around the intercellular spaces. e.g., aerial root of Manstera.

Angular Collenchyma

Deposition of thickenings takes place at the corners or angles of the cells. e.g., stem of Datura.

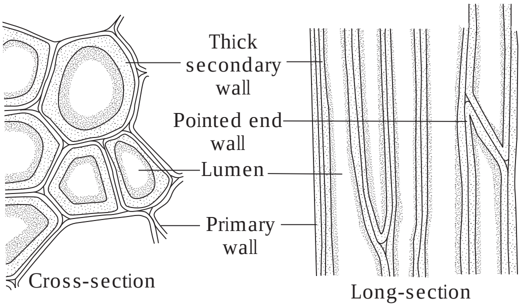






(c) Sclerenchyma

It (Gk. **scleros**–hard; **en, cheein–**to pour in) is a considerable thick-walled, lignified, supportive tissue characterised by the **absence of living protoplast**. **Mettenius** (1805) discovered and coined the term 'sclerenchyma'.



Structure of sclerenchyma

Types of Sclerenchyma

These are as follows

- **Sclerenchyma fibre** These are specialised cells being long, narrow, thick and lignified with pointed or blunt ends. They have great tensile strength, elasticity and flexibility.
- **Sclereids** The term 'sclereid' was given by **Tscherch** (1885). These are also known as **stone cells** or **sclerotic cells.** They are dead cells with small lumens.

Differences between Parenchyma, Collenchyma and Sclerenchyma

Parenchyma	Collenchyma	Sclerenchyma
Cells are living and filled with protoplasm.	Cells are living and filled with protoplasm.	Cells are dead and empty.
No wall thickening.	Wall thickenings not uniform and consists of cellulose.	Wall thickenings uniform and consists of cellulose, lignin or both.
Found in both the outer and inner parts of plant.	Restricted to the outer parts of plant.	Found in both the outer and inner parts, restricted to the areas, which have stopped elongation.
Provides mechanical strength only when they are fully turgid.	Provides mechanical strength as well as elasticity.	Provides only mechanical strength.

Parenchyma	Collenchyma	Sclerenchyma
No high refractive index	High refractive index.	Comparatively low refractive index.
Have ability to dedifferentiate and produces secondary meristem.	Ability to dedifferentiate is almost absent.	No dedifferentiation at all.

(ii) **Complex** (Permanent) **Tissues**

A complex permanent tissue is the collection of different types of cells that perform or help to perform a common function. These are the conducting tissues and classified as **xylem** and **phloem**.

(a) **Xylem** (Gk. xylos – wood; Nageli, 1858)

It is a complex permanent tissue mainly performing the function of conduction of water and solutes from the roots up to the top of plants. Simultaneously, it provides strength to the plants.

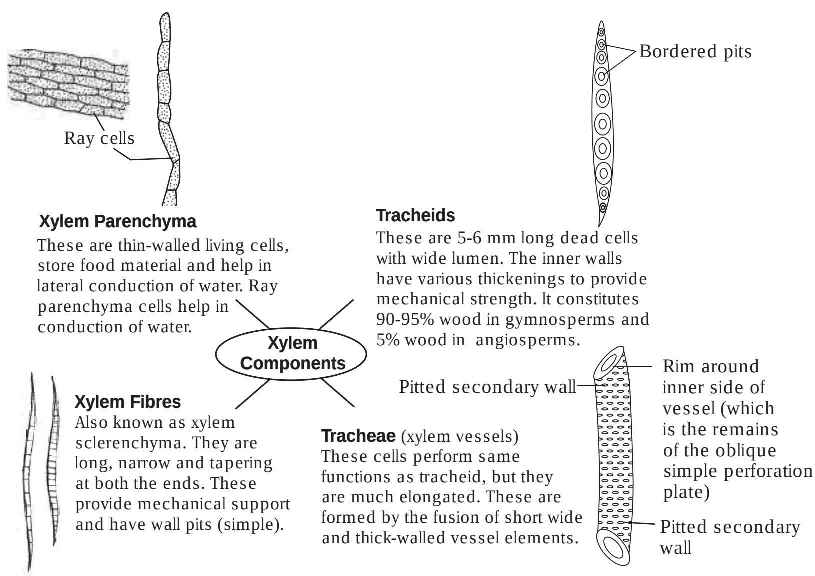
Apical meristem — Procambium — Primary xylem
Apical meristem — Vascular cambium — Secondary (wood) xylem

- Tracheid
- Vessel
- Xylem fibre
- Xylem parenchyma

Xylem: origin and components

Components of Xylem

The components of xylem are discussed below



Xylem components

Types of Xylem

- **On the basis of the time of origin**

Xylem

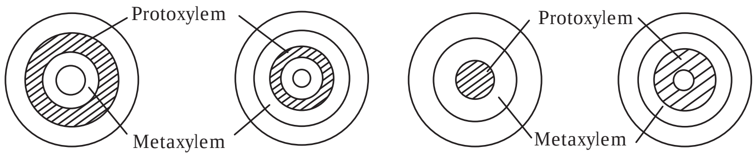
Protoxylem
It develops first from procambial strands, consists of smaller tracheids and vessels.

Metaxylem
It develops in later stage. It consists of large tracheids and vessels.

- **On the basis of position of protoxylem with respect to metaxylem**

Xylem

Exarch | **Mesarch** | **Centrarch** | **Endarch**

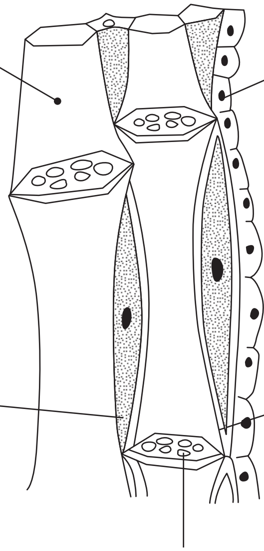


Exarch	Mesarch	Centrarch	Endarch
Protoxylem lying outside the metaxylem.	Protoxylem in middle of metaxylem.	Protoxylem in centre of metaxylem.	Protoxylem lies inside the metaxylem.

(b) **Phloem** (Gk. phlois – inner bark ; Nageli, 1858)

It is a complex permanent tissue which principally transports organic food in plants. It is also known as **bast**, because fibres of some plants are used for binding purpose.

It consists of four components. A new cell type called **transfer cells** has recently been reported from phloem. Transfer cells are much folded cells adjacent to sieve cells. They provide large area for the transfer of solutes.



Components of phloem

Protophloem and Metaphloem

- **Protophloem** is first formed part, which develops in parts that are undergoing enlargement. During elongation the protophloem elements get stretched and become non-functional.
- **Metaphloem** is formed in the organs when they stop enlargement.

(iii) **Special Tissues** (Secretory Tissues)

These cells or tissues are specialised to secrete or excrete products. The secreted substances may be useful for plants or may not be useful.

These tissues are of two types

(a) **Glandular Tissues**

These are present in form of glands (a gland is a group of specialised cells, which have capacity to secrete or excrete products).

The glandular tissues are of two types

- External glands
- Internal glands

External Glands

Glandular Hairs
These are present in epidermis. They may be unicellular or multicellular. These may be stinging hair, oil glands hair.

Digestive Glands
(enzyme secreting glands)
Insectivorous plants possess such hairs to digest proteins from the body of insects.

Secreting Glands
(nectaries)
These secrete nectars and present mostly on flowers. These may be
Floral nectaries–on flower and extra floral nectaries–on leaves.

Internal Glands

Oil Secreting
They secrete oil of aromatic and volatile nature, e.g., *Eucalyptus*, *Citrus*, *Cinnamomum*, etc.

Resin Secreting
Resin and mucilage of nutritional quality is secreted from these ducts, e.g., *Pinus*, *Cycas*, etc.

Water Secreting
Hydathodes or 'water stomata' exude water in the form of drops, e.g., in *Colocasia*.

(b) Laticiferous Tissues

This tissue is mainly composed of thin-walled elongated, branched and multinucleate tube-like structures that contain colourless milky or yellow-coloured fluid called **latex**.

They are scattered throughout the ground tissue of the plant and contain stored organic matter in the form of starch, rubber, tannins, alkaloids, mucilage, enzymes, proteins, etc.

This tissue is of two types

- **Latex cells** These are uninucleate cells, may be branched or unbranched. These cells are also known as non-articulated laticifers, **e.g. *Euphorbia*, *Thevetia***, etc.
- **Latex vessels** These are formed by large number of cells placed end to end with their transverse wall dissolved so as to form long vessels, **e.g., *Papaver*, *Hevea*,** etc.

Plant Tissue System

The functions of the tissues depend on their location in plant body. The tissues or a group of tissues which perform a common function, constitute the tissue system.

The principal tissues of a plant can be categorised into three important tissue systems (Sachs; 1875).

These are as follows

1. **Epidermal Tissue System** (Dermal Tissue System)

It is derived from **protoderm.** It performs several functions like mechanical support, absorption, excretion, etc., in plants.

Following flow chart provides the detail account of these tissues in plants

Epidermal Tissue System

- **Cuticle**
  It is a continuous layer of cutin. It is deposited on outer wall of epidermis. The cuticle is reinforced by a layer of wax in extremely dry conditions. In cereals, it allows the deposition of silica to protect them from grazing.
- **Epidermis**
  It is the outermost layer of cells. It is made up of continuous, closely arranged living cells. The root epidermis is referred to as epiblema or piliferous layer, because it has root hairs.
- **Epidermal Outgrowths**
  - **Trichomes**
    - **Hairs**
      Secretory in function
      - Glandular
        - Unicellular
        - Multicellular
      - Non-glandular
    - **Scales or Squamiform Hairs**
      Disc-like plate and multicellular in structure.
    - **Root Hairs**
      They originate from trichoblasts of epiblema.
  - **Emergences**
    (multicellular outgrowths) e.g., prickles that help in climbing, protection, etc.
- **Stomata**
  Epidermis of all green aerial parts of plants contains minute openings called stomata. It is surrounded by kidney-shaped guard cells. Stoma guard cells and neighbouring subsidiary cells are collectively termed as stomatal apparatus.

2. **Ground Tissue System** (Fundamental Tissue System)

It is partly derived from the **periblem** and partly from **plerome.** It constitutes the **main bulk of the body**. It consists of **simple permanent tissues** like parenchyma, collenchyma and sclerenchyma.

Following flow chart presents the detailed view of ground tissue system in plants

Ground Tissue System

- **Monocotyledons**
  - **Stem**
  - **Root**
- **Dicotyledons**
  - **Stem**
  - **Root**

Hypodermis
It consists of collenchyma or sclerenchyma cells that lie below epidermis. It provides mechanical strength and rigidity.

Parenchyma
These are non-vascular areas which occur between vascular bundles for lateral conduction.

Cortex
It is the main zone lying between the epidermis and pericycle. In monocots, it is homogenous, but in dicots, it is differentiated into **hypodermis**, **general cortex** and **endodermis**.

Pericycle
It is the outermost boundary of vascular strand, one to several cells in thickness. It may be **parenchymatous** or **sclerenchymatous**.

Medulla or Pith
The parenchymatous, central part of the ground tissue, which is often parenchymatous. Due to radial expansion, it becomes hollow as in Cucurbita.

3. **Vascular Tissue System** (Fascicular Tissue System)

The tissues derived from the **procambium** are called the **vascular** or **fascicular tissue system**. It consists of number of strands or bundles called **vascular bundles.**

Vascular Bundles (Components)

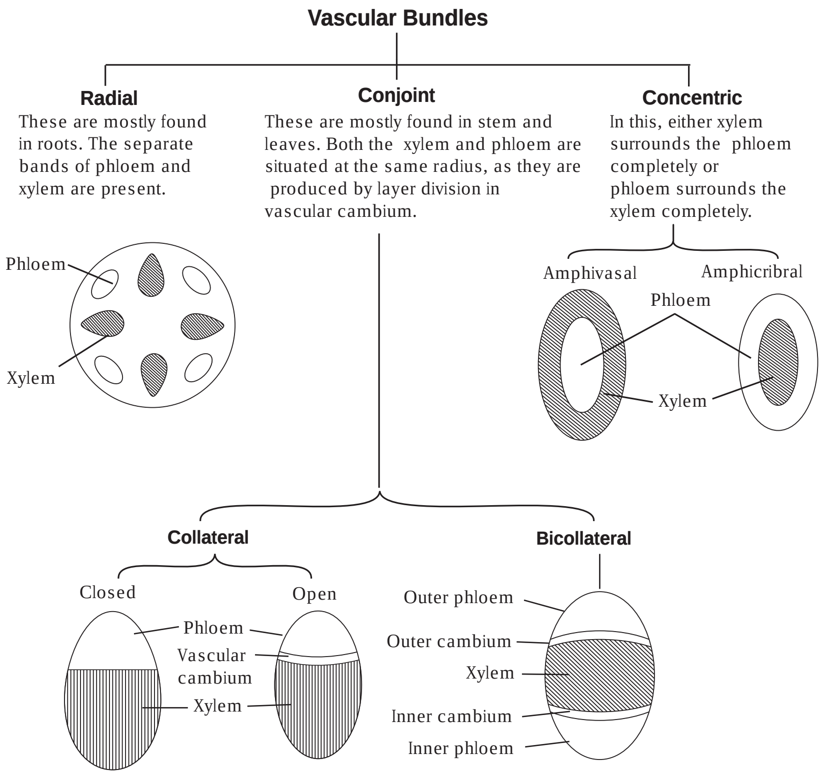
Xylem Element
The chief conducting tissues. Consists of tracheids, vessels, xylem fibre and xylem parenchyma.

Phloem Element
The tissue, concerned with the conduction of food materials. It consists of sieve cells, sieve tubes, companion cells, phloem parenchyma and phloem fibres.

- **Protophloem** (primarily differentiated)
- **Metaphloem** (later differentiated)

Cambium
It is a lateral meristem that gives rise to secondary xylem and phloem and occurs in the form of thin strip.
Cambium consists of two type of cells
1. Fusiform initials
2. Ray initials

The vascular bundles are classified into three categories on the basis of relative positions of xylem and phloem.

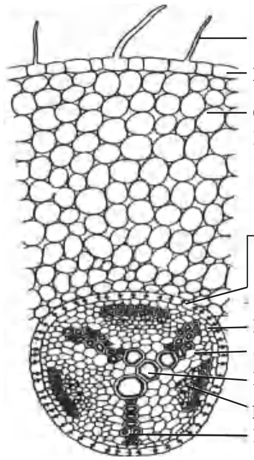


Anatomy of Dicot and Monocot Plants

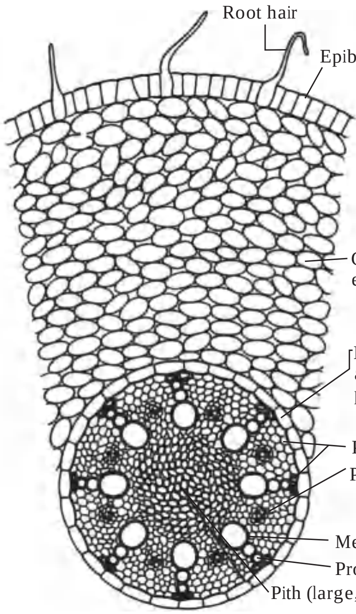
Various plant organs (**i.e.**, root, stem, leaves, etc.) have characteristic structures.

The comprehensive account of these structures with their internal details is as follows

Dicot and Monocot Roots

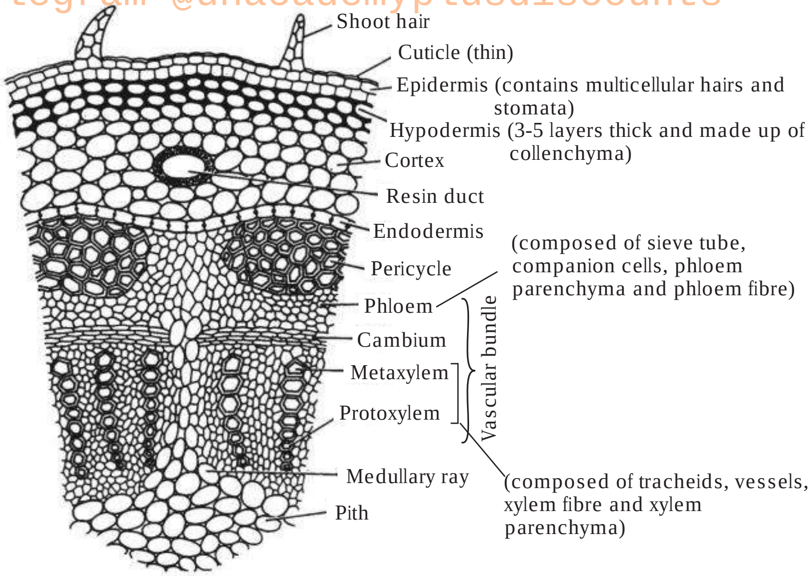


(a) Structure of a portion of TS of dicot root

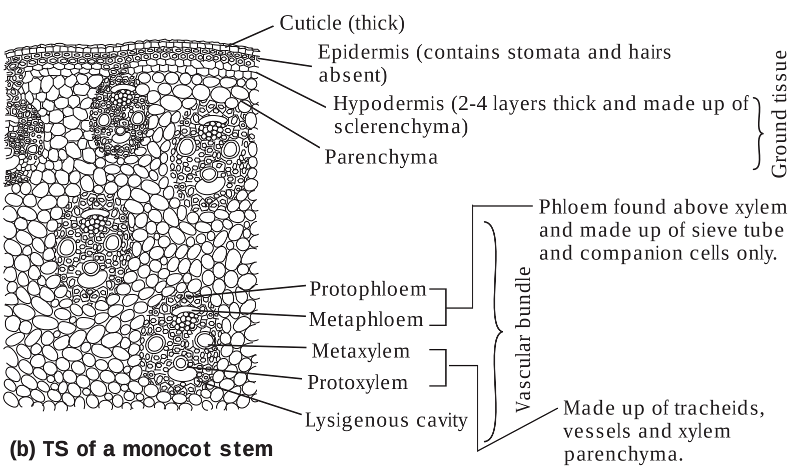


(b) Structure of TS of monocot root

Dicot and Monocot Stems

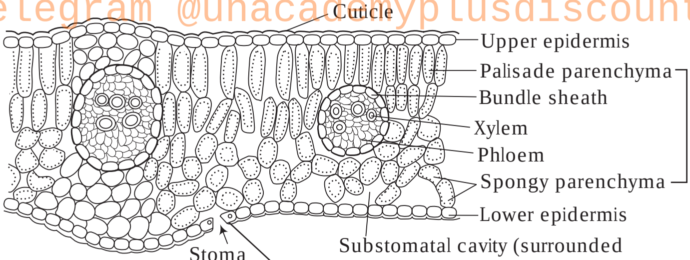


(b) TS of a dicot stem

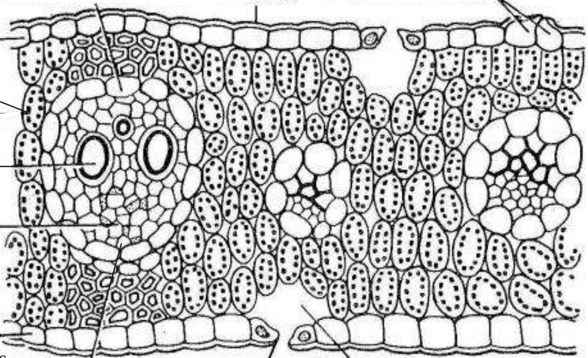


(b) TS of a monocot stem

Dicot and Monocot Leaves



(a) Detailed Structure of a part of TS of a dicot leaf (dorsiventral or bifacial leaf)



(b) Detailed sturcuture of part of TS of Monocot leaf (isobilateral or equifacial leaf)

Secondary Growth in Plants

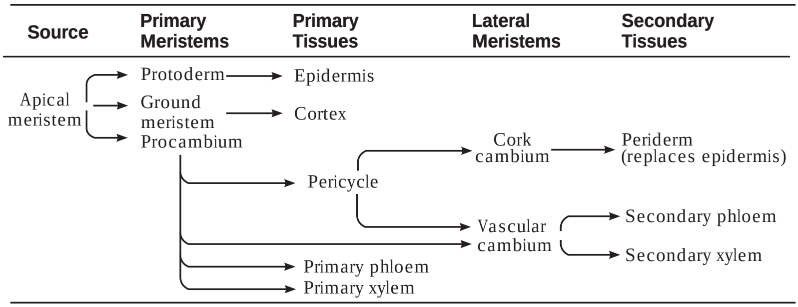
The formation of secondary tissues which lead to increase in girth is called **secondary growth**. Secondary tissues are formed by two types of lateral meristems– vascular cambium and cork cambium.

Cork cambium (phellogen) produces cork cells (phellem) on outerside and phelloderm on innerside. Phellem, phellogen and phelloderm together constitute the **periderm.**

Secondary Growth in Dicot Root

The secondary growth in dicot roots takes place in both stelar (by vascular cambium) and in extrastelar region (by cork cambium).

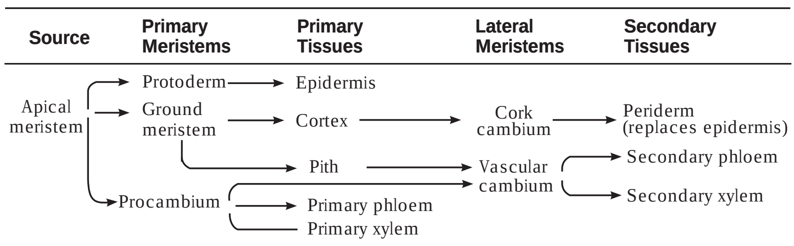
The whole process can be discussed as under



Summary of primary and secondary growth of root in a vascular plant

Secondary Growth in Dicot Stem

Secondary xylem produced by cambial ring is called **wood**. The wood formed in a single year is called **annual ring** or **growth ring. The whole process of growth can be discussed as under**



Summary of primary and secondary growth in stem of a vascular plant

Types of Wood

On the basis of time of formation

Wood

Spring Wood/Early Wood
(xylem vessels with wider cavities are produced)

Sapwood/Alburnum
(consists of living cells,tracheids and vessels not plugged by tyloses)

Autumn Wood or Late Wood
(xylem vessels with narrow cavities are produced)

Heartwood/Duramen
(living cells absent, tracheids and vessels plugged by tyloses)

7

Structural Organisation in Animals

In unicellular organisms, all vital cellular functions like digestion, respiration, excretion, etc., are performed by a single cell. The multicellular animals have complex body organisation, **e.g., Hydra**.

Tissue (By Bichat; Father of Histology)

It is a group of one or more cell types and their intercellular substances that perform a particular function.

Based on structure, function and location, **animal tissues are of four types**

Types of Tissues

Epithelial Tissue
Origin Ectoderm, mesoderm and endoderm.
Function Protection, secretion, reproduction, absorption and excretion.

Muscular Tissue
Origin Mesoderm.
Function Movement and locomotion.

Connective Tissue
Origin Mesoderm.
Function Attachment, support, storage, transport and protection.

Nervous Tissue
Origin Ectoderm.
Function Control and coordination by nerve impulse.

1. **Epithelial Tissue** (By Ruysch)

It consists of a sheet of tightly packed cells with the minimum of intercellular material and rest upon a non-cellular basement membrane or lamina propria.

Common junctions between epithelial cells include tight junctions, gap junctions, desmosomes, intercellular bridges and interdigitations. These occur at many points of cell to cell and cell to matrix junctions.

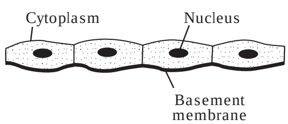
Epithelial tissues are of two types

(i) **Simple Epithelium**

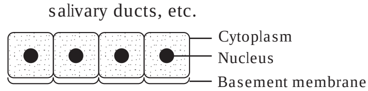
It consists of a single cellular layer and all the cells rest on the basement membrane. It covers the surface with little wear and tear activity. It performs secretory, absorptive and protective functions.

Simple Epithelia

Squamous
- Large flat cells.
- Centrally placed flat nuclei.
- Help in protection, gas exchange, excretion, secretion, etc.
- Found in blood vessels (endothelium) coelom (mesothelium), etc



Cuboidal
- Squarish cuboidal cells.
- Centrally placed round nuclei.
- Helps in protection, secretion, gamete formation, etc.
- Found in ovaries and seminiferous tubules (germinal epithelium), salivary ducts, etc.



Ciliated
- Cilia bearing cells.
- Centrally placed round nuclei.
- Helps to maintain CSF, urine and mucus flow in one direction.

Ciliated Columnar
- Columnar cells.
- Found in Fallopian tube, brain ventricles, etc.

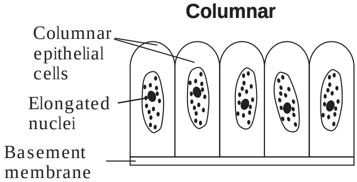
Ciliated Cuboidal
- Cuboidal cells.
- Found in certain parts of kidneys.

Pseudostratified
- Unequal columnar cells.
- Centrally placed oval nuclei in long cells and round nuclei in small cells.
- Helps in protection, movement of secretion, etc.

Pseudostratified Columnar
- Columnar cells
- Found in olfactory mucosa, male urethra, etc.

Pseudostratified Columnar Ciliated
- Cilia bearing cells
- Found in trachea, large bronchi, etc.

Columnar



- Elongated cells.
- Elongated nuclei near the base.
- Helps in protection, secretion, etc.
- Found in various glands (glandular epithelium), stomach, pancreatic lobules, etc.

Types of simple epithelium

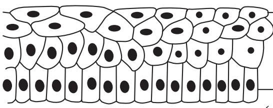
(ii) Compound Epithelium

It consists of multicellular layers and the cells of deepest layer rest on the basement membrane. It covers the surfaces with maximum wear and tear activity. It performs protective functions.

Compound Epithelium

Transitional Epithelium (urothelium)

- Consists of 4-6 layers of cells.



Stratified Epithelium

- Consists of two to many layers of cells.

Four types

Stratified Squamous

- Outer layers is of squamous cells and inner layer is of columnar cells which undergoes continuous mitotic division, hence, this layer is called germinative layer.
- It forms epidermis of land vertebrates, lines oral cavity, vocal cords, etc.

Stratified Cuboidal

- Outer layer possesses cuboidal cells and basal layer comprises columnar cells.
- It forms the epidermis of fishes and urodeles. It also lines sweat gland ducts and larger salivary and pancreatic ducts.

Stratified Columnar

- Both the outer and inner layer comprises columnar cells.
- It lines epiglottis, mammary gland ducts and parts of urethra.

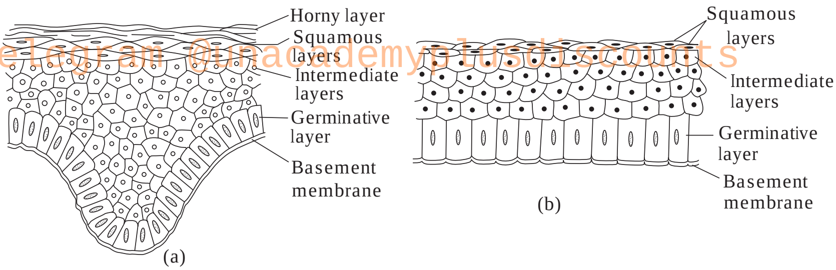
Stratified Ciliated

- Outer layer consists of ciliated columnar cells and basal layer is of columnar cells.
- It lines the larynx and upper part of the soft palate.

Stratified squamous epithelium is further of two types

(a) **Keratinised Stratified Squamous Epithelium** Keratin is present in the dead superficial cells. It is impermeable to water and forms well protective covering against abrasions. It forms epidermis of skin of land vertebrates.

(b) **Non-keratinised Stratified Squamous Epithelium** Its superficial cells are living and keratin is absent. It is permeable to water and forms moderately protective covering against abrasions. It lines the buccal cavity, pharynx, oesophagus, etc.



(a) Keratinised epithelium (b) Non-keratinised epithelium

(III) Glandular Epithelium

Some of the columnar or cuboidal cells get specialised for secretion and form the glandular epithelium. **They are mainly of two types**

- **Unicellular** Consisting of isolated glandular cells, **e.g.,** goblet cells of the alimentary canal.
- **Multicellular** Consisting of cluster of cells, **e.g.,** salivary gland.

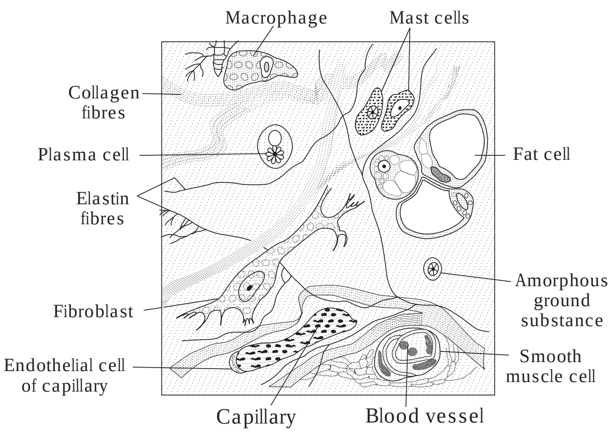
2. Connective Tissue

Most abundant and widely spread tissue, link and support other tissues of the body. **Basic components of connective tissue are**

(i) **Cells** embedded in the matrix including fibroblast, adipose cells, macrophages, mesenchyme cells, plasma cells, etc.

(ii) **Matrix** is a mixture of carbohydrates and proteins. The common mucopolysaccharide in matrix is hyaluronic acid.

(iii) **Fibres** including collagen fibres of white collagen protein, reticular fibres of reticulin protein and elastic fibres of yellow elastin protein.



Connective tissue (generalised)

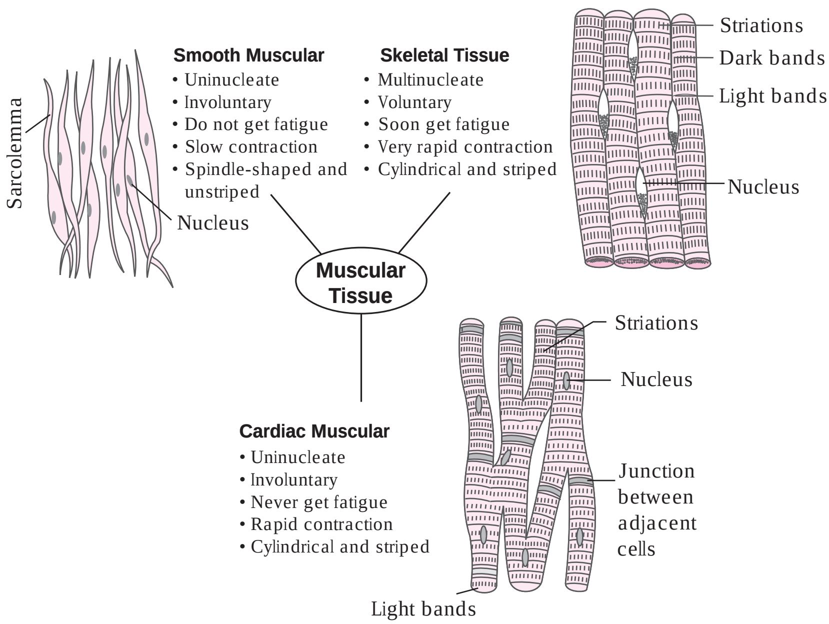
Types of Connective Tissue

- **Connective Tissue Proper**
  More intercellular material than cells, number of fibres, intercellular material of structural glycoprotein and glycoaminoglycans, matrix is soft containing cells and fibres.
  - **Reticular Connective Tissue**
    Consists of star-shaped reticular cells.
  - **Pigmented Connective Tissue**
    Consists of irregular pigment cells or chromatophores.
  - **Loose Connective Tissue**
    Loosely arranged cells and fibres in matrix.
    - **Areolar Tissue**
      Contains small spaces (areolar) in between the fine threads. Forms the basic framework of body.
    - **Adipose/Fatty Tissue**
      Contains fat storing adipocytes, acts as shock-absorber, produces blood corpuscles, etc.
      - **White (Yellow) Fat**
        Monolocular, i.e., single large fat globules present, less energetic.
      - **Brown Fat**
        Multilocular, i.e., several small fat globules present, iron containing cytochrome pigment is present, more energetic.
  - **Dense Connective Tissue**
    Compactly arranged cells and fibres in matrix.
    - **Dense Irregular**
    - **Dense Regular**
      - **White Fibrous Connective Tissue**
        Collagen is dominant, tough and inelastic, e.g., tendon.
      - **Yellow Elastic Connective Tissue**
        Contains loose network of yellow fibres, elastic and branched, e.g., ligaments.
- **Vascular Connective Tissue**
  Different cells suspended in the liquid matrix, fibres are absent.
  - **Lymph**
    Pale yellow tissue containing plasma and WBC, platelets are absent.
  - **Blood**
    Mobile connective tissue containing plasma and blood corpuscles. Platelets are present.
- **Skeletal Connective Tissue**
  Forms endoskeleton, support and protect the body, rigid matrix enclosing few cells and fibres.
  - **Bone**
    Hard, non-pliable tissue containing osteoblasts, osteocytes and osteoclasts matrix contain 62% in organic phase and 38% organic phase (ossein).
  - **Cartilage**
    Soft, avascular tissue containing chondrocytes, chondrin (matrix) and aggrecan (core protein).
    - **Hyaline Cartilage**
      Clear, elastic matrix with less fibres, most prevalent cartilage, found in articular surfaces, embryonic skeleton, etc.
    - **White Fibrocartilage**
      Firm matrix containing white fibres, strongest cartilage, found in intervertebral discs.
    - **Elastic Cartilage**
      Matrix contains yellow fibre, found in pinna, eustachian tube, etc.
    - **Calcified Cartilage**
      Matrix contains granules of calcium carbonate, hard, found in vertebral column of shark.

3. Muscular Tissue

Contractile tissue containing numerous fine fibrils called **myofibrils** in the cytoplasm (sarcoplasm). Muscle cells (myocytes) develop from myoblasts. Muscles have the capacity to respond to a stimulus (irritability) by two basic phenomena, **i.e.,** response to a stimulus and conductivity.

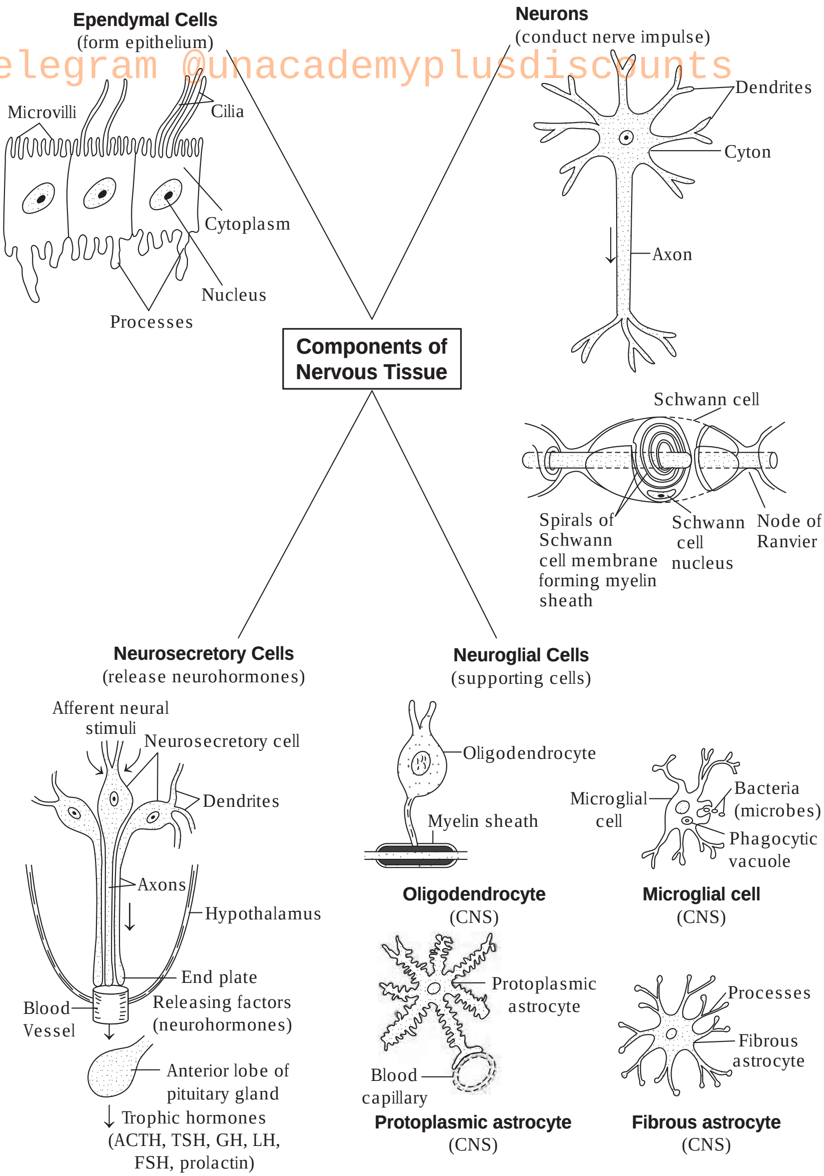
Muscular tissues are of following three types

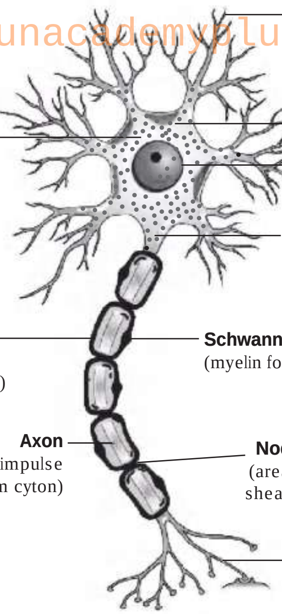


Types of muscles

4. Neural Tissue

This tissue is the second specialised tissue with the property of exicitability and conductivity. It consists of nerve cells and glial cells. Neurons are the structural and functional units of neural (nervous) tissue.


Components of Nervous Tissue
Ependymal Cells
(form epithelium)
Microvilli
Cilia
Cytoplasm
Nucleus
Processes
Neurons
(conduct nerve impulse)
Dendrites
Cyton
Axon
Schwann cell
Spirals of Schwann cell membrane forming myelin sheath
Schwann cell nucleus
Node of Ranvier
Neurosecretory Cells
(release neurohormones)
Afferent neural stimuli
Neurosecretory cell
Dendrites
Axons
Hypothalamus
End plate
Blood Vessel
Releasing factors (neurohormones)
Anterior lobe of pituitary gland
Trophic hormones (ACTH, TSH, GH, LH, FSH, prolactin)
Neuroglial Cells
(supporting cells)
Oligodendrocyte
Myelin sheath
Oligodendrocyte
(CNS)
Microglial cell
Bacteria (microbes)
Phagocytic vacuole
Microglial cell
(CNS)
Protoplasmic astrocyte
Blood capillary
Protoplasmic astrocyte
(CNS)
Processes
Fibrous astrocyte
Fibrous astrocyte
(CNS)



Structure of a neuron

Types of Neurons

On the basis of structural nature, **neurons are of following four types, i.e.,**

(i) **Apolar Neurons**, **i.e.,** neurons without polarity. Here, the fibres of neuron are not differentiated into axon and dendrites. All the fibres are of same nature and can carry information towards or away from the cell body, **e.g.,** neurons of **Hydra**.

(ii) **Unipolar Neurons**, **i.e.,** neurons with unidirectional flow of information. These have one axon or one dendrite only. Most sensory neurons are unipolar. These are common in invertebrate and vertebrate embryos.

(iii) **Bipolar Neurons**, **i.e.,** neurons with unidirectional flow of information, but with one dendron and one axon at opposite poles. These occur in the retina of eyes, olfactory epithelium, etc.

(iv) **Multipolar Neurons**, **i.e.,** neurons with unidirectional flow of information, but with one axon and many dendrites. They occur in the nervous system of adult vertebrates.

Neurons can also be classified according to their functions as

(i) **Sensory or Afferent neurons**, **i.e.,** these connect sensory or receptor cells or organs to the CNS and conduct sensory impulses. Branched or unbranched and naked or encapsulated free endings of numerous sensory neurons found scattered in skin epidermis. These serve as cutaneous sense organs or **exteroceptors**. Similar endings scattered in skeletal muscles, bone joints, ligaments and tendons serve as **interoceptors**.

(ii) **Motor or Efferent neurons**, **i.e.,** these connect the CNS to effectors (muscles and glands) and conduct motor impulses.

(iii) **Internuncial or Interneurons** These occur only in the CNS and serve to connect two or more neurons for distant transmission of impulses.

Similarly, nerve fibres can be categorised as

Nerve Fibres

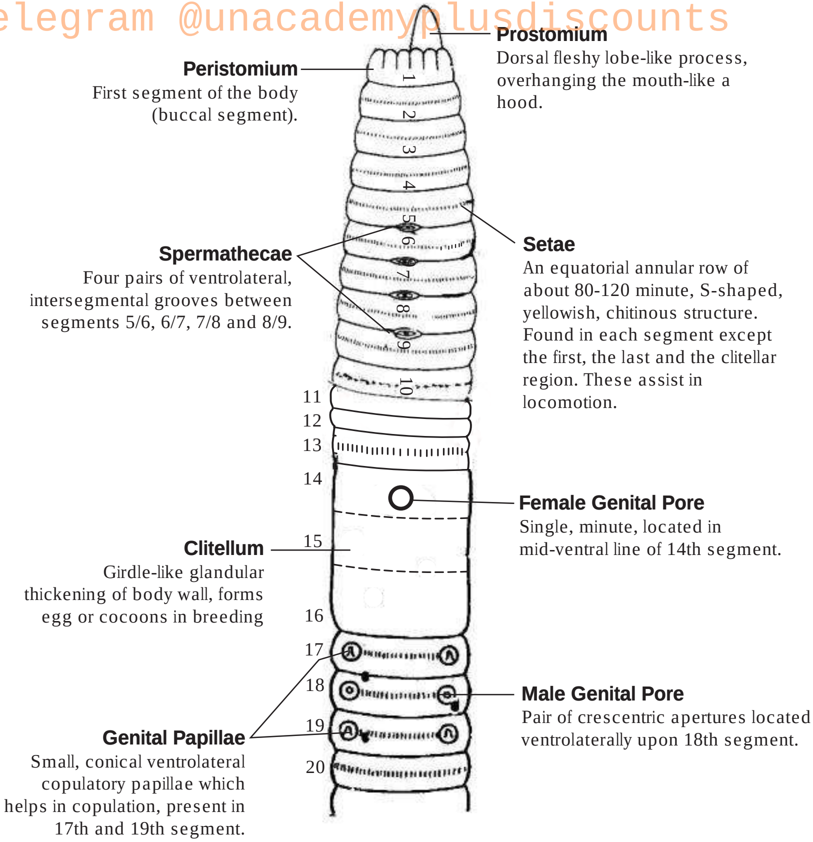
- **On the basis of Structure**
  - **Medullated**
    - Covered by myelin
    - Carry impulse faster
    - Nodes of Ranvier are present
    - White in colour
  - **Non-medullated**
    - Do not cover by myelin
    - Carry impulse slower
    - Nodes of Ranvier are absent
    - Grey in colour
- **On the basis of Function**
  - **Afferent**
    - Sensory
    - Carries impulse from sense organ to CNS
  - **Efferent**
    - Motor
    - Carries impulse from CNS to effector organs

Earthworm

It is a reddish-brown terrestrial invertebrate that inhabits the upper layer of the moist soil. The common Indian earthworms are **Pheretima** and **Lumbricus**.

Morphology

Bilaterally symmetrical with elongated, narrow and cylindrical body. It appears brown due to the presence of porphyrin pigment in the body wall. Dorsal body surface is demarcated by the ventral surface due to the presence of dark mid-dorsal line. Their body is metamerically segmented.



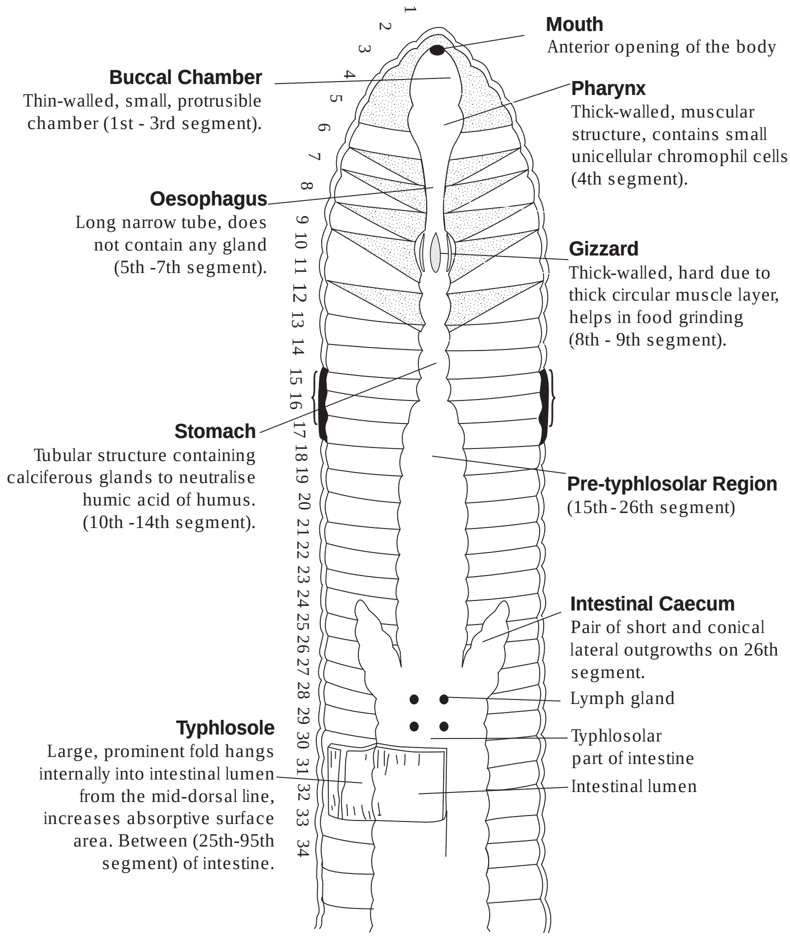
External structure of an earthworm

Metamerism

It is the repetition of organs and tissues at intervals along the body of an animal, thus dividing the body into a linear series of similar parts or segments (metamers). It is an internal mesodermal phenomenon and helps in more efficient locomotion.

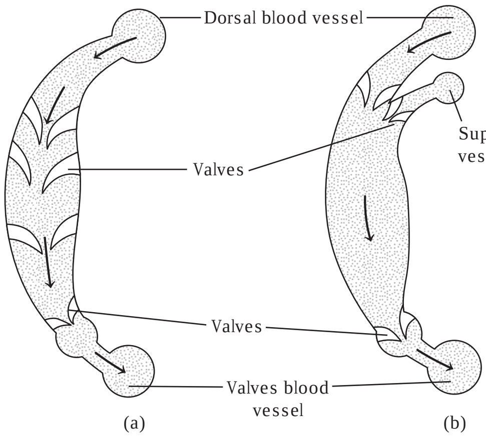
Anatomy and Physiology

- The body wall of the earthworm is covered externally by a thin non-cellular cuticle below which is epidermis, two muscular layers and an innermost coelomic epithelium. The epidermis is made up of a single layer of columnar epithelial cells which contain secretory gland cells.
- **Locomotion** It is brought about by a coordinated contraction and relaxation of circular and longitudinal muscles of body wall, assisted by setae, mouth and the hydrostatic pressure of coelomic fluid.
- **Digestive System** Earthworm possesses a straight alimentary canal from mouth to anus. The canal is differentiated into six regions–buccal chamber, pharynx, oesophagus, gizzard, stomach and intestine.



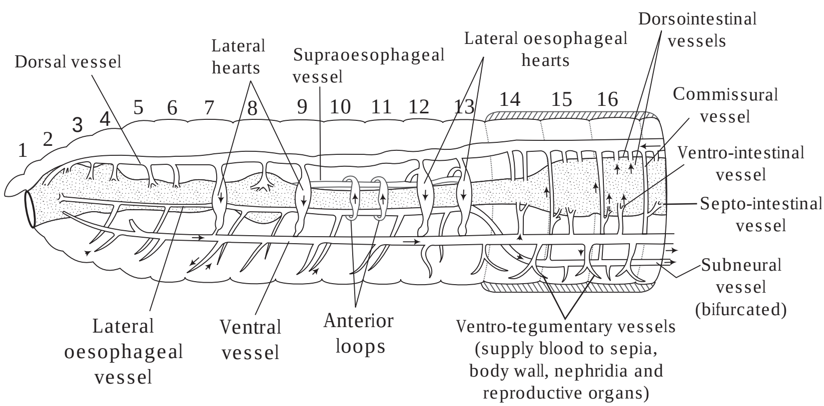
Alimentary canal of an earthworm

- **Circulatory System** Closed circulatory system, **haemoglobin** or erythrocruorin dissolved in blood plasma. Three main blood vessels in body are dorsal, ventral and sub-neural. **Dorsal blood vessel** is the largest blood vessel of the body. **Blood glands** are present on the 4th, 5th and 6th segments and they produce blood cells and haemoglobin. Blood cells are phagocytic in nature. Their heart do not have any kind of pulsative activity.

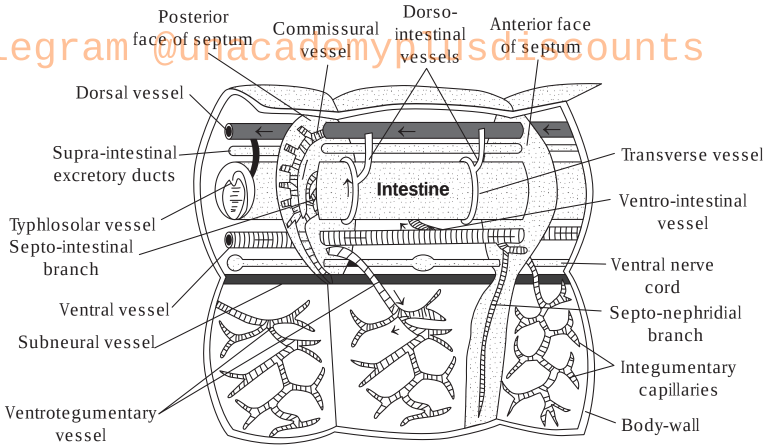


Heart of Pheretima : (a) Lateral heart (7th and 9th segments)
(b) Lateral oesophageal heart (12th and 13th segments)

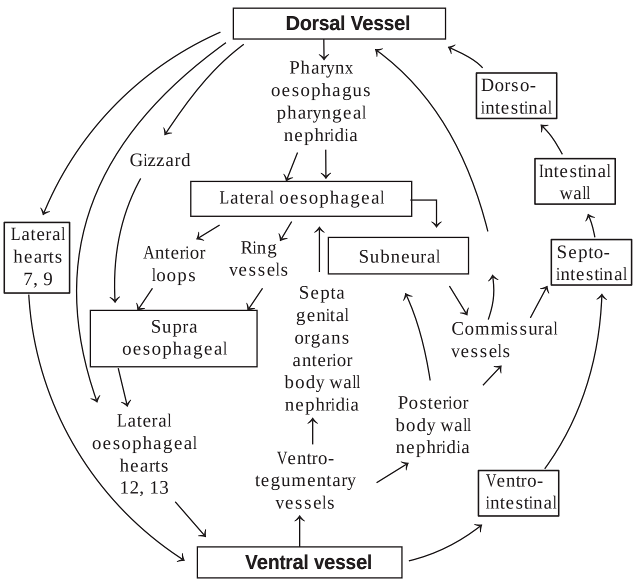
The number, nature and arrangement of blood vessels are very different in the first 13th segments from that in the rest of the body.



Pattern of blood vascular system in first 13th segments

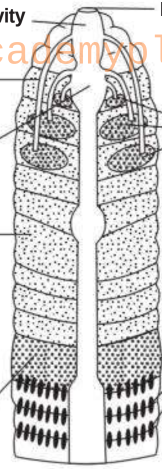


Pattern of blood vascular system behind 13th segment



Complete circulation plan of earthworm

- **Respiratory System** The animal is aerobic and gaseous exchange takes place through general body surface.
- **Excretory System** It is made up of segmentally arranged **nephridia** of **three types**.



Types of nephridia

Nervous System Metamerically segmented, divisible into three sections, **viz.,** central, peripheral and autonomic. All nerves are mixed, having both sensory and motor fibres.

Nervous System

Peripheral Nervous system
Includes all nerves that connect the brain and nerve cord with various body parts.

Autonomous Nervous System
Includes the nerve plexuses located in the gut wall and other internal organs.

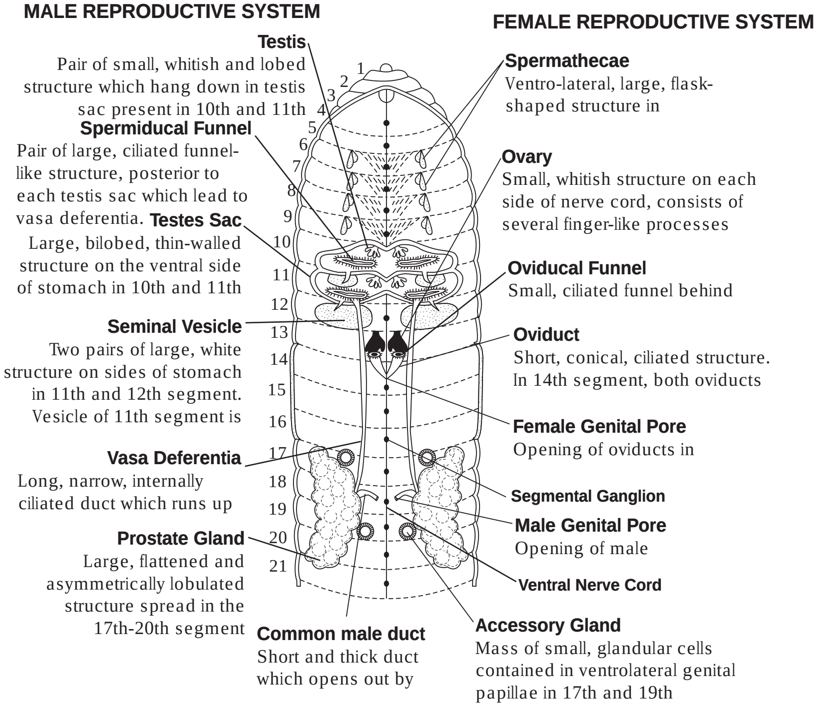
Central Nervous System

Brain Ring
Oblique ring around pharynx in 3rd and 4th segments. It has three parts

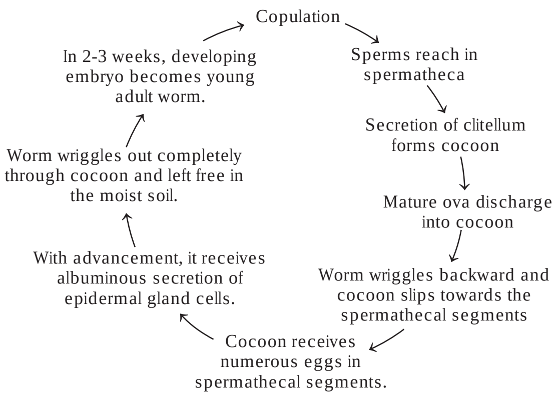
- **Cerebral or Suprapharyngeal Ganglia** — Mid-dorsal part, small paired and fused structure.
- **Subpharyngeal Ganglia** — Mid-ventral part, small paired and fused structure.
- **Circum or Peripharyngeal Connectives** — Loop-like structure, connect dorsal and ventral ganglionic parts.

Nerve Cord
Pair of slender cords arises from the subpharyngeal ganglia, extends behind upto posterior end of body. From 5th segment behind, it has a ganglionic swelling in the posterior part of each segment (segmental ganglion).

Reproductive System Earthworm is hermaphrodite (bisexual) and reproduces only sexually.



Reproductive system of earthworm



Events of reproduction in earthworm

Economic Importance of Earthworm

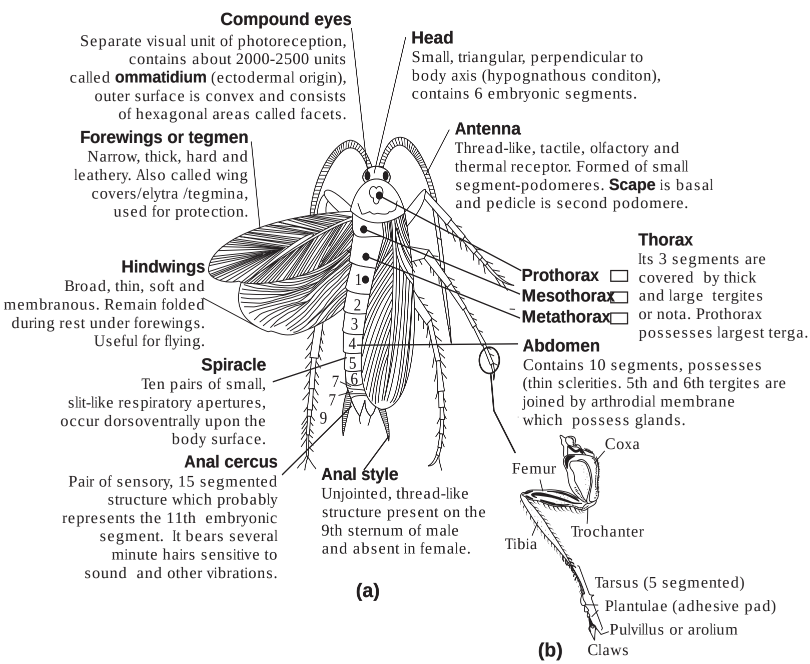
- They are used as bait for fishing.
- Their burrowing habit increases the fertility of soil. This is called vermicomposting.
- Their burrows cause the loss of water by seepage from ditches in irrigated lands.
- They are easily obtained and are of convenient size for dissections in laboratories.

Cockroach

They are brown or black-bodied animals that are included in class–Insecta of phylum–Arthropoda. The most common species of cockroaches in India is **Periplaneta americana**.

Morphology

Nocturnal, bilateral symmetrical invertebrate, distinctly segmented and covered by a shining brown exoskeleton. Their dorsal body surface is covered by dark brown wings. When wings are removed, the three regions of the body–head, thorax and abdomen become visible.



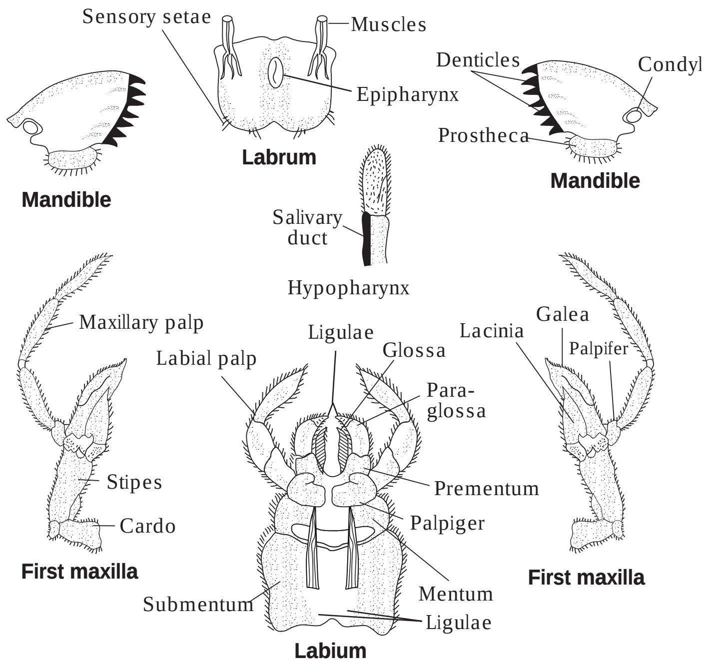
External features of cockroach : (a) Complete body (b) One walking leg

- **Sclerites** Small plate-like structures, which forms the exoskeleton. These structures are joined together by soft, intersegmental, flexible membrane called **arthrodial membrane**.

  The dorsal sclerites are called **tergites**, ventral one are **sternites**, while the lateral ones are called **pleurites**.

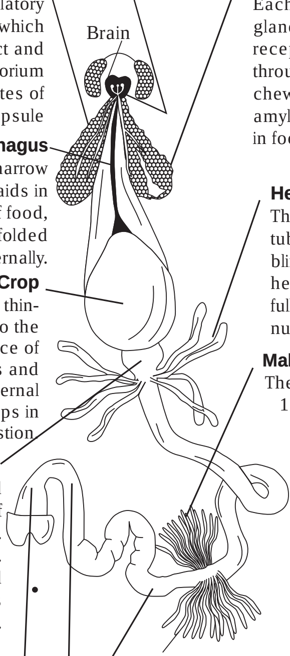
Anatomy and Physiology

- **Body Wall** The body wall contains cuticle, epidermis and basement membrane.
- **Body Cavity** Cockroaches are coelomate animals. But, true coelom occurs only in embryonic stage. In adults, it is found in small cavities only around the gonads.
- **Endoskeleton** Certain processes of exoskeleton extend into the body and form endoskeletal elements. These provide attachment to the muscles and hence called apodemes.
- **Locomotion** Cockroaches are good runners, but poor fliers as the muscles associated with the jointed legs are much more developed than those associated with the wings.
- **Digestive System** The mouth in animal is surrounded by well-defined appendages, which can be seen as



Mouth parts of cockroach

Alimentary canal is complete and well-differentiated in accordance with omnivorous mode of feeding. **It is divisible into following parts**



Digestive system of cockroach

- **Respiratory System** Every tissue of body is in direct communication with atmospheric air due to the absence of respiratory pigment in the blood.

It consists of following components

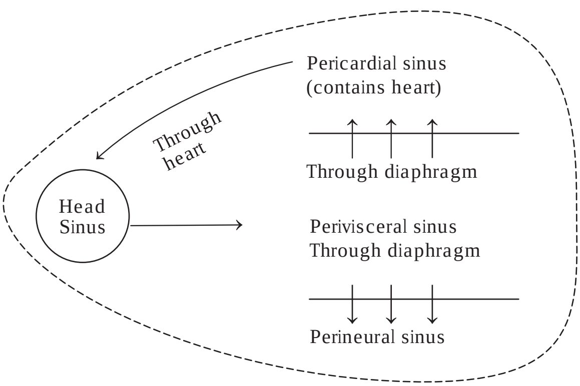
(a) **Trachea or Air Tubes** Numerous, shiny, transparent, branched tubes formed by extensive invagination of the hypodermis of skin (ectodermal in origin). There are six longitudinal tracheal tubes (2 dorsal, 2 ventral and 2 lateral) which are interconnected by transverse commissures.

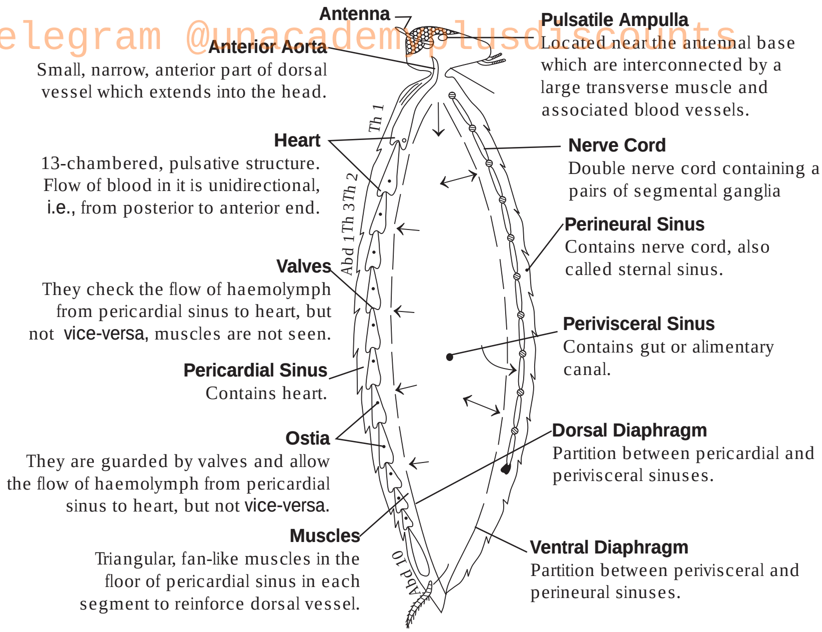
(b) **Spiracle or Stigmata** Ten pairs of slit-like apertures through which air enters and escapes from the trachea, located on lateral side of body, surrounded by a ring-like peritreme.

There are 2 thoracic pairs (larger than abdominal spiracle) and 8 abdominal pairs (first pair is dorso-lateral upon tergite and rest seven are upon the pleurites of 2nd - 8th segments).

- **Circulatory System** Cockroach possesses open type of circulatory system with blood flowing in the blood spaces or lacunae. The blood is without respiratory pigment and called haemolymph (possesses plasma and haemocytes). Body consists of three sinuses mainly with one head sinus.

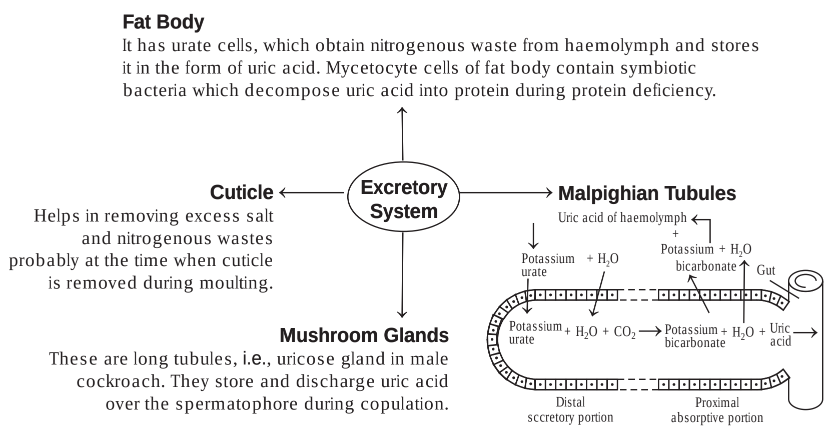
The flow of blood within the body looks like





Circulatory system of cockroach

Excretory System The animal is uricotelic and excretion occurs through the following structures

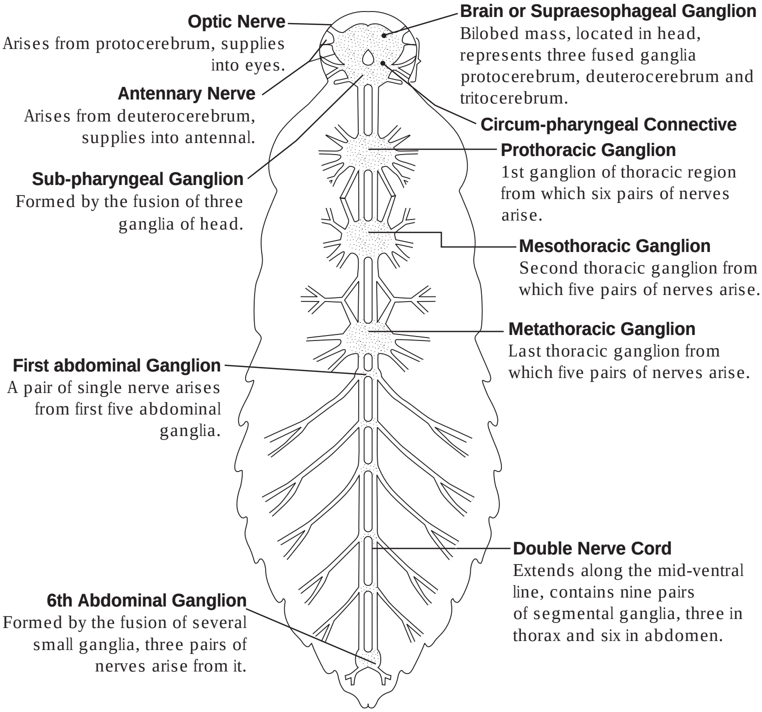


Excretory system in cockroach

- **Nervous System** **It is well-developed and divided into following three types**

(i) **Central Nervous System** It includes a brain, one suboesophageal or subpharyngeal ganglion and a doublet ventral nerve cord.

(ii) **Peripheral Nervous System** It includes the nerves that connect the various ganglia of CNS to different body parts.



Central and peripheral nervous system of cockroach

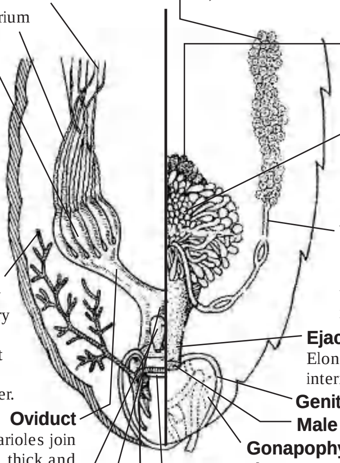
(iii) **Autonomic Nervous System** It is of sympathetic type and also called **visceral nervous system**. It performs both nervous and endocrine functions.

It is divided into three parts

1. **Caudal NS** Includes certain fine nerves that arise from last abdominal ganglion and innervate hindgut, reproductive organs and anal appendages.
2. **Spiracular NS** Includes certain fine paired nerves which arise from the ganglia of nerve cord and innervate the spiracles.
3. **Somatogastric NS** Includes certain fine nerves which arise from five ganglia and innervate the anterior parts of the gut.

Reproductive System Sexes are separate and sexual dimorphism is also seen

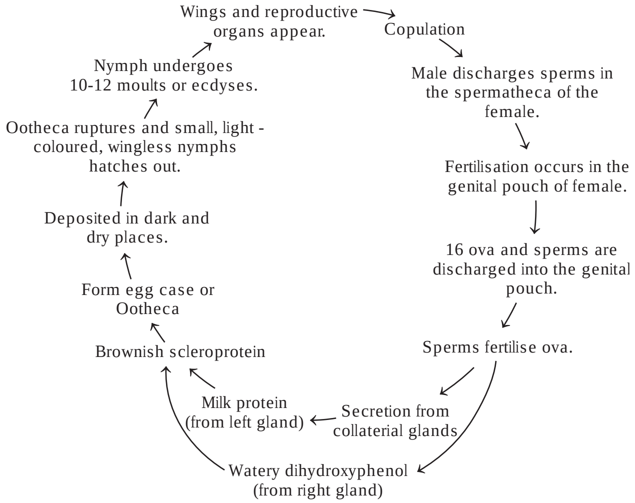
Female Cockroach	Male Cockroach
Body relatively larger and thicker.	Body relatively smaller and more flattened.
Abdomen has seven distinct segments.	Abdomen has nine distinct segments.
Hind end of abdomen is blunt and boat-shaped.	Hind end of abdomen is somewhat pointed.
Seventh sternite is divided.	Seventh sternite is undivided.
Anal styles are absent.	A pair of anal styles is articulated with 9th abdominal sternite.
Wings are smaller, extend only up to the hind end part of body.	Wings are relatively large, extend somewhat beyond the hind end of body.



Reproductive system of cockroach

- **Suspensory Filament** Thin, thread-like terminal filament formed of a syncytial chord of cytoplasm. It is terminally inserted upon dorsal body wall and serves to suspend the ovarioles into the perivisceral sinus.
- **Germarium** A small, multicellular structure in which oogonia forms and matures into oocytes.
- **Vitellarium** A long and narrow structure which receives the actively growing oocytes from germarium. It appears beaded due to gradually growing sizes of contained oocytes.
- **Egg Chamber** A small, thick and elliptical structure which contains, at a time, a single, large, mature ovum.
- **Pedicel** A small, hollow structure which unites to form oviduct.
- **Spermatophore** It is a three-layered, pear-shaped, tough structure which centrally contains spermatozoa in the nourishing fluid secreted by small tubules or utriculi breviores of male's mushroom gland.

Physiology of Reproduction



Process of reproduction in cockroach

Economic Importance of Cockroach

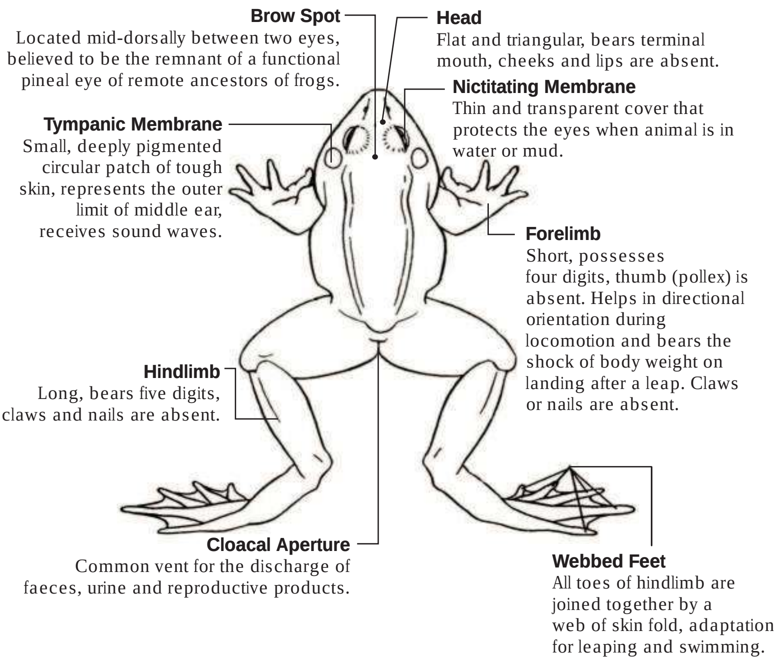
- They can be used as tools for the research of insect physiology and toxicology.
- They do not sting or bite, transport human pathogens.

Frog

They are called amphibians because they can live both on land and in freshwater. The most common species of frog is **Rana tigrina**.

Morphology

Frog is a dorsoventrally flattened and streamlined animal, adapted for an amphibious mode of life. Its body is divisible into head and trunk.



External structure of frog

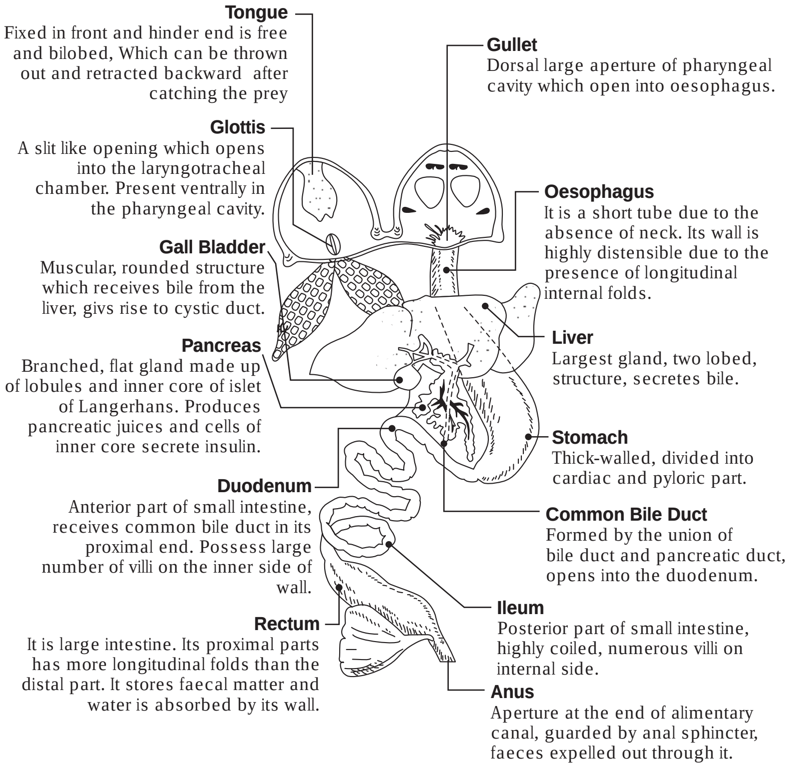
- **Croaking** During the rainy season or breeding season, frogs make peculiar sound with the help of their vocal cords to attract females for mating. The male frogs croak louder than the females.

- **Metachrosis** It is the capability of frog to change its body colour with the change in its surroundings and climatic conditions.

- **Nuptial Pad** It is a dark swelling on the inner finger of the male frog which helps the male frog in mating.

Anatomy and Physiology

- **Digestive System** Frogs are holozoic and carnivorous. Their alimentary canal is short, **coiled tube consisting of following structures**



Digestive system of frog

- **Respiratory System Respiration in frog occurs through three modes**

  (a) **Cutaneous Respiration** Frog's skin is ideally adapted for the process of gaseous exchange. It is without exoskeleton, highly vascularised skin, always remain moist due to the secretions of mucous glands. It is most common mode, especially during hibernation and aestivation.

(b) **Buccopharyngeal Respiration** Mucosa of buccopharyngeal cavity is highly vascularised which aids in gaseous exchange. By showing oscillatory movements of the floor of buccal cavity and keeping the mouth, gullet and glottis closed, breathing process is carried out. **Sternohyal** and **pterohyal** muscles help in the oscillatory movements. It is carried out in water and on land.

(c) **Pulmonary Respiration** It involves the lungs, which are positive pressure type with hollow, highly distensible walls. They are endodermal in origin. Inspiration and expiration involves **gulping movements** in between oscillatory motion of buccopharyngeal respiration.

Pulmonary Respiration

Inspiration

Contraction of sternohyal muscles

↓

Lowering of floor of buccal cavity.

↓

Air rushes into buccopharyngeal cavity.

↓

Contraction of submental muscles of lower jaw closes the external nostrils + Contraction of pterohyal muscles raises the floor of buccal cavity.

↓

Air moves inside the lungs.

Expiration

Contraction of sternohyal muscles

↓

Air from lungs rushes to buccopharyngeal cavity.

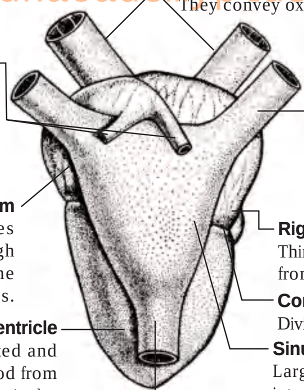
↓

Relaxation of submental muscles opens the external nostrils.

↓

Air leaves the buccopharyngeal cavity.

Circulatory System It consists of blood vascular system of closed type which represents the incomplete double circulation. **i.e.,** both oxygenated and deoxygenated blood enters the heart and get mixed in the ventricle. Blood vascular system comprises blood, heart and blood vessels. Their heart is myogenic.



Circulatory system of frog

(i) **Conus or Truncus Arteriosus** This accessory chamber is present towards the ventral side. It contains a spiral valve inside because of which its cavity is divided into cavum pulmocutaneum and cavum aorticum.

(ii) **Pylangium** The proximal, more muscular and longer portion of conus arteriosus. It is also called as **bulbus arteriosus**. It contains pulsative cardiac muscles.

(iii) **Synangium** The distal, less muscular portion of conus arteriosus. It is also called as **ventral aorta**.

(iv) **Columnae Carneae** These are the major muscle columns of ventricle. These columns are connected with the flaps of valves through elastic chords of fibres called **chordae tendineae**.

Mixed blood is pumped by frog's heart due to incomplete double circuit (**i.e.**, due to the presence of only one ventricle).

Lymphatic system It consists of lymphatic capillaries, sinuses, lymph hearts and lymph.

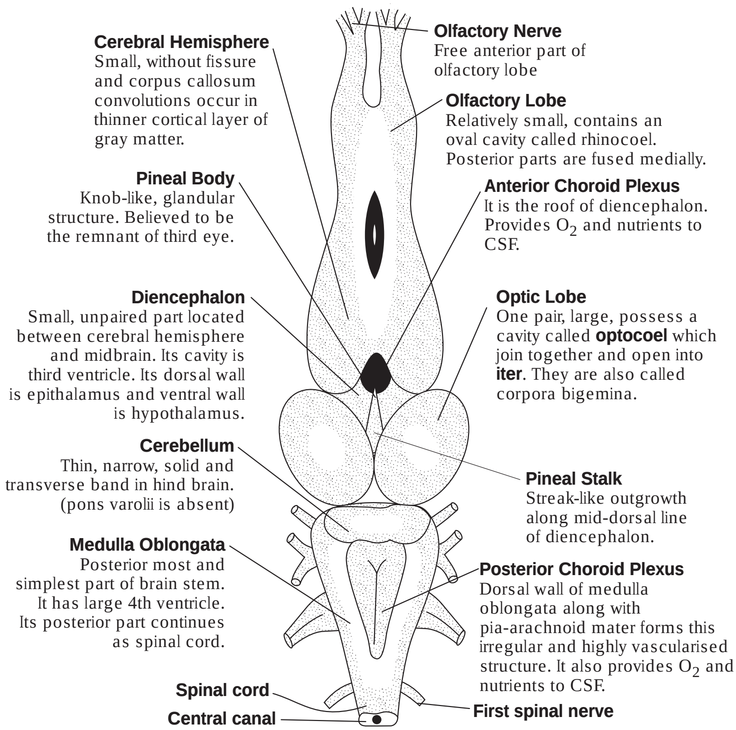
(i) **Lymph** Mobile connective tissue containing plasma with less number of proteins and corpuscles, containing numerous leucocytes, but no erythrocytes.

(ii) **Lymph sinuses** Thin-walled spaces around the tissues and between the organs. Subcutaneous and subventral sinuses are most common.

(iii) **Lymph hearts** Two pairs of thin-walled and muscular structure.

(iv) **Lymph capillaries** They end blindly in contact with the body cells and tissue spaces. Thin-walled, irregular and permeable to colloids, water and crystalloids.

- **Excretory System** It consists of two kidneys, ureter, urinogenital ducts and urinary bladder. The kidneys are of **mesonephric type**, **i.e.,** it develops from the middle part of intermediate mesoderm. The nephron is not much differentiated. In embryonic conditions, **nephrostomes** are functional and in adults, they get replaced by **glomerulus**. Frog is **ureotelic**.
- **Nervous System** It comprises CNS, PNS and ANS
  (i) **Central nervous system** It comprises brain and spinal cord. Brain is enveloped by two membranous meninges, **i.e.,** Pia arachnoid (inner, soft, highly vascularised) and Dura mater (outer, tough, collagen fibre covering).



Nervous system of frog

Exceptions to frog's brain as compared to humans are

- Rhincnceptialon is anterior in position, but not in humans.
- Optic lobes are one pair, whereas they are two pairs in humans.
- Corpus striatum is present upon the floor of cavities of cerebral hemisphere in frog.
- Hippocampi, corpus callosum and pons Varolii are absent in frogs.
- Frog's vision is monolocular and it is binocular in humans.

(ii) **Peripheral Nervous System** It is represented by cranial and spinal nerves.

There are 10 pairs of cranial nerves in frog.

Spinal accessory nerves and hypoglossal nerves are absent in it.

The number of spinal nerves in frog is 10 pairs, **i.e.,** 20.

(iii) **Autonomic Nervous System** It controls the involuntary activities such as homeostasis. **It comprises two antagonistic parts**

(a) **Sympathetic NS** It generally acts to stimulate the body to cope with stress. Its nerve endings are cholinergic and adrenergic.

(b) **Parasympathetic NS** It functions to calm the body. Its nerve endings are cholinergic.

(iv) **Endocrine system** Endocrine glands secrete hormones for chemical coordination of various organs of body. The prominent endocrine glands found in frog are pituitary, thyroid, parathyroid, thymus, pineal body, pancreatic islets, adrenals and gonads.

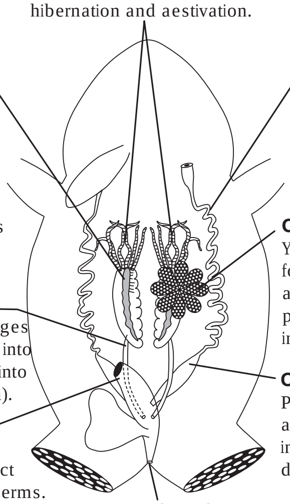
(v) **Skeletal system** In frog, exoskeleton is absent. the endoskeleton has two parts

(a) **Axial skeleton** includes skull in the head and vertebral column in trunk.

(b) **Appendicular skeleton** indudes limb bones in the arms and legs and girdles that connect the limb bones with vertebral column.

(vi) **Reproductive System** Sexes are separate and sexual dimorphism can be seen. The vocal sacs and nuptial pad can be observed in male frogs in breeding season.

Reproductive System



Reproductive system in frog

Economic Importance of Frog

- They control bugs and help keep the ecosystem in balance.
- They maintain the balance in food chain and food web by acting as consumers.

8

Cell : The Unit of Life

Cell

It is the basic structural, functional and biological unit of all known living organisms.

Robert Hooke (1665) observed honey-comb-like dead cells in a thin slice of cork and named them 'cell'. **Anton van Leeuwenhoek** (1667) was the first to describe a living cell.

The properties of a living organism depend on those of its individual cells. Cells contain DNA which is found specifically in the chromosome and RNA found in the cell nucleus and cytoplasm.

All cells are basically same in chemical composition in the organisms of similar species. Energy flow occurs within cells through metabolism and biochemical reactions.

Cell Theory (Magna Carta of Cell Study)

MJ Schleiden; 1838 and **Theodor Schwann**; 1839.

The postulates are

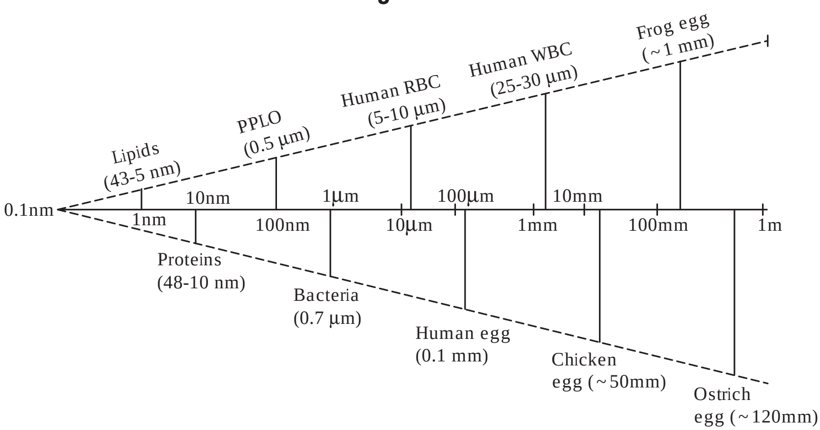
- All living beings are made up of cells. Cell is the smallest independent unit of life.
- All cells arise from pre-existing cells **(Omnis cellula-e-cellula**, **Rudolf Virchow**).

Shapes and Size of Cell

Cells differ greatly in shape. They may be amoeboid, cuboid, thread-like, polygonal, disc-like or columnar.

Size of biological cell is generally too small to be seen without a microscope. There are exceptions as well as considerable range in the sizes of various cell types.

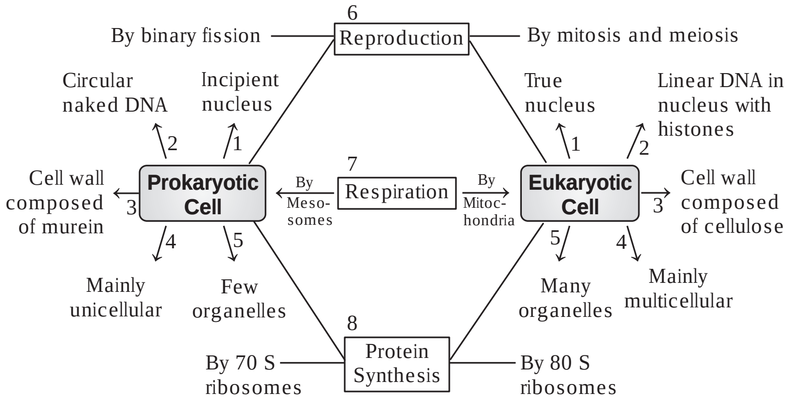
Relative size of different cells are given below



Relative size of different cells

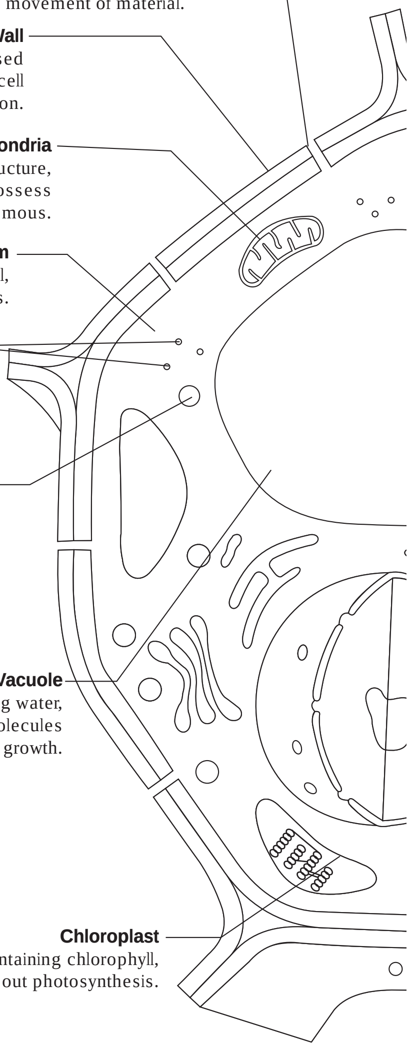
Types of Cells

Cells are classified into two types, **i.e.**, prokaryotic and eukaryotic cells. Prokaryotic cells have incipient nucleus and lack double membrane bound cellular organelles, whereas eukaryotic cells have true or advanced nucleus and possess many organelles.

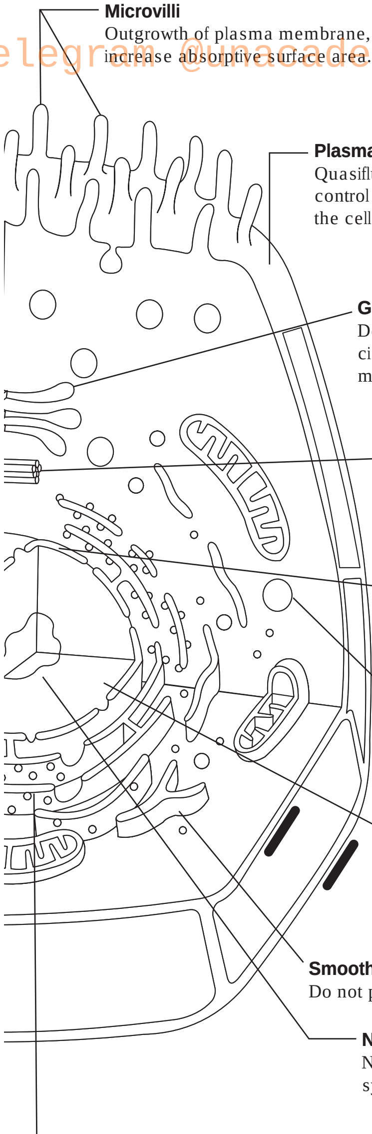


Differences between prokaryotic and eukaryotic cell

Structure and Components of Eukaryotic Cell
(Plant and Animal)



Structure of a plant cell



Microvilli
Outgrowth of plasma membrane, increase absorptive surface area.

Plasma Membrane
Quasifluid, elastic cell membranes, control movement of molecules in and out of the cell, aids in cell-cell signalling and cell-adhesion.

Golgi Apparatus
Densely stained reticular structures consists of sacs and cisternae. Process and sort lysosomal, secreted and membrane proteins to release their content.

Centriole
Present in centrosome as a paired structure, lying perpendicular to each other.
Form basal bodies of cilia and flagella.

Nuclear Envelope
Double membrane with perinuclear space. Outer membrane is continuous with RER, possesses nuclear pores.

Lysosomes
Membrane bound vesicular structures, contain hydrolytic enzymes, degrade worn-out material, active at acidic pH.

Nucleus
Filled with chromatin, composed of DNA and proteins synthesises mRNA and tRNA in dividing cells.

Smooth ER
Do not possess ribosomes, major site of lipid synthesis.

Nucleolus
Nuclear compartments where most of rRNA is synthesised.

Rough ER
Possess ribosomes on their surface, synthesise, process and sort secreted and lysosomal proteins.

Structure of an animal cell

Components of a Cell

Cell Wall

It was first discovered by **Robert Hooke** (1665). It is a rigid and non-living structure. It is present just below the glycocalyx (outermost glycoprotein covering) or murein in all eubacteria and cyanobacteria. It is absent in animal cell.

A typical cell wall consists of four layers namely

(i) **Middle lamella** Outermost cementing layer between the cells, made up of Ca and Mg pectates, absent in outer free spaces and ruptures to create intercellular spaces.

(ii) **Primary cell wall** Thin, elastic, capable of growing cells and diminishes as the cells mature possesses more hemicellulose and less cellulose in their cell wall, only cell wall in meristematic and parenchymatous cells.

(iii) **Secondary cell wall** Formed by accreration, they have more cellulose, found in collenchyma, sclerenchyma and xylem vessels; it is rigid and non-elastic, contains pits at intervals.

(iv) **Tertiary cell wall** It is present occasionally, purely cellulosic and sometimes contains xylem found in the tracheids of gymnosperms.

Growth of Cell Wall

The growth and formation of cell wall occurs by two ways

(i) **By intussusception** It is the deposition of wall material in the form of fine grains.

(ii) **By apposition** In this method, the new cell wall material secreted by protoplasm is deposited by definite thin plates one after other.

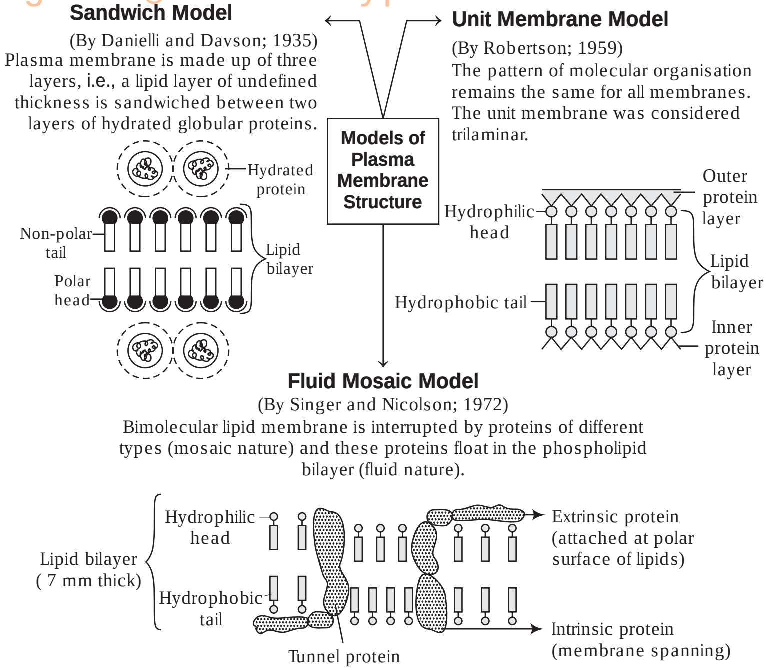
Functions of the Cell Wall

- It maintains the shape of plant cell and protects it from mechanical injury.
- It wards off the effect of pathogens.

Plasma Membrane

It contains about 58-59% proteins, 40% lipids and 1-2% carbohydrates.

To explain the structure of plasma membrane, various models were proposed by different scientists which are discussed below.



Models of plasma membrane structure

Functions of Plasma Membrane

- The cell membranes cause **compartmentalisation** as they separate the cells from their external environment and organelle coverings. They also allow the cell organelles to maintain their identity, internal environment and functional individuality.
- Plasma membrane protects the cell from injury.
- The membranes allow the flow of materials and information between different organelles of the same cell as well as between one cell and another.
- As plasmodesmata and gap junctions, the biomembranes provide organic connections between adjacent cells.

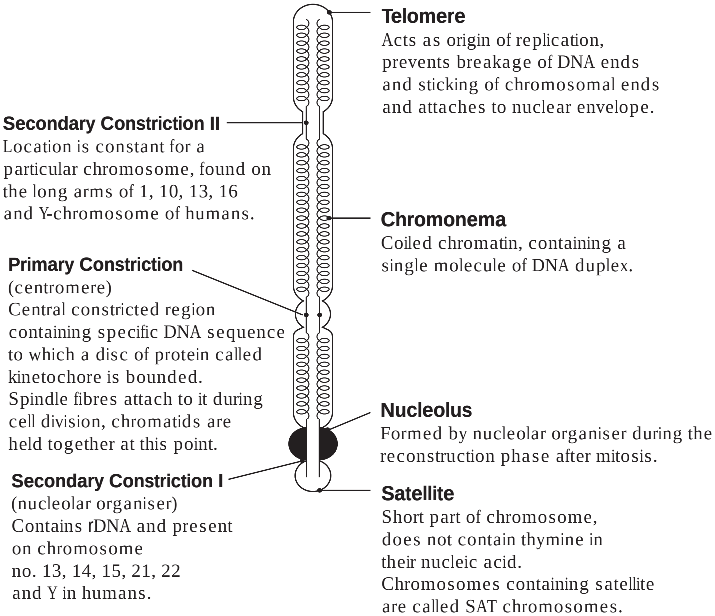
Nucleus

Nucleus or **karyon** was first discovered by **Robert Brown** (1831) in the cells of orchids roots. It is darkly stained, spherical and the largest cell organelle whose composition is as follows : 9-12% DNA, 15% histones (basic proteins), 15% enzymes, 5% RNA, 3% lipids, 65% acid and neutral proteins.

Nucleus has an outer double layered nuclear membrane with nuclear pores, a transparent granular matrix (nucleoplasm/karyolymph), chromatin network composed of DNA and histones and a directly stainable spherical body called **nucleolus**.

Chromosomes

They are rod-shaped and thread-like condensed chromatin fibres, which appear during karyokinesis. Each chromosome has two halves called **chromatids**, which are attached to each other by **centromere** or **primary constriction**.



Structural outline of a typical chromosome

Types of Chromosomes

Chromosomes

- Depending upon the position of centromere
  - **Submetacentric** Sub-medially placed centromere.
  - **Acrocentric** Subterminally placed centromere
  - **Metacentric** Medially placed centromere.
  - **Telocentric** Terminally placed centromere, rare.
- Depending upon the number of centromere
  - **Acentric** No centromere, does not take part in cell division.
  - **Polycentric** Many centromeres occur, diffused along the entire length.
  - **Monocentric** Single centromere, common.
  - **Dicentric** Two centromeres, appear as a result of translocation.

Besides, chromosomes can also be categorised on the basis of their specific properties. **These are**

Chromosomes

- **Supernumery or B-chromosomes** Genetically unnecessary, smaller than normal chromosomes. Found commonly in plants than animals. Reported in two species of flatworms and many species of angiosperms.
- **S and E-chromosomes** Somatic or S-type are found in both germ line and somatic cell. Eliminative or E-type are found in germ cells only. Reported in the family–Cecidomyiidae.
- **Polytene or Salivary Gland Chromosomes** (Giant chromosomes) Somatic chromosomes visible during interphase, possess darkly stained bands and lightly stained interbands. First observed by **Balbiani** (1881) in the salivary gland of *Chironomous*.
- **Lampbrush Chromosomes** (Giant chromosomes) Elastic chromosomes seen during extended diplotene in meiosis-I, consist of an axis having a row of dense granules. First observed by **Flemming** (1882) in amphibian oocyte.
- **Limited or L-chromosomes** Large and limited to germ line cell only. Reported in the family–Sciaridae of order–Diptera.
- **Minute or M-chromosomes** Small size, seen during meiosis, reported in bryophytes and bugs of family–Coreidae of order– Heteroptera.
- **Mega chromosomes** Heterochromatic large chromosomes, may be mono, di or acentric, not transmitted through gametes. Found in few species of *Nicotiana* hybrids.

On the basis of genes they possess, the chromosomes can be of following types

(i) **Autosomes** These are the somatic chromosomes which do not take part in fertilisation process. These are also called **allosomes.** They are 44 in number in human body.

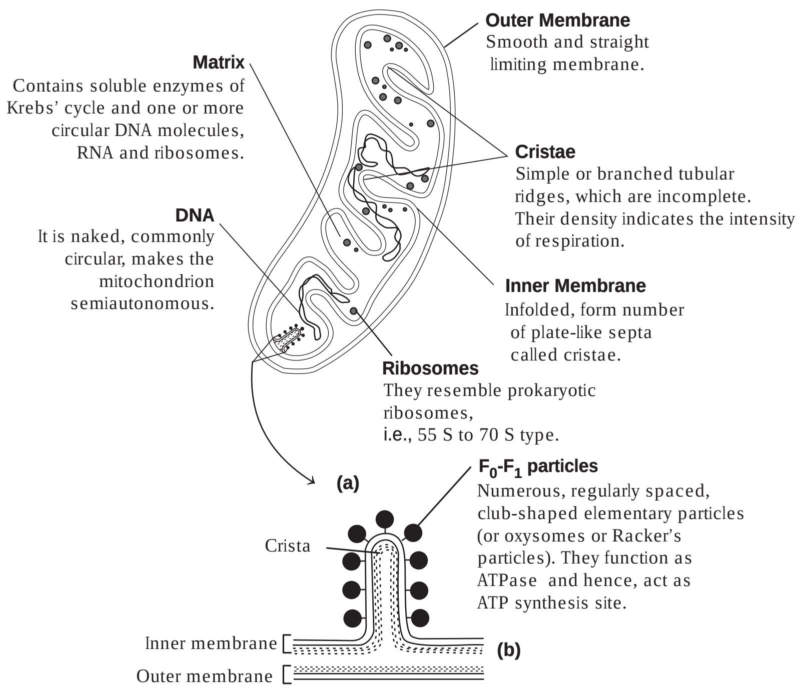
(ii) **Sex chromosomes** These are involved in fertilisation process and helps to pass information from one generation to another. These are also called **heterosomes** and are two in number in human body.

Functions of Chromosomes

- They carry hereditary information in the genes from parents to offspring.
- The SAT (stands for Satellite or Sine Acid Thymonucleonics means where thymine containing acid is absent) chromosomes form nucleoli in daughter cells at nucleolar organiser regions.
- Sex chromosomes (X and Y) play role in sex-determination.
- They undergo crossing over and mutations and thus, contribute to the evolution.

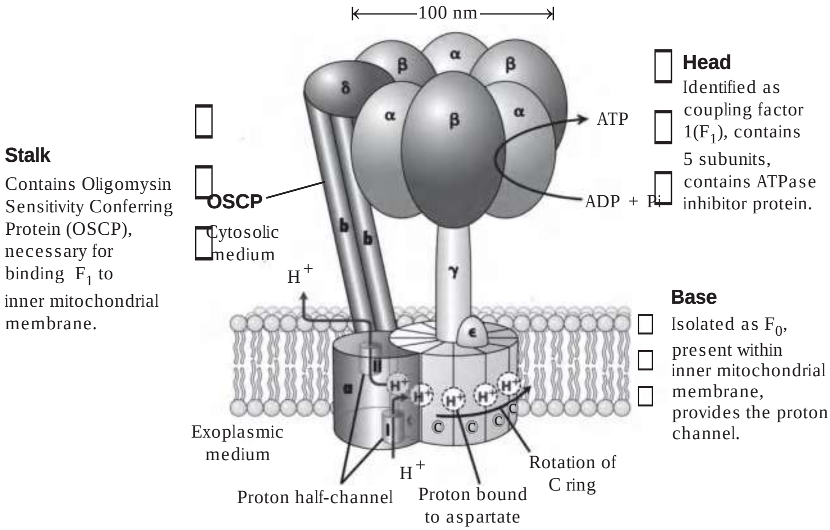
Mitochondrion

It is a spherical or rod-shaped, two-layered granular structure. It was first seen by **Kolliker** (1850) in the striated muscles and called **sarcosome**. Because of the formation of ATP, they are also called as powerhouses of the cell.



Mitochondria (a) Internal structure of a mitochondria (b) One crista magnified

Each F_0 - F_1 particle posseses head, a stalk and a base. These are shown in the figure below



Structure of ATP synthase

Functions of Mitochondria

- Synthesise and store ATP during aerobic respiration.
- Contain many lipid synthesising enzymes.

Plastids

These are the small bodies found free in most plant cells. They are not found in fungi, some bacteria, algae and multicellular animals. These double membrane bound structures are semiautonomous organelles having their own DNA.

Based on the type of pigment, they are of three types

(i) **Chromoplasts** They are yellow or red in colour due to the presence of carotenoids. They are found in fruits, flower and leaves.

(ii) **Leucoplasts** They are colourless plastids, which generally occur near the nucleus in non-green cells. They are further of three types depending upon the type of food stored, **e.g.**, amyloplasts (starch), aleuroplasts (proteins) and elaioplasts (lipids).

(iii) **Chloroplasts** These are green coloured plastids containing chlorophylls and carotenoids. These double membranous structures contain thylakoids in their stroma. The stroma also contains enzymes required for the synthesis of carbohydrates and proteins.

Functions of Plastids

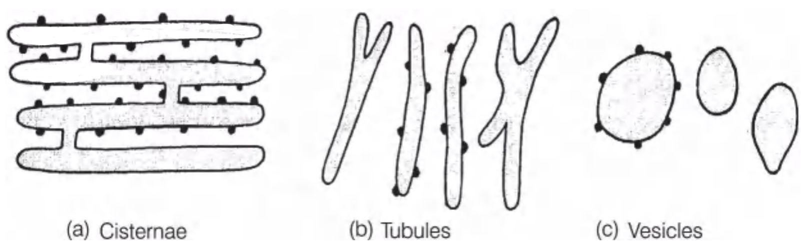
- Chromoplast traps electromagnetic radiations.
- Leucoplast stores food material.
- Chloroplasts are the centres of photosynthesis.

Endoplasmic Reticulum (ER)

These are membrane bound channels, which are seen in the form of a network of delicate strands and vesicles in the cytoplasm. These were first observed by **Porter**, **Claude** and **Fullam** (1945).

They are not found in mature erythrocytes and prokaryotes. Two basic morphological types of ER are Rough Endoplasmic Reticulum (RER) and Smooth Endoplasmic Reticulum (SER).

RER is granular, whereas SER is agranular depending on the basis of presence or absence of ribosomes on their surface. The ER membranes may assume the shape of cisternae, tubules or vesicles.



Morphology of the endoplasmic reticulum

Functions of ER

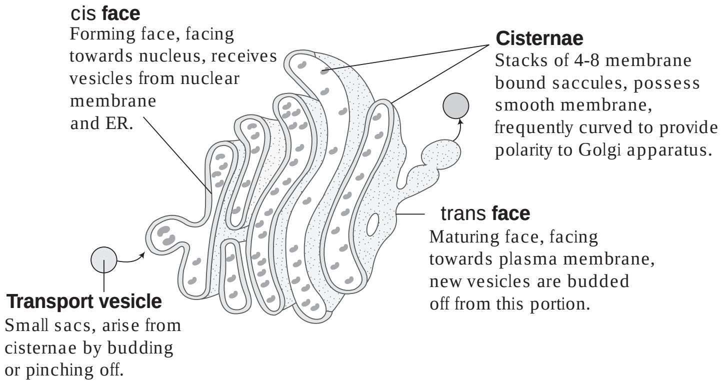
- RER is involved in protein synthesis and secretion.
- SER is the major site for the synthesis of lipids.
- The SER membrane shown to possess enzyme system with detoxification activities.

Golgi Apparatus

These are the flattened stacks of membranes found within the endomembrane system. This complex cytoplasmic structure is made up of cisternae, vesicles and vacuoles.

They are absent in prokaryotic cells, sieve tubes of plants, sperms of bryophytes, pteridophytes and RBCs of mammals. Golgi bodies were first described by **Camillo Golgi** in 1989. **Perroncito** (1910) used the term 'Dictyosomes' for smaller dividing units of Golgi apparatus.

Mollenhauer and **Whaley** (1963) suggested the polarised nature of Golgi complex. According to them, the margins of cisternae are slightly curved. So, each cisternae has a convex **cis** (forming face) facing towards nucleus and a concave **trans** (maturing face) facing towards the plasma membrane.



Structure of Golgi apparatus

Functions of Golgi Apparatus

- Helps in the formation of acrosome of sperms.
- Important sites for the formation of glycoproteins and glycolipids.
- Studies by autoradiographic ^{3}H glucose and ^{3}H galactose labelling have provided direct evidence of polysaccharide synthesis in Golgi apparatus.

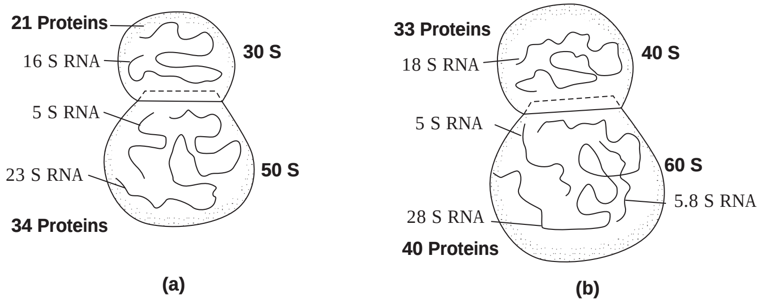
Ribosomes

They are large, non-membranous RNA-protein complexes, which are necessary for protein synthesis. These dense granules are found either in free state or attached to the outside of cytoplasmic membrane through ribophorins.

These are also called **Palade** particles as they were first observed by **George Palade** in 1955. In plants, they were reported by **Robinson** and **Brown** in the bean roots.

Types of Ribosomes

Ribosomes are of two basic types, **i.e., 70 S** and **80 S**, where 'S' refers to **Svedberg** unit of sedimentation coefficient.



Ribosomes : (a) 70 S (in prokaryotes) (b) 80 S (in eukaryotes)

Functions of Ribosomes

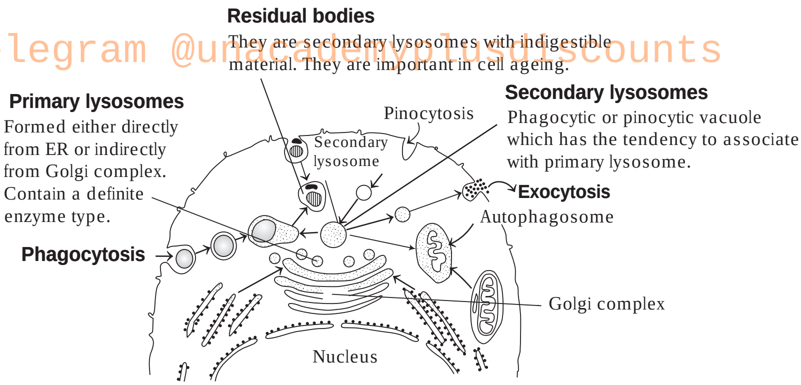
- They are the sites for polypeptide or protein synthesis (protein factories).
- They provide enzymes (peptidyl transferase) and factors for condensation of amino acids to form polypeptides.

Lysosomes

They are single membrane bound structures, supposed to contain hydrolytic enzymes in them. Therefore, they are known as **suicidal bags of the cell**. They were first observed by **C de Duve** (1949) in the liver cells. They were reported in plant cells by **P Matile**.

There are two basic types of lysosomes namely **primary lysosomes** and **secondary lysosomes**. Primary lysosomes are further categorised to phagosomes, autophagic vacuoles and residual bodies.

Autolysis is the phenomenon of self destruction of a cell with the help of lysosomes. Because of close relationship between Golgi complex, ER and lysosomes, **Novikoff et al.** (1961-64) denoted endomembrane system as **GERL system**, **i.e.,** Golgi complex, ER and lysosome system.



Outline sketch representing the dynamic aspects of the GERL system. Observe the relationship between the processes of phagocytosis, pinocytosis, exocytosis and autophagy.

Functions of Lysosomes

- They help in intracellular and extracellular digestion.
- They help in secretion of thyroid hormones and regulation of hormone secretion in mammotrophs.
- Acrosome of sperm is considered as a giant lysosome. It contains hyaluronidase and proteases, which are helpful in dissolving the covering of ovum. It is formed by the modification of Golgi body.

Vacuoles

About 90% of plant cells is occupied by a single membrane bound vacuole. They store biomolecules including ions, sugars, amino acids, proteins and carbohydrates. Tonoplast membrane covers the vacuole.

Functions of Vacuoles

- Important contribution to the osmotic properties of the cell.
- Storage of various substances including waste products.
- Function as contractile vacuoles, food vacuoles, gas vacuoles, etc.

Centrosome (Centrioles)

It was introduced by **Boveri** in 1888. Centrosomes are present in animal cells and absent in plant cells. It contains the organelles called as **centrioles**.

Functions of Centrioles

These are the structures concerned with spindle formation during cell division. They are found in pairs, oriented at right angles to each other.

Microbodies

They are small, single membrane bound cell organelles which absorb molecular oxygen and take part in oxidation. They were first seen by **Rhodin** (1954) in mouse kidney tubule cells.

They are of two types

(i) **Peroxisomes** They contain enzymes for peroxide biosynthesis. They are found in both plant and animal cells in close association with ER, mitochondria and chloroplasts. Despite the absence of DNA, they are believed to be able to replicate like plastids and mitochondria.

(ii) **Glyoxysomes** They contain enzymes for β-oxidation of fatty acids and glyoxylate pathway. They usually occur in fat rich plant cells. They are more prominent in plant seedlings and generally found in yeast and **Neurospora** cells. They are considered to be special peroxisomes. They were first reported by **Beevers** in 1969 in the endosperm of germinating seeds.

Functions of Microbodies

- Peroxisomes can metabolise unusual substances or xenobiotics.
- Glyoxysomes metabolise acetyl Co-A in glyoxylate cycle to produce carbohydrates.
- Peroxisomes are associated with lipid metabolism in animal cells in particular the oxidation of amino acid and uric acid.

Cytoskeletal Elements

These consist of following types

(i) **Microtubules** They are unbranched, hollow tubules made up of tubulin protein. They contain 13 protofilaments and are 25nm in diameter (**Roberts** and **Franchi**). They occur in centrioles, basal bodies, cilia/flagella, astral rays, spindle fibres, etc. They are non-contractile in nature.

(ii) **Microfilaments** They are long, narrow, cylindrical rods made up of actin protein. They are contractile, solid structures having diameter of about 7nm. They occur below cell membrane and at the interphase of plasmagel-plasmasol.

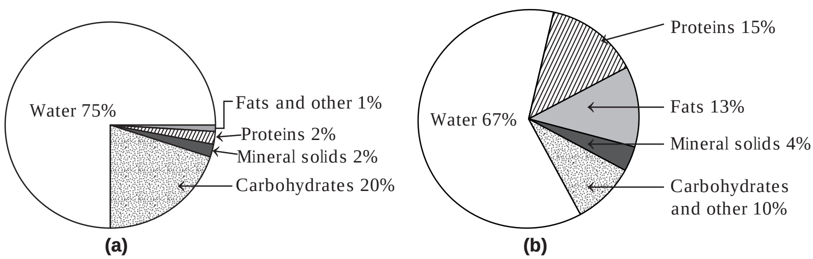
Functions of Cytoskeletal Elements

- Microtubules help in the movement of nuclei during division.
- Microfilaments are responsible for cellular movements like contraction, crawling, pinching during division and formation of cellular extensions.

9
Biomolecules

Chemistry is the foundation of biology. A number of chemicals (over 5000) are found in cells with a great quantitative and qualitative variations. These chemicals and their interactions are responsible for the formation of all the biological molecules or compounds which primarily have carbon as one of its constituents. These biological molecules can be collectively termed as **biomolecules**.

A quantitative (in percentage) account of four main organic compounds present in protoplasm of animal and plant cell is **shown in figure** (pie diagram) **below.**



Chemical constituents of the protoplasm : (a) Plants (b) Animals

Before discussing the biomolecules in detail, we need to take a look on the methods of chemical analysis to determine the composition of any cell or tissue in living state.

How to Analyse Chemical Composition?

We generally perform the chemical analysis to get an idea about the molecular formula and probable structure of a compound.

There are two general methods of analysis

(i) The living matter grinded in trichloroacetic acid and then filtered result in two fractions–**filtrate/acid soluble fraction** (micromolecules) and **pellet/acid insoluble fraction** (macromolecules).

(ii) All the oxidisable compounds oxidise and inorganic compounds remain in the form of ash through which composition can also be confirmed.

A comparative account of elements present in living and non-living matters is given in following table

Composition of Earth's Crust and Human Body

Elements	% Weight of	
	Earth's Crust	Human Body
Hydrogen (H)	0.14	0.5
Carbon (C)	0.03	18.5
Oxygen (O)	46.6	65.0
Nitrogen (N)	Very little	3.3
Sulphur (S)	0.03	0.3
Sodium (Na)	2.8	0.2
Calcium (Ca)	3.6	1.5
Magnesium (Mg)	2.1	0.1
Silicon (Si)	27.7	Negligible

Biomolecules

The collection or sum total of different types of biomolecules, compounds and ions present in a cell is called the **cellular pool.** A comprehensive account of various components of cellular pool are given below

The following flow chart provides a glance view of biomolecules

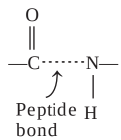
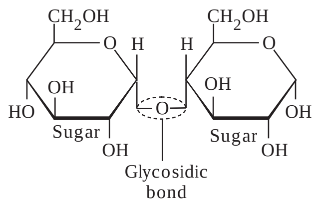
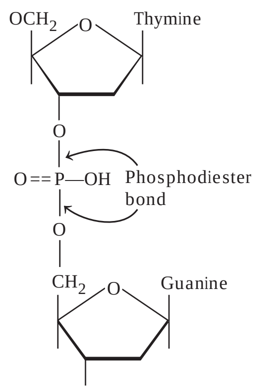
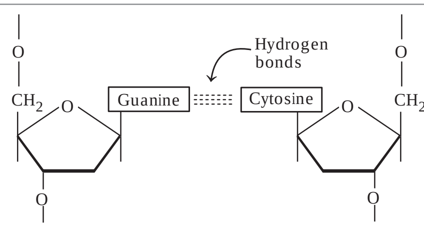
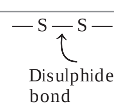
Biomolecules

- **Large Molecules** (Biomacromolecules)
  Include proteins, nucleic acids, polysaccharides and lipids.
- **Small Molecules** (Biomicromolecules)
  - **Primary Metabolites**
    Directly involved in growth and reproduction (enzymes and small peptides)
  - **Secondary Metabolites**
    Indirectly involved in growth process (antibiotics, pigments, alkaloids, etc).

Bonds Involved in Biomolecules

Despite having several basic bondings between their structure, some modified bonds and linkages are also involved in the organisation of biomolecules.

Some of them are briefly discussed here.

<table>
<tr><th>Name</th><th>Occurrence / Formed between</th><th>Diagram / Detail</th></tr>
<tr><td>Peptide bond</td><td>Protein / Two amino acids</td><td></td></tr>
<tr><td>Glycosidic bond</td><td>Carbohydrate / Two monosaccharides</td><td></td></tr>
<tr><td>Phosphodiester bond</td><td>Nucleic acid / Phosphate and hydroxyl group of sugar</td><td></td></tr>
<tr><td>Hydrogen bond</td><td>Nucleic acid / Two nitrogenous bases</td><td></td></tr>
<tr><td>Hydrophobic interaction</td><td>Protein / Two non-polar side chains of neutral amino acids</td><td>The interaction formed between two molecules as a strategy to avoid the contact with water.</td></tr>
<tr><td>Disulphide bonds</td><td>Protein / Two sulphur containing molecules</td><td></td></tr>
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Carbohydrates (Saccharides)

These are among the most widely distributed compounds both in plants as well as in animal kingdom. These are defined as polyhydroxy aldoses, ketoses and their condensation products.

These organic substances have carbon, hydrogen and oxygen where oxygen and hydrogen occur in ratio of 1 : 2. The carbohydrate shows the general formula $C_n(H_2O)_n$ or $(CH_2O)_n$.

On the basis of the products of hydrolysis, the carbohydrates are divided into three major groups

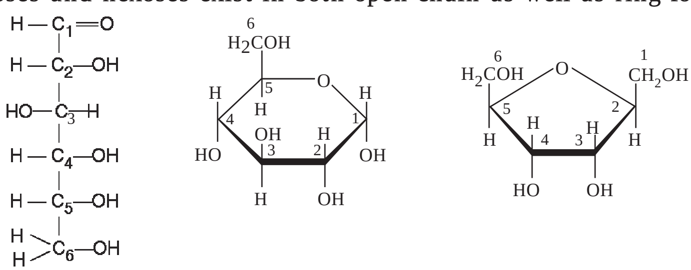
Carbohydrates		
→	**Monosaccharides** (Gr. mono-single; saccharon-sugar)	Such carbohydrates, which on further hydrolysis give compounds other than carbohydrates.
→	**Oligosaccharides** (Gr. oligo – few; saccharon – sugar).	Such carbohydrates, which on further hydrolysis yield 3 to 9 monosaccharide units.
→	**Polysaccharides** (Gr. poly – many; saccharon – sugar).	Such carbohydrates, which give many monosaccharide units on hydrolysis

1. Monosaccharides

These are the simplest sugars, which cannot be hydrolysed further. These can be **trioses** (3C), **tetroses** (4C), **pentoses** (5C), **hexoses** (6C) and **heptoses** (7C). On the basis of presence of **aldehyde group** (**i.e.,** $-\underset{\underset{O}{\|}}{C}-H$) and **ketone group** (**i.e.,** $-\underset{\underset{O}{\|}}{C}-$), these may be **aldoses** and **ketoses**, respectively.

On reacting with alcoholic and nitrogen group of other organic compounds, the aldoses and ketoses form a bond called **glycosidic bond** (C—O—C or C—N—C).

Pentoses and hexoses exist in both open chain as well as ring forms.



(a) (b) (c)

Structure of monosaccharides : (a) Open chain glucose (6C) (b) Pyranose ring form (6C) (c) Furanose ring form (5C)

Monosaccharides are sweet tasting, colourless solids having solubility in water, but sparingly soluble in alcohol and insoluble in ether. These have at least one **asymmetric carbon atom** (except dihydroxyacetone), hence they exist in different isomeric forms, **i.e.**, dextro or laevorotatory.

On the basis of reaction with different substances, monosaccharides can be divided into various categories

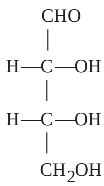
Monosaccharides

Deoxy Sugar	**Amino Sugars**	**Sugar Acid**	**Sugar Alcohol**	**Sulpho Sugars**
Monosaccharides with deoxy group, **e.g.**, deoxyribose, fucose, etc.	Monosaccharides with amino group, **e.g.**, galactosamine, glucosamine, etc.	Monosaccharides with carboxyl group, **e.g.**, ascorbic acid and glucuronic acid	Monosaccharides with multiple hydroxyl groups, **e.g.**, glycerol and mannitol	Monosaccharides sugar, **e.g.** sulphoquinovose (present in sulpholipid)

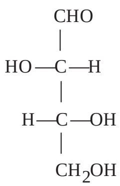
Examples of Monosaccharides

(i) **Trioses** ($C_3H_6O_3$) They include glyceraldehyde and dihydroxy acetone.

(ii) **Tetroses** ($C_4H_8O_4$) They include erythrose and threose, **i.e.**



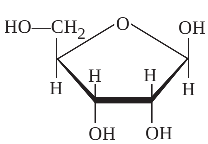
D- Erythrose



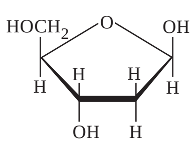
D-Threose

(iii) **Pentoses** ($C_5H_{10}O_5$) Among pentoses, **the important ones are as follows**

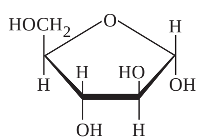
- **Ribose** This is found in Ribonucleic Acid (RNA), coenzymes, ATP, FAD, NAD and NADP.
- **Deoxyribose** This is found in Deoxyribonucleic Acid (DNA).
- **D-arabinose** This occurs as glycoside of tuberculosis bacilli.



Ribose



2-deoxyribose



D-arabinose

Some pentose sugars

- **Ribulose** An important pentose of photosynthetic pathway.

(iv) **Hexoses** ($C_6H_{12}O_6$)

- **D-glucose** This is the most widely distributed sugar in plants and animals. It is also known as **blood sugar**. It is a component of sucrose (another component is fructose).
- **D-galactose** This is found in glycolipids and glycoproteins of brain and other nervous tissues. It is a **component of milk sugar** (lactose).
- **D-mannose** This is widely distributed as mannans in plants. In small amounts, it is also present in some glycoproteins. It is converted to glucose in animals.
- **D-fructose** This is sweetest of all the sugars. It is found in fruit juices, honey and seminal fluid.

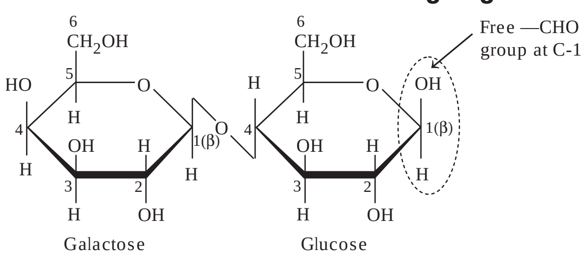
(v) **Heptoses** ($C_7H_{14}O_7$) Sedoheptuloses act as intermediates in Calvin cycle.

2. Oligosaccharides

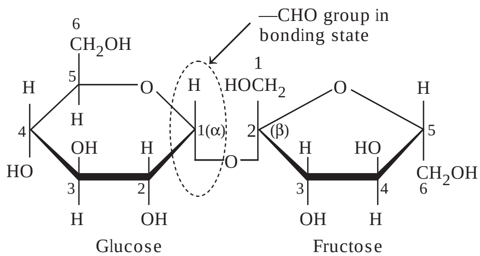
These are the compounds, which are formed by condensation of **2-9 monosaccharide units**. These units are joined with the help of specialised **glycosidic linkages**.

Reducing and Non-Reducing Sugar

The sugars which have unlinked aldehyde group at their first C-atom are called as **reducing sugars** and those which have aldehyde group in linked condition are called as **non-reducing sugars.**



Reducing sugar : Lactose (β-1, 4-linkage)

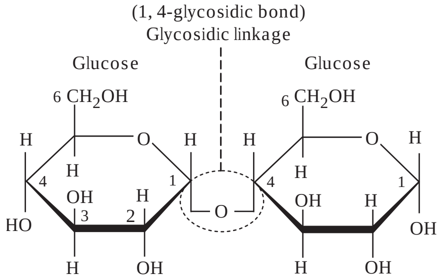


Non-reducing sugar : Sucrose (α-1, 2-linkage)

Examples of Oligosaccharides

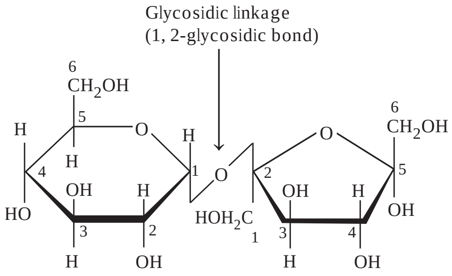
(i) **Lactose or Milk sugar** It is present in milk of mammals and made up of **one glucose** and **one galactose** units. It is a reducing sugar. Souring of milk is due to the conversion of lactose to lactic acid by the action of Lactic Acid Bacteria (LAB).

(ii) **Maltose or Malt sugar** It is named because of its occurrence in malted grain of Barley. Mostly found in germinating seeds and tissue where starch is broken down. It is a reducing sugar and formed by condensation of 2 glucose units.



Maltose

(iii) **Sucrose or Table sugar** It is also known as **cane sugar** or **invert sugar**. In this, fructose occurs in **pentagon** form, while glucose is in **hexagon** form. It is a non-reducing sugar.



Sucrose

(iv) **Raffinose** ($C_{18}H_{32}O_{16}$) It is a **trisaccharide**, contains glucose, galactose and fructose.

3. Polysaccharides

The term is usually employed to polymers containing minimum ten monosaccharide units. Polysaccharides are further categorised to Homo, **i.e.**, these containing similar monosaccharide units and Hetero, **i.e.**, these containing different saccharide units.

Examples of polysaccharides are

(i) **Glucans**, **i.e.,** which contain only glucose units, **e.g.,** starch, glycogen, cellulose, chitin, etc.

(ii) **Galactans**, **i.e,** which contain galactose units only, **e.g.,** agarose, pectin, galactan.

(iii) **Mannans**, **i.e,** which contain only mannose units, **e.g.,** yeast mannan.

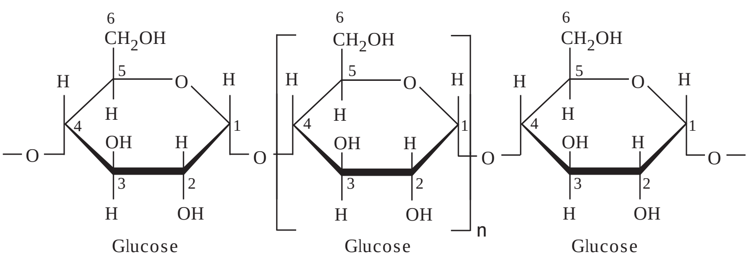
(iv) **Xylans**, **i.e,** which contain xylose units, **e.g.,** hemicellulose xylan.

(v) **Fructans**, **i.e,** those with fructose monomers, **e.g.,** inulin.

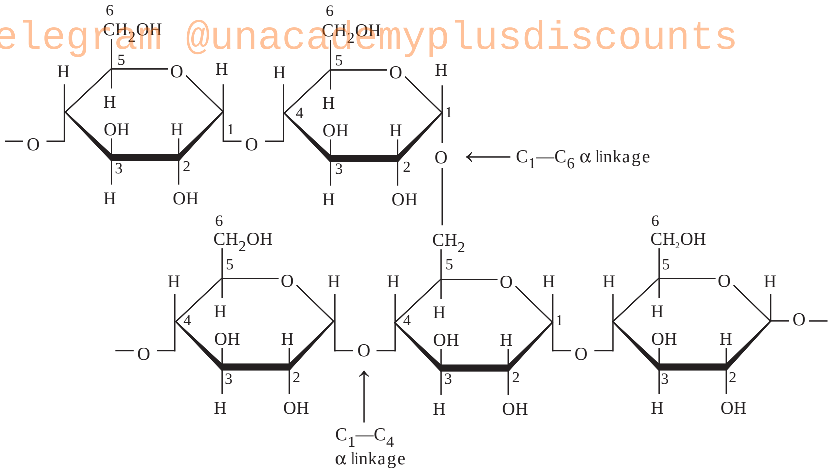
Starch

Starch $(C_6H_{10}O_5)_n$ is a polymer of D-glucopyranose units linked by α-1, 4-glycosidic linkages. It consists of a mixture of **amylose** (linear, 200-500 glucose units) and **amylopectin** (branched, more than 1000 glucose units) in 1 : 4 ratio, respectively. It is a reserve food material in plants.

The structure of amylose and amylopectin are as follows



Structure of amylose



Structures of amylopectin

Glycogen

About 5,000-15,000 glucose units make up glycogen $(C_6H_{10}O_5)_n$. It is extensively branched and forms the reserve food material in animals hence, also called as **animal starch**.

Cellulose

It is a linear polymer of β-D-glucose units connected through β-1, 4-glycosidic linkage. It is an important structural component of the cell wall of plants.

Chitin

It is the second most abundant organic substance. It is a complex polymer of N-acetylglucosamine. It is the structural component of fungal walls and exoskeletons of arthropods.

Properties of Carbohydrates

Enantiomers

Optical isomers which are mirror images of each other. The **d** (+) and **l** (–) forms of carbohydrates are classified on this basis. The sugar solution which rotates the axis of plane polarised light clockwise called **d** (+) isomers, while those rotates it to anticlockwise termed as **l** (–) isomers.

Diastereomers

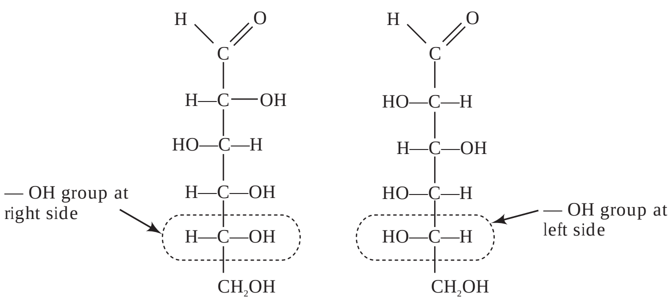
The isomers which are not the mirror images of each other. These are of following two types

(i) **Epimers** The diastereomers which have configurational change at a single interstitial C-atom.

(ii) **Anomers** These are specialised diastereomers which show configurational change at terminal carbon called **anomeric carbon** (the carbon which is involve in ring formation and contains functional group). Two anomers of glucose are defined, **i.e.,** α-form and β-form.

D and L Isomers

These are classified on the basis of direction of —OH group on **farthest chiral carbon** from the functional group.



D-isomer **L-isomer**

Proteins

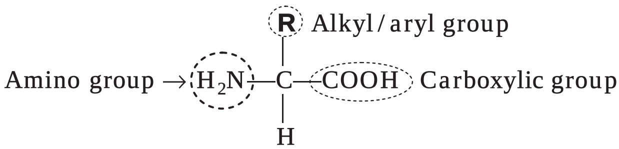
The word protein (Gk. **proteios** – first or foremost) was first coined by **Berzelius** (1838) and first used by **Mulder** (1838). It constitutes about 15% of our body by mass and involved in various functions like structural, storage, transport, signalling, movement, etc.

These are natural heteropolymer of substances like amino acids. To understand the detailed structure of protein, we first take a close view of amino acids.

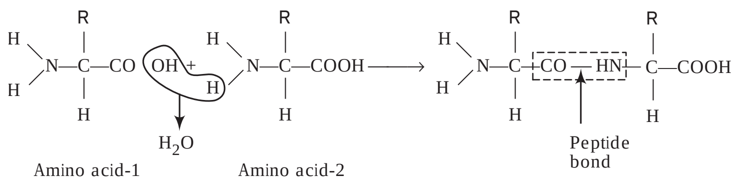
Amino Acids

The compounds which contain both amino (—NH_2) and acid (—COOH) groups in them.

The generalised structure is as follows



To form peptide (or proteins), amino acids get linked serially by **peptide bonds** (— CO—NH—) formed between amino group of one amino acid and the carboxylic group of the adjacent one.



Following flow chart indicates the physiological nature of amino acids

Amino Acids

- Side chain charged at physiological pH (about 6.0)
  - **All Hydrophilic**
    - Basic
      - Lysine
      - Arginine
      - Histidine
    - Acidic
      - Aspartic acid
      - Glutamic acid
- Side chain uncharged at pH 6.0
  - **Hydrophobic**
    - Glycine
    - Serine
    - Threonine
    - Asparagine
    - Glutamine
    - Cysteine
    - Methionine
  - **Hydrophilic**
    - Alanine
    - Valine
    - Leucine
    - Isoleucine
    - Phenylalanine
    - Tyrosine
    - Tryptophan
    - Proline

Amino acids and their physiological nature

There are 20 amino acids, which form proteins. These are called **proteinous amino acids**. Amino acids have both three letter and one letter code for convenient study. Following table gives information about the chemical nature and codes for amino acids.

Proteinous Amino Acids (with three letter code and one letter code in brackets)

Neutral	Glycine (Gly), (G) Alanine (Ala), (A) Valine (Val), (V) Leucine (Leu), (L) Isoleucine (Ile), (I)
Acidic	Aspartic acid (Asp), (D) Asparagine (Asn), (N) Glutamic acid (Glu), (E) Glutamine (Gln), (Q)
Basic	Arginine (Arg), (R) Lysine (Lys), (K)
S-Containing	Cysteine (Cys), (C) Methionine (Met), (M)
Alcoholic	Serine (Ser), (S) Threonine (Thr), (T)
Aromatic	Phenylalanine (Phe), (F) Tyrosine (Tyr), (Y) Tryptophan (Try), (W)
Heterocyclic	Histidine (His), (H) Proline (Pro), (P)

Non-Proteinous Amino Acids

They have physiological importance, but not form proteins.

Some of them are

(i) **Beta (β)-alanine** Component of Co-A and pantothenic acid (vitamin-B_5).

(ii) **Gamma (γ)-Amino-Butyric Acid** (GABA) Inhibitory neurotransmitter of CNS.

(iii) **Creatine** Important constituent of muscles.

(iv) **Ornithine and Citrulline** Intermediates in urea biosynthesis.

(v) **Histamine** Vasodilator, involved in allergic reaction.

(vi) **Serotonin** Vasoconstrictor, stimulates the contraction of smooth muscles.

(vii) **Epinephrine or Adrenaline** Derivative of tyrosine.

Structural Level of Proteins

There are four structural levels in proteins

(i) **Primary structure** This includes number of polypeptides, number and sequence of amino acids in each polypeptide.

(ii) **Secondary structure** There are three types of secondary structures α-**helix,** β-**pleated sheet** and **collagen helix**. The turns of helices and sheets are attached by hydrogen bonds.

(iii) **Tertiary structure** Tertiary structure is stabilised by several types of bonds-hydrogen bonds, ionic bonds, van der Waals' interaction, covalent bonds and hydrophobic bonds. It gives 3-D conformation to protein.

(iv) **Quaternary structure** Found only in multimeric protein, where two tertiary structures join as a subunit.

Lipids

They are chemically diverse group of compounds which are characterised by their relative insolubility in water and solubility in organic solvents. These are defined as the esters of fatty acids and alcohol. The lipids have wide distribution in both animal and plant kingdom.

Classification of Lipids

On the basis of their chemical structure, the lipids are classified into following classes

Lipids

- **Simple Lipids**
  - **Neutral Fats/ Triglycerides** (Composed of glycerol and fatty acids
  - **Waxes** (have higher melting point than neutral fats)
- **Compound Lipids**
  - **Phospholipids** (glycerol have two fatty acids and one phosphoric acid)
  - **Glycolipids** (glycerol is replaced by amino alcohol sphingosine)
  - **Lipoproteins** (protein complex of lipids)
- **Derived Lipids**
  - **Steroids** (derived from complex ring structure)
  - **Sterol Glycosides** (majorly act as signal sequence in protein transport)

The detailed explanation of these classes of lipids is given below

Triglycerides (Neutral Fats)

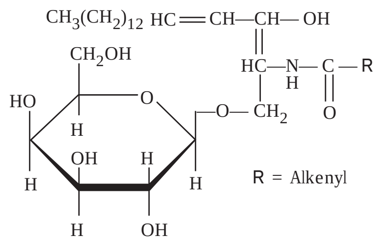
Neutral fats such as butter and vegetable oils are mostly triglycerides. Each has three fatty acids linked to a glycerol (glycerine or trihydroxy propane). In fats, when all three fatty acids are similar, they are called as **pure fats** and when these fatty acids are dissimilar, they are termed as **mixed fats**.

Waxes

These are long chains of fatty acid linked to long chain of alcohol or carbon ring. All waxes have firm consistency and repel water. In plants, it covers the surface of leaf and other aerial surfaces to avoid excess transpiration. In animals, **cutaneous glands** secrete wax, **lanolin** for forming a protective water insoluble coating on animal fur.

Glycolipids

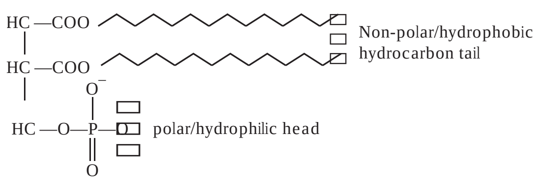
The lipids linked to monosaccharide unit through a glycosidic bond are called as glycolipids, **e.g.**, glycerolipids, sphingolipids.



Glycosphingo lipids (Cerebrosides, ceramides)

Phospholipids (Common Membrane Lipids)

These are triglyceride lipids with one fatty acid replaced by phosphoric acid which is often linked to additional nitrogenous group like choline, ethanolamine, etc.



Phospholipids

Lipoproteins

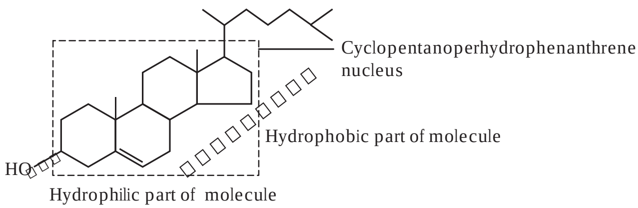
These are the complex of lipids and proteins and are present in blood, milk and egg yolk. **On the basis of compactness, these can be divided into**

(i) **LDL** Deposition of bad cholesterol

(ii) **HDL** Removal of bad cholesterol

Steroids

The group of complex lipids that possess a rigid backbone of four fused carbon rings. Sterols are the components of every eukaryotic cell membrane. The most common type in animal tissue is cholesterol. Chemically these contain cyclopentanoperhydrophenanthrene nucleus.



Terms Related to Lipids

(i) **Emulsion** Due to its insolubility in water, lipids form a colloidal complex and get dispersed uniformly in water in the form of minute droplets, called emulsions.

(ii) **Oils** Oils are those fats, which are liquid at room temperature of 20°C, **e.g.,** groundnut, cotton seed oil, etc.

(iii) **Hydrogenation** The process of conversion of unsaturated fatty acids to saturated form is called **hydrogenation**.

(iv) **Wax-D** Tuberculosis and leprosy bacteria produce a wax called wax-D. It is a major factor for their pathogenicity.

(v) **Amphipathic** The lipids which contain both the hydrophilic and hydrophobic groups are called **amphipathic**.

Functions of Lipids

Lipids generally perform following functions

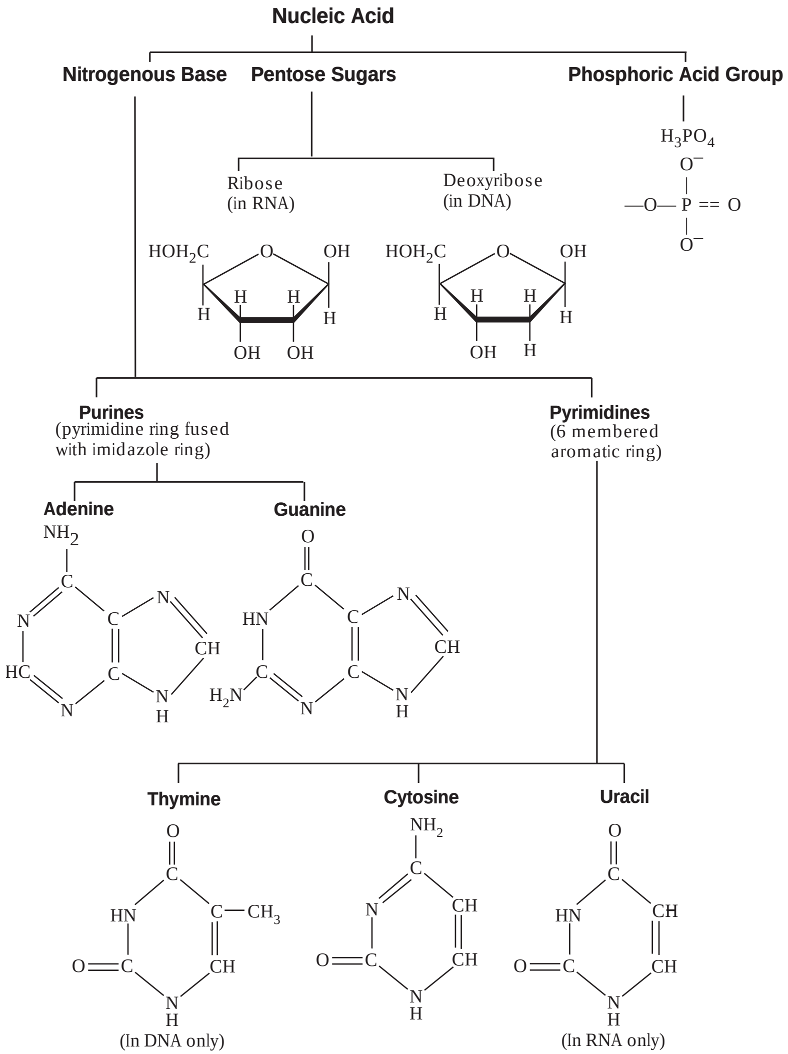
Functions

- **Energy Storage**
  - **Animals**
    - Fats (triglycerides)
    - In adipocytes
  - **Plants**
    - Oils
    - In seeds and other tissues.
- **Thermal Insulation**
  - **Animals**
    - As fats in form other than triglycerides.
  - **Plants**
    - Protective covering over leaf and stem; provides heat protection.
- **Buoyancy**
  - In plants, the leaf and stem have lipid covering to avoid wetting of plant and maintain buoyancy.

Nucleic Acids

These are long chains which are formed by end to end polymerisation of large number of units called **nucleotides**. The two most important nucleic acids, present in living cells are Deoxyribonucleic Acid (DNA) and Ribonucleic Acid (RNA).

Components of Nucleic Acids



Components of nucleic acid

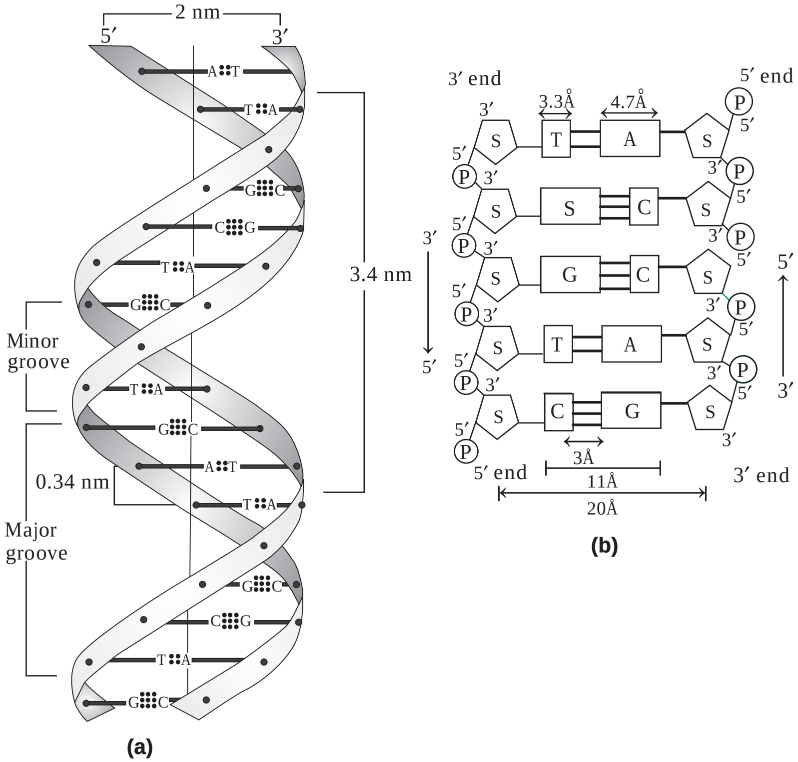
DNA

The DNA molecule is a polymer of several thousands pair of nucleotide monomers. A nucleotide is formed by the union of a phosphate group with a nucleoside.

Nucleoside = Nitrogenous base + Sugar

Nucleotide = Nucleoside + Phosphate group

DNA forms a double helical structure in which two strands are bonded through hydrogen bonds and are antiparallel to each other. The coiling pattern and antiparallel structure of DNA, **can be seen as**



DNA structure : (a) Coiling of two strands (b) Antiparallel strands and bond details

RNA

It is a single-stranded genetic material present in **lower organisms**. In higher organisms, it is present with DNA and performs various functions.

The main types of RNAs are

(i) **m**RNA (messanger RNA)
(ii) **t**RNA (transfer RNA)
(iii) **r**RNA (ribosomal RNA)
(iv) **hn**RNA (heteronuclear RNA)
(v) **mt**RNA (mitochondrial RNA)
(vi) **cp**RNA (chloroplastidal RNA)

Enzymes

An enzyme is a specific protein produced within the organism that is capable of catalysing specific chemical reactions. As they are of biological origin and catalyse various reactions, they are also called **biocatalysts.**

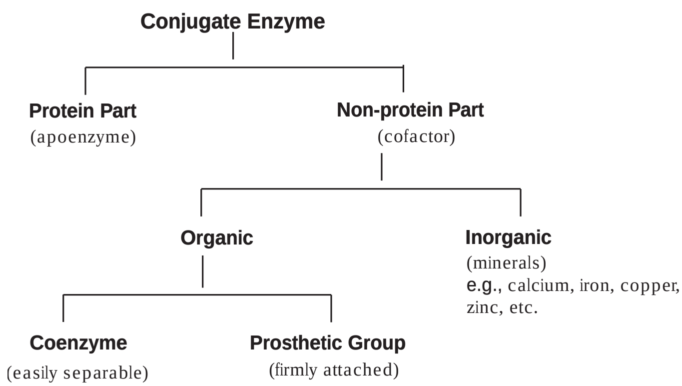
The term 'Enzyme' was coined by **Kuhne** (1878) for catalytically active substances previously called **ferments.** Protein nature of the enzyme was first found out by **Sumner** (1926). Like catalysts, the enzymes do not start a chemical reaction or change its equilibrium, but enhance the rate of reaction.

Chemical Nature of Enzymes

All enzymes are globular proteins with the exception of recently discovered RNA enzymes. Some enzymes may additionally contain a non-protein group.

There are two types of enzymes on the basis of composition

1. **Simple enzyme** The enzyme which completely made up of protein, **e.g.,** pepsin, trypsin, urease, etc.
2. **Conjugate enzyme It is the enzyme formed by two parts**



Enzymes and their constituents

Classification of Enzymes

On the basis of reaction they performed, enzymes are classified into six categories

(i) **Oxidoreductases** Oxidase, reductase and dehydrogenases are included in this class of enzymes.

(ii) **Transferases** These enzymes perform group transfer reaction.

(iii) **Hydrolases** These enzymes induce hydrolysis, **e.g.,** amylase, lactase, etc.

(iv) **Lyases** They induce the cleavage without hydrolysis and addition of double bond takes place, **e.g.,** aldolase.

(v) **Isomerases** Rearrangement of molecular structure, **e.g.,** isomerase, epimerase, mutase, etc.

(vi) **Ligases/Synthetases** These enzymes induced the bonding of two molecules after taking energy from ATP.

Nomenclature of Enzymes

Enzymes are named by adding the suffix-ase after the substrate (**e.g.,** lipase, amylase, maltase, etc.) or chemical reaction (**e.g.,** succinate dehydrogenase). Some old names also persist as pepsin, trypsin, etc.

Mechanism of Enzyme Action

The general mechanism of enzyme action has two steps

1. Formation of Enzyme-Substrate Complex

When an enzyme acts upon a substrate, it forms an enzyme-substrate complex. Subsquently, this complex decomposes the substrate, undergoes chemical change and the enzyme is regenerated afterwards.

$$E + S \rightarrow ES$$

$$ES \rightarrow E + P$$

Following two models have been put forth to explain the formation of ES complex

(i) **Lock and key model** Proposed by **Emil Fisher** in 1894. He states that both the components (**i.e.,** enzyme and substrate) have strictly complementary structure.

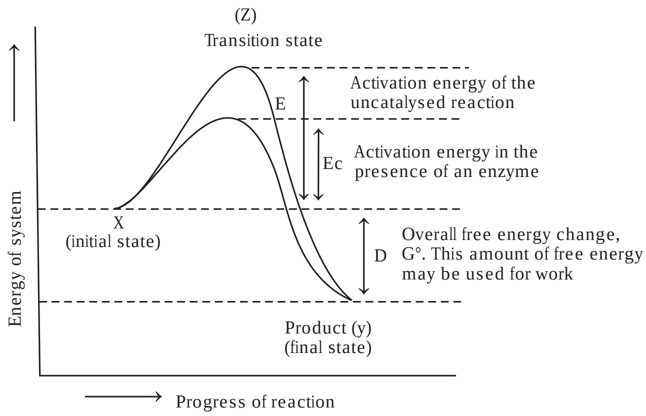
(ii) **Induced fit model** Proposed by **D Koshland** in 1958. According to this, when enzyme binds to substrate, the change in the shape of active sites of enzyme takes place.

2. Lowering of Activation Energy

All chemical reactions have a potential energy barrier that must be overcome before the reactants can be converted into products. The energy required to break this barrier is equivalent to activation energy.

The enzyme lowers the energy of activation during its complexing with substrate. After the combination of enzyme and substrate, the energy level of substrate gets raised, and it reacts faster.

The diagrammatic representation of the process is as follows



Graphical representation of enzyme catalysis

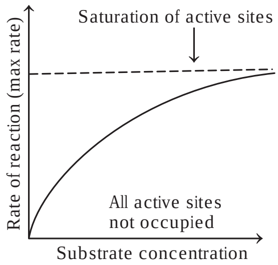
Turnover Number

Being large sized protein molecule, enzyme exists as colloid. Substrate molecule changed per minute into product is called **turn over number**, **e.g.,** 36 millions for carbonic anhydrase, 5 millions for catalase, etc.

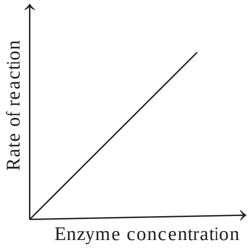
Factors Affecting Enzyme Activity

The activity of an enzyme can be affected by a change in the conditions which can alter the tertiary structure of the protein.

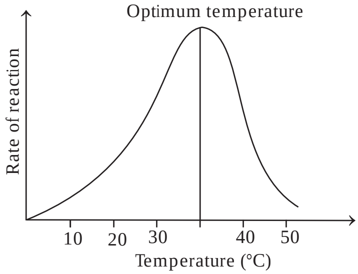
1. **Substrate concentration** Enzyme activity increases with increase in concentration of the substrate to a maximum and then it levels off.

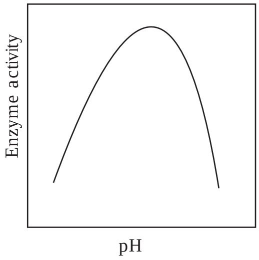


2. **Enzyme concentration** In general, the rate of reaction will increase with increasing enzyme concentration, due to availability of more active sites for reaction.



3. **Temperature and pH** In most of the enzymatic reactions, rise of 10°C in the temperature doubles the rate of reaction between 5-40°C. Enzymes are **denatured** (secondary and above level of structures degraded) at higher temperature due to proteinaceous nature and rate of reaction drops.





4. **Redox potential** Enzymes are sensitive to redox potential of the cell also. Many enzymes are affected by redox potential due to the presence of oxidisable SH-group.

Enzyme Inhibition

Reduction or stoppage of enzyme activity due to certain adverse conditions or chemicals is called **enzyme inhibition**.

Enzyme Inhibition

- On the basis of nature of inhibition
  - **Reversible Inhibition** (the effect of inhibitor is temporary)
  - **Irreversible Inhibition** (the effect of inhibitor is permanent)
- On the basis of cause of inhibition
  - **Competitive Inhibition** (substance which is similar to substrate occupies the active sites and inhibits the activity)
  - **Non-competitive Inhibition** (this is caused by the alternation of conformation of the active sites)

Metabolites

Plants and animals produce thousands types of chemicals. Some of the organic compounds like carbohydrate, fat, protein, nucleic acid, chlorophyll and heme, etc., are required for basic metabolic processes and found in the whole plant and animal kingdom. These are called **primary metabolites**.

Many plants, fungi and microbes synthesise a number of organic substances, which are not involved in primary metabolism **i.e.**, (respiration, reproduction, photosynthesis, protein and lipid metabolism) and seen to have no direct function in growth and development of these organisms, called **secondary metabolites**.

These are as follows

Class of Secondary Metabolites	Examples	Chief Functions
Pigments	Carotenoids, anthocyanins, etc.	Attract pollinators and help in seed dispersal.
Alkaloids	Morphine, codeine, etc.	Defence against herbivores and pathogens.
Terpenoides	Monoterpenes, diterpenes, etc.	Provide characteristic smell to plants.
Essential oils	Lemon grass oil, etc.	Protection against pathogens.
Toxins	Abrin, ricin	To kill pathogens.
Drugs	Vinblastin, curcumin, etc.	Stop the growth of bacteria and other pathogens.
Polymeric substances	Rubber, gums and cellulose	To inhibit the entry of pathogens.

10

Cell Cycle and Cell Division

Cell Cycle (Howard and Pelc; 1953)

It is a genetically controlled series of events occurring in a co-ordinated manner in newly formed cell by which it undergoes growth and divides to form two daughter cells. The cell cycle is divided into two parts, **i.e., interphase** and dividing or **M-phase**.

Interphase

It is the phase of the cell cycle in which the cell prepares itself for the initiation of cell division. It comprises G_1, S and G_2-phase. It represents the stage between two successive M-phase. The cells are actively involved in metabolic activities during this phase.

Note G_0-Phase (Quiescent stage)

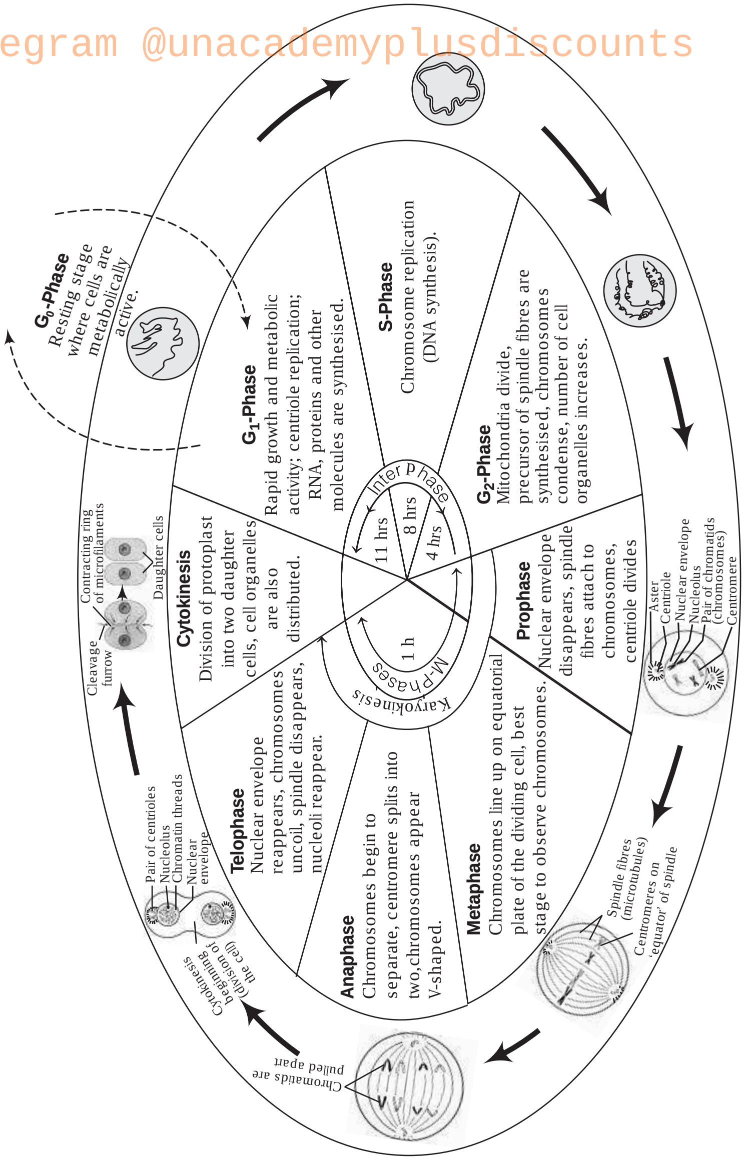
It is the quiescent phase during which the cell cycle is arrested for an indefinite period. Bone, muscle and nerve cells remain in this phase permanently. The cells remain metabolically active, but do not proliferate.

Dividing or M-phase

It is achieved in two major phases, **viz.,** karyokinesis and cytokinesis.

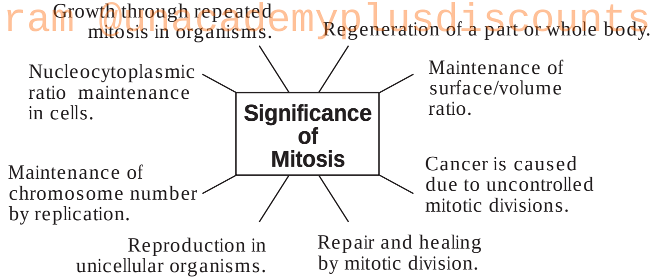
(i) **Karyokinesis** It involves the division of the nucleus. In karyokinesis, a nucleus can divide either through mitosis (equational division) or through meiosis (reductional division),

(a) **Mitosis** (Flemming, 1882) It is the frequent process of nuclear division in somatic cells by which two daughter nuclei are produced, each identical to the parent nuclei. It is divided into four phases, **i.e.**, prophase, metaphase, anaphase and telophase.



Cell cycle (pictorial view with events) (Durations given in approx. as per NCBI data)

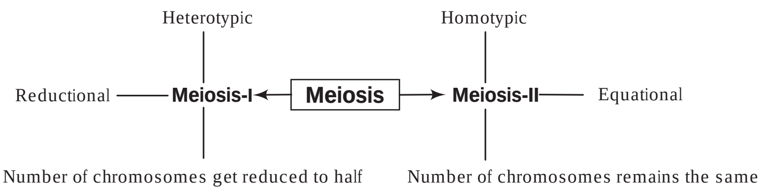
Significance of Mitosis



(b) **Meiosis** (Farmer and Moore; 1905) It is a type of indirect division, which occurs in diploid sex cells and gives rise to four haploid cells, each having half number of chromosomes as compared to parent cell.

It consists of two divisions

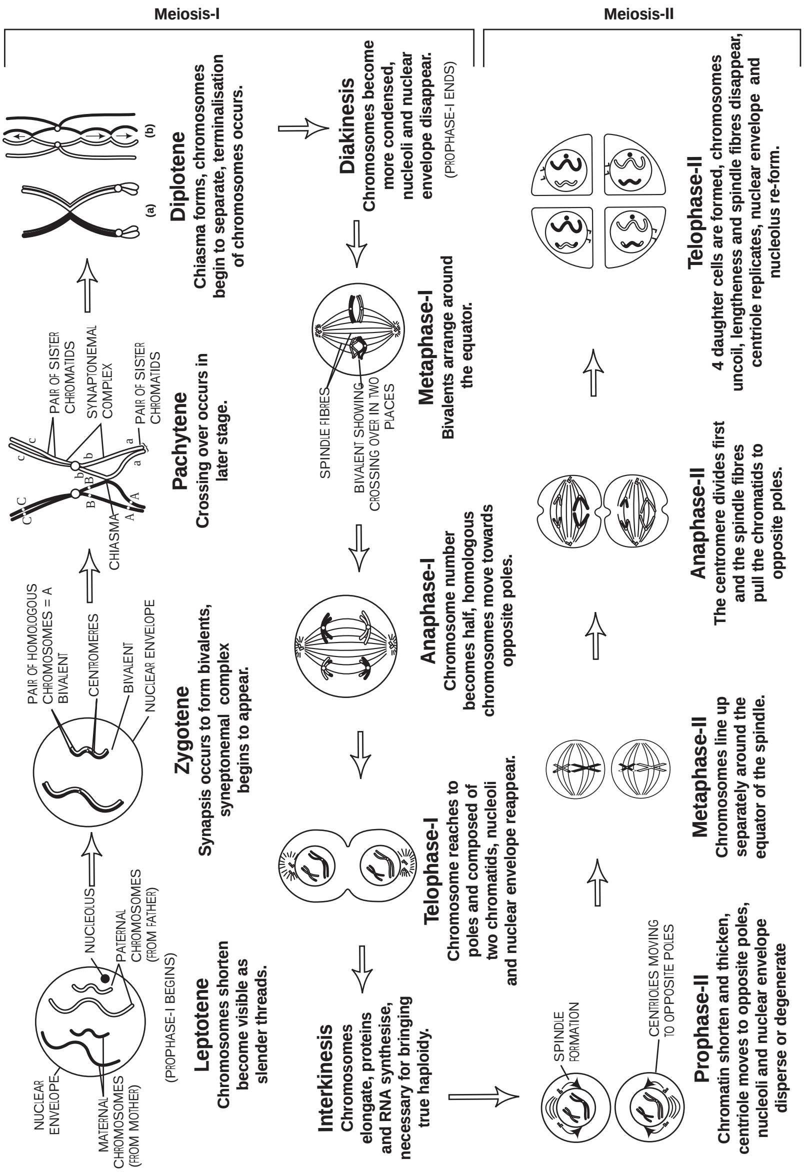
- Meiosis-I
- Meiosis-II



Important processes seen during meiosis are

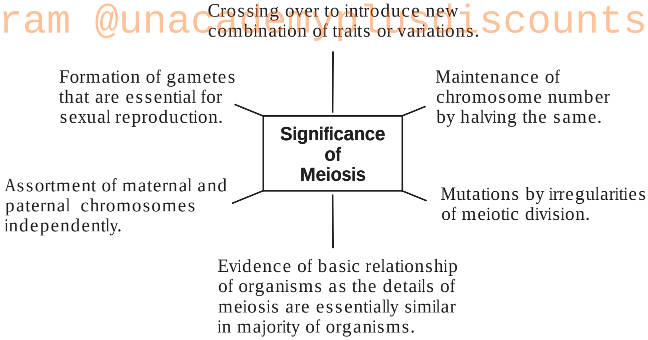
- **Synapsis** (Montgomery; 1901) It is the side-by-side pairing of homologous chromosomes during the **zygotene** phase of meiosis prophase-I.
- Depending upon the place of origin of pairing, it is **procentric** (starting from centromere), **proterminal** (starting from the ends) and **intermediate** (starting at various places). Synapsis is assisted by the formation of a complex known as **synaptonemal complex** and the complex formed by pair of homologous chromosomes (synapsed) is called a **bivalent**.
- **Crossing over** It is a recombinase-mediated process of exchange of genetic material or chromatid segments between two homologous chromosomes occurring during the **pachytene phase** of meiosis-I.
- The temporary joints or points of attachment between chromosomes during crossing over are called **chiasmata**. Formation of these structures is an indication of completion of crossing over & beginning

of separation of chomosomes, **i.e.**, process of **terminalisation**. In the process of terminalisation, chiasmata start moving towards their terminals. The complete process in pictorial view is given below.



Stages of meiosis

Significance of Meiosis



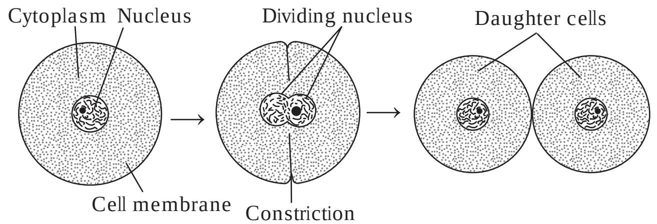
Differences between Mitosis and Meiosis

Mitosis	Meiosis
G_2-period of interphase is normal.	G_2-period is short or non-existent.
Division phase of one or two hours.	Division phase lasts several days to several years.
Occurs in most body (somatic) cells.	Occurs only in germ cells in the gonads.
Accounts for the growth of body, repair and regeneration of injured parts and embryonic development.	Accounts for the formation of gametes in sexual reproduction.
One chromosomal duplication is followed by one cell division, producing two diploid daughter cells.	One chromosomal duplication is followed by two consecutive divisions, producing four haploid daughter cells.
Resultant daughter cells are genetically similar to each other and to the parent cell.	Resultant daughter cells are genetically dissimilar to each other and to the parent cell.
Prophase relatively short and less complicated.	Prophase of first meiosis very long and complicated.
No synapsis, chiasmata formation and crossing over between homologous chromosomes.	Synapsis, chiasmata formation and crossing over between homologous chromosomes in prophase of first meiosis.
It is always the chromatids that segregate into resultant daughter cells.	It is the homologous chromosomes that segregate into resultant daughter cells in first meiosis and chromatids in the second.
Cytokinesis includes a single equatorial furrow around the parental cell.	Cytokinesis includes two furrows at right angles around the parent cell.
Occurs in body throughout the life.	Occurs in gonads only when these are mature for sexual reproduction.

(ii) **Cytokinesis** It involves the division of cytoplasm. It normally starts towards the middle anaphase and is completed simultaneously with the telophase. It is different in animal and plant cell. In animals, it occurs by **cleavage furrow method**, whereas in plants, it is carried out by **cell plate method**.

Amitosis (Remak; 1855)

It is a direct cell division by simple cleavage of nucleus and cytoplasm without the formation of chromosomes. It is seen in few monerans.



Stages of amitosis

Control of Cell Cycle

The checkpoints involved in the cell cycle regulation are as follows

(i) **G_1-checkpoint** at G_1/S boundary
(ii) **G_2-checkpoint** at G_2/M boundary
(iii) **Metaphase-checkpoint** at metaphase/anaphase boundary

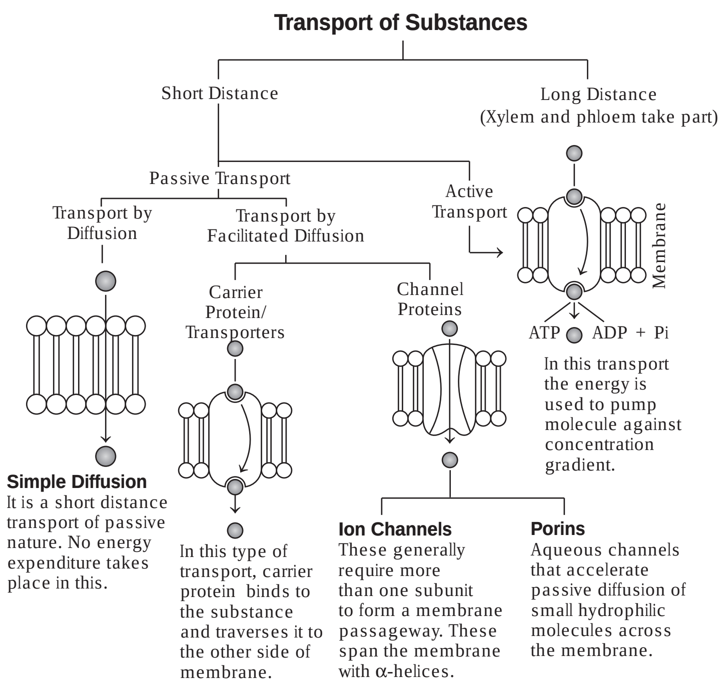
Significance of Cell Cycle

(i) It helps to maintain, controlled proliferation of cells.
(ii) Deregulation of cell cycle may lead to tumour formation.

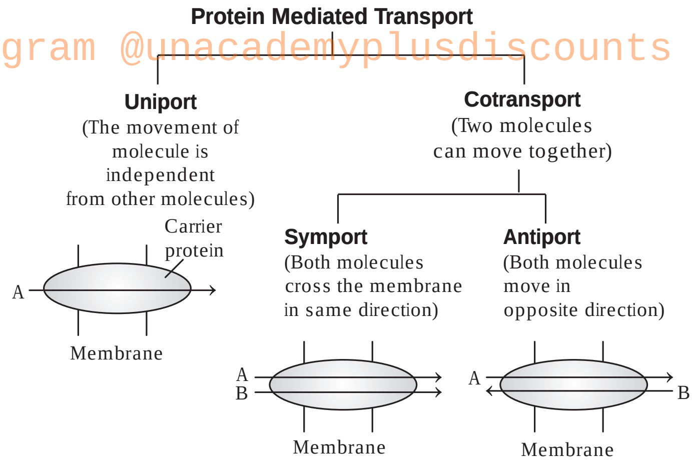
11

Transport in Plants

In plants, substances like growth regulators, nutrients, water, food, etc., have to be transported from one plant part to another.



Several methods of transport of substances



Types of protein mediated transport

Processes Involved in Passive Transport

Passive transport of water and solutes in plants may take place **via** diffusion, osmosis, plasmolysis, etc.

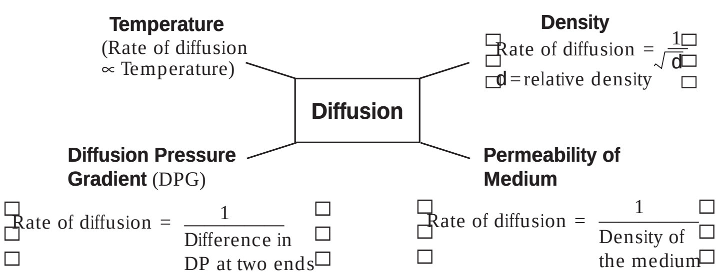
Diffusion

The tendency of even distribution of solid, liquid or gaseous molecules in available space is called **diffusion**. It is driven by **random kinetic motion.** Diffusion is defined as the movement of particles of substance from the region of their higher concentration.

Diffusion Pressure (DP) The pressure exerted by the even distribution of particles

$$\text{DP} \propto \text{concentration of diffusing particles}$$

Factors Affecting Diffusion



Osmosis

It is a special type of diffusion of solution/water that occurs through a semipermeable membrane.

The phenomenon of osmosis was discovered by **Nollet** in 1748.

Plasmolysis

When the protoplasm shrinks and leaves the cell wall due to exosmosis, the cell is called **plasmolysed** and phenomenon is called **plasmolysis**.

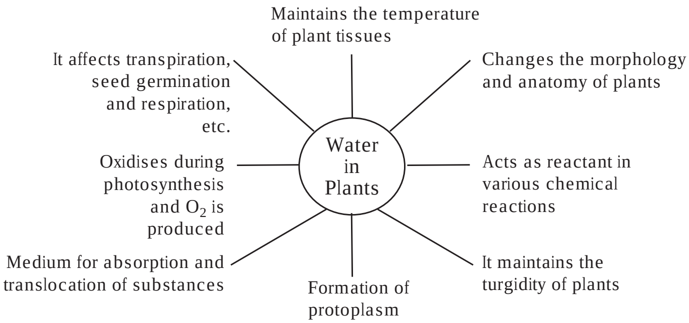
Imbibition

It is the absorption of water by the solid particles of an adsorbent causing it to enormously increase in size without forming a solution, **e.g.,** swelling of dry seeds in water.

(i) Solid substance or adsorbent is called **imbibant** and the liquid which is imbibed, is known as **imbibate**.

(ii) The swelling imbibant also develops a pressure called **imbibition pressure** (matric potential).

Plant-Water Relation



Roles of water in plants

Components of Plant-Water Relations

1. Osmotic Pressure (OP; Pfeffer, 1750)

The actual pressure, that develops in a solution, when it is separated from pure water by means of semipermeable membrane.

OP depends upon–
- Concentration
- Ionisation
- Hydration
- Temperature

It is measured in terms of atmosphere (atm)

$$
\begin{aligned}
1 \text{ atm} &= 14.7 \text{ pounds/inch}^2 \\
&= 760 \text{ mmHg} \\
&= 1.013 \text{ bar} \\
&= 0.1013 \text{ Mpa} \\
&= 1.013 \times 10^5 \text{ Pa}
\end{aligned}
$$

Osmotic Pressure $\boxed{\mathbf{OP = m\,i\,R\,T}}$

where, **m** = Molar concentration
i = Ionisation constant
R = Gas constant
T = Temperature

2. Chemical Potential

It is a quantitative expression of the free energy associated with water.

'It is the difference between the potential of a substance in a given state and the potential of same substance in standard state.'

3. Water Potential (Stalyer and Taylor, 1960)

The total kinetic energy of water molecules present in a system is known as its **water potential**. Hence, the **pure water will have the highest water potential**.

'It is the difference in the free energy or chemical potential per unit molal volume of water in a system and that of pure water at the same temperature and pressure.

Chemical potential of pure water at normal temperature and pressure (NTP) is **zero.** It is represented by ψ (psi) or more accurately ψ_w.

Unit of ψ_w = bars or pascal (1 Mpa = 10 bars)

$$\underset{\substack{\uparrow \\ \text{Water} \\ \text{potential}}}{\psi_w} = \underset{\substack{\uparrow \\ \text{Solute} \\ \text{potential}}}{\psi_s} + \underset{\substack{\uparrow \\ \text{Pressure} \\ \text{potential}}}{\psi_p} + \underset{\substack{\uparrow \\ \text{Potential} \\ \text{due to gravity}}}{\psi_g}$$

Water potential is a tool which informs us about the plant cells and tissues. The lower the water potential in a plant cell or tissues, the greater is its ability to absorb water.

4. Osmotic Potential (OP)/Solute Potential (ψ_s)

'It is the decrease in chemical potential of pure water due to the presence of solute particles in it.'

It can be calculated by

$$\psi_s = \mathbf{C} \times \mathbf{R} \times \mathbf{T}$$

where, **C** = Concentration of solute particles
R = Gas contant
T = Temperature

It always have **negative value**.

5. Turgor Pressure (TP)/Hydrostatic Pressure/Pressure Potential (ψ_p)

This can be understood by following schematic diagram

A living plant cell/tissue $\xrightarrow{\text{Placed in hypotonic solution}}$ Water enters into the cell/tissue by osmosis → Pressure is developed in cell sap → This pressure presses the protoplasm against the cell wall → Cell/tissue becomes turgid

This pressure is called **turgor pressure**.

6. Diffusion Pressure Deficit (DPD; Meyer, 1938)

The difference between the diffusion pressure of the solution and its solvent at a particular temperature and atmospheric condition is called **DPD**. It determines the direction of net movement of water.

DPD has a **positive value**.

DPD $\propto$ Concentration of solution

It is also known as **suction pressure**, as it is a measure of the ability of a cell to absorb water.

$$\text{DPD/SP} = \text{OP} - \text{WP}$$

$$\text{WP} = \text{TP}$$

$$\text{DPD} = \text{OP} - \text{TP}$$

Now-a-days the term 'Water potential' is used which is equal to DPD.

Long Distance Transport of Water

Long distance transport of substances within a plant cannot be accomplished by diffusion alone. Special systems are necessary to move substances across long distance and at a much faster rate.

Water, minerals and food are generally moved by a **mass** or **bulk flow system**.

Mass Flow System

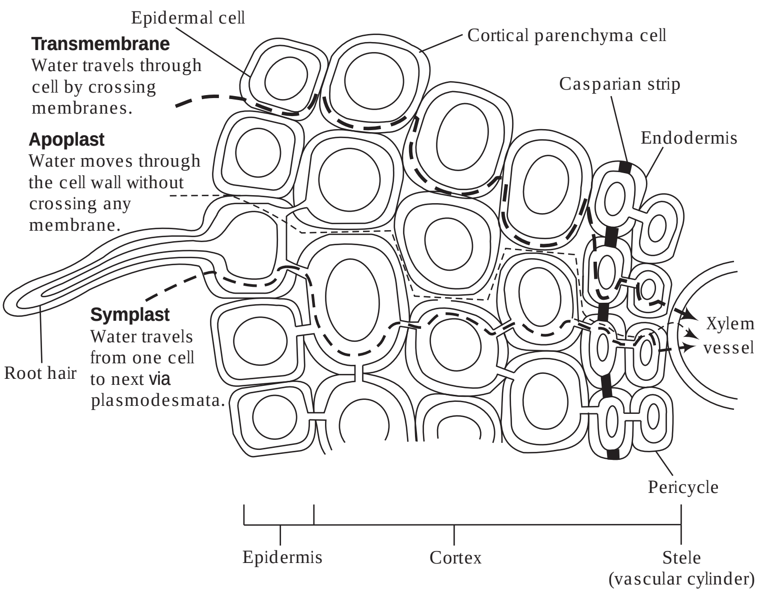
According to this theory, 'An increase in transpiration increases the rate of absorption of ions'. The bulk flow of substances through vascular system is called **translocation.**

Absorption of Water by Plants

Water is absorbed along with mineral solutes by the root hairs, purely by diffusion. Once water is absorbed, it can move through different pathways.

There are three pathways for the movement of water in plants.

(i) Apoplast pathway
(ii) Symplast pathway
(iii) Transmembrane pathway



Three routes of lateral transport in plant tissues or organ

Mechanism of Water Absorption

Water absorption is of two types

Water Absorption

Active
(root cells play an active role)

Osmotic absorption
(in this, the OP of cell sap of root hair is higher than that of soil water.)

Non-osmotic absorption
(this type of absorption is against the concentration gradient and also known as active non-osmotic absorption.)

Passive
(water is transported by the tension created by transpiration)

Factors Affecting the Rate of Water Absorption

Water Absorption

Concentration of CO_2
(rate of absorption is inversely proportional to the concentration of CO_2)

Amount of Water in Soil
(more water leads to more absorption)

Concentration of Soil Solution
(higher concentration of soil solution reduces absorption of water)

Temperature
(low temperature inhibits water absorption)

Concentration of O_2
(more O_2 concentration reduces water absorption)

Upward Water Movement in a Plant

For distribution to various parts of the plant, water has to move upward in a stem against gravity. There are two forces which provide the energy for this movement of water. **These are**

Root Pressure
It refers to **positive hydrostatic pressure** that develops in xylem sap of root which can raise the water to a certain height in the xylem.

Transpiration Pull
This can be explained by **cohesion–tension–transpiration pull model.** According to which, the transpiration from leaves generates a pull for water to reach to the leaves.

Guttation

It is the loss of water in the liquid state from uninjured parts of plants, usually from tips and margins of leaves. In this, water exudes from the group of leaf cells called **hydathodes.**

A hydathode is an opening or pore in the leaf epidermis, around which are grouped several thin-walled parenchyma cells. It occurs during night or early morning when there is high atmospheric humidity and transpiration is less.

Transpiration

It is an evaporative loss of water by plants, which occurs mainly through stomata. Transpiration reduces the water level in soil, but it is necessary for water and mineral absorption, **i.e.**, ascent of sap. Therefore, it is also known as **necessary evil**.

The transpiration driven ascent of xylem sap depends mainly on the following physical properties of water

- **Cohesion** Mutual attraction between water molecules.
- **Adhesion** Attraction of water molecules to polar surfaces (such as the surface of tracheary elements).
- **Surface Tension** Water molecules are attracted to each other in the liquid phase more than to water in the gas phase.

Types of Transpiration

(i) **On the basis of part of the plant in which it takes place**

Transpiration

- **Foliar Transpiration** (90%) (transpiration through leaves)
- **Cauline Transpiration** (10%) (transpiration through stem)

(ii) **On the basis of surface of plant**

Transpiration

- **Stomatal** (85-90%) These are small pores present on leaf surface, surrounded by bean-shaped cells called **guard cells**.
- **Cuticular** (3-8%) Also known as **peristomatal transpiration.** It continues throughout day and night.
- **Lenticular** (1-2%) Lenticels are small pores present on the woody trunk beneath the bark.
- **Bark** (~1%) Bark transpiration is very little, but its measured rate is higher than lenticular transpiration.

Advantages of Transpiration

(i) **Ascent of sap** It mostly occurs due to transpiration pull exerted by transpiration of water. This pull also helps in the absorption of water.

(ii) **Removal of excess water** It has been held that plants absorb far more amount of water than is actually required by them. Transpiration, therefore removes the excess of water.

(iii) **Cooling effect** Transpiration, by evaporating water, lowers down their temperature by 10 -15° C.

(iv) **Mechanical tissue** The development of mechanical tissue, which is essential for providing rigidity and strength to the plant, is favoured by the increase in transpiration.

(v) **Distribution of mineral salts** Mineral salts are mostly distributed by rising column of sap.

(vi) **Increasing concentration of mineral salts** The loss of water through transpiration increases the concentration of mineral salts in the plant.

(vii) **Root system** Transpiration helps in better development of root system which is required for support and absorption of mineral salts.

(viii) **Quality of fruits** The ash and sugar content of the fruit increase with the increase in transpiration.

(ix) **Resistance** Excessive transpiration induces hardening and resistance to moderate drought.

(x) **Turgidity** Transpiration maintains the shape and structure of plant parts by keeping cells turgid.

(xi) **Photosynthesis** Transpiration supplies water for photosynthesis.

Disadvantages of Transpiration

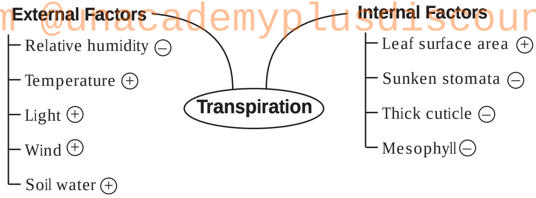
(i) **Wilting** Wilting or loss of turgidity is quite common during noon due to transpiration rate being higher than the rate of water absorption. Wilting reduces photosynthesis and other metabolic activities.

(ii) **Reduced growth** Transpiration reduces availability of water inside the plant. As reported by **Tumarov** (1925), a single wilting reduces growth by 50%.

(iii) **Abscisic acid** Water stress produces abscisic acid. Abscisic acid prevents several plant processes and promotes abscission of leaves, flowers and fruits.

(iv) **Wastage of energy** Since most of the absorbed water is lost in transpiration, it is wastage of energy.

Factors Affecting Transpiration



⊕ = increase the transpiration with increase in related factor.
□ = decrease the transpiration with increase in related factor.

Uptake and Transport of Mineral Nutrients

(i) **Mineral salt absorption** Earlier, scientists had opinion that inorganic salts are passively carried into plants with the absorption of water and the absorbed salts are translocated to the different parts of the plant through transpiration stream. Now-a-days, it has been established that mineral salt absorption is an active process rather than passive, as it was considered earlier.

(ii) **Active mineral absorption** The absorption of ions against the concentration gradient or with the help of metabolic energy is known as **active absorption**.

Following theory have been proposed to explain the phenomenon of active absorption.

The carrier concept (Vanden Honert, 1937) According to this theory, 'The carrier molecules of ions combine with ions in outer free space to form carrier-ion complex. This complex moves through intermediate space into inner space where it releases ions. The carrier compound can return back to outer space, but ions cannot'.

The observations like **isotopic exchange, saturation effect** and **specificity,** greatly support the carrier concept of active absorption of mineral salts.

Translocation of Mineral Ions

The translocation of mineral salts/ions takes place both by xylem and phloem. The upward movement usually occurs through xylem while bidirectional movement occurs through phloem.

pH < Decrease — Leads to absorption of anions
pH < Increase — Leads to absorption of cations

The chief sinks for the mineral elements are the growing regions of the plant such as apical and lateral meristem, young leaves, etc.

Translocation and Storage of Food in Plants

(PHLOEM TRANSPORT)

Food, primarily sucrose, is transported by the vascular tissue, phloem from source to a sink. The transport of food from the production centre (leaves) to the consumption centre (apices, roots, fruits, tubers) is called **translocation of organic solutes**.

Routes of Translocation

Solutes are translocated in various directions within the plants.
These may be

(i) Downward translocation of organic solute – From leaves to root and other parts of plant.

(ii) Upward translocation of organic solute – Roots to leaves or other apical regions.

(iii) Upward translocation of mineral salts – Occurs through xylem by active transport.

(iv) Upward movement of solute – Movement of salts to the leaves.

(v) Lateral translocation of solutes – Translocation in tangential direction in woody stems.

Mechanism of Translocation

There are several theories that have been put forward to explain the mechanism of organic solute movement.

The most accepted theory which explains the mechanism of translocation is **Mass Flow Theory**. **Some of the theories including mass flow are as follows**

Diffusion Theory (Mason and Maskell, 1928)

Translocation through transpiration stream.

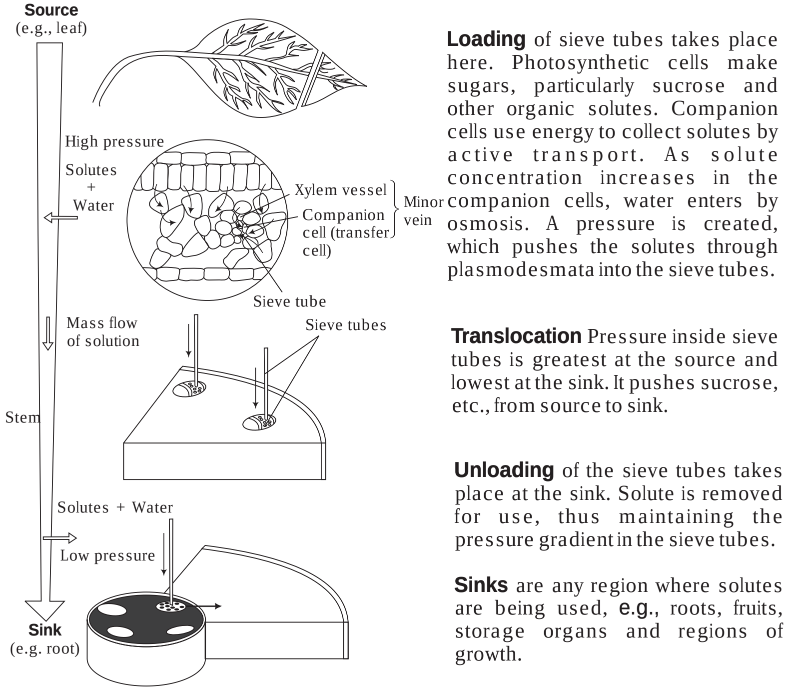
Mass or Pressure Flow Theory (Ernst Munch, 1930)

It is also known as **pressure flow hypothesis** or **Munch hypothesis**. According to this hypothesis, **the organic solute translocates in following steps**

(i) **Phloem loading** is an active transport mechanism. It is carried out by a specific carrier protein molecules in the cell surface membrane of companion cells that uses energy of ATP. This energy is obtained from the photosynthesising mesophyll cells. Transportation occurs to the sieve tubes by the veins of a leaf.

(ii) **Long distance transport** of sucrose in the stem and root phloem.

(iii) **Phloem unloading** is a passive transport mechanism from the sieve tubes to the cells at the root tip. It takes place passively down a concentration gradient of sucrose. The transfer cells are often present at unloading sites. Phloem unloading also requires metabolic energy, that is used by sink organs for respiration and biosynthetic reactions.



Movement of solutes such as sucrose through the phloem of a plant. Three stages are involved, namely movement of solutes from photosynthetic cells to sieve tubes (loading), translocation in phloem and unloading at a sink.

Transcellular Streaming Theory (Thaine; 1962, 1969)

Translocation through peristaltic movements in continuous tubular strands in sieve tubes.

12

Mineral Nutrition in Plants

Almost all organisms require several elements to perform various functions in their body. The elements are of biological importance and their absorption is the theme of mineral nutrition.

Classification of Mineral Nutrients

On the basis of their essentiality in body, the minerals can be categorised into

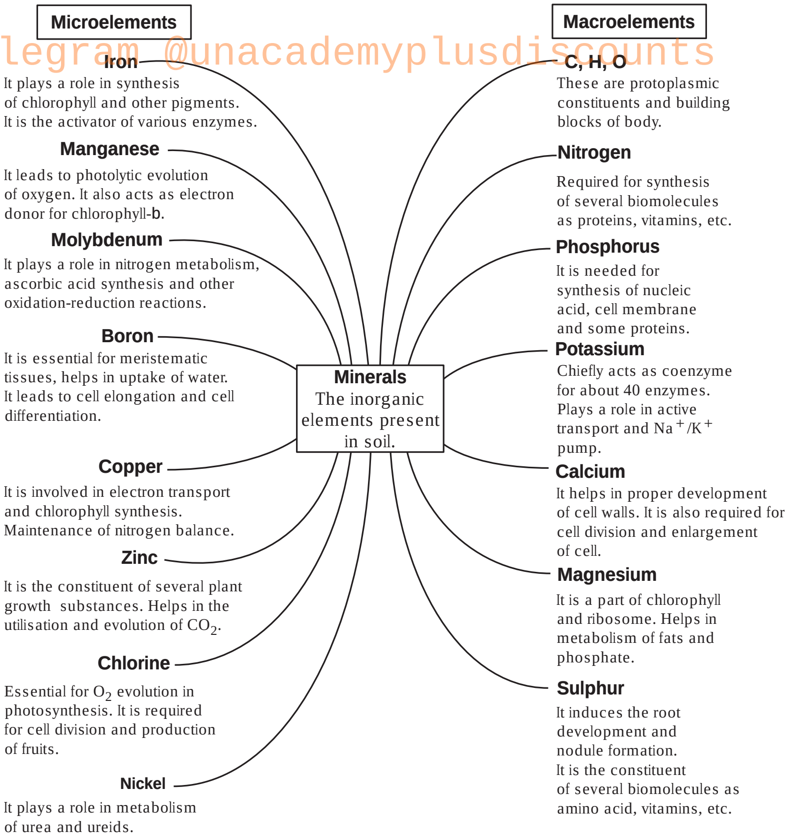
(i) **Essential Mineral Elements** (17 in number) These elements have specific structural or physiological role. These are indispensable for plants to complete their life cycle, e.g., nitrogen, phosphorus, etc.

(ii) **Non-Essential Mineral Elements** (other than 17 essential) These elements are required in some plants, but not all. Their absence does not produce any major deficiency symptoms in plants, e.g., cobalt, silicon, sodium, etc.

On the basis of their occurrence in dry matter of living organisms, minerals are of following types

(i) **Micronutrients/Microelements/Trace elements** (equal to or less than 100 mg/kg of dry matter) These act as cofactors or activators for the functioning of enzymes. These are eight in number, e.g., Zn, Mn, B, Cu, Mo, Cl, Ni and Fe.

(ii) **Macronutrients/Macroelements** (1000 mg/ kg of dry matter) These are involved in the synthesis of organic molecule. These are nine in number, e.g., C, H, O, N, S, P, K, Mg and Ca.



On the basis of their diverse functions, the essential elements can be classified into four different categories

(i) **As components of biomolecules**, **e.g.,** carbon, hydrogen, oxygen and nitrogen.

(ii) **As components of energy related compounds**, **e.g.,** Mg in chlorophyll and P in ATP.

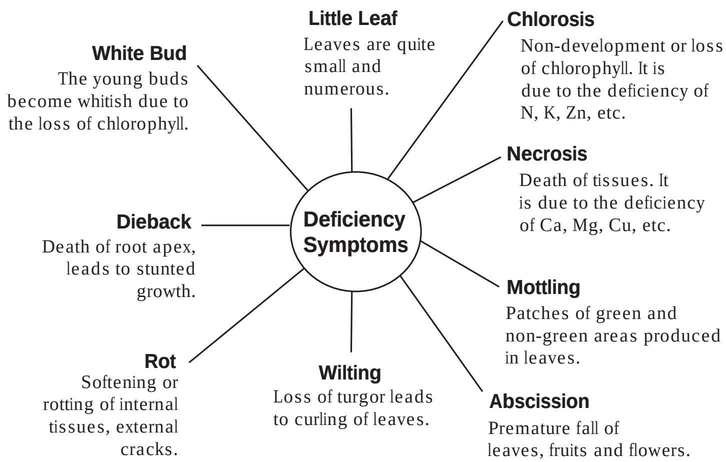
(iii) **Regulator of osmotic potential**, **e.g.,** potassium controls the opening and closing of stomata.

(iv) **As regulator of enzyme activity**, **e.g.,** Mg^{2+} activates RuBisCO, Zn^{2+} activates alcohol dehydrogenase.

Deficiency Symptoms of Essential Mineral Nutrients

These symptoms appear in plant when the mineral supply of an essential element becomes limited. The minimum concentration at which plant growth is retarded is termed as **critical concentration.**

A detailed account of certain symptoms is as follows



Deficiency symptoms of essential mineral elements

Toxicity of Micronutrients

(i) The moderate increase in the concentration of micronutrients causes its toxicity.

(ii) Any mineral ion concentration in tissues which reduces dry weight of tissue by 10% is called '**toxic concentration**'.

(iii) The critical toxic concentration is different for different micronutrients as well as different plants.

(iv) The toxicity of one mineral, mostly leads to the inhibition of absorption of other micronutrients.

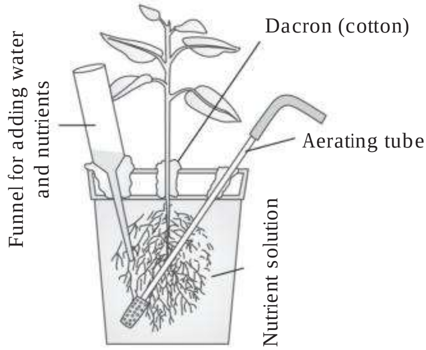
Hydroponics

In 1860, **Julius von Sachs** demonstrated for the first time that plant could be grown to maturity in a defined nutrient solution in complete absence of soil.

The soilless production of plants is called **hydroponics**. It is also known as **soilless culture** or **solution culture** (**Georick**; 1940).

There are three methods for growing plants with nutrient solutions

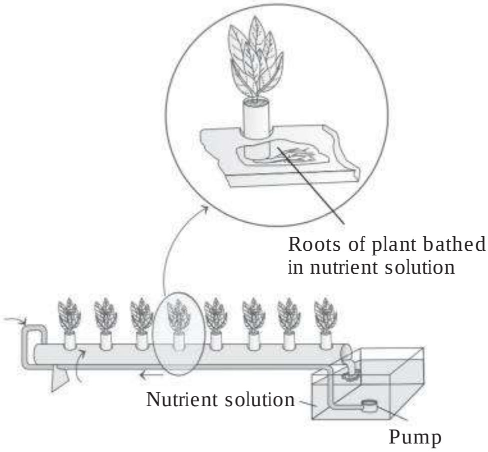
(i) **Hydroponic Culture** Using nutrient solution in this culture, an airtight container is supplied by air through a tube and nutrients through a funnel.



A typical tube for nutrient solution culture

(ii) **Slop Culture** Nutrient solution using sand. In this, the plants are grown on sand column, the nutrient solution is poured at regular intervals from upside.

(iii) **Nutrient Film Technique** The nutrient solution drains through plant roots, through a channel. In this process, the plant roots do not have any substratum but they are bathed regularly with nutrient solution.



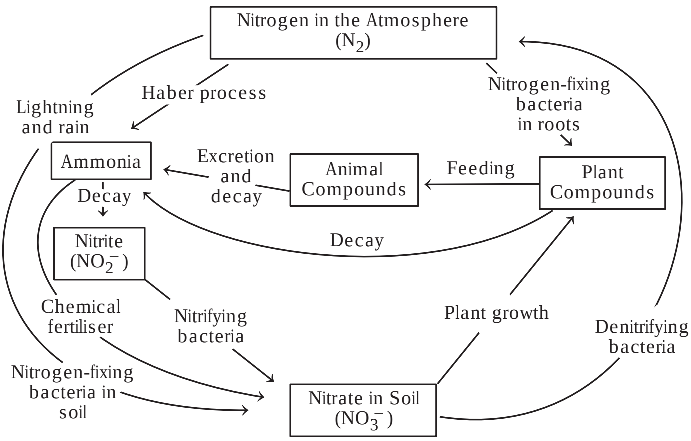
Hydroponic film growth system

Metabolism of Nitrogen

Nitrogen exists as two nitrogen atoms joined by a very strong triple bond. It is needed by plant for the production of protein, nucleic acid, chlorophyll and many other vitamins.

Nitrogen Cycle

It is an example of gaseous biogeochemical cycle, which leads to the cycling of nitrogen in various pools (**i.e.,** atmosphere, soil and living organisms).



Nitrogen cycle

A regular supply of nitrogen to the plant is maintained through nitrogen cycle. Plants obtain nitrogen from soil as NO_3^- (nitrate), NH_4^+ (ammonium) and NO_2^- (nitrite) ions.

Nitrogen-Fixation

It is the conversion of **free nitrogen** into **nitrogenous compounds** to make it available for absorption by plants.

Nitrogen-Fixation

Non-biological / Physical
(about 35 mg / m^2 / year)

Generally, this type of N_2 fixation takes place in rainy season during lightning, thunder storm and atmospheric pollution.

$$N_2 + O_2 \xrightarrow[\text{Thunder}]{\text{Lightning}} 2NO$$

$$2NO + O_2 \xrightarrow{\text{Oxidation}} 2NO_2$$

$$2NO_2 + H_2O \longrightarrow HNO_2 + HNO_3$$

$$HNO_3 + NH_3 \longrightarrow NH_4NO_3$$

Biological
(140-700 mg / m^2 /year)

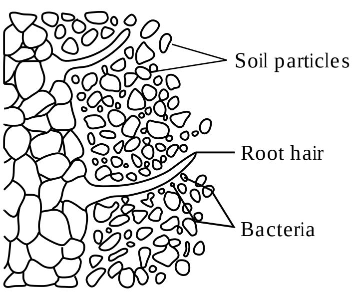
The fixation of nitrogen takes place by microorganisms like bacteria, fungi and algae.

Symbiotic
It is performed by symbiotic association of two organisms.

Non-symbiotic
It is performed by aerobic and anaerobic bacteria and BGAs, e.g., *Azotobacter*, *Clostridium*, *Chlorobium*, *Nostoc*, *Anabaena*, *Pullularia*, etc.

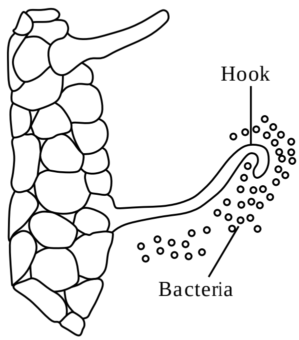
Through Nodulation
e.g., *Rhizobium* sp, *Frankia* (Actinomycetes)

Through Non-nodulation
e.g., Lichen, *Anthoceros*, *Azolla*, *Cycas*, *Gunnera*, *Digitaria*, etc.



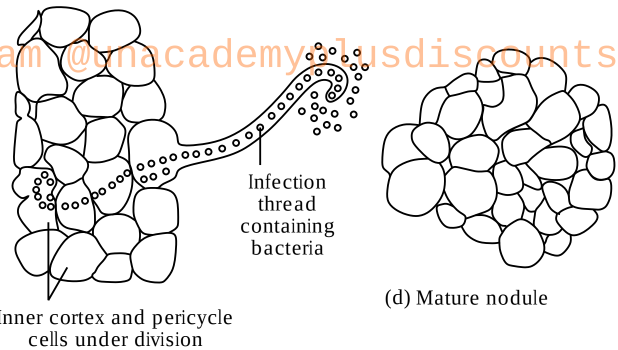
(*Rhizobia* multiply and colonise the surroundings of roots and get attached to epidermal and root hair cells)

(a) Chemical Recognition



(The root hairs curl)

(b) Curling of root hairs



(c) Formation of infection thread

(d) Mature nodule

Development of root nodules in soybean

Biochemistry of Nitrogen-Fixation

Schneider et al. (1960) and **Carnahan** et al. (1960) studied the nitrogen-fixation by radiolabelling and confirmed the conversion of nitrogen into ammonia.

Basic requirements for N_2**-fixation are as follows**

(i) Nitrogenase and hydrogenase enzyme.

(ii) A mechanism which protects **nitrogenase** from oxygen.

(iii) Ferredoxin.

(iv) Constant supply of ATP.

(v) Coenzymes and cofactors like TPP, Co-A, iP and Mg^{+2}.

(vi) Cobalt and molybdenum.

(vii) A carbon compound to trap released ammonia.

The most important requirement of N_2-fixation is nitrogenase enzyme which has two sub-units. **These are**

- **Fe containing unit** Dinitrogen reductase.
- **Mo containing protein** Dinitrogenase.

The enzyme nitrogenase is highly sensitive to molecular oxygen (O_2) and gets inactivated when exposed to it. The nodule formation is to provide anaerobic condition to this enzyme.

- Decomposition of organic nitrogen of dead plants and animals into ammonia is called **ammonification**.
- Ammonia is oxidised to nitrite which is further oxidised to nitrate called **nitrification**.

- The nitrate in soil is reduced to nitrogen by the process of **denitrification**.

The basic nitrogen-fixing reaction is as follows

$$N_2 + 8e^- + 8H^+ + 16ATP \xrightarrow[\text{enzyme complex}]{\text{Dinitrogenase}} 2NH_3 + 2H^+ + 16ADP + 16Pi$$

The chemically fixed nitrogen is used by both plants and animals to synthesise various biomolecules of diverse uses.

Fate of Ammonia

Ammonia produced combines with organic acids to produce amino acids by following methods.

- **Reductive Amination** Ammonia formed combines with keto acid to form amino acid in the presence of a reduced coenzyme and enzyme dehydrogenase.
- **Transamination** Transfer of amino groups from an amino acid with carboxyl group of a keto acid is transamination.

Soil as Reservoir of Essential Elements

Soil acts as the most stable reservoir for both nutrients and organisms to harbour in it. Various inorganic salts and ions derived from rock minerals present in soil are known as **mineral nutrients**. **Natural process** like weathering and humification enrich the nutritional content of soil, while some **artificial processes** like fertilisers (**i.e.,** chemical and organic) also lead to nutritional enrichment of soil.

13

Photosynthesis in Higher Plants

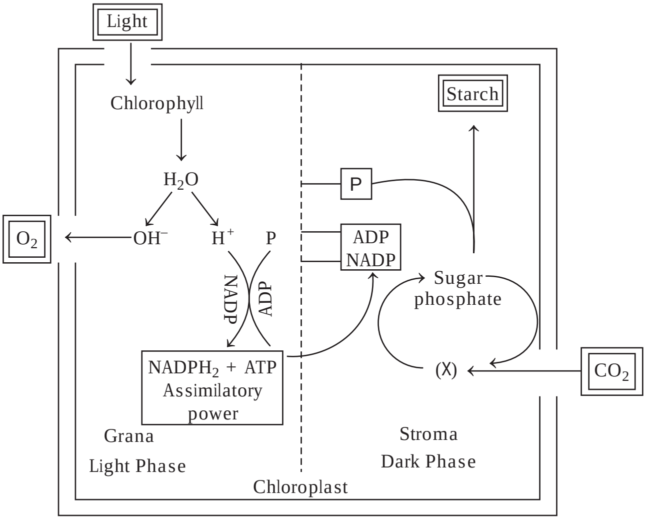
Photosynthesis is the only mechanism of energy input into living world. Only exceptions are chemosynthetic bacteria that obtain energy by oxidising inorganic substances.

The synthesis of organic compounds like carbohydrates or glucose by the cells of green plants in the presence of sunlight with the help of CO_2 and H_2O is called **photosynthesis**.

Photosynthesis is sometimes called as **carbon assimilation** and is represented by following equation,

$$6CO_2 + 6H_2O \xrightarrow[\text{Green plants}]{\text{Light energy (686 kcal)}} C_6H_{12}O_6 + 6O_2$$

The whole process can be demonstrated as



Demonstration of light dependent and light independent phases during photosynthesis

Chemistry and Thermodynamics of Photosynthesis

Photosynthesis is a chemical oxidation-reduction process in which water molecules are oxidised to form O_2 and CO_2 molecules are reduced to form carbohydrate. It is an enzyme regulated, anabolic process of producing organic compounds.

The annual CO_2 fixation is about 70 billion tonnes which requires about 1.05×10^{18} kcal of energy. The total solar energy falling on the earth is 5×10^{20} kcal/year. The plants are thus able to utilise only 0.2% of the solar energy received by the surface of the earth.

Historical Timeline of Photosynthesis

1779 → **Ingenhousz**: Only green plants have the capacity of purifying foul air in the presence of sunlight.

1877 → **Sachs**: Reported the role of chloroplast and found starch as the first product of photosynthesis.

1905 → **Blackmann**: Photosynthesis is a photochemical reaction in which CO_2 is fixed by using the product of light reaction.

1939 → **Robin Hill**: Demonstrated the photolysis of water in light reaction.

1954 → **Malvin Calvin**: Traced the path of carbon in photosynthesis and gave details about C_3 cycle.

1960 → **Hill and Bendall**: Explained the Z-scheme for light reaction.

1967 → **Hatch and Slack**: Reported C_4 cycle for carbon-fixation.

1985 → **Huber, Michel and Deisenhofer**: Crystallisation of photosystem of purple sulphur bacteria.

Landmark discoveries related to photosynthesis

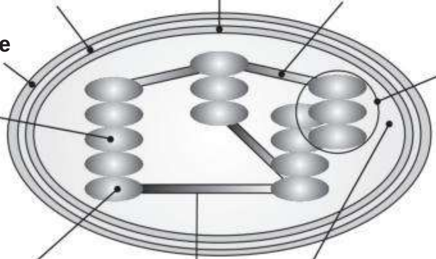
Chloroplast : Photosynthetic Organ of Cell

Chloroplasts are the green plastids which occur in all green parts of the plants. These are the actual sites of photosynthesis.

These occur mostly in chlorenchymatous cells (particullary in mesophyll) of leaves and young stem. It is a double membranous organelle in which the envelope encloses a liquid proteinaceous matrix called **stroma**.

It is a semi-autonomous organelle as it contains its own DNA and is a characteristic feature of plant cells only. As complete food synthesis takes place in chloroplast, it is also known as **kitchen of the cell**.

Internal Structure of Chloroplast



Detailed structure of a chloroplast

Photosynthetic Pigments

The pigments present in plants are of two types

Plant Pigments

- **Photosynthetic Pigments**
  - Fat-soluble pigments
    - **Chlorophylls** (Green coloured)
      - Chlorophyll-a ($C_{55}H_{72}O_5N_4Mg$)
      - Chlorophyll-b ($C_{55}H_{70}O_6N_4Mg$)
      - Chlorophyll-c ($C_{55}H_{32}O_5N_4Mg$)
      - Chlorophyll-d ($C_{54}H_{70}O_6N_4Mg$)
      - Chlorophyll-e
      - Bacteriochlorophyll-a
      - Bacteriochlorophyll-b
    - **Carotenoides**
      - Carotenes (yellow coloured) ($C_{40}H_{56}$)
      - Xanthophylls (brown coloured) ($C_{40}H_{56}O_2$)
  - Water soluble pigments
    - **Phycobilins**
      - Phycocyanin (blue coloured)
      - Phycoerythrin (red coloured)
- **Non-photosynthetic Pigments**
  - Anthocyanin (red)
  - Anthoxanthin (purple)
  - Phytochromes (blue-green)
  - Haematochromes (red)

Pigments involved in photosynthesis

- Both **chlorophyll-**a and β-**carotene** are universal photosynthetic pigment.

- The heaviest pigment of chloroplast is **chlorophyll-**b and the lightiest one is **carotene.**
- Chlorophylls are directly involved in trapping of sunlight, while carotenes protect the chlorophyll from photo-oxidation by bright sunlight.

Mechanism of Photosynthesis

The process of photosynthesis is distinctly divided into two phases

1. Photochemical phase
2. Biosynthetic phase

1. Photochemical Phase/Light Reaction/Hill Reaction

It occurs inside the thylakoids. The function of this phase is to produce assimilatory powers (**i.e.,** ATP, NADPH, etc). It occurs in grana of chloroplast.

It includes following events

(i) Light absorption
(ii) Splitting of water
(iii) Release of oxygen
(iv) Formation of high energy chemical intermediates

Several complexes of protein and other pigments are involved in **light reaction** or **photochemical phase**.

(i) Light Absorption

The molecule which is responsible for absorption of light is a protein based complex called **Light Harvesting Complex** (LHC), which is organised into PS-I and PS-II.

(a) **Photosystem-I or Pigment System-I** The **reaction centre** in this pigment system is P_{700}, which absorbs the light of wavelength 700 nm. It has more of chlorophyll-**a**, chlorophyll-**b** and carotenoids are comparatively less.

PS-I can carry on cyclic photophosphorylation independently. The PS-I with electron carriers is located on both the non-appressed part of grana thylakoid and stroma thylakoids.

(b) **Photosystem-II or Pigment System-II** P_{680} functions as reaction centre in this photosystem. The photons of lower wavelength are absorbed by this photosystem. It is located in appressed part of thylakoid and carries out non-cyclic photophosphorylation with PS-I.

PS-II has chlorophyll-**a**, **b** and carotenoids (according to some physiologists, **xanthophyll** also functions as antenna in this system).

(ii) Photolysis of Water/Splitting of Water

In photosynthesis, water is used as a source of hydrogen required for the reduction of CO_2 to form carbohydrate.

$$CO_2 + 2H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} CH_2O + H_2O + O_2$$

$$4H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} 2H_2O + 4H^+ + 4e^- + O_2$$

The first demonstration of photolysis of water was done by **R Hill** (1937) and it was described by **Van Niel** (1931).

As a result of photosynthesis, the oxygen is released.

(iii) Formation of High Energy Chemical Intermediate

These intermediates are reduced molecules which provide energy during biosynthetic phase. There are various intermediates such as $NADPH_2$, NADPH and ATP.

These are produced by two types of reaction

(a) Photophosphorylation

(b) Chemiosmosis in chloroplast

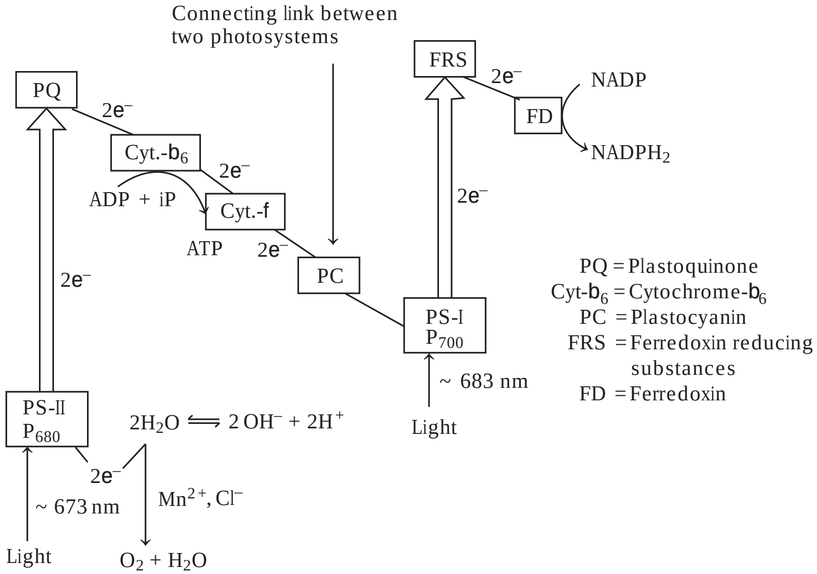
(a) Photophosphorylation

The formation of ATP molecule from ADP and H_3PO_4 in the presence of light and chlorophyll-**a** is called **photophosphorylation**.

$$ADP + H_3PO_4 \xrightarrow[\text{Chl-}\mathbf{a}]{\text{Light}} ATP$$

ATP formation takes place through the following two types of phosphorylation reactions

I. **Non-cyclic photophosphorylation** Both ATP and $NADPH_2$ are produced in this reaction. This takes place as follows



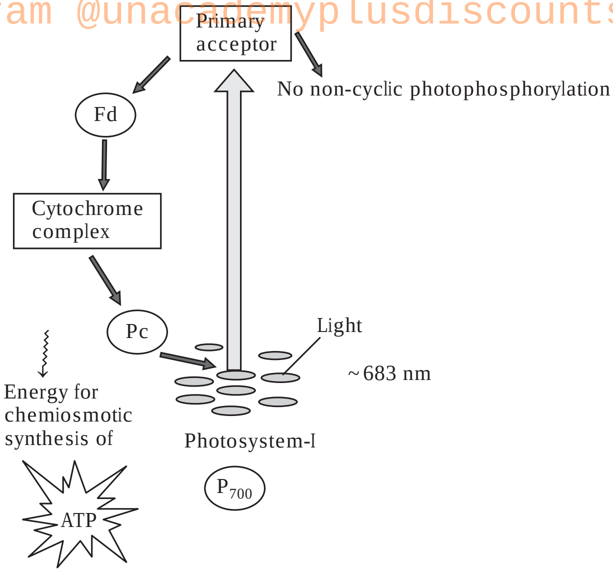
Diagrammatic representation of the non-cyclic photophosphorylation process (Z-scheme)

During non-cyclic photophosphorylation, the initial donor and final acceptor of electrons are different. After the illumination of PS-II, the released electrons are passed to PS-I **via** various electron carriers.

From PS-I, electron is finally provided to ferredoxin (FD), which helps in the synthesis of $NADPH_2$ from NADP. It is known as **Z-scheme**, due to its characteristic shape.

II. **Cyclic photophosphorylation** In this process, the initial donor and the final acceptor of electron is same, **i.e.,** chlorophyll-**a** of PS-I.

Only PS-I is involved in this phosphorylation.



Diagrammatic representation of the cyclic photophosphorylation process

This occurs when activity of PS-II gets ceased or non-cyclic photophosphorylation is stopped due to certain reasons. The electron emitted after illumination of PS-I returns back to its original place **via** several electron carriers which ultimately lead to the synthesis of NADPH.

Three Diverse Methods of Synthesising ATP

Process	Energy Source	Site
Photophosphorylation	Sunlight	Chloroplast
Substrate level phosphorylation	Reaction not involving oxygen	Cytosol
Oxidative phosphorylation	Oxidation with oxygen	Mitochondria

(b) **Chemiosmosis in Chloroplast**

Like respiration, in photosynthesis too, ATP synthesis is linked to development of a proton gradient across a membrane.

2. **Biosynthetic Phase** (Dark Reaction/Blackmann's Reaction)

It occurs in stroma and the chief function of this phase is to produce carbohydrate by using the assimilatory powers (**i.e.,** products of light reaction).

It includes

1. **C_3 Pathway**
   Completed through
   - Carboxylation
   - Reduction
   - Regeneration

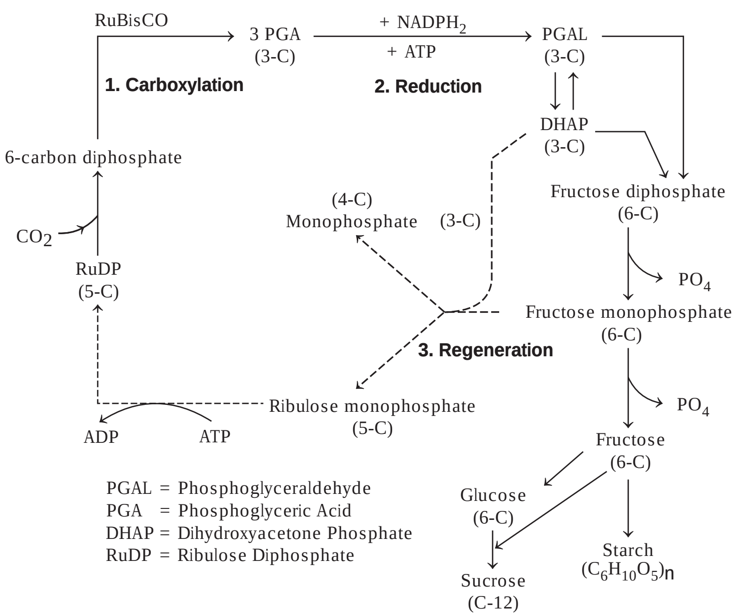
2. **C_4 Pathway**
   Completed through
   - Fixation
   - Decarboxylation
   - Regeneration

This process does not directly depend on the presence of light, but it is dependent on the products of light reaction, **i.e.,** ATP and NADPH, besides CO_2 and H_2O. **There are three different pathways for** CO_2 **fixation in plants**

(i) C_3 Pathway or Calvin Cycle

The cycle was discovered by **Calvin Benson et. al.,** through experimenting with **Chlorella** and **Scendesmus** with CO_2 containing radioactive ^{14}C. In this pathway, the assimilatory powers, **i.e.,** NADPH and ATP produced in light phase are used to reduce CO_2 into carbohydrate.

The scheme of C_3 pathway is as follows



PGAL = Phosphoglyceraldehyde
PGA = Phosphoglyceric Acid
DHAP = Dihydroxyacetone Phosphate
RuDP = Ribulose Diphosphate

Diagrammatic representation of Calvin cycle, regeneration of RuDP is indicated by broken lines

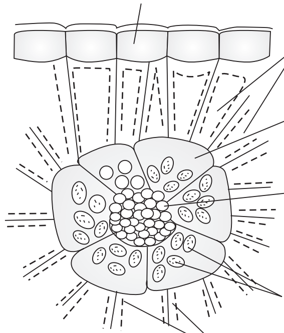
In this cycle, 6 molecules of CO_2 are used and one molecule of fructose-6-P is produced as a byproduct at the expense of 12 molecules of NADPH and 18 molecules of ATP.

The overall reaction is expressed as

$$6\,CO_2 + 12\,NADPH + 12\,H^+ + 18\,ATP + 11\,H_2O \longrightarrow$$
$$F\text{-}6\text{-}P + 12\,NADP^+ + 18\,ADP + 17Pi$$

(ii) C_4 Pathway or Hatch-Slack Cycle

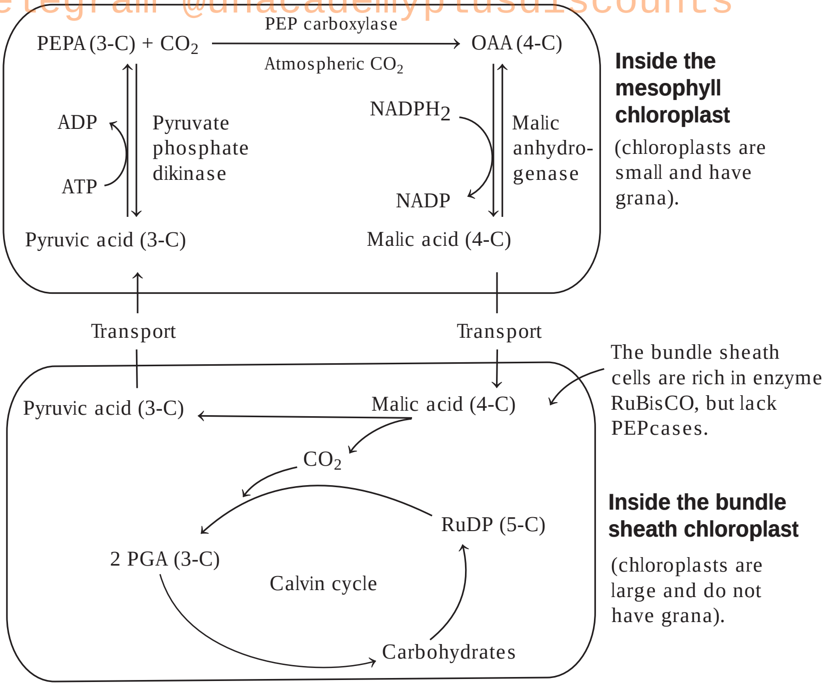
This cycle is present in those plants, which are adapted for hotter climatic regions. Plants also possess a specific anatomy called **Kranz anatomy** to fulfil the structural demand for C_4 pathway.



Kranz Anatomy : Part of C_4-plant leaf showing mesophyll and bundle sheath cells

These plants have Oxaloacetic Acid (OAA) as their first CO_2 fixation product. Through processes like fixation, decarboxylation and regeneration, the carbohydrate is synthesised in bundle sheath cells of leaf.

The schematic representation of C_4 cycle is as follows



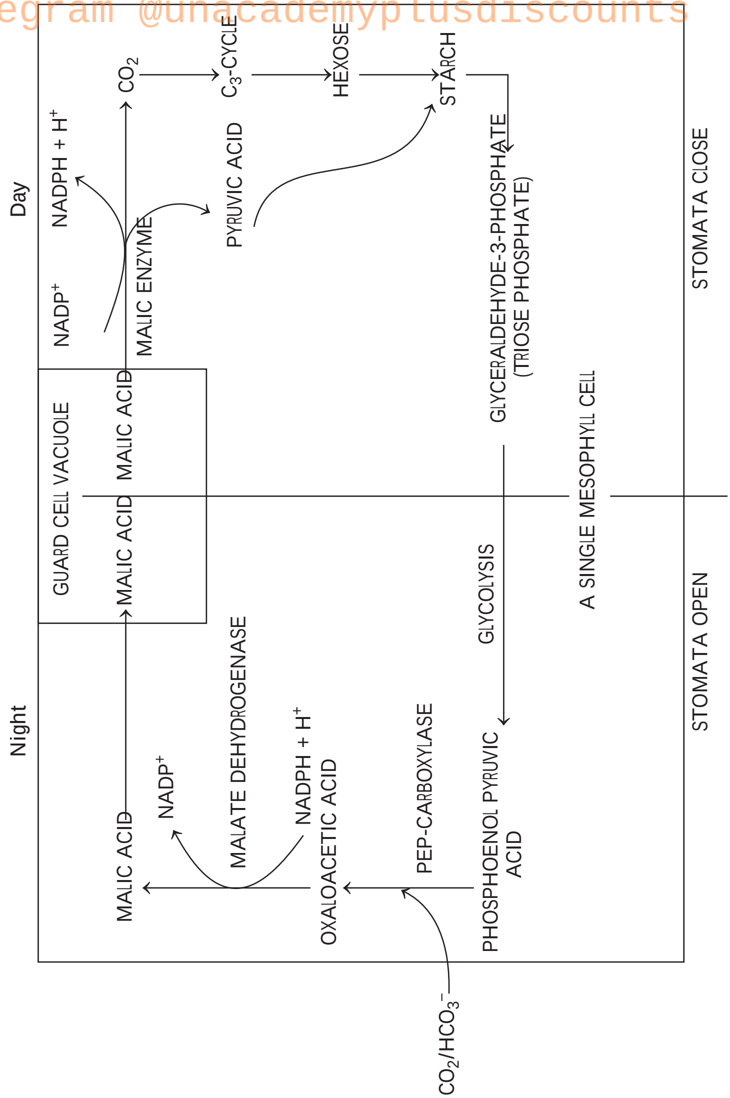
Schematic representation of Hatch and Slack pathway

(iii) **CAM** (Crassulacean Acid Metabolism) **Pathway**

This pathway is mostly present in the succulent xerophytes, such as the members of Crassulaceae, Euphorbiaceae, etc.

In this process, during night time, the stomata are open and **CO_2 enters through them, which is accepted by OAA** and converted into malic acid.

The schematic representation of CAM pathway is as follows



Schematic representation of the CAM pathway

During daytime, the malic acid produces both pyruvic acid and CO_2 after **decarboxylation**. The pyruvic acid enters into glycolysis, while CO_2 enters into Calvin cycle.

Photorespiration (C_2 Cycle)

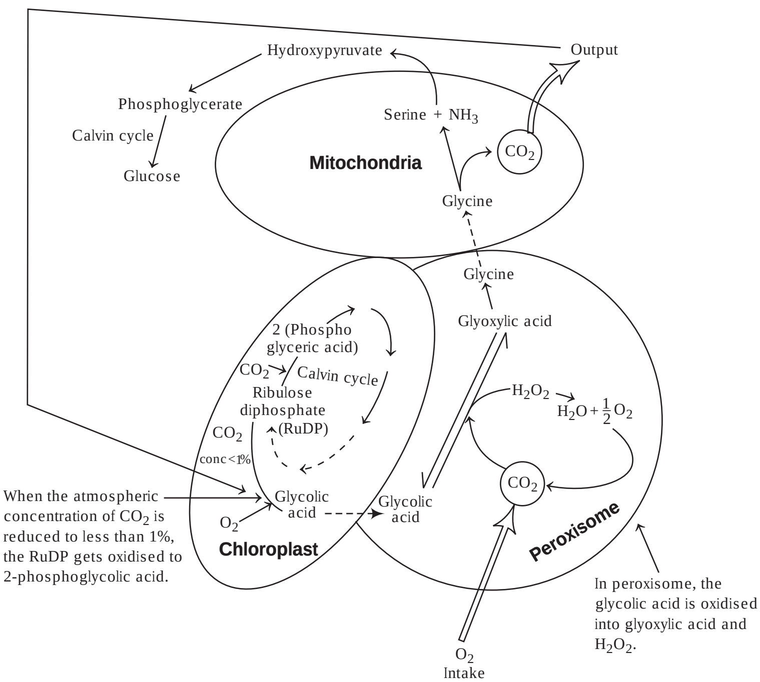
It was discovered by **Dicker** and **Tio** (1959) in tobacco plants.

The **chloroplast**, **peroxisome** and **mitochondria** are required to complete this reaction.

The CO_2 in the form of output reaches to the chloroplast and runs the Calvin cycle smoothly.

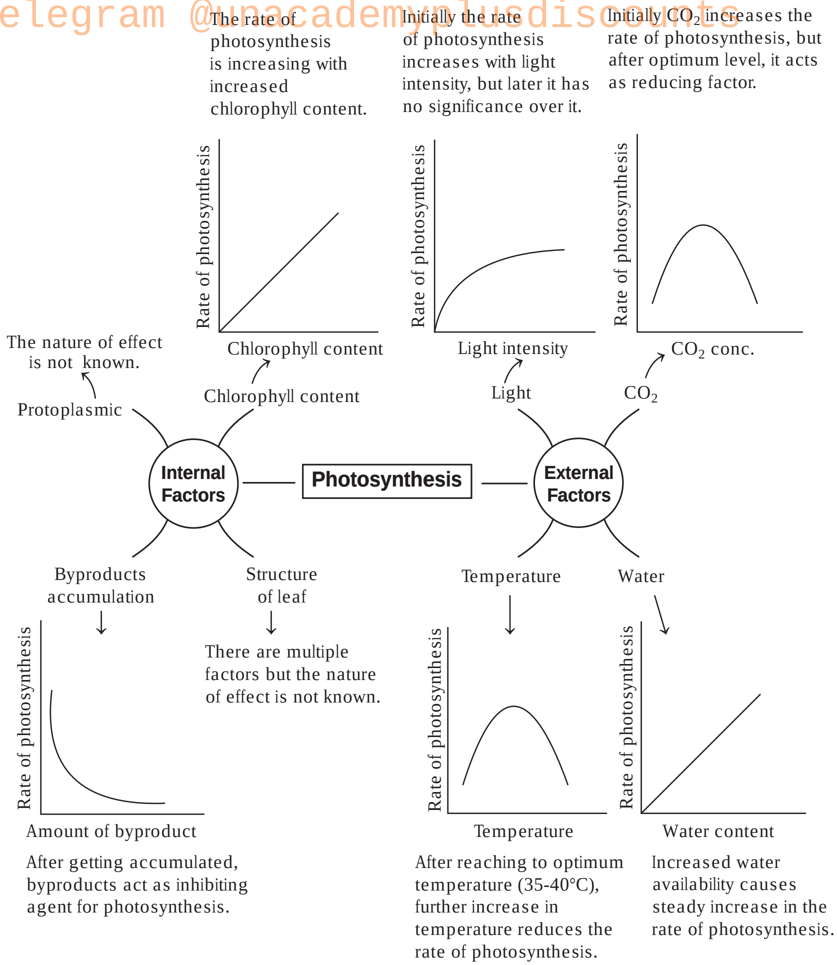
This reaction is also termed as **glycolate metabolism**.

The schematic representation of photorespiration is as follows



Diagrammatic representation of various steps of photorespiration

Factors Affecting Photosynthesis



Law of Limiting Factors (Blackman; 1905)

If a chemical process is affected by more than one factors, then its rate will be determined by the factor which is nearest to its minimal value. It is the factor which directly affects the process.

14

Respiration in Plants

Respiration is the most important, cellular, enzymatically controlled, catabolic process which involves the liberation of energy by oxidative breakdown of food substances inside the living cells. The term respiration was coined by Dutrochet.

It has two phases, **i.e., first phase** involves gaseous exchange between environment and organism through body surface or special respiratory organs and **second phase** is cellular respiration.

Cellular Respiration

In this process, the oxidation of organic food takes place inside living cell for the liberation of energy. On the basis of requirement of oxygen, **this may be categorised as**

Cellular Respiration

Aerobic Respiration

Organic food is completely oxidised with the help of oxygen. It takes place in mitochondria and the products are **CO_2 and water**.

(~ 673 kcal/mol, energy released)

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Enzymes}} 6CO_2 + 6H_2O + 686 \text{ kcal}/2810 \text{ kJ}$$

Anaerobic Respiration

Organic food is broken down incompletely to release energy in the absence of oxygen. The products are **CO_2, ethyl alcohol and lactic acid**.

(~ 21 kcal/mol, energy released)

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} 2CO_2 + \underset{\text{(ethyl alcohol)}}{2C_2H_5OH} + 59 \text{ kcal}/247 \text{ kJ}$$

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} \underset{\text{(lactic acid)}}{2C_3H_6O_3} + 36 \text{ kcal}/150 \text{ kJ}$$

Respiratory Substrate

The substrates which are used as fuel in respiration are called **respiratory substrates**. The main respiratory substrates are carbohydrates and fat, but proteins can also be used in special circumstances. The most common respiratory substrate is **glucose**.

On the basis of respiratory substrate**, respiration is of two types**

(i) **Floating respiration** Carbohydrate and fat are used as respiratory substrate.

(ii) **Protoplasmic respiration** Protein is used as respiratory substrate.

Respiratory Quotient

It is the ratio of volume of CO_2 released to the volume of oxygen absorbed. The value can be zero, one, less than one or more than one.

RQ can be calculated as

$$RQ = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ absorbed}}$$

RQ = 0, in succulents

RQ > 1, in anaerobic respiration

RQ = 1, Carbohydrates

RQ = 0.9, Proteins

RQ = 0.7, Fats

Aerobic Respiration

It is stepwise catabolic process of complete oxidation of organic food into CO_2 and water with oxygen acting as a terminal oxidant.

It is completed in two pathways—**Common pathway** and **Pentose Phosphate Pathway** (PPP).

Aerobic respiration consists of three steps

1. Glycolysis
2. Krebs' cycle
3. Electron transport chain and terminal oxidation.

1. **Glycolysis** (Gk. Glycos – sugar; lysis – dissolution)

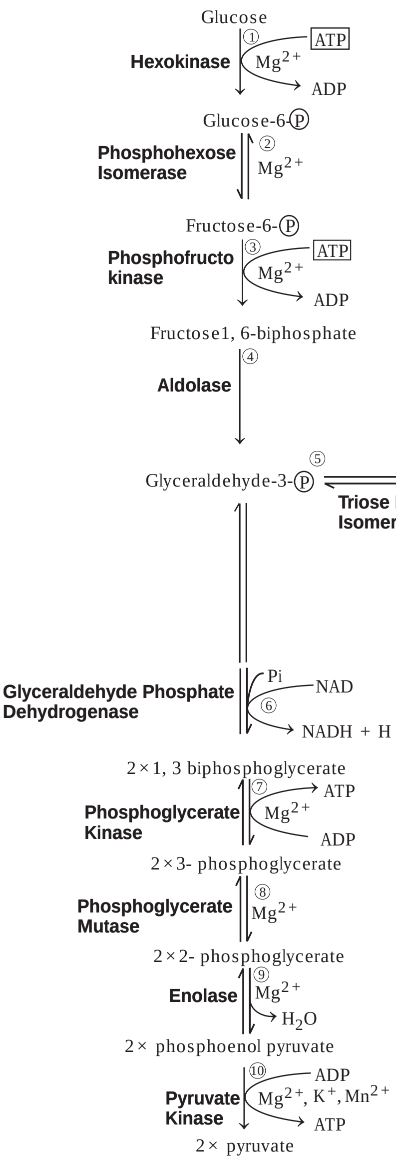
Glycolysis was discovered by three German scientists **Embden, Meyerhof** and **Paranas**, so also called as **EMP Pathway**. Glycolysis occurs in **cytoplasm**.

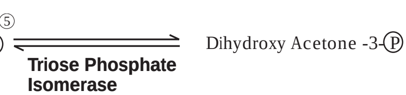
Glycolysis is a major pathway for ATP synthesis in tissues lacking mitochondria, **e.g.**, erythrocytes, cornea, lens, etc.

Net reaction of Glycolysis

$$\text{Glucose} + 2NAD^+ + 2ADP + 2H_3PO_4 \longrightarrow 2\ \text{Pyruvate} + 2NaOH + 2H^+ + 2ATP$$

Schematic Representation of EMP Pathway





1. It is an irreversible reaction in which terminal phosphate of ATP is transferred to an acceptor nucleophile. Hexokinase is present in all cells of organisms. In liver cells it is called as **glucokinase**. It is the **first priming reaction**.

2. This is a reversible reaction which can proceed in either directions by small change in standard free energy.

3. It is the **second priming reaction** of glycolysis and first 'committed' step. Some bacteria and protists have a phosphofructokinase that use Pi not ATP as the **phosphoryl group donor**.

4. This reaction is an example of **reversible aldol condensation**. Zn^{2+} is the cofactor which cleaves the fructose 1, 6 biphosphate into two 3-carbon units.

5. As only glyceraldehyde-3-(P) can proceed in further reactions of glycolysis, the dihydroxy acetone phosphate is converted reversibly into glyceraldehyde-3-(P). It is the last reaction of preparatory phase.

6. The **first step of payoff phase** that eventually leads to the formation of ATP. This reaction is irreversibly inhibited by Mg^{2+}.

7. It is an **exergonic reaction** which is in combination with step-(6) and constitutes an energy coupling process. It is an example of **substrate level phosphorylation**.

8. In this reaction the enzyme, phosphoglycerate mutase catalyses a reversible shift of phosphoryl group between C_2 and C_3.

9. The enzyme enolase promotes reversible removal of H_2O molecule from 2 phosphoglycerate to produce phosphoenol pyruvate.

10. In this **substrate level phosphorylation**, the product first appears in its enol form that rapidly and non-enzymatically changes to its keto form at pH 7.

Net Result of Glycolysis

- Two molecules of pyruvic acid
- Two molecules of ATP
- Two molecules of $NADH_2$
- Two molecules of H_2O

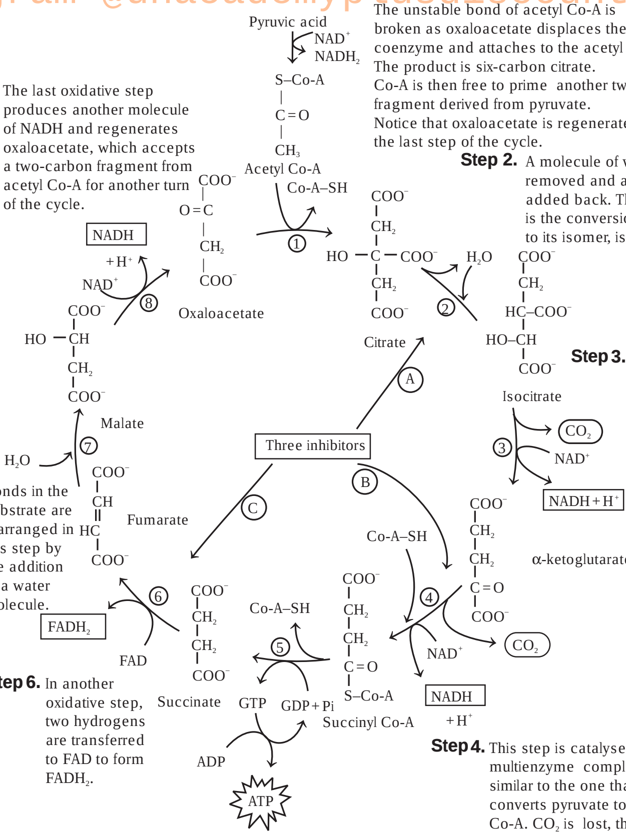
ATP released	4 ATP	
From 2 $NADH_2$	6 ATP	
Total released	10 ATP	
Total ATPs consume	2 ATP	
	8 ATP	Net yield of glycolysis

2. Krebs' Cycle or Tricarboxylic Acid Cycle

- It is also known as **citric acid cycle** because citric acid (tricarboxylic acid) is the first product of this cycle.
- In eukaryotic organisms, all the reactions of Krebs' cycle takes place in matrix of mitochondria because enzymes of this cycle are present in matrix except succinic dehydrogenase (situated in inner membrane of mitochondria).
- In prokaryotes, the Krebs' cycle occurs in cytoplasm. It is basically a **catabolic reaction**, as it oxidises acetyl Co-A and organic acid into CO_2 and H_2O.
- It acts as an **amphibolic pathway** because it serves in both catabolic and anabolic processes. It is a series of 8 reactions which occur in **aerobic environment**.
- The overall reaction of aerobic degradation of pyruvic acid is as follows (This includes oxidative decarboxylation and TCA)

$$\text{Pyruvic Acid} + 4NAD^+ + FAD + 2H_2O + ADP + Pi \longrightarrow$$
$$3CO_2 + 4NADH + 4H^+ + FADH_2 + ATP$$

The scheme of reactions with their detail are explained as follows



Step 1. Acetyl Co-A adds its two-carbon fragments to oxaloacetate, a four-carbon compound. The unstable bond of acetyl Co-A is broken as oxaloacetate displaces the coenzyme and attaches to the acetyl group. The product is six-carbon citrate. Co-A is then free to prime another two-carbon fragment derived from pyruvate. Notice that oxaloacetate is regenerated by the last step of the cycle.

Step 2. A molecule of water is removed and another is added back. The net result is the conversion of citrate to its isomer, isocitrate.

Step 3. The substrate loses a CO_2 molecule and the remaining five-carbon compound is oxidised, reducing NAD^+ to NADH.

Step 4. This step is catalysed by a multienzyme complex very similar to the one that converts pyruvate to acetyl Co-A. CO_2 is lost, the remaining four-carbon compound is oxidised by the transfer of electrons to NAD^+ to form NADH and is then attached to coenzyme–A by an unstable bond.

Step 5. Substrate level phosphorylation occurs in this step. Co-A is displaced by a phosphate group, which is then transferred to GDP to form Guanosine Triphosphate (GTP). GTP is similar to ATP, which is formed when GTP donates a phosphate group to ADP.

Step 6. In another oxidative step, two hydrogens are transferred to FAD to form $FADH_2$.

Step 7. Bonds in the substrate are rearranged in this step by the addition of a water molecule.

Step 8. The last oxidative step produces another molecule of NADH and regenerates oxaloacetate, which accepts a two-carbon fragment from acetyl Co-A for another turn of the cycle.

The Krebs' cycle

The enzymes involved in these reactions are

1. Citrate synthase
2. Aconitase
3. Isocitrate dehydrogenase
4. α-ketoglutarate dehydrogenase
5. Sunccinyl Co-A synthetase
6. Succinate dehydrogenase
7. Fumerase
8. Malate dehydrogenase

Three inhibitors are

A. Fluoroacetate
B. Arsenic dehydrogenase
C. Malonate

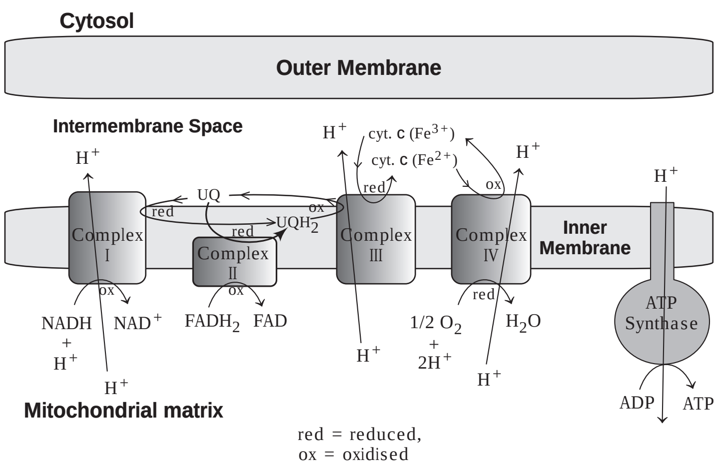
Output of Krebs' Cycle

One molecule of pyruvic acid after entering into mitochondria undergoes **three decarboxylations** and **five oxidations**. One molecule of pyruvic acid through Krebs' cycle yields an equivalent of 15 ATP molecules.

3. Electron Transport Chain (ETC)

Electron Transport Chain (ETC) or Respiratory Chain (RC) is present in the inner membrane of mitochondria. When the electrons pass from one carrier to another in electron transport chain, they are coupled to ATP synthase for the production of ATP from ADP and inorganic phosphate.

A diagrammatic representation of electron flow **via** various electron carrier complexes is shown in figure.



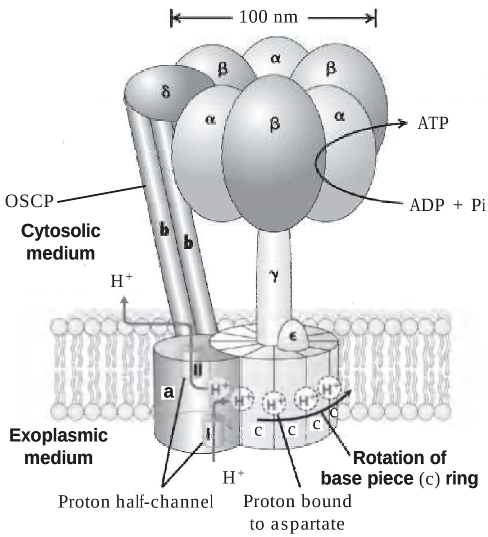
Electron transport chain in plants

The enzymes of inner membrane appear to exist as components of these five complexes. The first four members among these complexes constitute the electron transport system, while the 5th complex is connected with oxidative phosphorylation, **i.e.,** conservation and transfer of energy with ATP synthesis. **These complexes are**

(i) Complex I — NADH/NADPH : CoQ reductase
(ii) Complex II — Succinate : CoQ reductase
(iii) Complex III — Reduced CoQ ($CoQH_2$) Cytochrome-**c** reductase
(iv) Complex IV — Cytochrome-**c** oxidase
(v) Complex V — ATP synthase

The complex V is ATP synthase complex which has a head piece, stalk and a base piece. Out of these, the head piece is identified as the coupling factor 1 (F_1) by **Racker** (1965). It contains 5 subunits namely — α (MW 53000), β (MW 50000), γ (MW 33000), δ (MW 17000) and ε (MW 7000). In addition to these, an ATPase inhibitor protein is also seen in this portion.

The stalk portion contains OSCP **(i.e.,** Oligomyosin Sensitivity Conferring Protein) and is necessary for binding F_1 to the inner mitochondrial membrane. The base piece is isolated as F_0 and present within the inner mitochondrial membrane. It provides the proton channel. **Thus, the complete complex looks like**



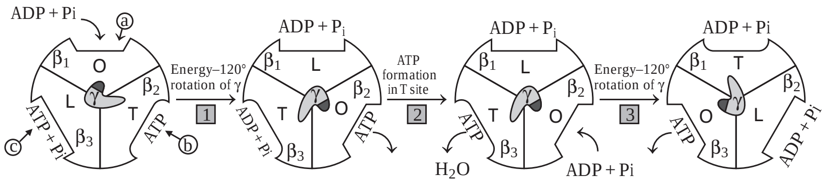
F_0 – F_1 complex (γ, ε and c constitute the rotatory part)

Oxidation phosphorylation was discovered in 1939. There are three hypotheses regarding the mechanism of oxidative phosphorylation. **These are**

- The chemical coupling hypothesis
- The chemiosmotic hypothesis
- The conformational hypothesis

The most accepted mechanism among these hypotheses is the **conformational hypothesis**.

According to conformational coupling hypothesis, the membrane of cristae is found to assume different forms during functional states of mitochondrion as shown in the following figures



The binding change mechanism of ATP synthesis from ADP and Pi is carried out by the F_0-F_1 complex.

The β subunits of head piece are designated as β_1, β_2 and β_3 as shown. **Look at the middle γ subunit structure which shows different appearance in three different β subunits as**

(i) **Darker pointed portion indicating open conformation** (O) of β-subunit with suppressed margins so that, ADP and Pi can attach easily.

(ii) **Lighter pointed portion indicating tight conformation** (T) with elevated tight margins helpful in converting ADP + Pi to ATP.

(iii) **Lighter rounded portions indicating low conformation** (L) is intermediate of above two conformations, binds ADP and Pi loosely.

The movement of γ subunit is possible only with the help of energy. See the conformational changes step by step with ATP formation. The energy provided for γ subunit movement is through proton translocation as shown in first diagram.

A formation of 3 ATP molecules occurs for every 360° rotation of γ.

The conformational hypothesis does not affect the central theme of Mitchell's chemiosmotic hypothesis. **Mitchell** (1976) himself considered the involvement of conformational changes in chemiosmotic coupling. Infact Mitchell's hypothesis becomes more convinced when coupled with conformational processes.

Oxidative Phosphorylation

The aerobic respiration is ended with the oxidation of 10 molecules of NADH + H^+ and 2 molecules of $FADH_2$ generated from a molecule of glucose. In this, the oxygen from atmosphere is used for the oxidation of reduced coenzyme and it is called as **terminal oxidation**. The production of ATP with the help of energy liberated during oxidation of reduced coenzyme and terminal oxidation is called **oxidative phosphorylation**.

Summary of Aerobic Respiration

1. Glycolysis produces 2ATP molecules and 2 NADH $+2H^+$.
2. Pyruvate oxidation yields 2 NADH + $2H^+$.
3. Krebs' cycle produces 2GTP molecules, 6 NADH + $6H^+$ and $2FADH_2$.
4. Electron transport system
   - (i) 2 NADH $+ 2H^+$ molecules from glycolysis yield 4 ATP molecules **via** route-2 of ETC (glycerol-phosphate shuttle) or six ATP molecules **via** route-1 (malate-aspartate shuttle).
   - (ii) 2 NADH $+ 2H^+$ molecules from pyruvate oxidation yield 6ATP molecules **via** route-1 of ETC.
   - (iii) 6 NADH $+ 6H^+$ molecules from TCA (Krebs' cycle) yield 18 ATP molecules **via** route-1 of ETC.
   - (iv) 2 $FADH_2$ molecules from TCA cycle yield 4 ATP molecules **via** route-2 of ETC (Electron Transport Chain).

Hence, ETS alone produces 32 or 34 ATP molecules.

$$\underset{\text{(Glycolysis)}}{2ATP} + \underset{\text{(TCA cycle)}}{2GTP} + \underset{\text{(ETS/ ETC)}}{32/34\,ATP} \rightarrow 38/36\,ATP$$

34 or 36 ATP + 2 GTP molecules are produced from one glucose molecule.

A cytoplasmic enzyme **nucleoside diphosphate kinase** readily converts the GTP formed in TCA cycle to ATP.

In prokaryotic cells, oxidation of glucose molecule always yields 38 ATP molecules as NADH $+H^+$ molecules are not to enter mitochondria, which are absent here.

Overall Result of Aerobic Respiration

Complete oxidation of one molecule of glucose results into the following products

- Release of 6 carbon dioxide molecules.
- Utilisation of 6 oxygen molecules.
- Formation of 12 H_2O molecules.

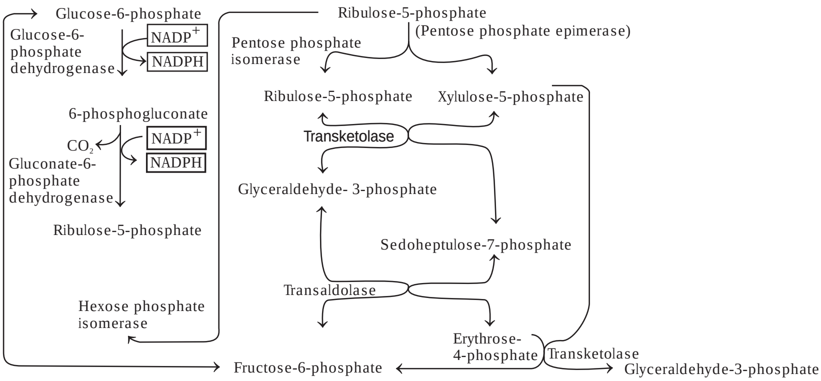
So, overall process of aerobic respiration may be shown by the following equation

$$C_6H_{12}O_6 + 6O_2 + 10H_2O \longrightarrow 6CO_2 + 16H_2O + 686 \text{ kcal energy.}$$

Pentose Phosphate Pathway (PPP)

This pathway is a major source for the NADPH required for anabolic processes. There are three distinict phases – **Oxidation**, **isomerisation** and **rearrangement**. Gluconeogenesis is directly connected to the PPP.

Pentose phosphate pathway (Warburg-Lipman-Dickens cycle) is an alternate method of aerobic respiration, which occurs in the cytoplasm of mature plant cells. This pathway accounts for 60% total respiration in liver cells. In this, for every six molecules of glucose, one molecule is completely oxidised in CO_2 and reduced coenzymes, while five molecules are regenerated.



Reactions of the oxidative pentose phosphate pathway in higher plants

The Pentose Phosphate Pathway (PPP) is an alternate path to generate ATP beside glycolysis and Krebs' cycle.

Anaerobic Cellular Respiration

This type of respiration has fermentation as its main process.

Fermentation

It is the general term for such processes which extract energy (as ATP), but do not consume oxygen or change the concentration of NAD^+ or NADH. It is similar to anaerobic respiration.

Generally, the fermentation is of four types

Fermentation

Alcoholic Fermentation
It is common in yeast in which breakdown of the substrate takes place outside the cell. The end products are ethyl alcohol, CO_2 and energy.

Butyric Acid Fermentation
This pathway is common in Clostridium butyricum. This type of fermentation normally occurs in rotten butter due to which it gives fowl smell.

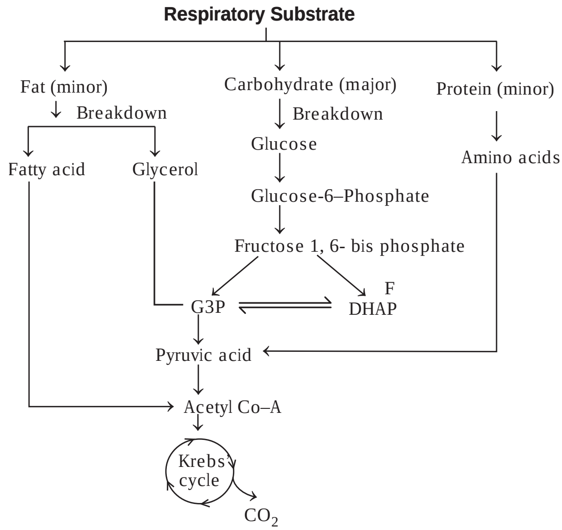
Lactic Acid Fermentation
It is common in lactic acid bacteria. Enzyme involved in fermentation is lactic acid dehydrogenase. Here only lactic acid, NAD and energy are produced.

Acetic Acid Fermentation
This pathway is common in acetic acid bacteria. The oxygen is used in this fermentation process. The end products are ethyl alcohol and acetic acid.

Krebs' Cycle (RESPIRATION)as Amphibolic Pathway

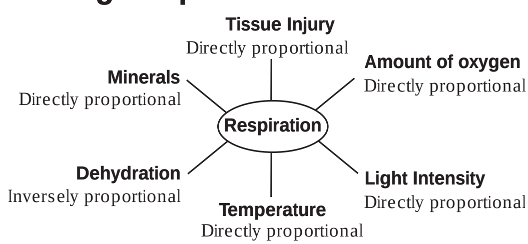
This pathway involves both breakdown (catabolism) and formation (anabolism) of biomolecules. Krebs' cycle is amphibolic in nature, as its intermediates are used in other anabolic processes.

A general representation of amphibolic pathway is as follows



Amphibolic pathway of respiration

Factors Affecting Respiration



Conclusively, respiration is a vital phenomenon in almost all living organisms, involved in breakdown of different substances, **i.e.,** respiratory substrates. In all of the organisms, it is involved in both catabolism and anabolism. Respiration and its strategies are also the determining factor for several physical, physiological and geographical adaptations in animal and plant varieties.

15

Plant Growth and Development

Every living organism shows growth, which can either be in size or in number. Hence, we can say that the growth is a characteristic feature of all living forms of life.

Growth

It can be defined as 'an irreversible permanent increase in size of an organ or its part or even a cell'. It is accomplished by metabolic processes that utilise energy obtained by nutrition. The **development** is actually the sum of two processes, **i.e.,** growth and differentiation.

During growth, anabolic processes exceed catabolic processes or growth is final end product of successful metabolism. Characteristically, the **growth is intrinsic in living beings**.

Types of Growth

The growth in an organism can be divided on the basis of various criteria. **These growths can be understood through following flow chart**

Growth in Plants

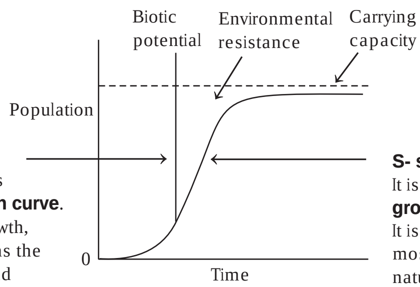
On the basis of sequence of growth
- **Primary growth** The division is at the root and shoot apex.
- **Secondary growth** The growth is in diameter because of cambium.

On the basis of continuity of growth
- **Unlimited growth** The growth of root and stem in length in plants.
- **Limited growth** The growth of leaves, fruit and flower after obtaining certain size.

On the basis of growing plant organ (morphogenesis)
- **Vegetative growth** The growth of vegetative parts like leaves, stem and roots.
- **Reproductive growth** The growth of flower, fruits and other reproductive parts of plants.

Types of Growth Curves

By plotting the size or weight of an organism against time, the growth curve can be obtained. On the basis of their shapes, these curves can be — **J-shaped curve** and **S-shaped curve**. Through these curves, the pattern of growth in an organism can be traced out.

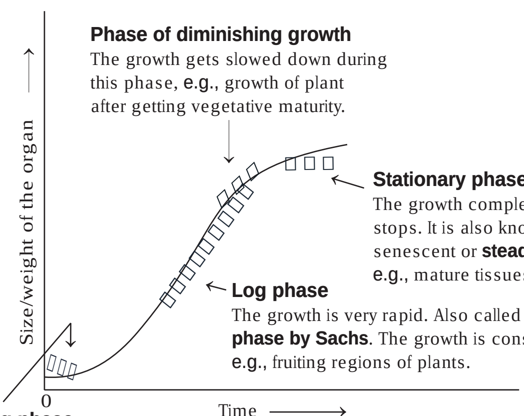


J- shaped curve
It is also known as **geometric growth curve**. In this type of growth, the progeny retains the ability to divide and continues to do so. Mostly shown by unicellular organisms algae and insects.

S- shaped curve
It is also known as **sigmoid growth curve**. It is a typical growth curve of most living organisms in their natural habitat. This is divided into four phases–lag phase, log phase, phase of diminishing growth and stationary phase. It is shown by higher plants and animals.

Phases of Growth

The sigmoidal growth curve can be categorised into four distinct phases. **These growth phases and their details are discussed in the following figure**



Phase of diminishing growth
The growth gets slowed down during this phase, e.g., growth of plant after getting vegetative maturity.

Stationary phase
The growth completely stops. It is also known as senescent or **steady phase**, e.g., mature tissues.

Log phase
The growth is very rapid. Also called as **grand phase by Sachs**. The growth is constant, e.g., fruiting regions of plants.

Lag phase
The growth is slow. The growth is continuously increasing, e.g., the growth of root apex and shoot apex region.

Measurement of Growth

(i) The growth can be measured by horizontal microscope and an instrument called **auxanometer**

(ii) **Bose** developed an instrument called **crescograph** for measuring growth. It magnifies growth up to 10000 times.

(iii) Growth can also be measured by calculating increase in cell number, weight, volume and diameter.

Growth Rate

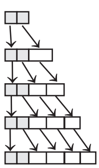
'The increase in growth per unit time is called as growth rate.'

With the passage of growth phases of an organism, the growth rates show increase or decrease, which may be **arithmetic** or **geometric**. **The increasing pattern of growth rates can be understood through following description.**

Growth

Arithmatic Growth

In such growth pattern, after mitotic cell division only one cell continues to divide, while the other differentiate and mature, e.g., constantly elongating root.



It can be represented mathematically as

$L_t = L_0 + rt$

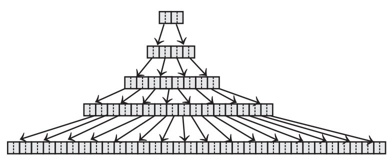
L_t = Length at time 't'

L_0 = Length at time 'zero'

r = Growth rate

Geometric Growth

Here both the progeny cells resulted after mitosis, continue to divide. However, with limited nutrient supply the growth slows down and becomes stationary.



It can be represented mathematically as

$W_1 = W_0 e^{rt}$

W_1 = Final size (weight, height, number)

W_0 = Initial size

r = Growth rate

t = Time of growth

e = Base of natural logarithms.

Here, **r** is the **relative growth rate** and also the measure of the ability of plant to produce new plant material, often referred to as **efficiency index**.

The quantitative comparisons between the growth of living systems can be made by

(i) **Absolute growth rate** which is the measurement of total growth per unit time.

(ii) **Relative growth rate** which is the growth per unit time per unit initial parameter.

Differentiation, Dedifferentiation and Redifferentiation

The three phases of cellular growth are **cell division, cell enlargement** and **cell differentiation**, which bring maturity to the cells.

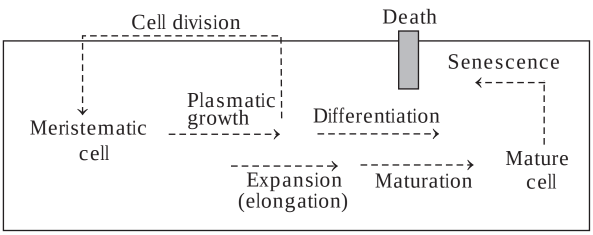
(i) **Differentiation** It is the permanent qualitative change in structure, chemistry and physiology of cell wall and protoplasm of cells, tissues and their organs. It is the result of repression of genes, **e.g.,** to form a tracheary element, the cells would lose their protoplasm.

(ii) **Dedifferentiation** It is the process of despecialisation of differentiated cells so that they regain the capacity to divide and form new cells, **e.g.,** formation of interfascicular cambium from parenchymatous cell during secondary growth.

(iii) **Redifferentiation** It is the structural, chemical and physiological specialisation of cells derived from dedifferentiated meristematic cells, **e.g.,** secondary phloem, secondary cortex, etc.

Development

The sequence of events from seed germination to senescence of a plant is called **development**.



Sequence of the developmental process in a plant cell

Every organism has capacity to adapt to its environment by making some changes among themselves in response to prevalent environmental conditions. The capacity to change under the influence of environmental conditions is called **plasticity**.

Plant Hormones/Phytohormones/ Plant Growth Regulators (PGRs)

A plant hormone is an organic compound synthesised in one part of a plant and translocated to another part, where its low concentration causes a physiological response.

Plant hormones can be broadly divided into two groups based on their functions in a living plant body. One group is involved in **growth promoting activities**, **e.g.,** auxin, gibberellins and cytokinin. The other group is involved in **growth inhibiting activities**, **e.g.,** abscisic acid, ethylene, etc.

1. Auxins

The term 'Auxin' (Gk. **auxein** –to increase) was first used by **Frits Went**. These hormones are found in meristematic regions of plant, **e.g.,** in coleoptile tips, in buds, etc.

Chemically the auxin is Indole 3-Acetic Acid (IAA). **Kogl** and **Haagen-Smit** (1931) isolated the active compound of molecular weight 328 from human urine, which was called as **auxin-A** (Auxanotriolic acid).

Auxins

Naturally Occurring
- Indole Acetic Acid (IAA)
- Phenyl Acetic Acid (PAA)
- Indole Butyric Acid (IBA)
- Indole acetaldehyde
- Indoleacetonitrile
- Indole ethanol

Synthetic Auxins
- Naphthalene Acetic Acid (NAA)
- 2, 4 - Dichlorophenoxyacetic acid
- 2, 4, 5 - Trichlorophenoxy
- MCPA
- IPAC

The natural auxin in plant is synthesised by the amino acid **tryptophan**.

Auxins are applied in very low concentration for good results. Higher concentration inhibits growth and exerts toxic effects in plants.

2. Gibberellins

These growth regulators were discovered from a fungus called **Gibberella fujikuroi** that causes foolish seedling disease of rice.

The first pure Gibberellic Acid (GA) was isolated by **Cross** (1954) and **Borrow** et al. (1955) in Britain.

The GAs are diterpenoid acids derived from the tetracyclic diterpenoid hydrocarbon, **ent-Kaur 16-ene** having 20-carbon atoms.

3. Cytokinins

Miller et al. (1954) isolated the third growth substance from autoclaved herring sperm DNA. Because of its cell division activity on tobacco pith callus, it was called as **kinetin**.

Chemically, it is a derivative of adenine with a furfuryl group at C-6 and is called as 6-furfurylaminopurine.

The kinetin is formed from deoxyadenosine, a degradation product of DNA.

4. Abscisic Acid

It is the most recently discovered plant hormone. **Okhuma** et al. (1965) first isolated it from young cotton fruits. Abscisic acid is sesquiterpene. It inhibits the action of **auxin**, **gibberellins** and **cytokinin**, hence it is also known as a growth inhibitor.

5. Ethylene

It is a ripening hormone and is produced in traces in the form of gas by almost all tissues. The secretion of ethylene can be detected by gas chromatography.

These are synthesised by amino acid methionine as

$$\text{Methionine} \xrightarrow[\text{deamination}]{\text{Oxidative}} \text{Methionol} \rightarrow \text{Ethylene}$$

The plant hormones, their functions and location in plants are given in the following table

Plant Hormones, their Functions and Location

Hormone	Major Function	Location in Plant
Auxin (IAA)	Promotion of stem elongation and growth; formation of adventitious roots; inhibition of leaf abscission; promotion of cell division (with cytokinins); inducement of ethylene production; promotion of lateral bud dormancy (apical dominance).	Apical meristems; other immature parts of plants.
Cytokinins	Stimulation of cell division; but only in the presence of auxin, promotion of chloroplast development; delay of leaf ageing; promotion of bud formation.	Root apical meristems; immature fruits.
Gibberellins	Promotion of stem elongation (bolting in cabbage), stimulate enzyme production in germinating seeds.	Roots and shoot tips; young leaves; seeds.
Ethylene	Promotion of fruit ripening, control of leaf, flower and fruit abscission.	Roots, shoot apical meristems; leaf nodes; ageing, flower, ripening fruits.

Hormone	Major Function	Location in Plant
Abscisic acid	Inhibition of bud growth; control of stomatal closure; some control of seed dormancy; inhibition of effects of other hormones.	Leaves, fruits, root caps, seeds.
Brassinosteroids	Overlapping function with auxins and gibberellins.	Pollen, immature seeds, shoot, leaves.
Oligosaccharides	Pathogen defence, possibly reproductive development.	Cell walls

Other plant hormones are

Florigen – Flowering hormone
Vernalin – Vernalisation hormone
Anthesins – Flowering hormone
Calines – Formative hormone
Traumatic acid – Wound healing hormone

Applications of Phytohormones

(i) **Stem elongation** It is induced by auxin, cytokinin and gibberellins. The process is extensively used in horticulture and other vegetative growth. The increased plant height helps in the production of increased biomass wherever required.

The process of stem elongation is mainly accomplished by **apical dominance**, which helps in proper growth of plant. In the absence of apical dominance, the plants require physical support for growth and development.

(ii) **Delay of leaf ageing and promotion of chloroplast development** It is induced by cytokinin. It helps to **improve productivity** as the chloroplasts in leaf are the sites of food production.

(iii) **Formation of adventitious roots** This is performed by auxin. More adventitious roots help in **vegetative propagation** of several plants.

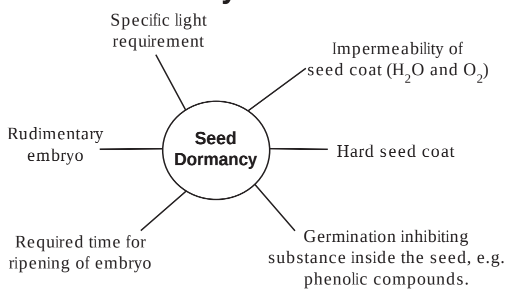
(iv) **Promotion of lateral buds development** It is induced by hormone cytokinin. Lateral bud development has significance in production of bushy plants, which can be equally used in **horticultural** and **ornamental plants**.

Seed Dormancy

The inhibition of seed germination of a normal or viable seed due to internal factors, even when it is placed under favourable conditions required for germination, is called **seed dormancy**.

The dormancy period for a seed may vary from days to years, **e.g.,** the seeds of mangroves lack dormancy period and in most cereal grains it is of several months long.

Causes of Seed Dormancy



Processes to Break Seed Dormancy

Following processes are employed to break seed dormancy

(i) **Scarification** Mechanical or chemical breakdown of seed coat.

(ii) **Stratification** Exposure of seed to well-aerated, moist condition.

(iii) **Alternating temperature** Treatment of seed with low or high temperature.

(iv) **Light** Exposure of suitable (red or far-red) light to seed.

(v) **Pressure** Exposure of high hydraulic pressure (~2000 atm) at low temperature.

(vi) **Growth regulator application** Kinetin and gibberellins are used to induce germination.

Biological Significance of Seed Dormancy

(i) It allows storage of seeds in viable state for longer duration.

(ii) It helps to retain seed viability in extreme conditions as well.

(iii) It helps in distant spreading of seeds.

(iv) It is useful in desert conditions for the postponement of seed germination.

Photoperiodism

Effect or requirement of relative length of day and night on flowering is called photoperiodism.

The phenomenon of photoperiodism was first discovered by Garner and Allard. Their experimental material was 'Maryland mamoth' a mutant variety of tobacco. They manipulated the photoperiod for these plants. Due to this change in flowering time was observed. Thus, they concluded that plants differ in their requirements for day length. Most plants flower only when they are subjected to a light phase for less or more than a critical period. A critical period is the period of light or darkness required by the plant to induce flowering.

Depending upon the duration of photoperiod, plants have been divided into following categories

1. **Short-day plants** (SDP) Photoperiod of these plants is lesser than the critical photoperiod. Thus, they require shorter photoperiod in order to initiate flowering, e.g. **Xanthium** (cocklebur), **Chrysanthemum, Cosmos, Dahlia**, rice, sugarcane, strawberry, tobacco, **Glycine max** (soyabean), etc.
2. **Long-day plants** (LDP) These require a light period more than the critical length. Thus, they require longer day light period for flowering. Long night period may prevents flowering in LDP. These are sometimes also called as short-night plants, e.g. **Hyoscyamus niger** (henbane), **Spinacia** (spinach), **Beta vulgaris** (sugarbeet), wheat, oat, raddish, lettuce, etc.
3. **Day neutral plants** (Indeterminate plants) These plants flower in all photoperiods. Thus, the floral initiation in them is independent of photoperiodism. These can blossom throughout the year, e.g. tomato, cotton, maize, sunflower, cucumber, etc.
4. **Long-short day plants** (L-SDP) These are short-day plants. These plants require long photoperiods for floral initiation and short photoperiod for blossoming, e.g. **Bryophyllum.**
5. **Short-long day plants** These are long-day plants. They require short days for floral initiation and long day for blossoming, e.g. certain varieties of wheat (**Triticum**) and rye (**Secale**).

Vernalisation

It is the promotion of flowering by low temperature treatment. Spraying gibberellins is a substitute to cold treatment and biennials can be made to flower in one year without the cold treatment.

Vernalisation stimulus is perceived by the apical meristem. This stimulus is believed to be a hormone called **vernalin**.

Conditions Necessary for Vernalisation

These are as follows

(i) Actively dividing cells
(ii) Low temperature
(iii) Aerobic condition
(iv) Water
(v) Proper nourishment

Mechanism of Vernalisation

G Melcher, studied vernalisation. He believed that stimulus of vernalisation is a hormone. This hypothetical hormone was named as "vernalin". The stimulus is received by the actively dividing cells of shoot or embryo tip. In the presence of vernalin induces a physiological change is induced in the plant which leads to flowering. It is believed that during vernalisation, gibberellins increases in amount.

Uses of Vernalisation

These are as follows

- Vernalisation shortens the vegetative period of plant. Thus, crops can be grown earlier.
- It increases yield of the plant.
- It increases resistance to cold and diseases.

Abscission of Plant Parts

Abscission can be selectively used to control the growth of some parts of plants. It can also help in timely harvesting of fruits and other products and to enhance productivity.

16 Digestion and Absorption

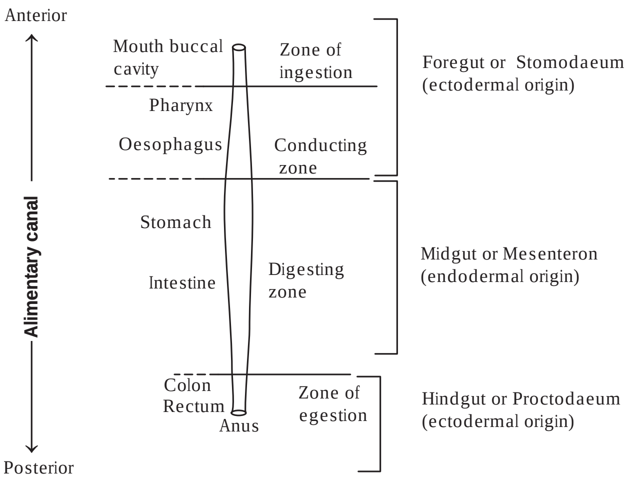
Human Digestive System

The organ system of human body responsible for breaking our complex food into simple food particles, so that, it can be utilised by our cells. In humans, it consists of two main parts, **i.e.,** alimentary canal and digestive glands.

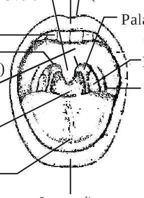
Alimentary Canal

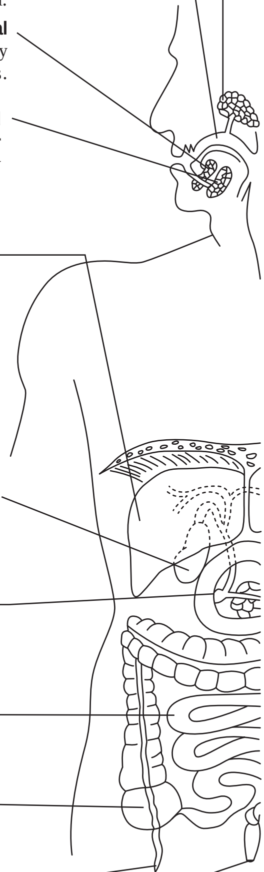
It is the first visceral organ to evolve. It is the tube responsible for the conversion of intracellular mode of digestion to extracellular mode. It is the tubular passage of mucous membrane and muscles extending about 8.3 m from mouth to anus.

The structural and functional classification of alimentary canal is as follows



Digestive System





Parotid Salivary Gland
Largest salivary gland, open near the upper second molar in the buccal cavity, zymogenic in nature, secrete serous fluid and enzyme salivary amylase or ptyalin. Their duct is called Stenson's duct.

Oral Cavity
It is the opening on the ventral side and guarded by two movable lips. It contains teeth, tongue and palate. Palate forms the roof and tongue forms its floor.

Sublingual
Smallest salivary glands, open at the floor of buccal cavity through ducts of Rivinus.

Sub Mandibular Salivary Gland
Medium-sized glands, open in buccal cavity near the lower central incisors through Wharton's duct. They secrete mucus and some enzymes, also called submaxillary glands.

Liver
Largest gland containing phagocytic Kupffer cells. Divided into two lobes covered by Glisson's capsule. Its cells, i.e., hepatocytes secetes bile, heparin, etc. Processess like glycogenesis, deamination, lymph and blood protein synthesis, etc., occurs in it.

Gall Bladder
Pear-shaped, sac-like structure, store bile, absent is rat and horse.

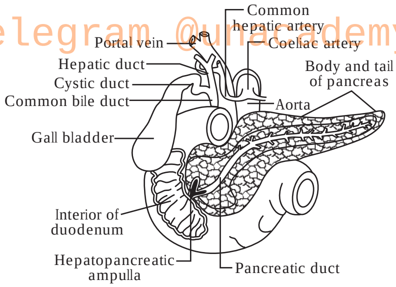
Hepatopancreatic Ampulla
It receives bile duct from the liver and main pancreatic duct from the pancreas. Also called ampulla of vater and open in duodenum.

Jejunum
Thick walled, vascular, middle part of small intestine. Its diameter is about 4cm.

Caecum
Pouch-like structure, walls contain prominent lymphoid tissue. It is normally intraperitoneal.

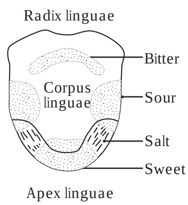
Appendix
Outgrowth of caecum, vestigeal part, slightly coiled blind tube.

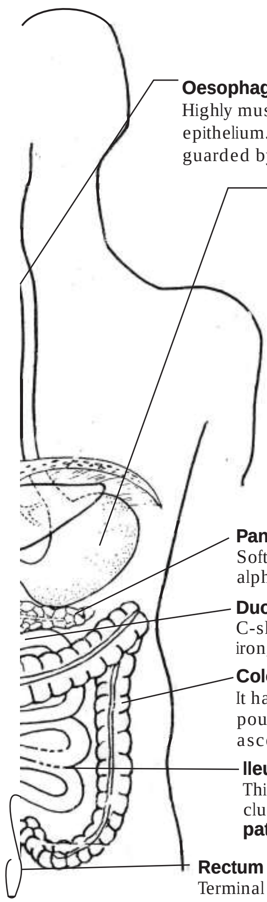
Anus
Opening to exterior.



Pancreas and Duodenum

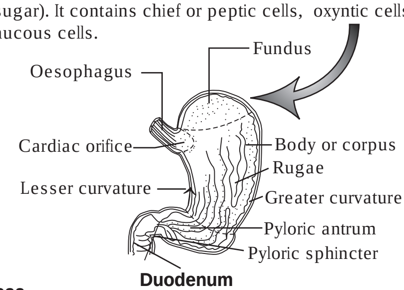
Tongue
Highly muscular structure containing voluntary muscles. Rests upon hyoid bone and attached to the floor of buccal cavity by a connective tissue fold called fernulum linguae. It possesses taste buds. It helps in tasting the food, process of speech, etc.





Oesophagus
Highly muscular, long, conducting tube lined by stratified squamous epithelium. Its opening is called gullet. Its upper and lower ends are guarded by sphincters.

Stomach
J-shaped dilated sac, consists of two curvatures, 4 parts and longitudinal folds formed of mucous membrane (sugar). It contains chief or peptic cells, oxyntic cells and mucous cells.



Pancreas
Soft, lobulated gland, both endocrine and exocrine, contains alpha, beta, delta cells and pancreatic polypeptide cells.

Duodenum
C-shaped structure containing foliate villi. It mainly absorbs iron, **Brunner's glands** are present in it.

Colon
It has 3 longitudinal bands called taeniae coli and small pouches called **haustra**. It is divided into 4 regions ascending, transverse, descending and sigmoid.

Ileum
Thin-walled, longest part of small intestine, contains clustered lymphatic nodules in groups called **Payer's patches** which produce lymphocytes.

Rectum
Terminal part of large intestine and digestive tract. Composed of two parts, i.e., pelvic part containing ampulla of rectum and perineal part containing anal canal.

Rest of the components of digestive system are discussed below

Zygomatic Glands

These are the fourth type of major salivary gland (rest 3 are parotid, submadibular and sublingual). These are also the compound racemose gland and pour their secretion into the mouth. These are not seen in humans and rabbit. These are present below the eyes in dogs and cats and hence called infraorbital glands.

Ebner's Glands

These are zymogenic or enzyme secreting accessory glands. These secrete minute quantities of salivary lipase. They are found in the mucous membrane of lips (labial), cheeks (buccal), tongue (lingual) and palates (palatine).

Mucus secreting minor or accessory glands are Unicellular goblet cells, **Nuhn's glands** and **Weber's glands**.

Tonsils

The lymphoid tissue of pharynx and oral cavity is seen as lymph nodes called tonsils. Within the pharynx, tonsils are arranged in the form of a ring Waldeyer's ring from top to bottom. **This ring consists of following tonsils**

(i) **Lingual tonsils** Irregular masses of lymphoid tissue near the basal part of the tongue.

(ii) **Palatine or faucial tonsils** These are present as two masses in the lateral walls of oropharynx.

(iii) **Tubal tonsils** These are present near the opening of eustachian tube as a collection of lymphoid tissue.

(iv) **Nasopharyngeal tonsils** These are present in the porterior wall of nasopharynx. These tonsils may get enlarged in children and cause an obstruction in normal breathing. This condition is called **adenoids**.

Circopharyngeal Sphincter

It is the upper sphincter of oesophagus, which prevents the air passing into the oesophagus during inspiration and expiration of oesophageal content.

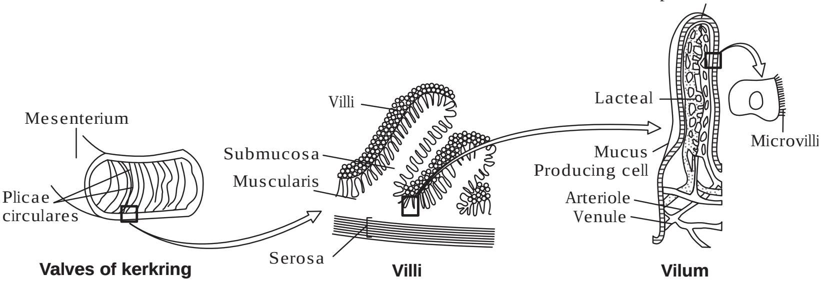
Cardiac Sphincter

It is the lower sphincter of oesophagus, which prevents the reflux of acidic contents of gastric juice into the oesophagus.

Valves of Kerkring

These are the circular folds of the mucous membrane present along the entire small intestine. These are more prominent in the jejunum and increase the absorptive surface area considerably. These are also called **plicae circulares**.

These contain villi over their exposed surface. A single villus on the other hand contains brush bordered cells or microvilli over it, thus increasing the absorptive surface area many folds.



Valves of kerking showing arrangement of villi and microvilli

Dentition

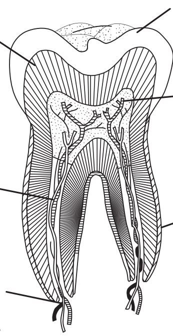
Dentition pertains to the development of teeth and their arrangement in the mouth. It accounts the characteristic arrangement, kind and number of teeth in a given species at a given age.

Depending upon the appearance of teeth, dentition is of two types

(a) **Homodont dentition** All the teeth in the jaw are alike, **e.g.,** alligator.

(b) **Heterodont dentition** Teeth differ in general appearance throughout the mouth, **e.g.,** human.

A tooth with its structure looks like



Internal structure of tooth

Few important terms related to teeth structure are given below

Peridontal Ligament

It is a layer of thick collagen fibres, which helps in the fixation of teeth within the sockets. These collagen fibres are called **Sharpey's fibres**.

Closed Pulp Cavities

This condition is seen in humans where apical foramen closes after the teeth is fully grown and no cell type is present in this region.

Open or Rootless Pulp

This condition can be seen in rabbit, rat, etc., where apical foramen of some teeth like incisors, contains a group of ameloblast cells. Such teeth grow throughout life, but their size remains constant.

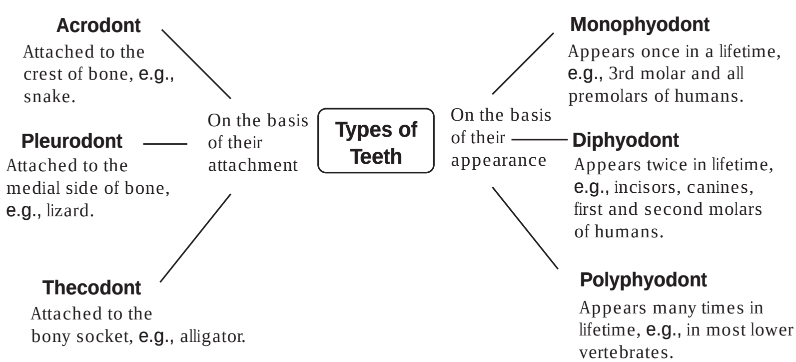
Different Classes of Teeth

On the basis of their persistance, teeth are of two types

(i) **Deciduous teeth** These are temporary or milk teeth which erupt in early stages of life. These have thinner layers of enamel and dentine. These do not possess premolars and number of molars present is two. These are 20 in number in humans and soon replaced by permanent teeth.

(ii) **Permanent teeth** These are stronger than milk teeth and persist for a longer period. They possess premolars and three molars.

However, on the basis of attachment and appearance the teeth may be



Teeth in Mammals

On the basis of their position in mouth

- **Anterior Teeth** Found anteriorly in the buccal cavity.
  - **Incisors** Used for cutting or clipping.
  - **Canines** Used for holding or tearing or puncturing.
- **Posterior Teeth** Found posteriorly in the buccal cavity. Also called cheek teeth.
  - **Premolars**
  - **Molars**

  Used for crushing or grinding food.

Molars

On the basis of length of crown and root, the molars can be of two types

(i) **Hypsodont** Teeth are long, crown with short roots, **e.g., horses.**

(ii) **Brachydont** Teeth are short, crown with deep roots, **e.g., humans.**

Cusps

Cheek or molariform teeth have specialised medial depressions over their crowns known as **cusps**.

According to the food and feeding habits, the cheek teeth are of various types depending upon the shape of cusps.

Types of molars on the basis of shape of cusp

- **Secodont** They have pointed cusp margins forming sharp cutting crowns, e.g., carnivorous animals.
- **Bunodont** They have small, separate and rounded cusp margins for grinding, e.g., man, pigs, monkeys.
- **Lophodont** They have multicuspid condition with cusp margins are irregularly drawn as ridges, e.g., horses, rhinoceros, elephant.
- **Selenodont** They have multicuspid condition with cusp margins arranged in the form of concentric rings to form ridges, e.g., cattles, camels, deer, etc.

Dental Formula

The number and kinds of teeth in mammals are represented by an equation called **dental formula**. Since, two halves of each jaw are identical hence, the teeth of only one side are recorded.

Dental formula is represented as

$$\frac{I\,C\,P_m\,M}{I\,C\,P_m\,M}$$

where, I = Incisors, C = Canines, P_m = Premolar, M = Molar

Total number of teeth = Number of teeth in dental formula × 2

Dental Formula of Some Animals

Animals	Dental Formula	Animals	Dental Formula
Pig and Mole	$\frac{3143}{3143} \times 2 = 44$	Cow, Sheep and Goat	$\frac{0033}{3133} \times 2 = 32$
Opossum	$\frac{5134}{4134} \times 2 = 50$	Cat	$\frac{3131}{3121} \times 2 = 30$
Dog	$\frac{3142}{3143} \times 2 = 42$	Rabbit	$\frac{2033}{1023} \times 2 = 28$
Lemur	$\frac{2133}{2133} \times 2 = 36$	Squirrel	$\frac{1023}{1013} \times 2 = 22$
Kangaroo	$\frac{3124}{1024} \times 2 = 34$	Rat	$\frac{1003}{1003} \times 2 = 16$
Man	$\frac{2123}{2123} \times 2 = 32$	Elephant	$\frac{1003}{0003} \times 2 = 14$

Digestive Glands

They include salivary glands, gastric glands (containing chief cells, oxyntic cells and mucous cells), liver, pancreas (containing alpha cells, beta cells, delta cells and pancreatic polypeptides) and intestinal glands (crypts of Lieberkuhn and Brunner's gland). Salivary glands and liver have already been discussed earlier in this chapter.

The other glands are

1. Pancreatic Glands

These consist of two parts, i.e., exocrine part and endocrine part.

(i) **Exocrine part** This part consists of rounded lobules (acini) that secrete an alkaline pancreatic juice with pH 8.4. It contains sodium bicarbonate and 3 proenzymes namely trypsinogen, chymotrypsinogen and procarboxypeptidase. It also contains some enzymes such as lipase, elastase, α-amylase, DNase, RNase, etc. The pancreatic juice helps in the digestion of starch, proteins, fats and nucleic acids.

(ii) **Endocrine part** This part consists of groups of Islets of Langerhans. It is most numerous in the tail of the pancreas.

They consist of following types of cells

(a) **Alpha** (α) **cells** Most numerous towards the periphery of the Islet and constitute about 15% of the Islet of Langerhans. They produce glucagon hormone.

(b) **Beta** (β) **cells** Most numerous towards the middle of the Islet and constitute 65% of it. They produce insulin hormone.

(c) **Delta** (δ) **cells** They are found towards the periphery of Islet and constitute 5% of it. They secrete somatostatin hormone.

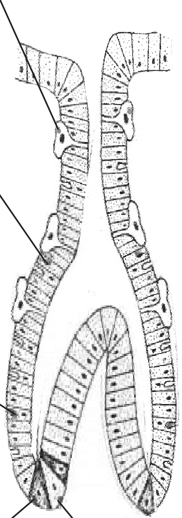
(d) **Pancreatic Polypeptide** (PP) **cells** They constitute about 15% of the Islet of Langerhans and secrete pancreatic polypeptides, which inhibit the release of pancreatic juice. These are also called **F-cells**.

2. Gastric Glands

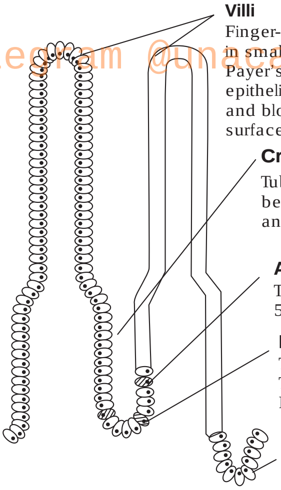
They are microscopic, tubular glands formed by the epithelium of the stomach. They contain chief cells, oxyntic cells, mucous cells and endocrine cells (G cells and Argentaffin cells).

3. Intestinal Glands

They are formed by the surface epithelium of small intestine. These are of two types, **i.e.,** crypts of Lieberkuhn and Brunner's gland. Crypts of Lieberkuhn consists of **Paneth cells** and **Argentaffin cells** at its base.



Gastric glands



Intestinal glands

Physiology of Digestion

The process in which large macromolecules of food are broken up into smaller usable molecules with the help of enzymes is called **digestion**.

The process or physiology of digestion begins with the following processes

(i) **Mastication** It is process of biting and grinding the food in mouth with the help of teeth so as to make it soft enough to swallow.

(ii) **Deglutition** It is the process of swallowing, **i.e.,** the collection of food or bolus is pushed inward through the pharynx into the oesophagus. Swallowing is controlled by swallowing centre located in the medulla oblongata and lower pons Varolii of the brain.

(iii) **Peristalsis** It is wave of contraction and relaxation produced by the involuntary contraction of circular muscles in the oesophagus and simultaneous contraction of longitudinal muscles.

Digestive Enzymes

These are present in digestive juices and secreted by various components of alimentary canal. Depending upon their functional site, they are categorised as exo and endoenzymes.

(i) **Exoenzymes** They require a terminus for their functional ability, **i.e.,** cut the substrate from its end.

(ii) **Endoenzymes** They do not require any stimulus for their functioning, **i.e.,** cut the substrate interstitially.

Process of Digestion in Alimentary Canal

Digestive Juice	pH	Source	Stimulation by	Proenzyme (inactive)	Activator	Enzyme	Substrates	End Products
Saliva	6.8	Salivary glands	Neuronal reflex	....	....	Ptyalin	Some polysaccharides	Disaccharide maltose
Gastric juice	1.0 - 3.5	Gastric glands	Neuronal reflexes and gastrin hormone	Pepsinogen	HCl	Pepsin*	Proteins	Proteoses, peptones and large polypeptides
			....	Prorennin	HCl	Rennin**	Milk proteins	Calcium paracaseinate
			.....	.....	....	Gastric lipase, gastric amylase	Fats, starches	Negligible Negligible
Bile***	7.7	Liver	Secretin and CCK hormones	....	.....	....	Fats	Emulsified fats
Pancreatic juice	7.5 - 8.3	Pancreas	Neuronal reflexes, secretin and CCK hormones	....	....	Amylopsin or pancreatic amylase	Polysaccharides	Maltose
						Steapsin or pancreatic lipase	Emulsified fats	Monoglycerides, fatty acids, cholesterol
				Trypsinogen	Enterokinase	Trypsin	Proteins, proteoses, peptones, large peptides	Small peptides
				Chymotrypsinogen	Trypsin	Chymotrypsin	Proteins, proteoses, peptones, large peptides	Small peptides

Digestive Juice	pH	Source	Stimulation by	Proenzyme (inactive)	Activator	Enzyme	Substrates	End Products
				Procarboxy-polypep tidase	....	Carboxypoly - peptidase	Small peptides	Amino acids
					...	Deoxyribonuclease	DNA	Nucleotides Nucleosides
				...	...	Ribonuclease	RNA	Nucleotides Nucleosides
Intestinal juice or succus entricus	7.5 - 8.0	Intestinal glands	Neuronal reflex enterokinin hormone	....	....	Erepsin group (exopeptidase)	Small peptides and dipeptides	Amino acids
						Carbohydrases		
				.....	.....	Maltase	Maltose	Glucose (2 molecules)
				......	......	Sucrase	Sucrose	Glucose and fructose
				.....	.....	Lactase	Lactose	Glucose and galactose
						α-dextrimax	α-dextrin	Glucose
						Enterokinase	Trypsinogen	Active trypsin
						Intestinal lipase	Emulsified fats	Fatty acids and glycerol
						Nucleases and Nucleosidases	Nucleotides and nucleosides	Nitrogenous bases and pentose sugars
Symbiotic bacteria and Protozoa of caecum	.....	.....	.....	.....	......	.....	Cellulose	Sugars

*** Pepsin** Secreted as pepsinogen (inactive form) and activated by HCl, exopeptidase in nature. Converts protein molecules into proteoses, peptones and ultimately into large polypeptides.

****Rennin** Secreted as prorennin (inactive form) and activated by HCl. Convert-milk protein — casein to paracasein. Paracasein combines with calcium to form calcium paracaseinate (curd). This action is required so that, the liquid milk does not leave stomach without being acted upon by the pepsin (acts on calcium paracaseinate to form peptones).

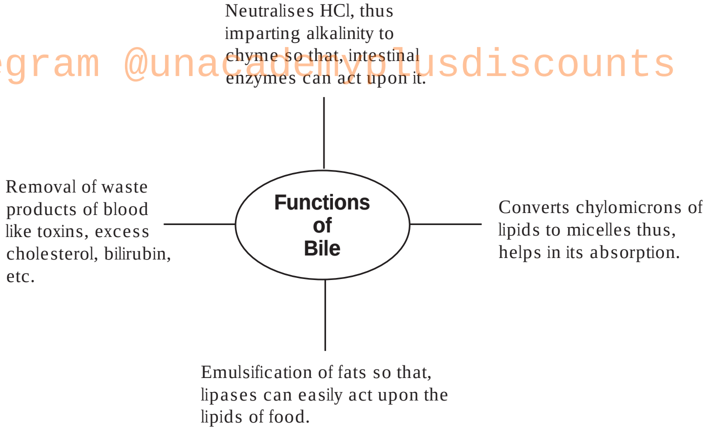
*** **Bile** Greenish-blue, alkaline (pH 7.7) fluid containing 92%. water, 6%. bile salts, 0.3% bile pigments (bilirubin and biliverdin), 0.3-1.2% fatty acids and 0.3 to 0.9% cholesterol along with 0.3% lecithin. It does not contain any digestive enzyme.

Digestive Hormones

These hormones are involved in the regulation of digestive secretions.

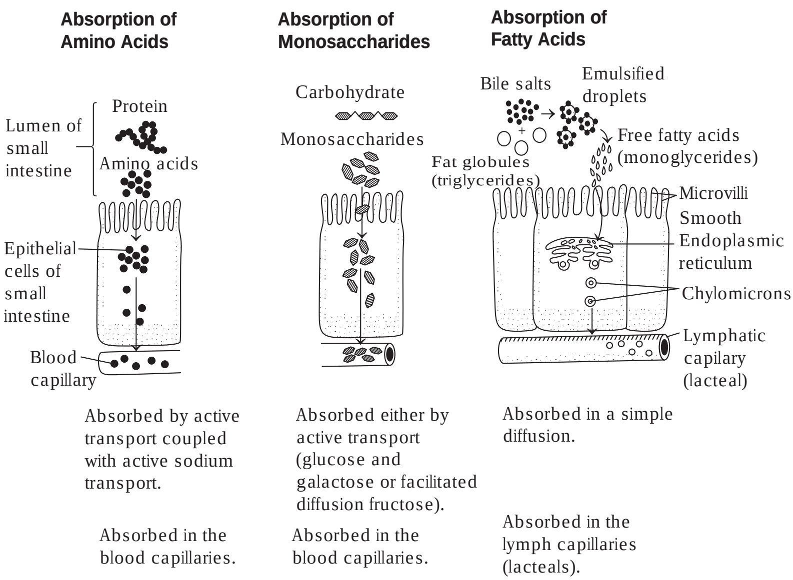
Gastrointestinal Hormones

Hormone	Source	Target Organ	Action
Gastrin	Pyloric region of stomach	Stomach	Stimulates gastric glands to secrete and release the gastric juice. It also stimulates gastric mobility and HCl secretion.
Enterogastrone (Gastric Inhibitory Peptide–GIP)	Duodenum epithelium	Stomach	Inhibits gastric secretion and motility (slows gastric contraction).
Secretin first hormone discovered by scientists	Duodenum (epithelium)	Pancreas, liver and stomach	Releases bicarbonates in the pancreatic juice. Increases secretion of bile. Decreases gastric secretion and motality.
Cholecystokinin-Pancreozymin (CCK-Pz)	Small intestine (entire epithelium)	Gall bladder and pancreas	Contracts the gall bladder to release bile. Stimulates pancreas to secrete and release digestive enzymes in the pancreatic juice.
Duocrinin	Duodenum (epithelium)	Duodenum	Stimulates the Brunner's glands to release mucus and enzymes into the intestinal juice.
Enterocrinin	Small intestine (entire epithelium)	Small intestine	Stimulates the crypts of Lieberkuhn to release enzymes into the intestinal juice.
Vasoactive Intestinal Peptide (VIP)	Small intestine (entire epithelium)	Small intestine and stomach	Dilates peripheral blood vessels of gut. Inhibits gastric acid secretion.
Villikinin	Small intestine (entire epithelium)	Small intestine	Accelerates movements of villi.
Somatostatin (SS)	Delta cells of Isets of Langerhans of pancreas.	Pancreas and gastrointestinal tract	Inhibits the secretion of glucagon by alpha cells and insulin by beta cells. It also inhibits absorption of nutrients from the gastrointestinal tract.
Pancreatic Polypeptide (PP)	Argentaffin cells of gastric and intestinal glands	Gastrointestinal tract	Supresses the release of hormones from the digestive tract.
	Pancreatic polypeptide cells of Islet of Langerhans.	Pancreas	Inhibits the release of pancreatic juice from the pancreas.



- Bile is alkaline in man, but in cats and dogs, it is acidic in nature.

Absorption of Nutrients



Micelles These are the small, spherical, water soluble molecules. The products of fat digestion are incorporated into them with the help of bile salts and phospholipids. Hence, the fat molecules are absorbed into the intestinal cells in the form of micelles and reach directly to lymph in lymph vessels (lacteals).

Chylomicrons These are the products of fat digestion, which are used for synthesising new fats. These are released by the intestinal cells into the lymph, in the form of droplets. Hence, the synthesised fats are liberated from the intestinal cells in the form of **chylomicrons**.

Absorption in Different Parts of Digestive System

(i) **Oral Cavity** Certain drugs, alcohol, etc.

(ii) **Stomach** Water, alcohol, some salts, drugs like aspirin, simple sugars, etc.

(iii) **Small Intestine** Principal organ of absorption, absorb glucose, fructose, fatty acids, glycerol, amino acids, etc.

(iv) **Large Intestine** Water, some minerals, drugs, products of bacterial digestion (amino acids + vitamin-B complex + vitamin-K), etc.

- **Chyle** The lacteals after absorption of lipids contain white-coloured liquid inside them known as chyle.
- **Assimilation** The process of utilisation of the absorbed substances that finally reach the tissues is called assimilation. The tissues further perform various metabolic activities like storage, synthesis, breakdown, transport, etc.
- **Egestion** The digestive wastes, solidified into coherent faeces in the rectum initiate a neural reflex causing an urge or desire for its removal. The process of removal or expulsion of faeces to the outside through the anal opening is called **egestion**. It is a voluntary process carried out by a mass peristaltic movement.

Disorders of Digestive System

Deficiency Diseases

They include Protein Energy Malnutrition (PEM) and disorders due to the deficiency of vitamins, iodine, etc.

PEM is of two types, **i.e.,** kwashiorkor and marasmus.

Deficient Nutrient	Name of Deficiency	Deficiency Symptoms
Protein (PEM)	Kwashiorkor (usually observed in children in the age group of 1-5 years)	Thin limbs, retarded growth of body and brain, swelling of legs due to retention of water (oedema), reddish hair, pot belly and diarrhoea.
Protein and calorie (PEM)	Marasmus (it usually affects infants below age of one year)	Impaired growth and replacement of tissue proteins, thin limbs and prominent ribs (very less fat in the body), dry, wrinkled and thin skin, diarrhoea.

Deficient Nutrient	Name of Deficiency	Deficiency Symptoms
Vitamin-A	Nyctalopia (night blindness)	Difficulty to see in night due to the deficiency of retinol.
Vitamin-D	Rickets	Pigeon breast, bow legs, knock knee due to low calcification of developing bones.
Vitamin-E	Macrocytic anaemia	Increased fragility and haemolysis of RBCs.
Vitamin-K	Hypoprothrombinemia	Deficiency of prothrombin in blood.
Vitamin-B_1 (thiamine)	Beri-beri	Retarded growth, degeneration of bones and muscles.
Vitamin-B_2 (riboflavin or vitamin-G)	Dermatitis	Rough, dry and scaly skin.
Vitamin-B_3 (niacin)	Pellagra	3D disease as its symptoms include dermatitis, diarrhoea and dementia.
Vitamin-B_5	Achromotrichia	Premature greying of hairs.
Vitamin-B_7 (vitamin-H)	Acne vulgaris	Appearance of pimples and boils in young people.
Vitamin-B_{10} (vitamin-M or folic acid)	Sprue	Ulceration of mouth, diarrhoea, etc.
Vitamin-B_{12}	Pernicious anaemia	Large, oval and fragile RBC formation in bone marrow.
Vitamin-C (ascorbic acid)	Scurvy	Swelling and bleeding of gums.

Vomiting

Ejection of stomach content through the mouth. This reflex action is controlled by the vomiting centre located in the medulla oblongata.

Ulcerative Colitis

This inflammatory disease affects the large intestine, diarrhoea occurs when waste products move through the large intestine quickly and constipation occurs when this movement is too slow.

Constipation

It is infrequent or difficult defecation caused by decreased motility of the intestines. Due to the prolonged collection of faeces in the colon, excessive water absorption occurs and faeces become dry and hard. Due to this, their egestion becomes difficult.

Cirrhosis

It is the scarring of the liver due to the loss of liver cells. Alcohol and viral hepatitis-B and C are the common causes of cirrhosis. It may cause weakness, loss of appetite, jaundice, etc. Jaundice is characterised by yellowish colouration of the sclerae, skin and mucous membrane due to the accumulation of yellow compound called **bilirubin**.

17

Breathing and Exchange of Gases

Respiration

It is the oxidation reaction process in cellular metabolism that involves the sequential degradation of food substances and generation of energy.

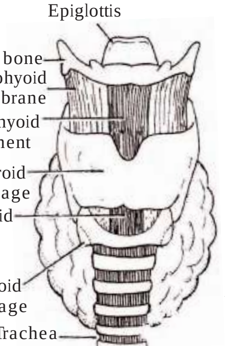
Based on the mode of oxidation of nutrients respiration is of following two types

1. **Aerobic respiration** It occurs when the cells utilise molecular oxygen for oxidising nutrient. It occurs in the mitochondria of the cells. It produces a lot of ATP per glucose molecule. It is done under normal circumstances by an animal, when heart rate and breathing rates are normal.
2. **Anaerobic respiration** It occurs, when nutrients are oxidised without using molecular oxygen. It is also called **fermentation**. It occurs in the cytoplasm of the cells. It produces less ATP per glucose molecule. It is done during oxygen deficient situations, i.e. like the first 1-2 minutes of exercise.

Human Respiratory System

The special features of mammalian respiratory system are presence of a nose, elongation of nasal passage and its complete separation from buccal passage through palate, long windpipe due to the presence of well-defined neck, spongy and solid lungs.

External Nose
These are paired openings that open into nasal cavities. The portion inside nose is called **vestibule** which contains mucous lining and hair epithelium.



(b)

Nasal Cavities
External nostrils open into 2 nasal cavities which are separated from each other by a thin, cartilaginous medial vertical partition called **nasal septum**.

Larynx
It is the uppermost portion of trachea made up of nine cartilages in humans. Its opening is **glottis**, which is covered by cartilaginous epiglottis. It is called as **voice box** and is more prominent in man (Adam's apple).

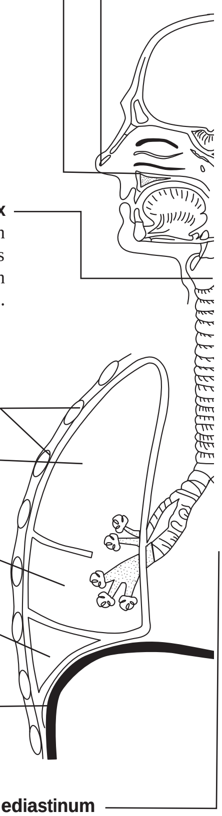
Cut end of ribs

Right Lung
It has 3 lobes and 2 fissures. It is broader, larger and heavier than the left lung.

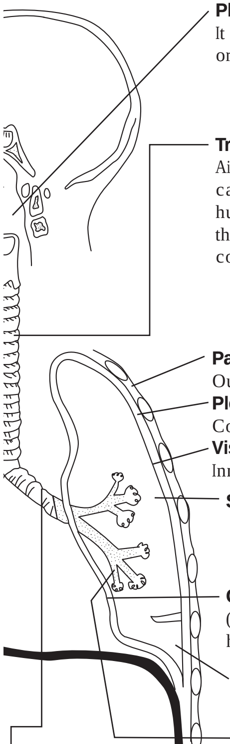
Superior Lobe
Divided by horizontal fissure
Middle Lobe
Divided by oblique fissure
Inferior Lobe

Diaphragm
It is a muscular partition that separates the abdominal and thoracic cavities.

Mediastinum
Partition between the two lungs, includes the pleura of both sides. Contains heart, oesophagus, etc.


(a)

(a) Respiratory system in humans (b) A magnified larynx



Pharynx
It provides the passage to both air and food. It comprises nasopharynx, oropharynx and laryngopharynx (hypopharynx).

Trachea
Air conducting tube with non-collapsible walls due to the presence of cartilaginous C-shaped, incomplete rings. Their number is 16-17 in humans. It enters into the lungs after their first branching. It helps in the conduction of air as it is lined by pseudostratified ciliated columnar epithelium bearing mucous glands.

Parietal Pleura
Outer membrane

Pleural Cavity
Contains pleural fluid

Visceral Pleura
Inner membrane

Pleurae
Two membranes that cover the lungs. These membranes enclose a pleural cavity containing pleural fluid.

Superior Lobe
↕ Divided by horizontal fissure

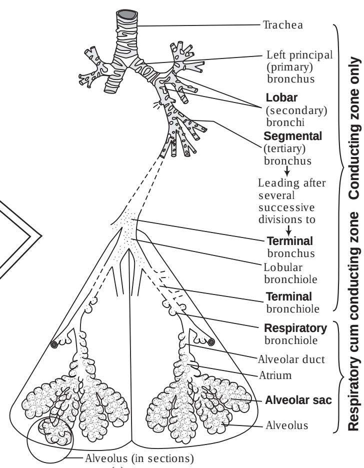
Cardiac Notch
(accommodates heart)

Left Lung
Smaller, lighter and narrower than right lung. Possesses two lobes and a cardiac notch.

Inferior Lobe

Alveoli
Basic functional unit of lungs, approx 300 million in number in humans, specialised air-filled sacs which are richly supplied with blood capillaries.

Bronchus
Trachea enter into lungs after their branching into bronchus. They are further divided into bronchioles (lobular, terminal and respiratory) which further ends into alveolus.



(c) A magnified bronchus

Respiration is carried out in different forms with the help of specialised gaseous exchange devices, **which are of two types**

(i) **Diffusion devices** Exchange of gases with environment takes place through the process of diffusion, **e.g.,** diffusion lungs found in **Pila** (pulmonary sac), spiders (book lungs), etc.

(ii) **Ventilating devices** Gaseous exchange structures are not in direct contact with the environmental air. The air is taken to the gaseous apparatus with the help of specialised tubular network, **e.g.,** trachea or windpipe, ventilating lungs, etc.

Lungs

These are the organs associated with the gaseous exchange. They are also called **pulmones**. It is the characteristic feature of vertebrates. These can operate through diffusion (diffusion lungs of **Pila**, spiders, etc.) or operate through ventilation (ventilating lungs as of vertebrates).

Ventilating lungs are of two types

(i) **+ve Pressure Lungs** In this, the pressure inside the lungs is +ve in comparison to the atmospheric pressure at the time of inspiration. Thus, in take of air requires pumping action, **e.g.,** frog (hollow lungs).

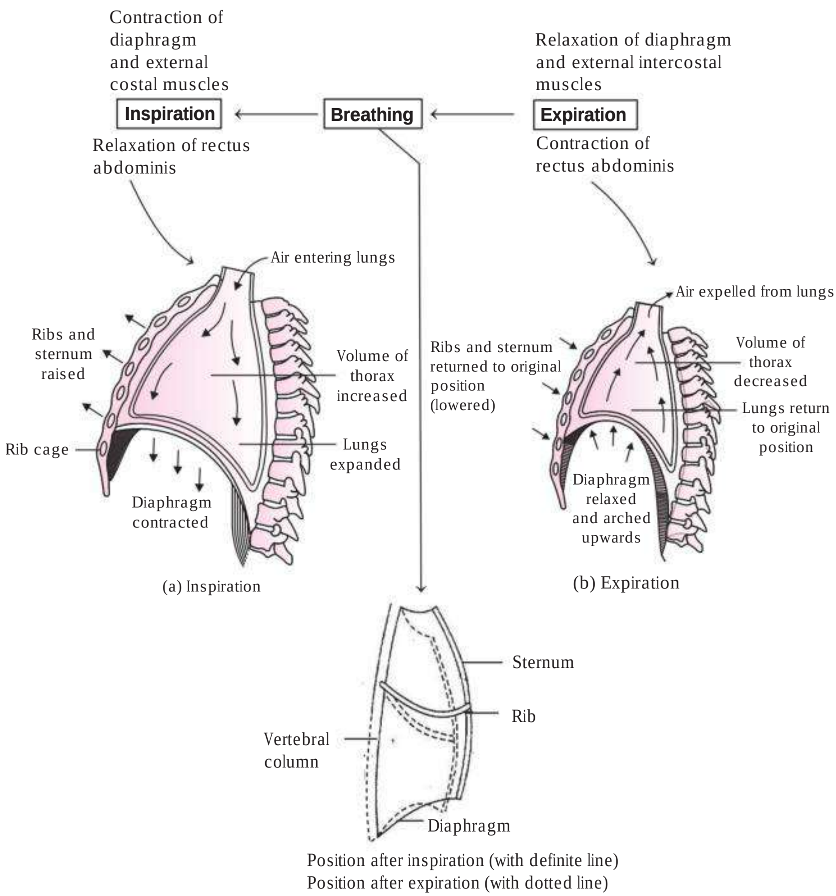
(ii) **–ve Pressure Lungs** In these, the pressure inside the lungs is –ve as compared to atmospheric pressure at the time of inspiration. Thus, intake of air is spontaneous, **e.g.,** humans (solid lungs).

Breathing

It is the process of exchange of oxygen (O_2) from the atmosphere with carbon dioxide (CO_2) produced by the cells.

Physiology of Breathing

Breathing is associated with the inflow (inspiration) and outflow (expiration) of air between atmosphere and the alveoli of the lungs.



Process of breathing in human

Movement of fresh air into the lungs is as follows

External nares → Nasal cavities → Internal nares → Pharynx → Glottis → Larynx → Trachea → Bronchi → Bronchioles → Alveolar duct → Alveolar sac → Alveoli

Movement of foul air out of the lungs occurs in reverse pathway, **i.e.,** from alveoli to external nares.

Lung Volume and Capacities

Terms	Symbols	Descriptions
Vital Capacity (3500-4500 mL)	VC	Maximal volume of air exhaled after forced inspiration (includes TV, IRV and ERV).
Tidal Volume (500 mL)	TV	Volume of air inhaled or exhaled during quiet breathing.
Inspiratory Reserve Volume (2500-3000 mL)	IRV	Maximal air that can be inhaled after a quiet inspiration.
Expiratory Reserve Volume (1000-1100 mL)	ERV	Maximal air that can be expelled out after quiet expiration.
Residual Volume (1100-1200 mL)	RV	Volume of air remaining in lungs after full expiration.
Inspiratory Capacity (3000-3500 mL)	IC	Maximal volume of air inspired with maximum effort
Expiratory capacity (1500-1600 mL)	EC	Maximal volume of air that can be expired after a normal expiration.
Forced Expiratory Volume, per time interval in seconds	FEV	Volume of air exhaled in a given period during a complete forced expiration (FVC).
Functional Residual Capacity (2500 mL)	FRC	Amount of air remaining in the air passages and alveoli after normal expiration
Total Lung Capacity (5800-6000 mL)	TLC	Total volume of air in lungs at the end of a forceful inspiration.

Dead Space

In lungs, the volume occupied by gas which does not participate in gaseous exchange is called dead space. A fixed quantity of each tidal volume goes to the dead space.

Anatomical Dead Space ← **Dead Space** → **Physiological or Total Dead Space**

Anatomical Dead Space: Tha portion of respiratory passage, in which incoming and outgoing air is completely locked. This air is not used in gaseous exchange and can be calculated as

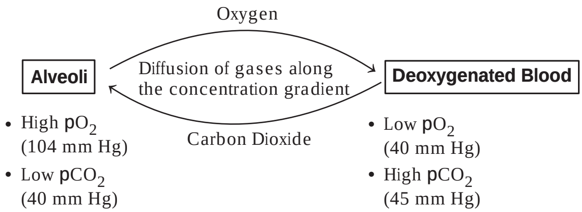
$$TV \times \frac{[CO_2\% \text{ in alveolar air} - CO_2\% \text{ in expired air}]}{CO_2\% \text{ in alveolar air}}$$

Physiological or Total Dead Space: Anatomical dead space + oxygen in excess supplied by the body demand + oxygen trapped in blind alveoli (alveoli where gaseous exchange does not take place).
No dead space is seen in the lungs of birds.

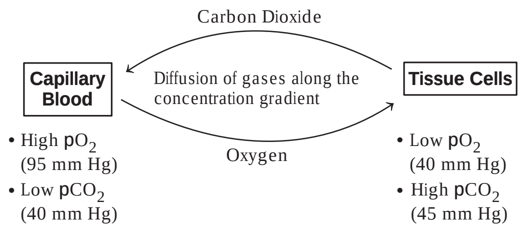
Exchange of Gases

In the process of respiration, gaseous exchange occurs at two level, **i.e.,** (i) between alveoli and blood (external respiration) and (ii) between blood and tissue cells (internal respiration).

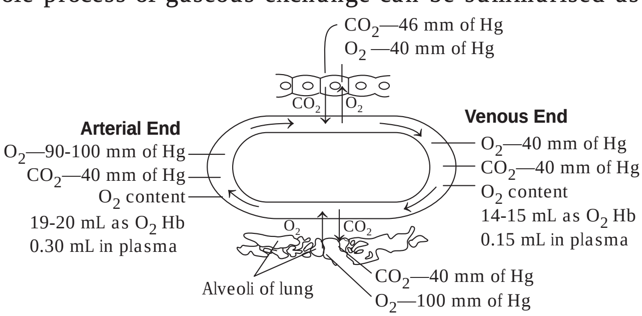
(i) Exchange of gases between alveoli and blood.



(ii) Exchange of gases between blood and tissue cells.



The whole process of gaseous exchange can be summarised as



Transport of Gases

Blood carries oxygen from the lungs to tissue cells for oxidation and carbon dioxide from the tissue cells to the respiratory surface for elimination.

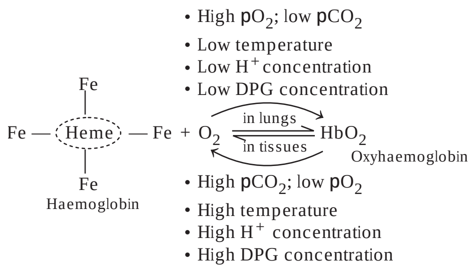
(i) Transport of Oxygen

Oxygen enters the venous blood in the lungs and leaves the blood stream in the tissue capillaries and goes to the tissue cells.

Oxygen is carried in the blood in the following forms

(a) **As dissolved gas** Under normal conditions of temperature and pressure, about 0.30 mL of O_2 is carried in physical solution in 100 mL of arterial blood.

(b) **As chemical compound** Oxygen is carried in combination with haemoglobin as oxyhaemoglobain.

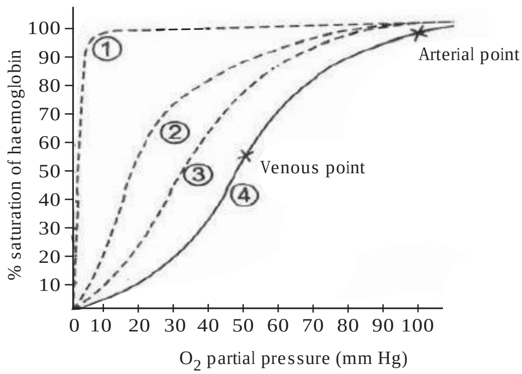


where, Fe = Iron (have strong affinity for oxygen).

DPG = Diphosphoglyceraldehyde

O_2-Hb Dissociation Curve

This curve is the graphical representation of per cent saturation of haemoglobin at various partial pressure of oxygen.



where, 1 = At room temperature with CO_2.

2 = At body temperature without CO_2.

3 = At body temperature + 20 mm of Hg CO_2.

4 = At body temperature + 40 mm of Hg CO_2.

Following interpretations can be made from the given curve

(a) The curve is sigmoid or S-shaped under normal condition.

(b) With increased CO_2 levels and increased temperatures, the curve is shifted towards right and **vice versa**.

(c) The curve is completely sigmoid for strong electrolytes, while it is hyperbolic for weak electrolytes.

(d) The curve for foetal haemoglobin is towards the left hand side as compared to maternal haemoglobin. It shows that foetal haemoglobin have greater affinity for oxygen as compared to that of mother.

(e) Oxyhaemoglobin dissociation curve for myoglobin is rectangular hyperbola with more towards left end side.

(f) The partial pressure of oxygen at which 50% saturation of haemoglobin takes place is called p_{50} value.

$$p_{50} \text{ value} \propto \frac{1}{\text{Affinity of blood for } O_2}$$

- Under normal body conditions, whatsoever increase occurs in partial pressure of O_2 (even upto 100 mm of Hg), the haemoglobin is never fully saturated because of the presence of CO_2 and temperature conditions in body.
- The entry of CO_2 in blood helps in the dissociation of oxyhaemoglobin and to increase acidity (decreased pH) of blood which promotes the lesser affinity of blood for oxygen (Bohr's effect).
- The entry of O_2 in blood (**i.e.,** more and more formation of oxyhaemoglobin) is more responsible for more and more replacement of CO_2 from the venous blood.

(ii) Transport of Carbon Dioxide

Transportation of CO_2 is much easier due to its high solubility in water. CO_2 **is transported in three ways**

Transport of CO_2

As Carbamino Compounds
CO_2 binds directly with Hb to form an unstable compound (carbamino compounds) (CO_2 HHb); 23% CO_2 is transported in this form.

In Dissolved State
Under normal temperature and pressure, about 7% of CO_2 is carried by physical solution.

As Bicarbonate Ions
CO_2 reacts with water to form carbonic acid (H_2CO_3) in the presence of carbonic anhydrase in RBC. (H_2CO_3) dissociates into hydrogen and bicarbonate ions (HCO_3^-).

The whole reaction proceeds as follows

Interstitial Fluid	Plasma	Erythrocytes
Dissolved CO_2 ⟶	Dissolved CO_2 ⟶	$CO_2 + H_2O \xrightarrow{\text{Carbonic anhydrase}} H_2CO_3$ (carbonic acid) ⟶ $HCO_3^- + H^+$
	HCO_3^- ⟵	HCO_3^-
	Cl^- ⟶	Cl^-
		Chloride shift
		$CO_2 + Hb \longrightarrow \boxed{Hb.CO_2}$ Carbamino haemoglobin

Chloride shift Most of the bicarbonate ions move out of the erythrocytes into the plasma **via** a transporter that exchanges one bicarbonate for one chloride ion. This is called **chloride shift** or **Hamburger phenomenon**.

Regulation of Respiration

Process of respiration is under both nervous and chemical control

(i) **Neural regulation** The group of neurons located in the medulla oblongata and pons Varolii acts as the respiratory centre which is composed of groups of neurons. Hence, respiratory centre is divided into the medullary respiratory centre and pons respiratory centre.

Dorsal Respiratory Group (DRG) ⟵ **Medulla Respiratory Centre** ⟶ **Ventral Respiratory Group** (VRG)

Dorsal Respiratory Group (DRG)
- Causes inspiration
- Located in the dorsal portion of medulla

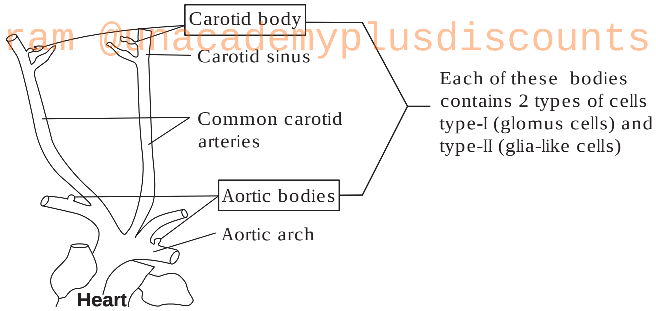
Ventral Respiratory Group (VRG)
- Causes expiration
- Located in the ventrolateral portion of medulla

Pneumotaxic Centre ⟵ **Pons Respiratory Centre** ⟶ **Apneustic Centre**

Pneumotaxic Centre
- Fuctions to limit inspiration
- Located in dorsal part of pons Varolii

Apneustic Centre
- Controls the depth of inspiration
- Located in the lower part of pons Varolii

(ii) **Chemical regulation** It includes the effect of CO_2, O_2 and H^+ concentration in blood. Its receptors are located in **carotid bodies** (largest number), **aortic bodies** and in **brain**.



Carotid and aortic bodies

Carotid bodies and aortic bodies are the **peripheral chemoreceptors**, whereas these located in brain are called **central chemoreceptors**.

Peripheral chemoreceptors ← **Chemoreceptors** → **Central chemoreceptors**

Peripheral chemoreceptors: Stimulated by decreased pO_2 and increased H^+ concentration

Central chemoreceptors: Stimulated by increased pO_2 in brain's extracellular fluid

Disorders of Respiratory System

(i) **Bronchitis** Inflammation of the bronchi caused by irritants such as cigarette smoke, air pollution or infection. The inflammation results in the swelling of mucous membrane lining of bronchi, increased mucus production and decreased movement of mucus by cilia which impairs the ventilation process.

(ii) **Emphysema** It results in the destruction of the alveolar walls due to the decreased respiratory surface, which decreases gaseous exchange. Its symptoms include shortness of breath and enlargement of thoracic cavity. The progress of emphysema can be slowed, but there is **no cure**.

(iii) **Asthma** It is associated with the periodic episodes of contraction of bronchial smooth muscles, which restricts the air movement. It results from allergic responses to pollen, dust animal dander or other substance.

(iv) **Pulmonary fibrosis** It is an occupational lung disease. It involves the replacement of lung tissue with fibrous connective tissue, making the lungs less elastic and breathing more difficult. Its common causes include the exposure to silica, asbestos or coal dust.

18

Body Fluids and Circulation

Body Fluids

They are the medium of transport in the body. They may be either intracellular or extracellular fluid. The intracellular fluid contains large amount of potassium ions, phosphate ions and proteins. Extracellular fluid includes blood, lymph, cerebrospinal fluid, etc.

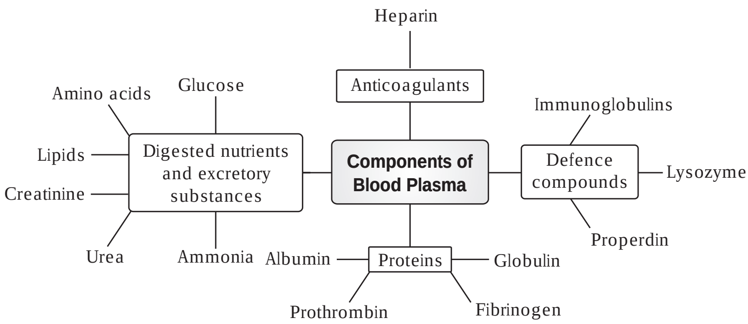
Blood

It is the most common body fluid in higher organisms, consisting of plasma, blood corpuscles, etc. This extracellular fluid is slightly alkaline having pH 7.4.

It is composed of a watery fluid called **plasma** and floating bodies called **formed elements** (blood cells).

Blood Plasma

Crystallo-colloidal mixture, makes 55-60% of blood, contains 90-92% of water and 0.9% salts, slightly alkaline, constitutes about 5% of the body weight.



Functions of Plasma Proteins

(i) Fibrinogen, globulins and albumins are the major proteins.

(ii) Fibrinogen is required for blood coagulation.

(iii) Globins are primarily involved in defense mechanisms of the body.

(iv) Albumins help to maintain osmotic balance.

Blood Cells

They constitute about 40-45% of the blood. They have specific gravity of about 1.09, **i.e.,** these are slightly heavier than the plasma.

The three types of cellular elements in blood are

Blood Cells

Red Blood Cells or Erythrocytes

Haemoglobin containing cells that carry oxygen in the blood (non-nucleated in humans).

Blood Platelets or Thrombocytes

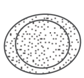
Non-nucleated, disc-shaped fragments of bone marrow cells, involved in blood coagulation.

White Blood Cells or Leucocytes

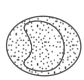
Colourless, motile, nucleated cells, involved in body defense mechanism. Also called PMNCs, i.e., Poly Morpho Nuclear Corpuscles

Agranulocytes
(Granules are not found in cytoplasm)

Lymphocytes
20-25%
- Large rounded nucleus
- Non-phagocytic
- They produce antibodies

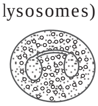


Monocytes
2-10%
- Bean-shaped nucleus
- Phagocytic
- They engulf bacteria and cellular debris

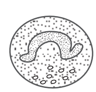


Granulocytes
(Contains granules in their cytoplasm)

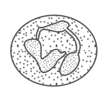
Eosinophils
2-3%
- Bilobed nucleus
- Non-phagocytic
- Play role in allergy and hypersensitivity reactions (correspond to lysosomes)



Basophils
0.5-1%
- Three-lobed nucleus
- Non-phagocytic
- Contain heparin, histamine and serotonin (correspond to mast cells)



Neutrophils
60-65%
- Multi-lobed nucleus
- Phagocytic
- Correspond to macrophages



Major characteristics of blood cells are as follows

Characteristic Features	Erythrocytes	Leucocytes	Thrombocytes
Number	4.5-5 million mm^3 of blood	6000-8000 mm^3 of blood	1,50,000-3,50,000 mm^3 of blood
Shape	Biconcave and circular	Rounded or irregular	Rounded or oval disc-like bodies.
Size	7-8 μm in diameter 1-2 mm thick	12-20 μm in diameter	2-3 μm in diameter
Colour	Red (due to the presence of haemoglobin)	Colourless (due to the absence of haemoglobin)	Colourless (due to the absence of haemoglobin)
Formation	Erythropoiesis occurs in liver and spleen (before birth) and in bone marrow (after birth).	Leucopoiesis occurs in bone marrow, lymph nodes, spleen, thymus, tonsils and Peyer's patches.	Thrombopoiesis occurs from very large cells of bone marrow, **i.e.,** megakaryotes.
Lifespan	About 120 days	Few hours to few days (granulocytes) or few months (agranulocytes).	About 8-10 days.

B-Cells and T-Cells

Lymphocytes exist in two major groups, i.e., B-lymphocytes and T-lymphocytes.

B-lymphocytes (B-cells) **and T-lymphocytes** (T-cells)

B-Cells	T-Cells
They form a part of the humoral immune system.	They form a part of the cell-mediated immune system.
They are processed in the liver or bone marrow.	They are processed in the thymus gland.
They release antibodies which finally enter the blood.	They do not release antibodies.
They produce antibodies to kill the antigens.	The whole cell directly attacks the antigens.
They defend the body against invading bacteria/virus. They do not reach against transplants and cancerous tissues.	They defend the body against pathogens, but also attack the transplants and the cancerous cells.

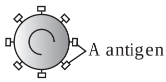
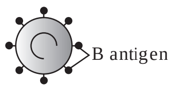
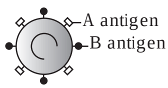
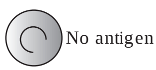
Blood Groups

There are more than 30 antigens on the surface of blood cells that give rise to different blood groups. During agglutination, reaction occurs between antigens (agglutinogens) in red blood cells and antibodies (agglutins) in blood plasma.

Two types of blood grouping are widely used all over the world namely; **ABO blood group** and **Rh** (rhesus) **blood group**.

1. **ABO Blood Groups**

A, B and O blood groups were reported first time by **Karl Landsteiner** in human beings. ABO blood group is based on the presence or absence of two antigens on the RBCs, **i.e.,** A and B.

Phenotype	Genotype	Antigen on RBC Membrane	Antibody In Plasma	Can Receive Blood From	Can Donate Blood To
A (40%)	$I^A I^A$ or $I^A I^o$		Anti-B antibodies	A, O	A, AB
B (10%)	$I^B I^B$ or $I^B I^o$		Anti-A antibodies	B, O	B, AB
AB (4%)	$I^A I^B$		No antibodies	A, B, AB, O (universal acceptor)	AB
O (46%)	$I^o I^o$		Anti-A and Anti-B antibodies	O	A, B, AB, O (universal donor)

I represents isoagglutinin gene possessing 3 alleles– I^A, I^B, I^O.

2. **Rhesus** (Rh) **Blood Group**

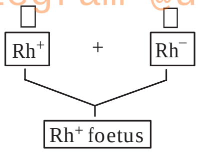
It was discovered by **Landsteiner** and **Wiener** in the blood of **rhesus monkey**. Depending upon the presence or absence of rhesus antigen on the surface of red blood corpuscles, individuals are categorised as **Rh positive** (Rh^+) and **Rh negative** (Rh^-), respectively. Rh^+ is dominant to Rh^-.

Rh Incompatibility During Pregnancy

It is seen when father's blood is Rh^+ and mother's blood is Rh^-.

Rh^+ being a dominant character expresses in the foetus and causes a serious problem.

The first child of Rh^- mother will not suffer, but Rh^+ blood of foetus stimulates the formation of anti-Rh^- factors in the mother's blood.



In the subsequent pregnancies with foetus, the anti-Rh antibodies in the mother's blood destroy the foetal RBCs and result in **Haemolytic Diseases of the Newborn** (HDN) or erythroblastosis foetalis.

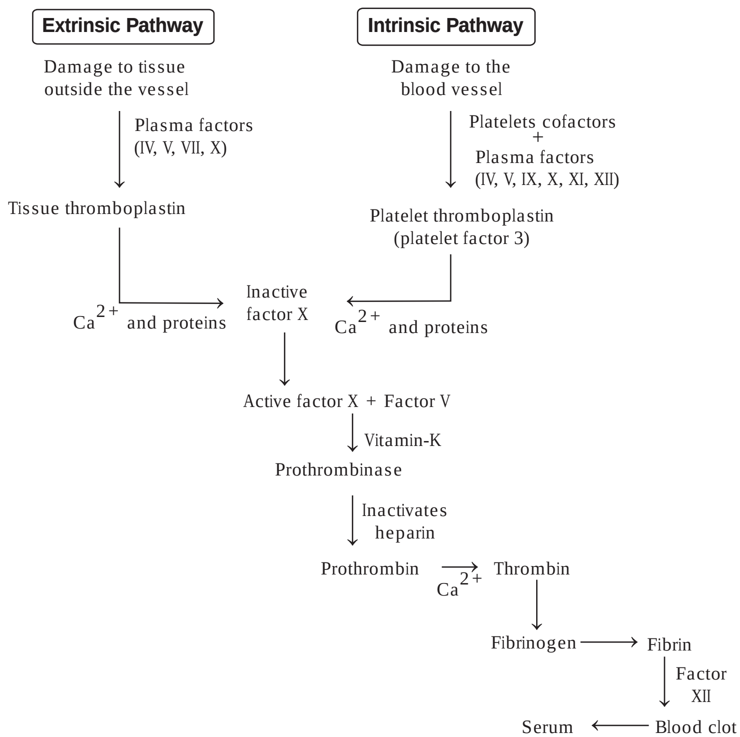
Rh Incompatibility During Blood Transfusion

The first transfusion between Rh^+ and Rh^- blood causes no harm, because Rh^- person develops anti Rh antibodies in his blood. But in the second transfusion of Rh^+ blood to Rh^- blood, the anti Rh antibodies in the latter's blood destroy the RBCs of the donor.

Coagulation of Blood

Coagulation or clotting is one of the characteristic feature of blood. It is defined as 'conversion of normal viscous blood fluid into jelly-like mass within 3-10 minutes after its exposure to air'.

The pathways of mechanism of blood clotting are as follows



Description of various clotting factors

Clotting Factor	Synonym	Characteristic
Factor I	Fibrinogen	Glycoprotein, synthesised in liver, contains 3 pairs of non-identical polypeptide chains, soluble in plasma
Factor II	Prothrombin	Glycoprotein, synthesised in liver by vitamin-K
Factor III	Thromboplastin or tissue factor	Lipoprotein, secreted in inactive form, prothromboplastin which gets activated by proconvertin of plasma tissues
Factor IV	Calcium ions	Required for the formation of intrinsic and extrinsic thromboplastin and for the conversion of prothrombin to thrombin
Factor V	Proaccelerin or labile factor	Glycoprotein, heat labile, synthesised in liver, absent in serum
Factor VI	Accelerin	Hypothetical activation product of proaccelerin
Factor VII	Serum Prothrombin Accelerator (SPA) or stable factor or autoprothrombin	Synthesised in liver by vitamin-K, associated with prothrombin and accelerates tissue thromboplastin formation from damaged tissues
Factor VIII	Anti-haemophilic factor or platelet cofactor	Glycoprotein, synthesised in liver, required for prothrombin activator formation from blood constituents, its deficiency causes haemophilia-A
Factor IX	Anti-prothrombin II or platelet cofactor II or Plasma Thromboplastin Component (PTC)	Glycoprotein, synthesised in liver by vitamin-K, its deficiency causes haemophilia-B
Factor X	Stuart factor	Glycoprotein, synthesised in liver by vitamin-K, its deficiency causes nose bleeding (epistaxis)
Factor XI	Plasma Thromboplastin Antecadent (PTA)	Glycoprotein, required for stage 1 of intrinsic pathway, synthesises in liver, deficiency, causes haemophilia-C
Factor XII	Hageman factor or surface factor	Glycoprotein, present in both plasma and serum, required for the formation of prothrombin activator complex, deficiency results in delayed blood clotting
Factor XIII	Fibrin stabilising factor	Glycoprotein, causes polymerisation of soluble fibrinogen to insoluble fibrin, deficiency causes haemorrhagic state

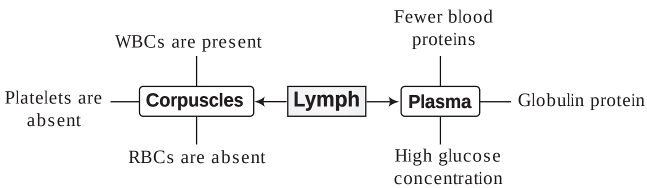
Functions of Blood

(i) Helps in transportation of respiratory gases (**i.e.**, O_2, CO_2, etc.), hormones from endocrine glands to target organs and body wastes from different body parts to kidney.

(ii) Maintains body pH, water, ionic balance and normal body temperature.

Lymph (Tissue Fluid)

It is an interstitial mobile connective tissue comprising lymph plasma and lymph corpuscles. It contains little O_2, but lot of CO_2 and metabolic waste.



Infact, when blood flows from arterial end to venous end of a capillary, most of its contents move into tissue (at the arterial end). 90% of these constituents return back at the venous end, while remaining 10% constitute the lymph.

Lymphoid Organs

These are the lymph secreting/accumulating organs. They include lymph nodes, tonsils, thymus, spleen and Peyer's patches. The spleen is the largest lymphoid organ in the body.

Functions of Lymph

- Its white blood corpuscles help in defence mechanism, tissue repair and healing.
- It is an important carrier for nutrients, hormones, etc.
- It helps in the absorption of fats in the lacteals present in the intestinal villi.

Circulatory System

This system is primarily concerned with the circulation of substances through body fluids like blood and lymph.

The two types of circulatory system found in animals are

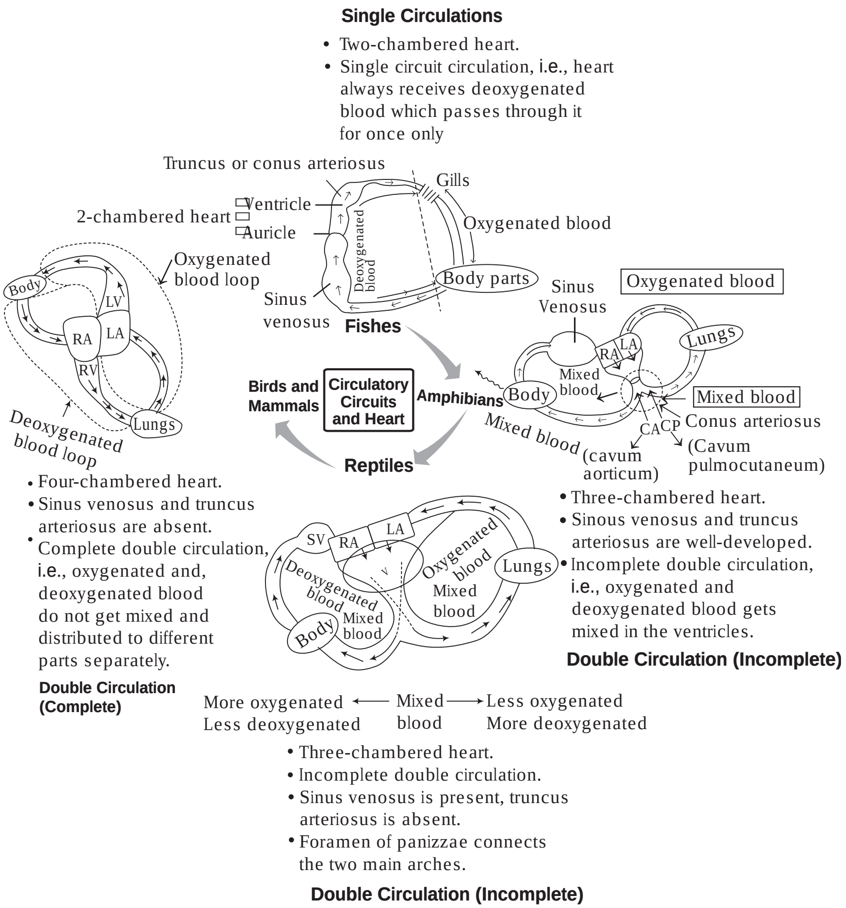
1. **Open Circulatory System** Blood pumped by the heart passes through large vessels into open spaces or body cavities called **sinuses**. It is found in arthropods and molluscs.

2. **Closed Circulatory System** Blood pumped by the heart circulates through a closed network of blood vessels. It is found in annelids and chrodates.

The general vertebrate closed circulatory systems can be

(a) Single circuit or single circulation

(b) Double circuit (complete or incomplete) or double circulation



Circulatory circuits and heart

Types of Heart

Heart can be classified into different types on the basis of origin of impulse for contraction and their structure.

Heart

Groups

- On the basis of origin of impulse for contraction
  - **Myogenic heart**
    (genic-genesis (origin)myo-muscle)
    Muscles are responsible for origin of impulse, e.g., vertebrate.
  - **Neurogenic heart**
    Nerves are responsible for origin of impulse e.g., heart of cockroach and most other invertebrates
- On the basis of structure
  - **Tubular**
    Muscle responsible for impulse generation is external, e.g., heart of cockroach which beats with the help of alary muscles.
  - **Pulsatile**
    Muscle responsible for impulse generation is situated within heart, e.g., heart of earthworm.
  - **Ampullary**
    Ampullary heart is situated below the appendages like antennae, wing, etc. Ampullary heart is found in insects.
  - **Chambered**
    Chambered heart founds in vertebrates, e.g., fishes, amphibians, aves, mammals.

Human Circulatory System

It constitutes the closed type of blood vascular system and lymphatic system.

(i) **Blood vascular system** comprises heart, blood and blood vessels.

(ii) **Lymphatic system** comprises lymph, lymphatic capillaries, lymphatic vessels, lymphatic nodes and lymphatic ducts.

Human Heart

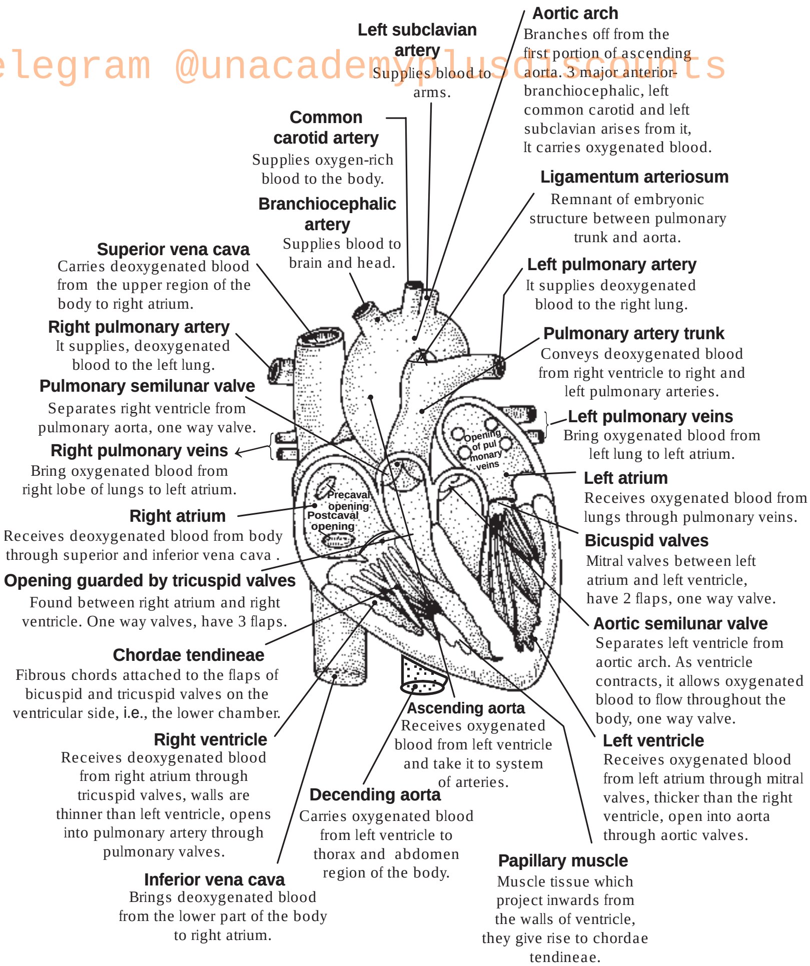
It is a hollow, fibromuscular organ of somewhat conical or pyramidal form with upper broad part, the base and the lower narrow apex which is slightly directed to the left.

Histologically, the heart consists of three layers

(i) **Pericardium** Outermost smooth coelomic epithelium.

(ii) **Myocardium** Thick muscular middle layer, composed of cardiac muscle fibres.

(iii) **Endothelium** Innermost layer consisting of simple squamous epithelial cells.



Internal human heart

Other components of heart which are not shown in the figure are described below

(i) **Grooves** (Sulci) These are partitions that separate the various components of the heart. **These are**

(a) **Interatrial groove or sulcus** The left and right atria are separated by this shallow, vertical groove.

(b) **Atrioventricular sulcus** It divides the atria from the ventricle.

(c) **Interventricular sulcus** It divides the right and the left ventricles.

(d) **Coronary sulcus** It separates atria and ventricles.

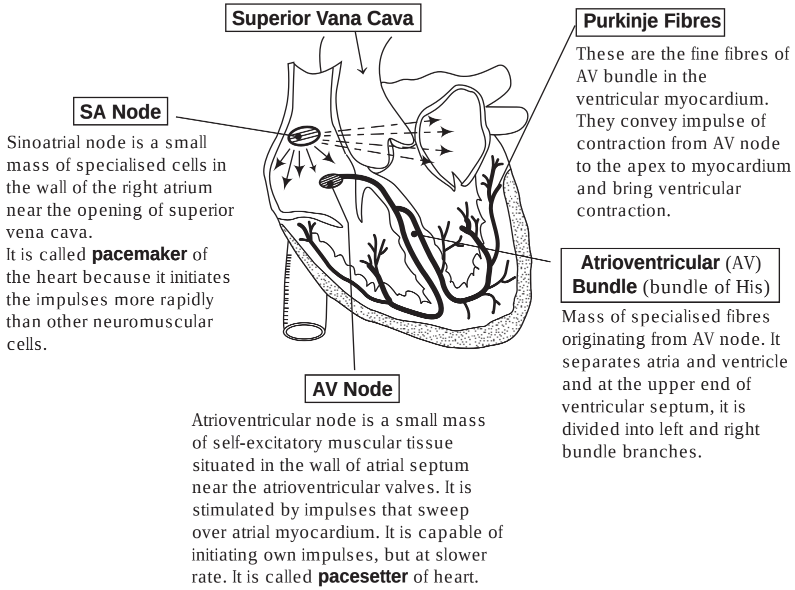
(ii) **Coronary sinus** It delivers deoxygenated blood into the right atrium through coronary veins. Its opening is guarded by coronary valves or thebesian valve.

(iii) **Fossa ovalis** It is an oval depression present in the interauricular septum within the right auricle. This depression is present as an oval foramen in embryo and known as **foramen ovale**. This foramen ovale helps in the communication of blood from right auricle to left auricle in embryo.

Conducting System of Heart

The human heart has an intrinsic system whereby the cardiac muscles are automatically stimulated to contract without the need of a nerve supply from the brain. But this system can be acclerated or depressed by nerve impulses initiated in the brain and by circulating chemicals (hormones).

The conducting system possesses the following components



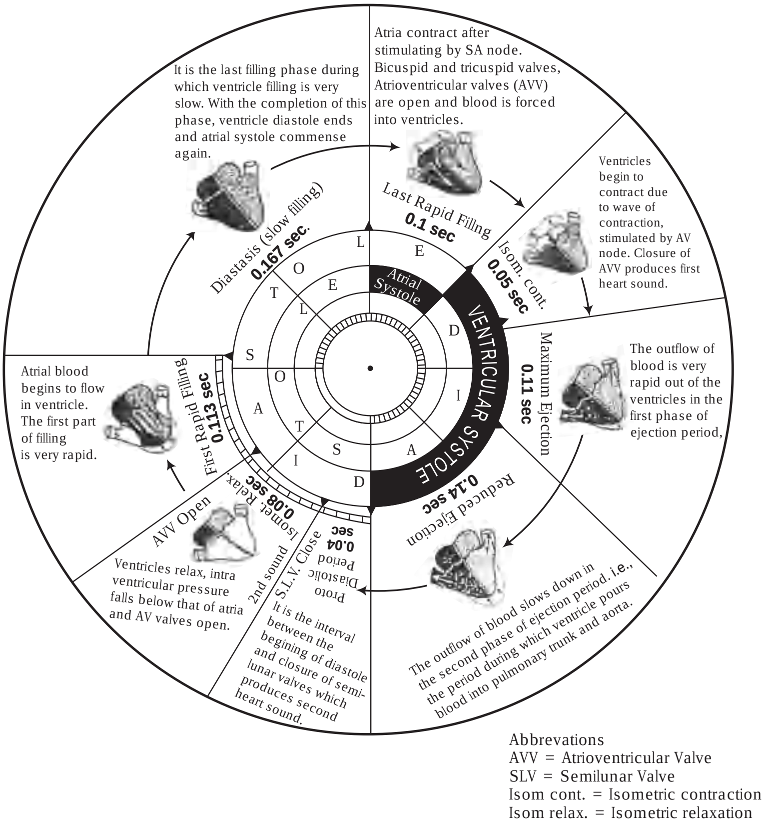
Components of heart's conducting system

Cardiac Cycle

It is the event during which one heartbeat or one cycle of contraction and relaxation of cardiac muscle occurs.

The time of cardiac cycle is in reverse ratio of the rate of heartbeat. In man, the heart rate is about 72 times/min, therefore time of a cardiac cycle is 60/72 = 0.8 sec approx.

Time Taken	Atria		Ventricle	
	Systole	Diastole	Systole	Diastole
	0.1 sec	0.7 sec	0.3 sec	0.5 sec



Cardiac cycle

Heart Sounds

The beating of heart produces characteristic sounds which can be heard by placing the ear or stethoscope against the chest. The two sounds are produced per heartbeat, **i.e.,** 'lubb' and 'dubb'.

Differences between First and Second Heart Sounds

First Heart Sound	Second Heart Sound
It is produced by the closure of bicuspid and tricuspid valves.	It is produced by the closure of aortic and pulmonary semilunar valves.
It is low pitched, less loud and of long duration.	It is higher pitched, louder and of short duration.
It lasts for 0.15 sec.	It lasts for 0.1 sec.

Heartbeat

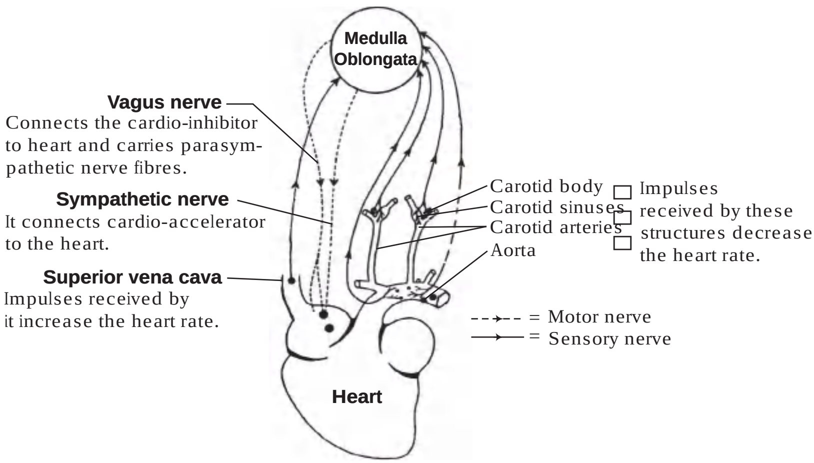
It is the rhythmic contraction and relaxation of the heart. Each heart beat includes a **contraction phase** (systole) and a **relaxation phase** (diastole) to distribute and receive blood to and from the body.

Adult healthy heart beats 72 times per minute (average) to pump approximately 5 litres of the blood.

Regulation of Heartbeat

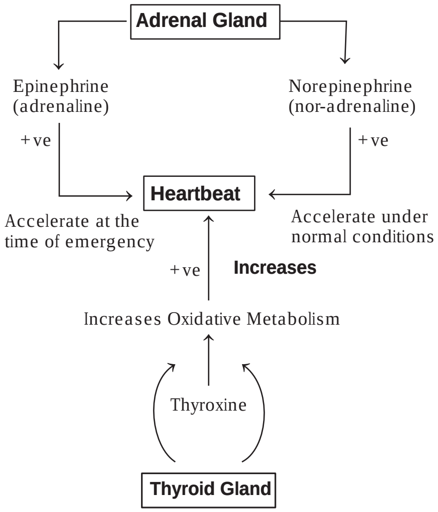
The rate of heartbeat is regulated by two mechanism

(a) **Neural regulation** Medulla oblongata is the cardiac centre which is formed of cardio-inhibitor and cardio-accelerator parts. They decrease and increase the rate of heartbeat respectively.



Neural regulation of heartbeat

(b) **Hormonal regulation** Hormones secreted by the medulla region of adrenal gland help in regulating the heartbeat.



Hormonal regulation of heartbeat

Cardiac Output

It is the amount of blood pumped by heart per minute

Cardiac output = Normal heart rate of an adult per minute × Amount of blood pumped by heart per minute

= 72 per minute × 70 mL

= 5040 mL per minute (5 L/min).

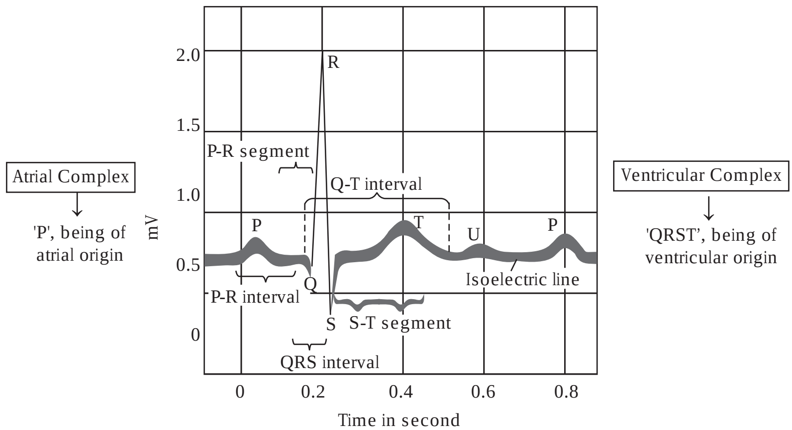
Electrocardiogram (ECG)

It is a graphic record of the electric current produced by the excitation of the cardiac muscles.

Electrocardiograph It is the machine by which the electrocardiogram is recorded.

Waller (1887) first recorded the ECG, but **Einthoven** (1903) studied ECG in detail and got Nobel Prize in 1924 for the discovery of electrocardiography. He is also considered 'Father of Electrocardiography'.

A human electrocardiogram shows the following 5 consecutive waves, i.e., P Q R S T



Reading an ECG

There are two isoelectric periods in ECG

(a) The shorter one, between P and Q.

(b) The longer one, between S and T.

Waves involved in ECG are described below

(i) **P-wave** Represents atrial depolarisation,impulse is originating at SA node, there is no defect of conduction.

(ii) **Q-wave** Caused by the activity of septum. It is small, negative, often inconspicuous deflection.

(iii) **R and S-wave** R is the most constant and conspicuous wave having tallest amplitude, represents first positive deflection during ventricular depolarisation, 'S' is downward deflection, constant and inconspicuous.

(iv) **T-wave** Broad, smoothly rounded deflection, caused by the contraction of the basal part of ventricles, represents ventricular repolarisation.

(v) **U-wave** This wave is often seen just after the T-wave. It is possibly due to slow repolarisation of the intraventricular conducting system.

Significance of ECG

Significance of different intervals involved in ECG

- **R-R interval** Rhythmical depolarisation of ventricles.
- **P-P interval** Rhythmical depolarisation of atrium.
- **P-R interval** Measures conduction time of the impulse from SA node to the ventricles. It varies from 0.13-0.16 sec.
- **Q-R-S interval** Measures total ventricular depolarisation time. It varies from 0.08-0.1 sec.
- **Q-T interval** Measures the ventricular total systolic time. It is about 0.36 sec.
- **T-P interval** Measures the diastolic period of the heart.

Abnormalities in ECG and their significance

(i) **Inverted P-wave** Indicates that SA node fails to initiate the impulse and atrial muscles depolarised by the impulse originating in AV node.

(ii) **Enlarged P-wave** Enlargement of the atria.

(iii) **Absent Q-wave** Infants suffering from congenital patency of the septum.

(iv) **Abnormal T-wave** Serious myocardial damage, cardiac hypoxia.

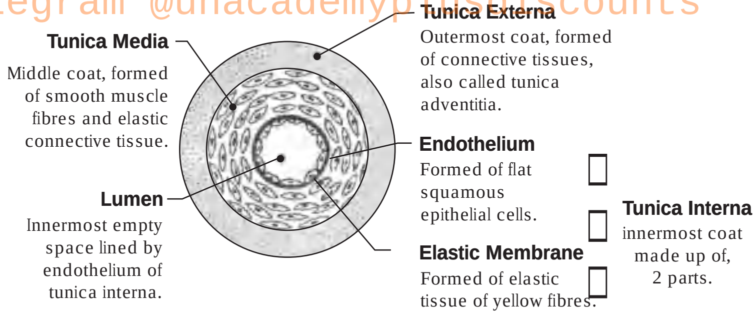
(v) **Enlarged P-R interval** Inflammation of atria and AV node.

(vi) **Repressed S-T segment** Heart muscles receive insufficient oxygen.

Blood Vascular System

It consists of a system of vessels that supply the blood throughout the body. Oxygenated and deoxygenated blood is transported to different body parts through different vessels namely **arteries** and **veins**, respectively.

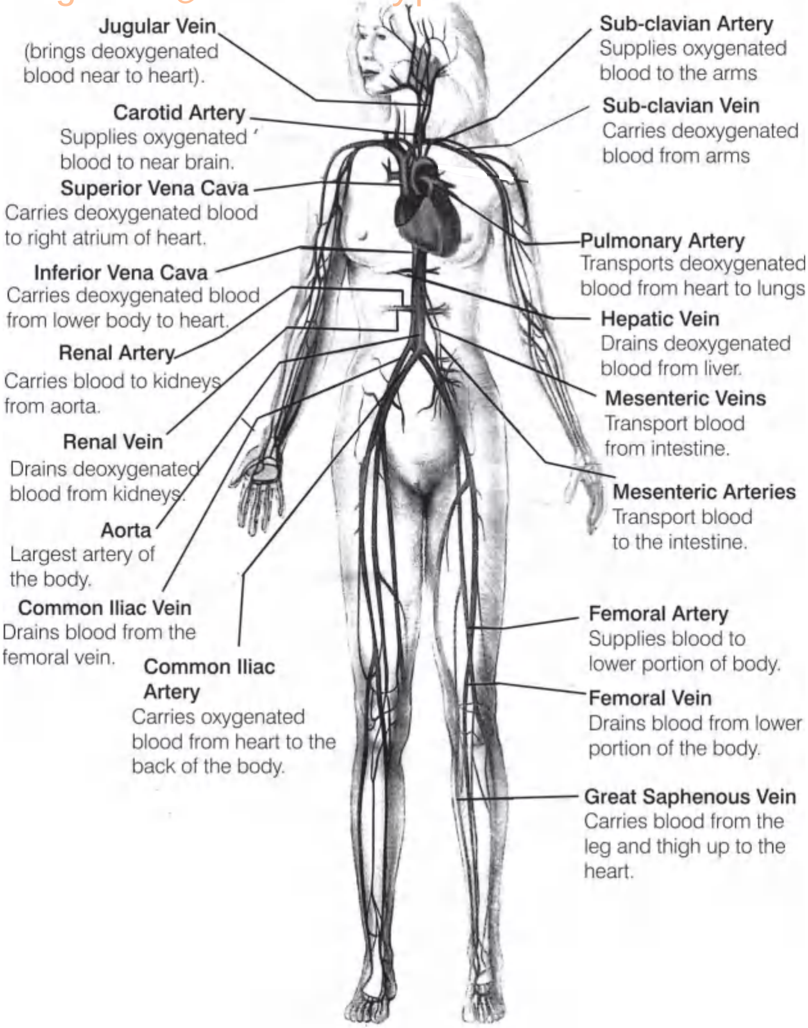
The walls of artery and veins consist of 3 coats as follows



TS of artery and veins

Arteries	Veins
They distribute blood from the heart to the different parts of the body.	They collect blood from different parts of the body and pour it into the heart.
Tunica media is thick, having more muscle fibres.	Tunica media is thin, having fewer muscle fibres.
Tunica interna has strong elastic membrane and more elongated endothelial cells.	Tunica interna has simple, elastic membrane and elongated endothelial cells.
The walls of the arteries are thick and muscular.	The walls of the veins are thin and non-muscular.
Arteries are not collapsible as they have thick walls.	Veins are collapsible because they have thin walls.
Arteries have no valves.	Veins have valves which prevent backward flow of blood.
The flow of the blood is fast as the blood in them is under great pressure.	The flow of blood in veins is not so fast because the blood in veins is under low pressure.
Except the pulmonary arteries, all the arteries carry oxygenated blood.	Except pulmonary veins, all the veins carry deoxygenated blood.

Some Major Arteries and Veins of Human Body



Portal System

It is a part of venous circulation which is present between the two groups of capillaries, **i.e.,** it starts in capillaries and ends in capillaries.

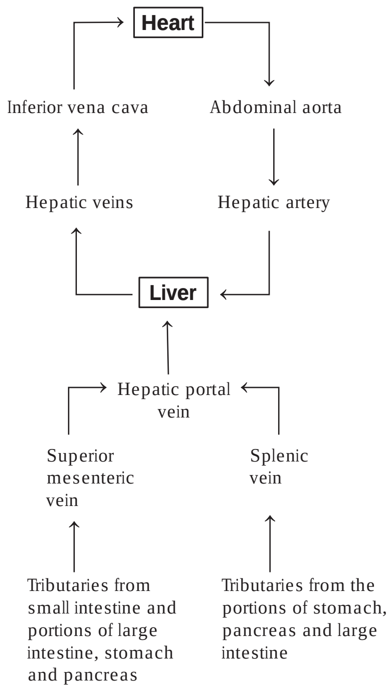
Portal vein It is the vein that drains blood into organs other than heart. This vein along with other small veins constitutes a portal system.

1. Renal Portal System

This system supplies blood from the posterior region of the body to the kidneys by renal portal vein to remove the waste products before sending it to the heart. It is present in fishes and amphibians, reduced in reptiles and birds, and is absent in mammals.

2. Hepatic Portal System

The hepatic portal system or portal venous system consists of numerous veins and tributaries, including the hepatic portal vein.



Significance of Hepatic Portal System

(i) Proper action of various drugs on the body by activating them by liver before reaching to other organs.

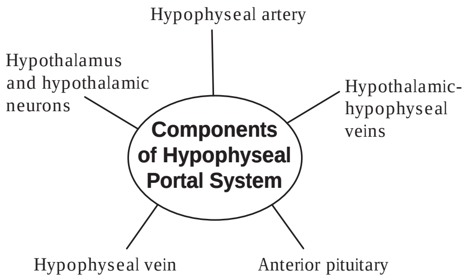
(ii) Takes most of the absorbed nutrients from digestive tract to liver for their processing.

(iii) Neutralise many toxic materials absorbed from digestive tract.

(iv) Venous drainage from the pancreas and spleen.

3. Hypophyseal Portal System

This system carries blood from the hypothalamus of the brain to the anterior lobe of pituitary gland. It allows the endocrine communication between the two structures.



Significance of Hypophyseal Portal System

(i) It allows a fast communication between pituitary gland and hypothalamus.

(ii) The fenestral structure of the hypophyseal portal system needs only a small amount of hormones to tolerate a rapid exchange between two structures.

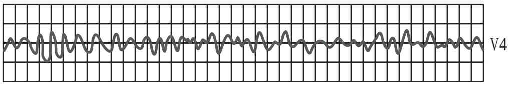
Disorders of Circulatory System

(i) **Angina** It is also called **angina pectoris** means chest pain. In this disease, enough oxygen does not reach the heart muscles. The patient experiences pain in chest.

(ii) **Arteriosclerosis** It refers to the hardening and loss of elasticity of the arteries. In arteriosclerosis, calcium salts precipitate with the cholesterol which forms plaques. Calcification of the plaques makes the walls of the arteries stiff and rigid. The affected arteries lose their elasticity and their walls may get ruptured. The blood coming out of the ruptured walls may clot and block the blood flow which further may lead to heart attack.

(iii) **Coronary Artery Disease** (CAD) **or Atherosclerotic heart disease** It is the deposition of fatty substances specially cholesterol and triglycerides in the tunica interna and smooth muscles of arteries. Such a deposition is called **atheromatous plaque** which deforms the arterial wall. These plaques reduce the lumen of artery which interfere with the blood flow to the heart. This may result in heart stroke or heart attack.

(iv) **Fibrillation** It is a condition in which the heart muscles contract very rapidly, but in uncoordinated fashion. There are atrial and ventricular fibrillations. Ventricular fibrillation is life threatening unless it can be stopped by defibrillation.

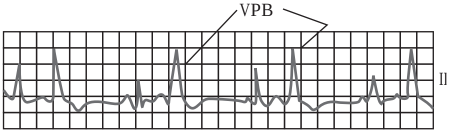


Ventricular fibrillation

(v) **Heart attack** (Myocardial infarction) It is the death of a part of heart muscle following cessation of blood supply to it. It is an acute heart attack. The heart muscles suddenly get damaged by inadequate blood supply.

(vi) **Heart failure** It is the condition when heart does not pump blood effectively enough to meet the need of the body. It is sometimes called congestive heart failure because, lung congestion is one of the main symptom of this disease.

(vii) **Ventricular premature beat or extra-systole** The series of ventricular premature beat or extra-systole are shown in the figure given below. Sometimes, a portion of the myocardium becomes irritable and **ectopic beat** occurs before the **expected next normal beat**. This ectopic beat causes **transient** interruptions of the **cardiac rhythm**. This type of ectopic beat is known as **ventricular extra-systole or premature beat**.



Ventricular premature beat

19

Excretory Products and Their Elimination

Excretion

It is the elimination of metabolic waste products from the animal body to regulate the composition of the body fluids and tissues.

Various types of metabolic waste (excretory) products in animals are nitrogenous waste material, mineral salts, vitamins, hormones, etc.

Excretory Products

Depending upon the type of nitrogenous waste excreted, **animals are of three types**

1. **Ammonotelic** Ammonotelism involves the excretion of ammonia, occurs in aquatic animals as ammonia is highly toxic and highly soluble in water, e.g., protozoans, sponges, tadpole, etc.
2. **Ureotelic** Ureotelism involves the excretion of urea, occurs in semi-aquatic animals as urea is less toxic and less solube in water, e.g., cartilaginous fishes, frogs, toads, mammals, etc.
3. **Uricotelic** Uricotelism is the excretion of uric acid, occurs in animals living in dry conditions to conserve water in their bodies, uric acid crystals are non-toxic and almost insoluble in water, e.g., land crustaceans, land snails, birds, etc.

Other excretory products in different animals include

(i) **Allantoin** is the oxidation product of uric acid. The name given to this compound is because of the fact that it is excreted through the extraembryonic membrane allantois.

(ii) **Hippuric acid** is seen among the excretory products only when benzoic acid is present in diet. This benzoic acid reacts with glycine to form the hippuric acid. It is present in traces in human urine.

(iii) **Amino acids** are excreted in certain invertebrates like **Unio**, **Limnaea** (molluscans) and **Asterias** (echinoderm). These animals are called aminotelic and the phenomenon is called **Aminotelism**.

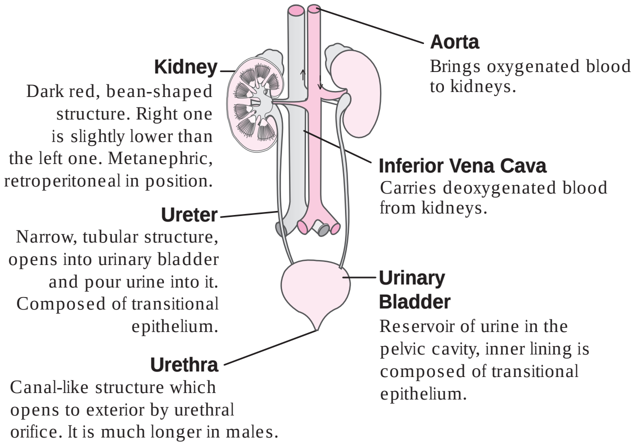
(iv) **Guanine** is the excretory material of spiders. The mode of formation of guanine is not clear. It is excreted in almost solid form.

(v) **Creatine** is seen as excretory product in foetus, pregnant and the lactating women. It is most probably associated with the processes of histolysis and histogenesis going on in above written examples.

(vi) **Creatinine** is the end product of creatine metabolism.

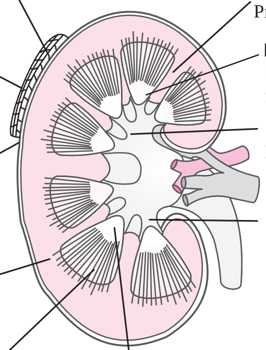
Human Excretory System

It functions to remove waste products from the human body. This system consists of specialised structures and capillary networks that assist in the excretory processes. It includes two kidneys (possessing its functional unit, the nephron), two ureters, urinary bladder and urethra.

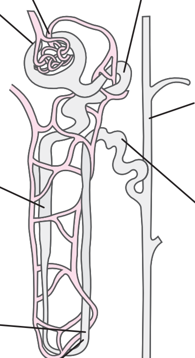


Human urinary system

Kidney



Longitudinal section of kidney



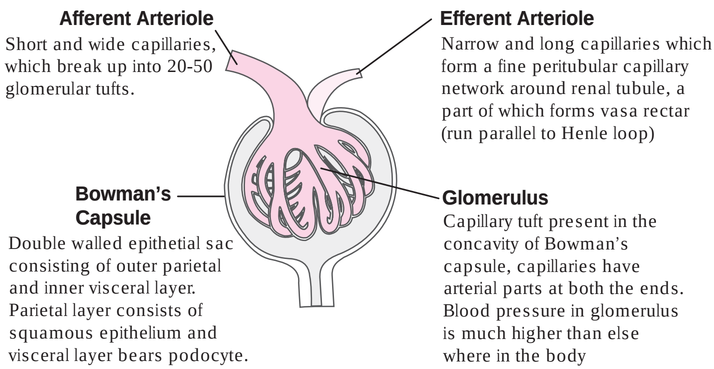
Nephron showing blood vessels, duct and tubule

Types of Nephrons

On the basis of location and size, nephrons are of two types

(i) **Cortical nephrons** These nephrons mainly lie in the renal cortex; form about 85 per cent of total nephrons and the loop of Henle is too short and extends only very little into the medulla.

(ii) **Juxtamedullary nephrons** These nephrons lie in the inner margin of cortex; form about 15 per cent of total nephrons and the loop of Henle is very long and runs deep into the medulla.



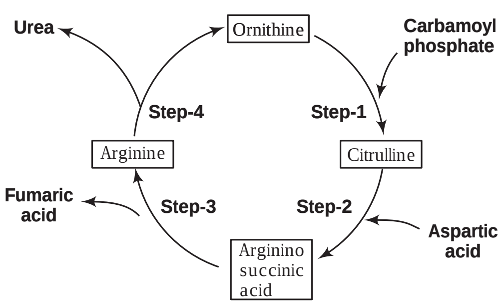
Malpighian body

Urine Formation

Urine formation in human beings occurs in following two steps

1. Urea Formation within the Liver

The centre process of urea formation takes place with the cycle called **ornithine cycle** or **Kreb-Henseleit cycle**.



Urea cycle

2. **Formation of Urine by the Kidney**

It can be divided into following three sub-categories

(i) Glomerular filtration or ultrafiltration

(ii) Selective reabsorption

(iii) Tubular secretion

1. Ultrafiltration

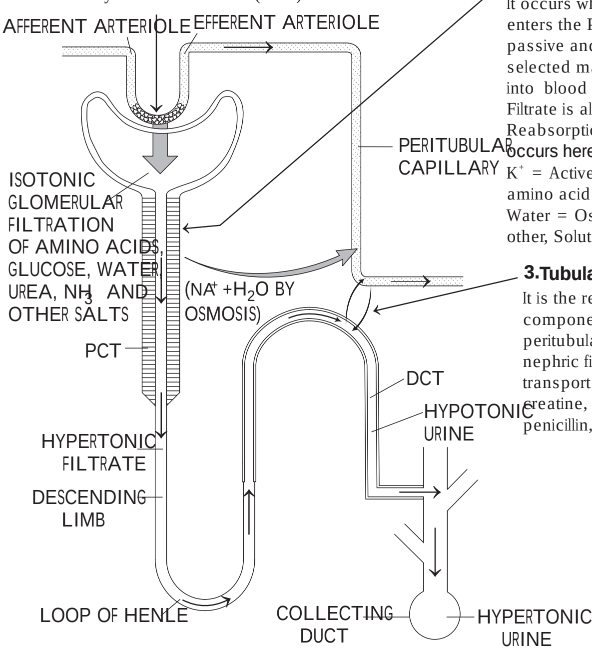
Carried out due to very high pressure in the glomerular capillaries due to its semipermeable membrane. Glomerular filtrate contains large amount of water and essentially all constituents of blood except blood cells, proteins, pigments, certain drugs (if present in blood), etc. It is a complete passive force and main force for filtration is Glomerular Hydrostatic Pressure (GHP).

2. Tubular Reabsorption

It occurs when glomerular filtrate enters the PCT. It involves both passive and active transport of selected material from the filtrate into blood across tubular epithelium. Filtrate is almost isotonic to plasma. Reabsorption of various components occurs here as follows Na^+ and K^+ = Active transport Glucose and amino acids = Passive transport Water = Osmosis , Cl^-, urea and other, Solutes = Simple diffusion

3. Tubular Secretion

It is the removal of selected components from the blood of the peritubular blood capillaries into the nephric filtrate. It involves the active transport of ammonia, urea, uric acid, creatine, hippuric acid, drugs like penicillin, etc.



Processes involved in urine formation by kidney

Glomerular Filtration Rate (GFR)

It is the quantity of glomerular filtrate formed per minute in all the nephrons of both kidneys. In normal person, GFR is 125 mL/min or about 180 litres per day.

Filtration Fraction

It is the fraction of the renal plasma which becomes the filtrate. It is the ratio between the renal plasma flow and glomerular filtrate which is expressed in percentage. The normal filtration fraction varies from 15-20%.

$$\text{Filtration fraction} = \frac{\text{Glomerular filtration rate}}{\text{Renal plasma flow}} \times 100$$

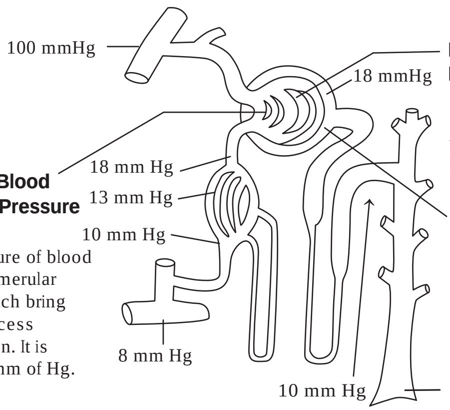
$$= \frac{125}{650 - 700}$$

$$= 17.8 - 19.2\%$$

(The renal plasma flow is about 650-700 mL/m or about 940 litres/day.)

Pressures in the Renal Circulation

During renal circulation, pressure varies at different regions of nephron as follows



Pressures at different points in the vessels and tubules of nephron

Effective Filtration Pressure (EFP)

It is the total pressure that promotes filtration (as both BCOP and CHP oppose the process of filtration).

It can be calculated as

$$\text{EFP} = \text{GHP} - (\text{BCOP} + \text{CHP})$$

$$= 60 \text{ mmHg} - (30 \text{ mmHg} + 18 \text{ mmHg})$$

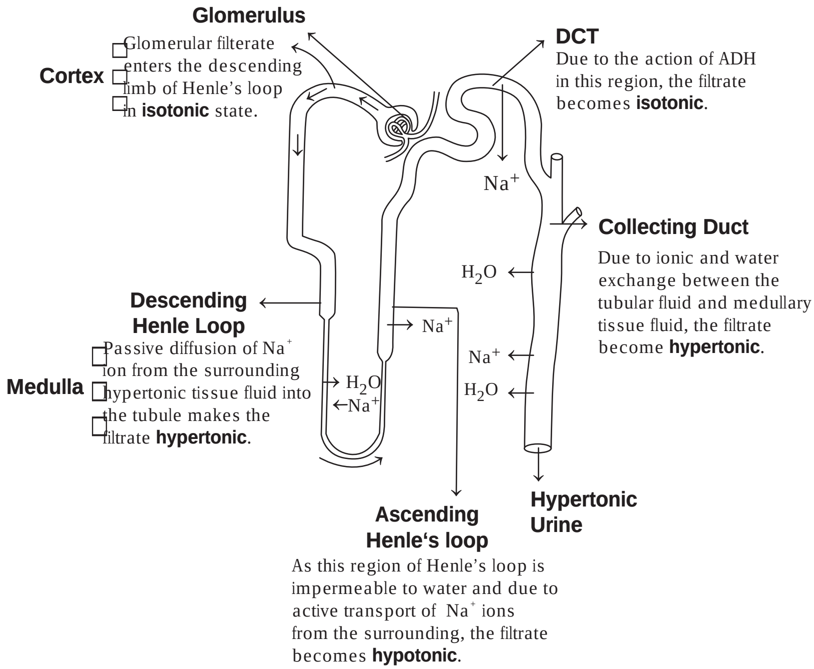
$$= 12 \text{ mmHg}$$

Thus, a pressure of about 12 mmHg causes a normal amount of blood plasma to filter from the glomerulus into the Bowman's capsule.

Mechanism of Filtrate Concentration

Mammals have the ability to produce a concentrated or hypertonic urine. The different phases through which the urine becomes hypertonic in relation to body fluids have been studied by **Wirz** and associates (1951) and later on by **Bray** (1960).

It is a complex process and related to the anatomical distribution of tubules along with Na^+ ion concentration at different depths from the cortex towards the medulla of kidney.



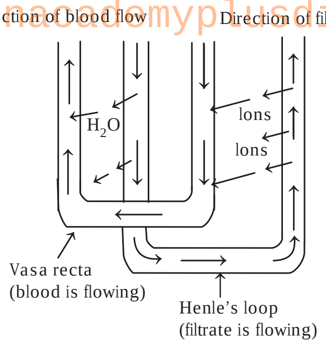
Mechanism of tubular reabsorption and secretion

Counter-current Mechanism

The theory of countercurrent mechanism was given by **Berliner et. al.** (1958). According to this theory, the role of vasa recta is very important in urine concentration.

The flow of the filtrate in the two limbs of vasa recta is in opposite direction similarly as in the two limbs of Henle's loop.

The arrangement of vasa recta and Henle's loop can be seen as follows



Arrangement of vasa recta and Henle's loop

As the descending limb of vasa recta gradually enters deep into the medulla, some water diffuses out from it and more ions are taken in. In the ascending limb, on the other hand, the diffusion process is just in opposite direction, thus isotonic blood leaves the medulla.

The counter exchange reduces the rate of dessipation, thus reduces the rate at which the countercurrent multiplier must pump Na^+ to maintain any given gradient.

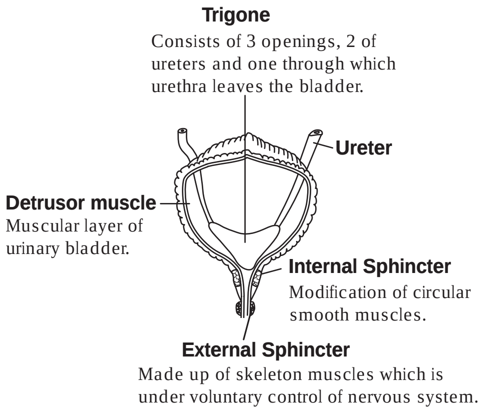
Regulation of Kidney Function

The functions of kidneys are regulated by following three mechanisms

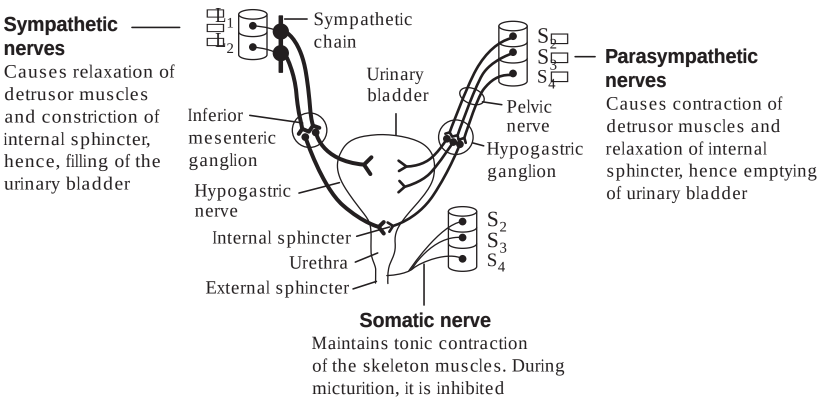
1. **Control by JGA** Juxta Glomerular Apparatus works through RAAS, i.e., renin-Angiotensin-Aldosteron-system when the blood pressure is decreased. In response, Renin enzyme is released from JG cells.Rennin acts upon plasma protein angiotensinogen and convert it to a protein angiotension II. Angiotensin II increases blood pressure by constricting the arterioles, by increasing water and NaCl reabsorption in PCT and by stimulating adrenal gland to secrete aldosterone which work on DCT for the same cause.
2. **Control by ANF** Atrial natriuretic factor opposes the RAAS. ANF is released by atrial walls in response to increased blood pressure. It inhibits the release of renin from JGA, reduces aldosterone release from adrenal gland and inhibit NaCl reabsorption by collecting duct.
3. **Control by ADH** Antidiuretic hormone is produced by hypothalamus and secreted by posterior lobe of pituitary gland. When osmolarity of blood increases above 300 mos mL^{-1}, in response, osmoreceptors of hypothalamus promote thirst.

Micturition

The expulsion of urine from the urinary bladder is called micturition. It is a reflex process, but in grown up children and adults, it can be controlled voluntarily.



The urinary bladder and the internal sphincter are supplied by both sympathetic and parasympathetic nerves whereas, the external sphincter is supplied by the somatic nerve.



Nerve supply to urethra and urinary bladder

Role of other Organs in Excretion

Apart from kidneys, some other organs are also involved in the process of excretion they are as follows

(i) **Lungs** These help in the elimination of CO_2 (~18 L/day) and water as water vapour (~400 mL/day.)

(ii) **Liver** It plays a vital role in elimination of urea and bile containing substances.

(iii) **Skin** It excretes NaCl, glucose and fats with the help of sweat and sebaceous glands.

(iv) **Intestine** It eliminates salts, glucose and minerals like calcium and iron.

(v) **Salivary glands** It helps in the excretion of heavy metals.

Disorders of Excretory System

(i) **Glomerulonephritis** It is also called Bright's disease which is caused by the injury to the kidney, by congenital kidney defects or by an allergic reaction to the toxins of bacteria such as **Streptococcus**. The glomeruli become inflamed and engorged with blood. Proteins and red blood cells enter the filtrate.

(ii) **Kidney stone** The stone in the kidney gives rise to severe colic pain starting in the back and radiating down to the front of the thigh. It may come down in the bladder and would cause frequent and painful urination and blood in urine.

(iii) **Pyelonephritis** It is inflammation of the renal pelvis and the medullary tissue of the kidney. It is usually caused by bacteria that reaches the kidney by the way of urethra and ureter. It usually affects countercurrent mechanism in the medulla. Affected person has inability to concentrate his urine.

(iv) **Renal tubular acidosis** In this condition, the person is unable to secrete the adequate quantities of hydrogen ions and as a result, large amount of sodium bicarbonate are continuously lost into the urine.

Artificial Kidney

In patients with damaged kidneys, urea and other nitrogenous wastes are removed from the blood by an artificial kidney. The process is called haemodialysis. Dialysis works on the principle of diffusion of solutes and ultrafiltration of fluids across a semipermeable membrane. The pores of the membrane allow the passage of nitrogenous wastes in dialysing fluid based on concentration gradient. The blood is thus cleared of the nitrogenous wastes.

Renal Transplantation

It is a process of transplanting a functional and compatible kidney into a patient with kidney failure. The donor should be a close relative of the patient to avoid rejection by the immune system. Some special drugs are also used to suppress the immune system in order to prevent rejection.

20 Locomotion and Movement

Locomotion

It is the self-propelled movement or the ability of an individual to move from one place to another. An animal cannot locomote without movement.

Movement

It refers to the change of position that does not entail the change of location. Movements are brought about by internal or external forces.

The movement of a non-living object is induced (due to external force), while the movements of living things are autonomic (self-sustained).

Following types of movements are shown by the different cells of the human body

Types of Movements

Amoeboid
Affected by pseudopodia and cytoskeletal elements like microfilaments, occurs in macrophages and leucocytes in blood.

Ciliary
Occurs in most of internal tubular organs, which are lined by ciliated epithelium, e.g., trachea, female reproductive tract,etc.

Muscular
It is carried by the contractive property of muscles. Movement of limbs, jaws, tongue, etc., are muscular movements.

Flagellar
Propulsion of flagella helps the human sperms to move towards the ovum.

Muscle

It is a specialised contractile tissue that brings about the movement of different body parts. It is mesodermal in origin and contributes to 40-50% of the body weight.

Based on their location, muscles are of 3 types**, i.e.,** striated, non-striated and cardiac.

Striated	Non-striated	Cardiac
They are present in the limbs, body walls, tongue, pharynx and beginning of oesophagus.	They are present in the oesophagus (posterior part only), urinogenital tract, urinary bladder, vessels, iris of eye, dermis of skin and arrector pili muscles of hair.	They are present in the wall of the heart, pulmonary veins and superior vena cava.
Cylindrical.	Spindle-shaped.	Cylindrical.
Fibres unbranched.	Fibres unbranched.	Fibres branched.
Multinucleate.	Uninucleate.	Uninucleate.
Bounded by sarcolemma.	Bounded by plasmalemma.	Bounded by sarcolemma.
Light and dark bands present.	Light and dark bands absent.	Faint light and dark bands present.
No oblique bridges and intercalated discs.	No oblique bridges and intercalated discs.	Oblique bridges and intercalated discs present.
Nerve supply from central nervous system.	Nerve supply from autonomic nervous system.	Nerve supply from the brain and autonomic nervous system.
Blood supply is abundant.	Blood supply is scanty.	Blood supply is abundant.
Very rapid contraction.	Slow contraction.	Rapid contraction.
They soon get fatigued.	They do not get fatigued.	They never get fatigued.
Voluntary.	Involuntary.	Involuntary.

Birds and mammals have **two kinds** of **striated muscle fibres**, in their **skeletal muscles**, **i.e.,** red (or slow) and white (or fast) muscle fibres.

Red and White Muscle Fibres

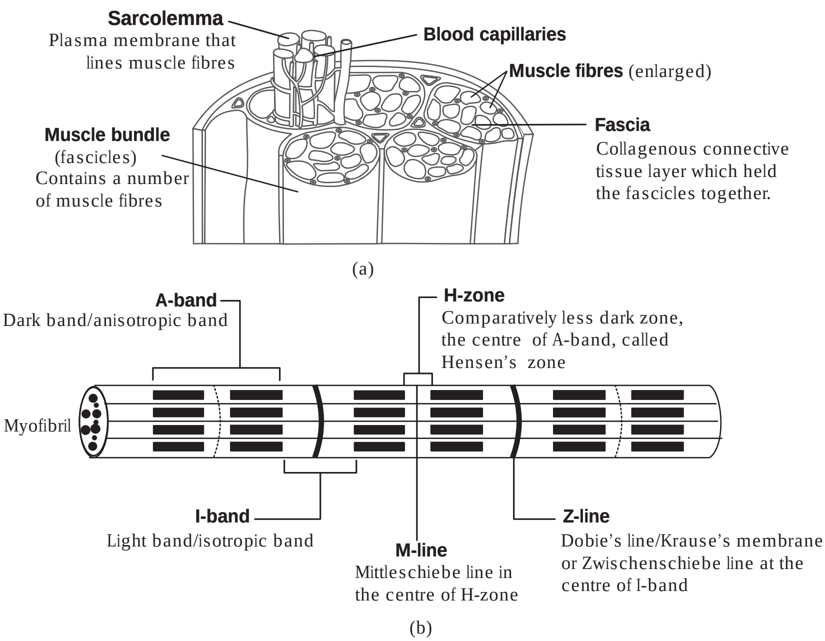
Red muscle fibres are those striated muscle fibres, which are thinner but dark red in colour. The dark red colour is due to the accumulation of **myoglobin**. These are rich in mitochondria. They perform slow contractions. Because of this, they are also known as **slow muscle fibres**. However, they can perform sustained contraction over long periods without getting fatigued. The reason for this is non-accumulation of lactic acid.

Red muscle fibres are more abundant in athletes like long distance runners and cyclists. Extensor muscles present on the back of human body are rich in red muscle fibres because these are required to undergo prolonged contraction for the maintenance of erect posture against the force of gravity. Avial flight muscles used in prolonged slow flying (**e.g.,** kite) are also rich in red muscle fibres.

White muscle fibres are a type of striated muscle fibres which are thicker and of pale-yellow colour. These muscle fibres do not contain myoglobin and mitochondria are fewer in number. These muscle fibres contract very quickly, but for short durations that's why these are also termed as **fast muscle fibres**.

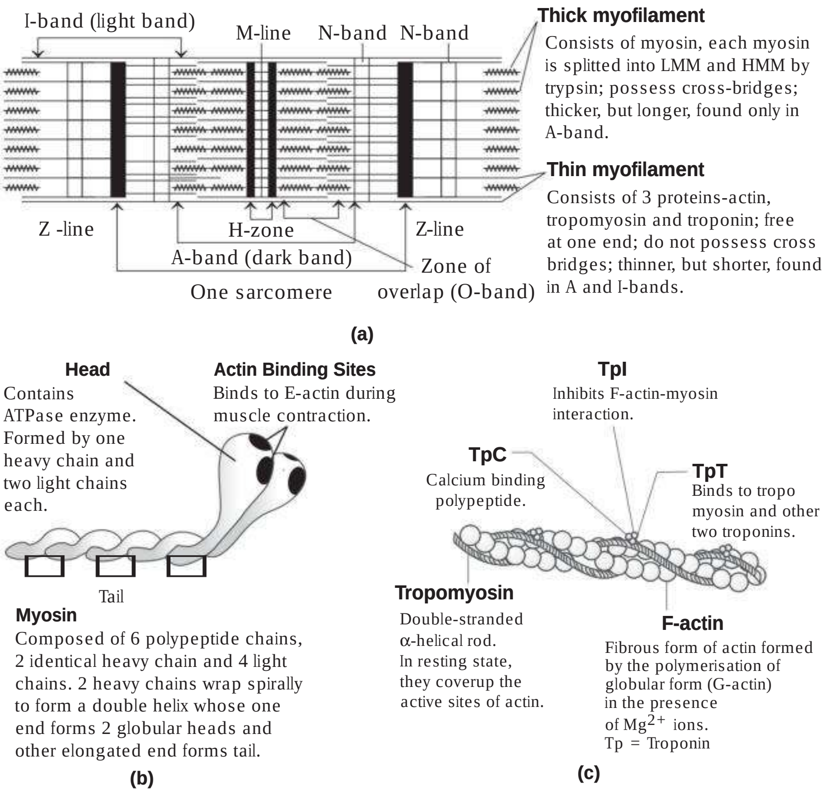
These fibres mostly perform anaerobic glycolysis for the liberation of energy. Therefore, these fibres get fatigued quickly. These muscle fibres are more abundant in short distance runners and other athletes. Muscles which move our eyeballs are rich in white fibres. Similarly, **avial flight** muscles used in short distance, but fast flying (**e.g.,** sparrow) have white fibres only.

Structure of Skeletal Muscle



(a) Muscle bundles and Muscle fibres
(b) Structure of myofibril

The part of myofibril between two successive Z-lines is **sarcomere** (functional unit of myofibril).

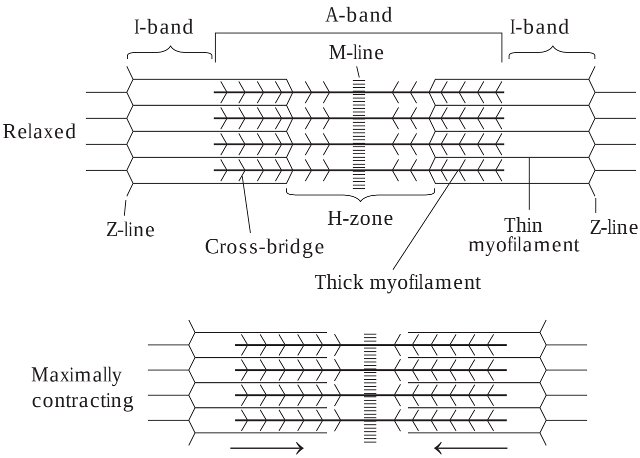


Muscle structure : (a) A sarcomere (enlarged) (b) Myosin filament (c) Actin filament

Mechanism of Muscle Contraction

Sliding filament theory proposed by **Huxley** and **Hanson** (1954) best explains the mechanism of muscle contraction. **The essential features of this theory are**

- During the process of muscle contraction, the thin myofilaments show sliding inward towards the H-zone.
- The sarcomere shortens, without changing the length of thin and thick myofilaments.
- The cross bridges of the thick myofilaments connect with the portions of actin of the thin myofilaments. These cross bridges move on the surface of the thin myofilaments resulting in sliding of thin and thick myofilaments over each other.
- The length of the thick and thin myofilaments does not change during muscle contraction.

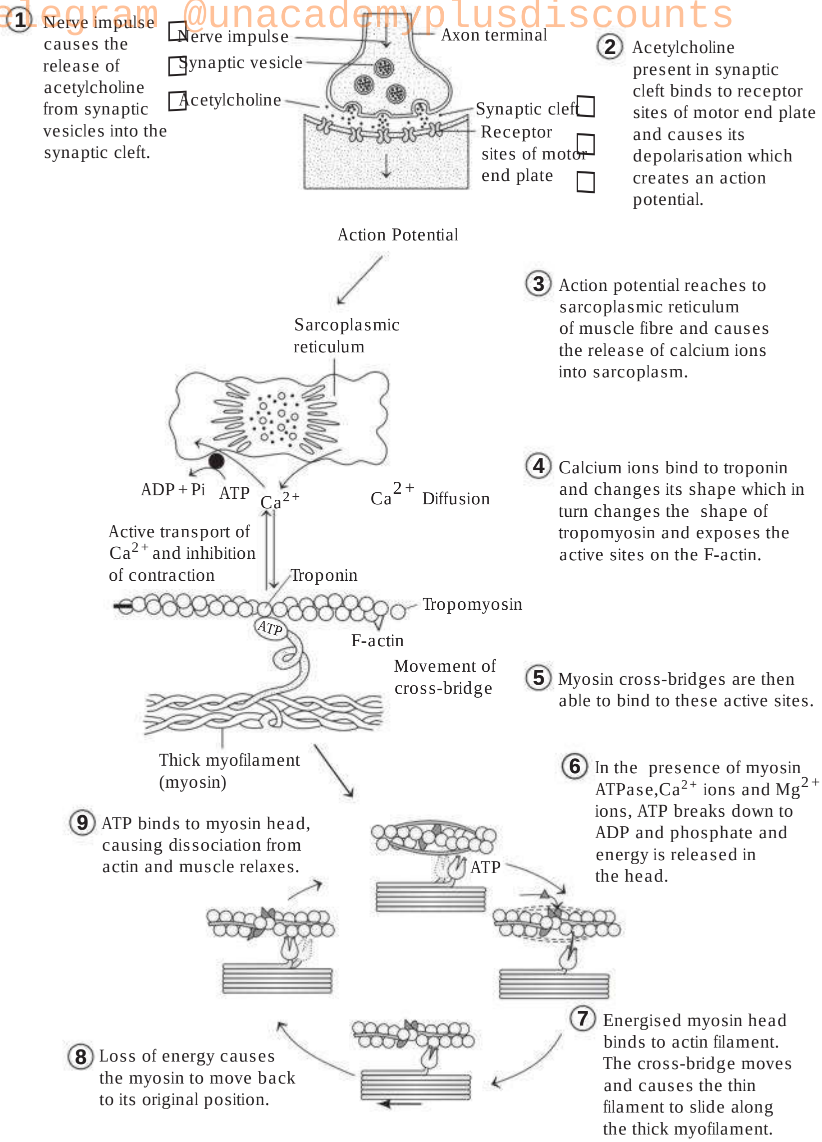


Contraction in a sarcomere of muscle

Electrical and Biochemical Events in Muscle Contraction

These events have been worked out by **Albert Szent Gyorgyi** and others and involve sliding filament procedures as well.

These are as follows



Types of Muscle Contraction

A skeletal muscle contraction may be any of several types.

These are as follows

Types of Muscle Contraction

Isotonic
Tone or tension within a muscle remains the same, but muscle length changes (shortens), producing movement.

Convulsions
Abnormal uncoordinated tetanic contractions of varying groups of muscles.

Tonic
Small number of total muscle fibres in a muscle contract, producing a toutness of muscle rather than a recognisable contraction and movement.

Tetanic
Sustained contraction produced by a series of stimuli bombarding the muscle in rapid succession.

Treppe
Increasingly stronger twitch contractions occur in response to constant-strength stimuli repeated at the rate of about once or twice a second.

Twitch
Quick, jerky contraction in response to a single stimulus.

Isometric
Muscle tension increases, while the muscle length remains the same.

Fibrillation
Individual fibres contract asynchronously, producing a flutter of muscle, but no movement.

Muscle Relaxation

After contraction, the calcium ions are pumped back to the sarcoplasmic cisternae, blocking the active sites on actin myofilaments. The Z-line returns to original position, **i.e.,** relaxation of muscle fibre takes place.

Specialised Muscle Phenomena

Certain specialised phenomena associated with muscles are as follows

All-or-None Law (Bowditch's Law)

It is a principle which states that response of a muscle/nerve to a stimulus is not proportionate to the intensity of stimulus, but is either present in full strength or completely absent.

A single muscle fibre (striated, unstriated or cardiac) does not show any gradation in contraction in relation to the degree to stimulus, **i.e.,** like a nerve fibre, a muscle fibre does not respond to a stimulus till it is equal to or above a minimum (threshold) value.

The degree of contraction also shows independence with the intensity of stimulus. At or above all the threshold value, a muscle fibre will always contract with the maximum force irrespective of the strength of the stimulus.

However, the force of contraction may increase or decrease with the change in pH, temperature, stretching of muscle fibre, etc., though even under such condition increase or decrease in the value of stimulus would not alter the force of contraction. Further, the entire muscle does not follow the all-or-none rule.

Oxygen Debt

It is the extra oxygen required by the body muscles during relaxation or recovery period over the resting state. During strenuous exercise, the requirement of oxygen and hence, energy far exceeds its availability through breathing.

Therefore, other sources are tapped. These include oxygen from oxymyoglobin, dephosphorylation of creatine phosphate, etc. After their exhaustion, the muscles begin to respire anaerobically along with aerobic respiration.

Muscle contraction or activity under anaerobic conditions is termed as **anaerobic contraction**. The lactic acid produced here accumulates in the muscles. When exercise is stopped, the recovery process starts. During recovery, extra oxygen is required for which deep breathing continues.

The extra oxygen (extra to normal aerobic breathing) is used in

(i) Regeneration of oxymyoglobin.
(ii) Oxidation of accumulated lactic acid.
(iii) Restoration of depleted ATP.
(iv) Restoration of creatine phosphate.

Oxygen debt decreases with regular exercise because the regular exercise increases oxymyoglobin content of the muscles and allows sufficient deep breathing during exercise to perform aerobic contractions.

Cori's Cycle

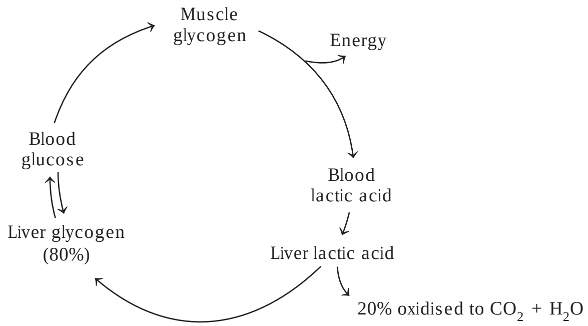
A cyclic process involving the formation of lactic acid in the muscles and regeneration of glycogen from it (in the liver) in order to reduce accumulation of lactic acid in muscles and continued supply of glucose to them.

This cycle was discovered by **Cori**. The lactic acid formed in the muscle passes into the bloodstream and reaches the liver where roughly 4/5 of it is changed to glycogen, while rest 1/5 is oxidised to CO_2 and H_2O.

Afterwards, this glycogen is hydrolysed to form glucose that passes into the bloodstream and reaches the muscles for the liberation of energy and the production of fresh lactic acid.

Importance With the help of **Cori's cycle**, lactic acid is not allowed to accumulate beyond a certain concentration within the muscles.

This protects the neuro-muscular junction which is sensitive to lactic acid. The cycle also replenishes glucose/glycogen in the muscles.



Cori's cycle

Muscle Fatigue

The decrease in the force of contraction of a muscle after prolonged stimulation is called **muscle fatigue**.

Cause A muscle is able to contract for a short time in the absence of oxygen. But, it gets fatigued sooner because in the absence of oxygen, the metabolic products of glycolysis (mainly lactic acid) accumulate around it.

This accumulation leads to muscle fatigue. Normally, pain is experienced in the fatigued muscle. The site of fatigue is the neuromuscular junction.

Rigor Mortis

Just few hours after death, muscles stiffen and become hard. This condition is called rigor mortis. It first appears in lower jaw and then appears in all body muscles. It occurs due to permanent irreversible contraction between actin and myosin, which in turn occurs due to exhaustion of ATP from blood.

Functional Classification of Skeletal Muscles

Type of Skeletal Muscle	Function	Example
Flexors	Muscles which bend one part of the body over the other.	Biceps bending forearm towards upper arm.
Extensors	Muscles which extend or straighten the limbs.	Triceps extending forearm and is antagonous to biceps.
Abductors	Muscles which pull a limb away from the median line.	Deltoides of shoulder.
Adductors	Muscles which bring a limb towards the median line of the body.	Latissimus dorsi which draw the whole forelimb towards the body and is antagonous to deltoides.
Depressors	Muscles which lower some parts.	Depressor mandibularis lowers the lower jaw (similarly pectoralis major is the depressor muscle for the wings of birds).
Elevators	Antagonistic to depressors as they raise a body part.	Masseter which lifts the lower jaw (similarly pectoralis minor is the elevator muscle for the wings of birds).
Pronators	The muscle that turns the palm downward or backward.	Pronator teres in mammalian limbs.
Supinators	Antagonistic to pronator, **i.e.,** turns the palm upward or forward.	Supinator in human forelimbs.
Sphinctors	Decreases the size of an opening and close it.	Pyloric sphincter of alimentary canal.
Dilators	The muscles around the openings, which increase their size and open them. Antagonistic to sphinctors.	Iris.
Ratators	Associated with rotatory movements of a body part.	Pyriformis which raises and rotates the thigh.

Skeletal System

It consists of a framework of bones and cartilages. They form the internal framework (endoskeleton) of the body. Tendons and ligaments are also associated connective tissues of the skeletal system.

Components of Skeletal System

Bone

Hardest tissue, homeostatic reservoir of calcium, magnesium, phosphorus, etc. It is the major component of vertebrate endoskeleton.

Types of Bones

A. **On the basis of shape, there are following categories of bone**

Types of Bones

Long Bones
Possess an elongated shaft (diaphysis) and 2 expanded ends (epiphyses), shaft has a central medullary cavity e.g., femur, ulna, etc.

Short Bones
Broad, short, can be of any shape, e.g., carpals, tarsals, etc.

Pneumatic Bones
Irregular, contain large air spaces which make them light, e.g., sphenoid, ethmoid of skull.

Sesamoid Bones
They are in the form of nodules embedded in tendons and joint capsules, ossification occurs after birth, e.g., patella.

Flat Bones
Resemble shallow plates and form boundaries of certain body cavities, e.g., scapula, ribs, sternum, etc.

Irregular Bones
Completely irregular in shape, e.g., hip bone, vertebral, bones in the base of skull, etc.

B. **On the basis of development, bones are of three types**

Developmental Basis of Bone

Membranous Bones
Ossify from mesenchymal condensations, intra-membranous ossification occurs, e.g., bones of skull, facial bones.

Cartilaginous Bones
Ossify from perforated cartilage models, intra-cartilaginous ossification occurs, e.g., bones of limbs, vertebral column.

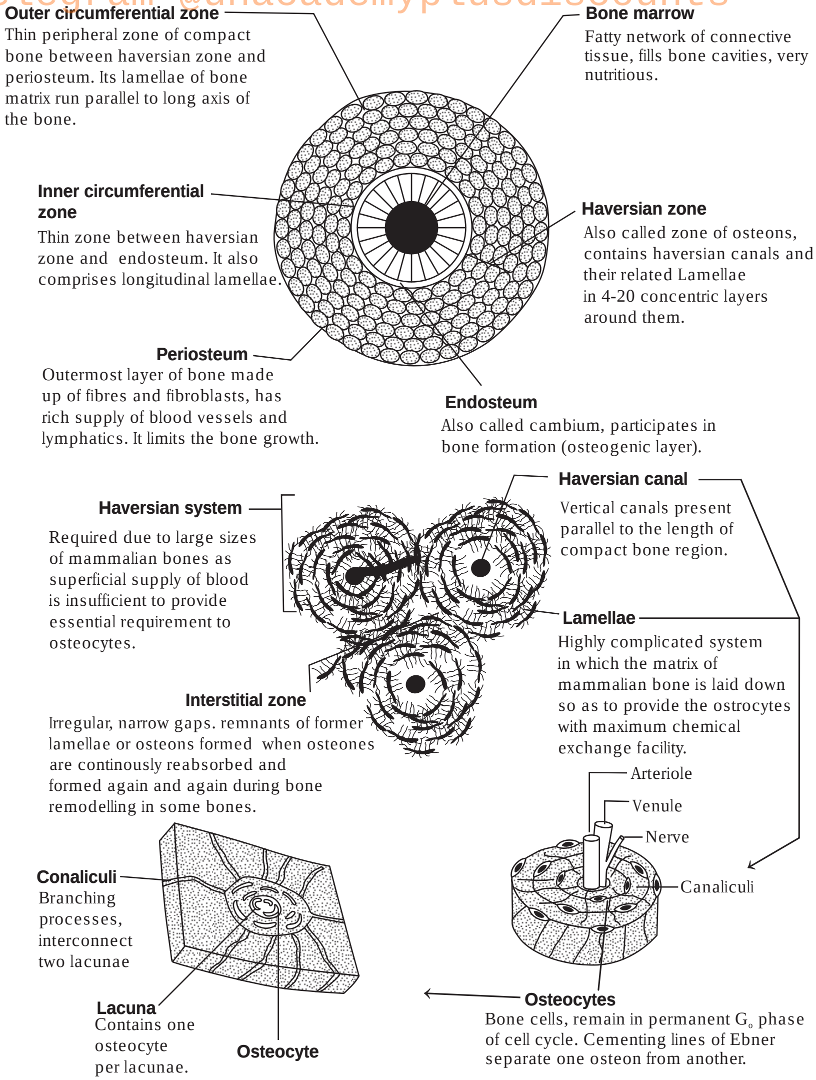
Membrocartilaginous Bones
Ossify partly from cartilage and partly from mesenchymal condensations, e.g., clavicle, temporal, etc.

C. **Based on their histological structure, there are two major types of bone**

(i) **Compact bone** It forms most of the diaphysis (shaft) of long bones and the thinner surfaces of all other bones. Their lamella is surrounded into sets of concentric ring, with each set surrounding a **Haversian** or **central canal**.

(ii) **Spongy bone** It is mainly located in the epiphysis (ends) of long bones. It forms the interior of all other bones. It consists of delicate inconnecting rods or plates of bone called **trabeculae**, which add strength to bone without adding the weight.

Various components of the bone and their arrangements is shown in the figure below



Generalised internal structure of bone

Cartilage

It is a semi-rigid dense connective tissue composed of cells called **chondrocytes** dispersed in a firm gel-like ground substance called **matrix**. It is non-vascular and does not contain blood vessles.

Nutrients are diffused through the matrix enriched with glycosaminoglycans, proteoglycans and macromolecules that interact with collagen and elastic fibres.

Types of Cartilage

Hyaline
It has crystal clear matrix with less fibres, forms articular surfaces at the joints of long bones.

Elastic
It has numerous yellow elastic fibres, found in ear pinna, external auditory meatus, eustachian tube, etc.

Fibrous
It has numerous white fibres, found in pubis symphysis and sterno clavicular joints.

Perichondrium It is a fibrous membrane that surrounds the cartilage. It contains chondroblasts with the potential of cartilage formation. Articular cartilage that covers the bones of movable joints is devoid of perichondrium.

Types of Skeletal System

On the basis of the position of the skeletal structures in the body, **the endoskeleton is of two types**

Skeletal System

Axial Skeleton
Present on the median longitudinal axis of the body. It consists of skull, vertebral column, sternum and ribs.

Appendicular Skeleton
Present at the lateral sides which extend outwards from the principal axis. It consists of pectoral and pelvic girdle and bones of arms and legs.

1. Axial Skeleton

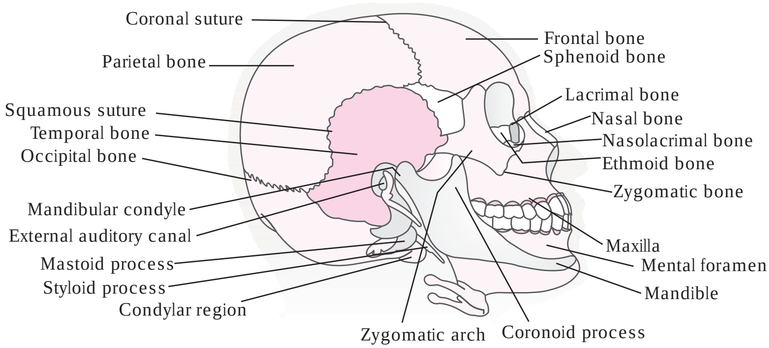
It consists of 80 bones. **The various components of axial skeleton are as follows**

Bones		Numbers
Axial Skeleton		
Skull		
Braincase		
Paired	Parietal	2
	Temporal	2
Unpaired	Frontal	1
	Occipital	1
	Sphenoid	1
	Ethmoid	1
Face		
Paired	Maxilla	2
	Zygomatic	2
	Palatine	2
	Nasal	2
	Lacrimal	2
	Inferior nasal concha	2
Unpaired	Mandible	1
	Vomer	1

Bones		Numbers
	Total Skull Bones	22
Auditory Ossicles	Malleus (outer)	2
	Incus (middle)	2
	Stapes (inner)	2
	Total Auditory Ossicle Bones	6
Hyoid		1
Vertebral Column		
Cervical vertebrae		7
Thoracic vertebrae		12
Lumbar vertebrae		5
Sacrum		1 (5)
Coccyx		1 (4)
	Total Vertebral Column Bones	26 (33)
Thoracic Cage		
Ribs		24 (12 × 2)
Sternum (3 parts, sometimes considered 3 bones)		1
	Total bones of thoracic cage	25
	Total bones of axial skeleton	80

(I) Skull

The skull of human beings is **tropibasic**, **i.e.**, the eyes are not situated much apart and the brain and eyes are present at different planes in the skull in well-defined sockets. Human skull is **dicondylic**, **i.e.**, with two occipital condyles, which connect the skull with the vertebral column.



Human skull showing its various components

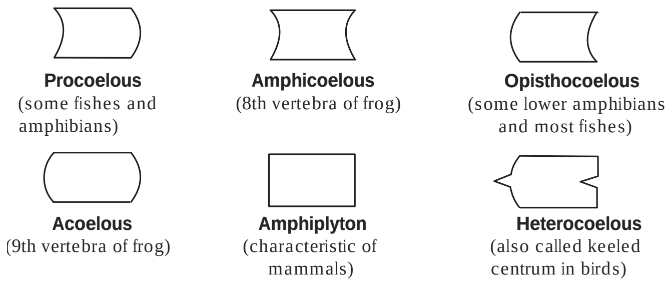
Functions of Skull

- This bony covering protects the brain from injuries.
- The skull bears jaws (craniostylic suspension), which help the animal for cutting and masticating the food.

(II) Vertebral column

It is the main bony region present at the axis of an individual body. Vertebral centrum is the portion which contains the vestiges of notochord. Hence, the centrum is the main identifiable part of a vertebrae.

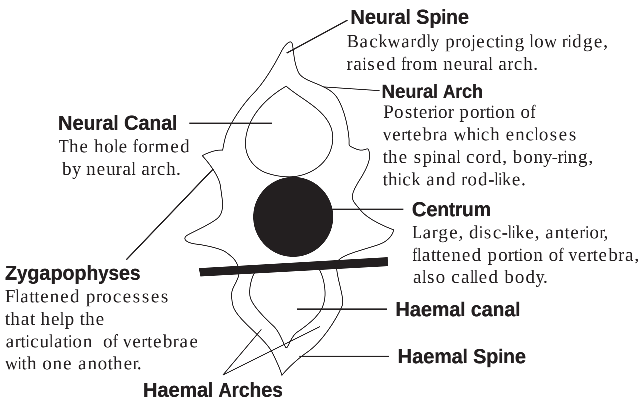
Various types of centrum in different animal groups are as follows



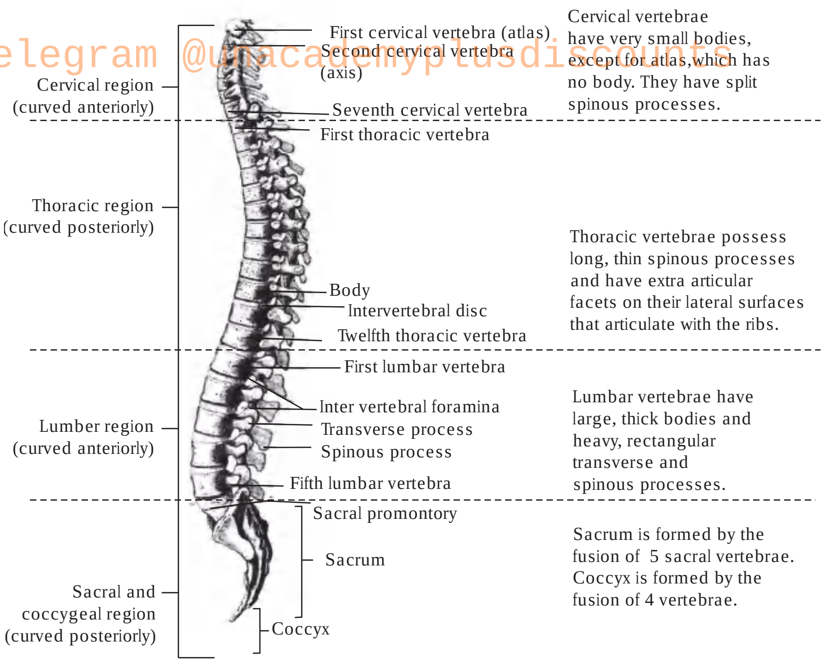
Types of centrum

Structure of a Typical Vertebra

Basic components of a typical vertebrae include neural canal, neural arch, centrum, neural spine and various processes. **These structures in outline diagrammatic view are as follows**



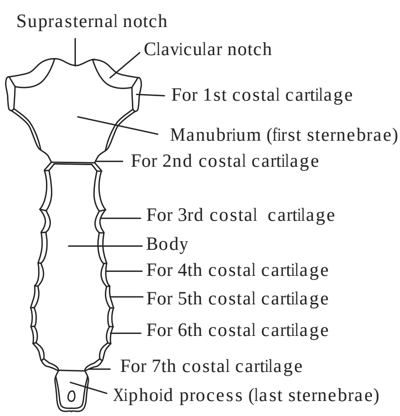
Typical vertebra



Vertebral column (right lateral view)

(iii) Thoracic Cage

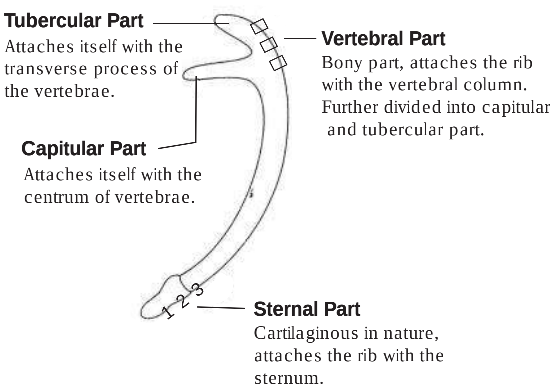
It consists of **sternum** and **ribs**. The sternum or breastbone is a flat bone which is made up of 8 skeletal elements (sternebrae).



The sternum (posterior view)

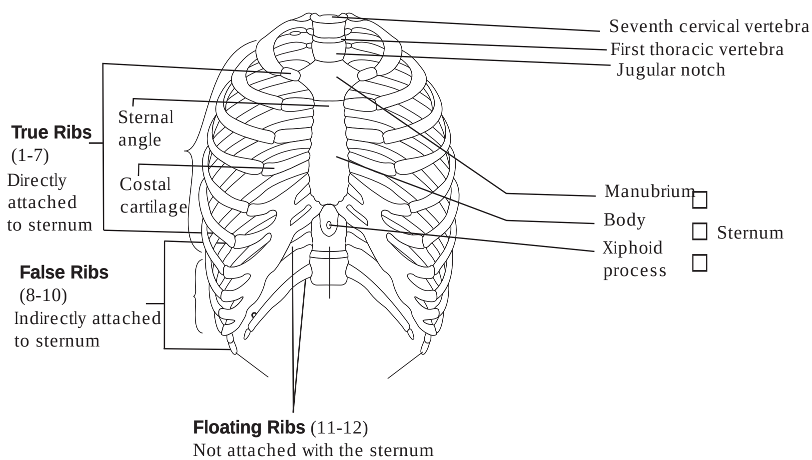
In mammals, the number of thoracic ribs are equal to the number of thoracic vertebrae, **i.e.,** humans has 12 number of thoracic ribs.

A generalised rib consists of a vertebral (dorsal) part and a sternal (ventral) part.



Generalised structure of a rib

Thoracic ribs of humans are double headed and classified as **true ribs**, **false ribs** and **floating ribs**. **The attachment and arrangement of ribs and sternum looks like**



The sternum and ribcage

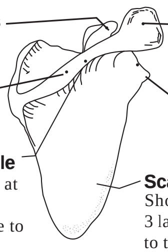
2. Appendicular Skeleton

It consists of total 126 bones. **The various components of it are as follows**

Bones		Number
Appendicular Skeleton		
Pectoral Girdle		
Scapula		2
Clavicle		2
Upper Limb		
Humerus		2
Ulna		2
Radius		2
Carpal bones		16 (8 × 2)
Metacarpal bones		10 (5 × 2)
Phalanges		28 (14 × 2)
	Total bones of pectoral girdle and forelimbs	64
Pelvic Girdle		
Coxal bone		2
Lower Limb		
Femur		2
Tibia		2
Fibula		2
Patella		2
Tarsal bones		14 (7 × 2)
Metatarsal bones		10 (5 × 2)
Phalanges		28
	Total bones of pelvic girdle and hindlimb	62
	Total bones of appendicular skeleton	126
	Total bones	206

(I) Pectoral girdle

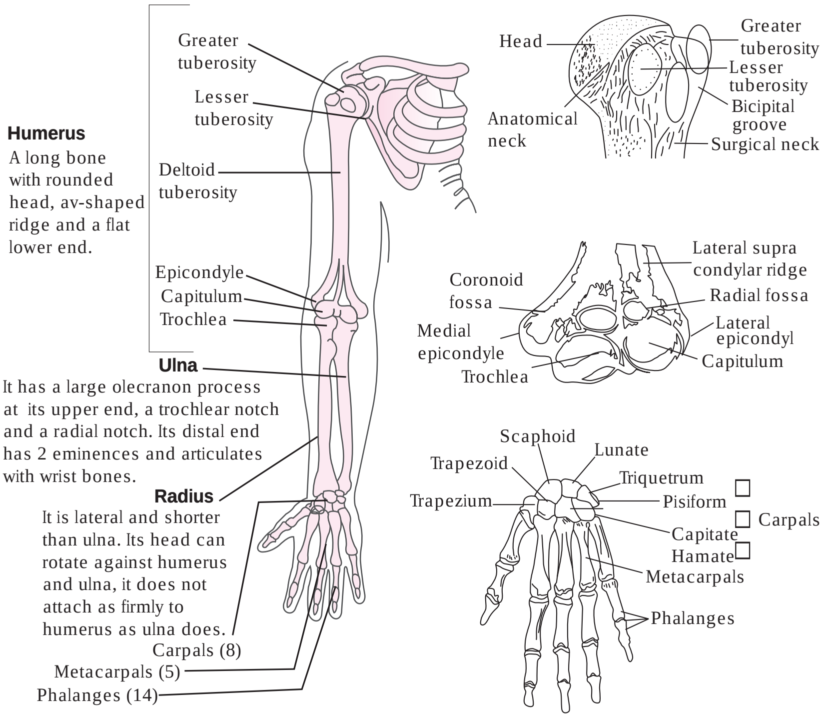
It is divided into separate right and left halves. Each half is composed of two bones, **i.e., scapula** and **clavicle**.



Components of pectoral girdle

(II) Bones of arm or Forelimb

It consists of total 60 bones including the humerus, ulna, radius, carpals, metacarpals and phallanges.



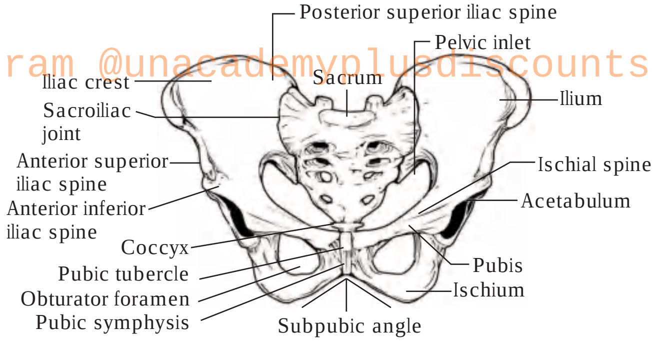
Bones of forelimb

(III) Pelvic girdle

Each half of pelvic girdle is known as coxal or innominate bone. The right and left **coxal** or **hip bones** join each other anteriorly and the sacrum posteriorly to form a ring of bone called the pelvic girdle.

Each coxal bone is formed by three bones fused to one another to form a single bone. The **ilium** is the most superior, the **ischium** is inferior and posterior and the **pubis** is inferior and anterior.

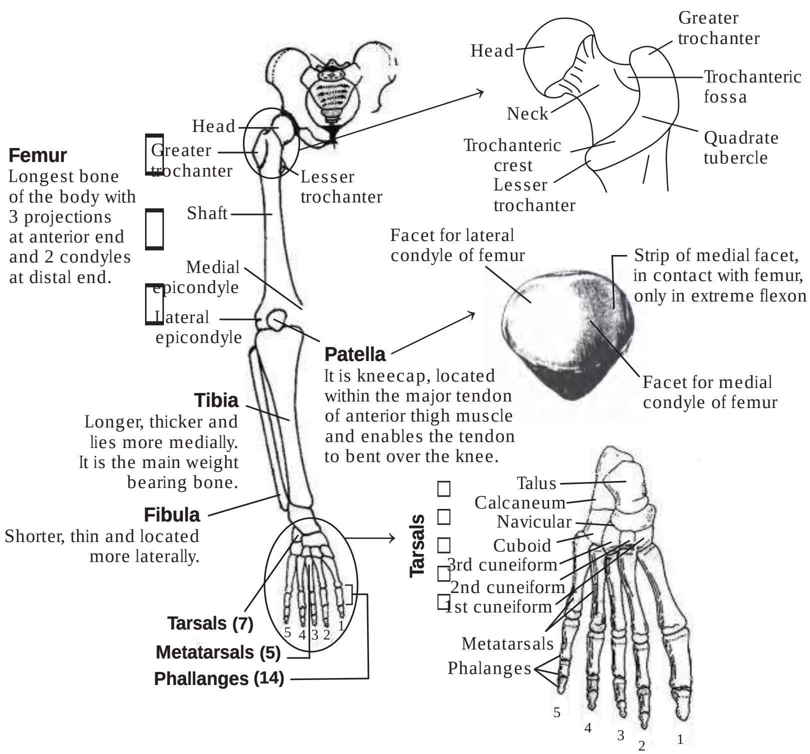
Acetabulum It is the socket of the hip joint. All the three bones, **i.e.**, ilium, ischium and pubis participate equally in the formation of acetabulum.



Anterosuperior view of pelvis

(IV) **Bones of leg or hindlimb**

It consists of total 60 bones including femur, tibia, fibula, patella, tarsals, metatarsals and phallanges.



Bones of hindlimb

Joints

A joint or an articulation is a place where two bones of the skeletal system meet. **Arthrology** is the science of joint structure, function and dysfunction.

Based on the degree of motion, joints are of following types

Types of Joints

Synarthroses
Fibrous, immovable joints. Adjacent bones are bound by collagen fibres.

- **Syndesmoses**
Bones are separated by some distance and held together by ligaments, e.g., fibrous membrane connecting distal parts of radius and ulna.
- **Gomphoses**
It consists of pegs fitted into the sockets and held in place by ligaments, e.g., joint between tooth and its socket.
- **Sutures**
Fibrous joints between the bones of the skull. They occur nowhere else in the body except skull.

Amphiarthroses
Cartilaginous, slightly movable joints. Adjacent bones are linked by cartilage.

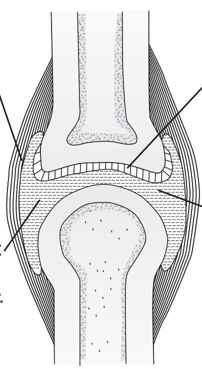
- **Synchondroses**
Bones are bound by hyaline cartilage, e.g., attachment of first rib to the sternum by a hyaline costal cartilage.
- **Symphyses**
Bones are joined by fibro cartilage, e.g., pubic symphysis in which right and left pubic bones are joined by the cartilaginous inter-pubic disc.

Diarthroses
Freely movable, synovial joints. Structurally most complex type of joints.

- **Multiaxial**
They can move in any 3 fundamental mutually perpendicular planes (x, y and z), e.g., ball and socket joint.
- **Biaxial**
They are able to move in only two planes, e.g., condylar, saddle and plane joints.
- **Monoaxial**
They can move in only one plane, e,g., hinge joint and pivot joint.

Structure of Synovial Joints (Diarthroses)

Synovial membrane
Composed of secretory epithelial cells (which secrete synovial fluid) and macrophages (that remove debris from the joint cavity).



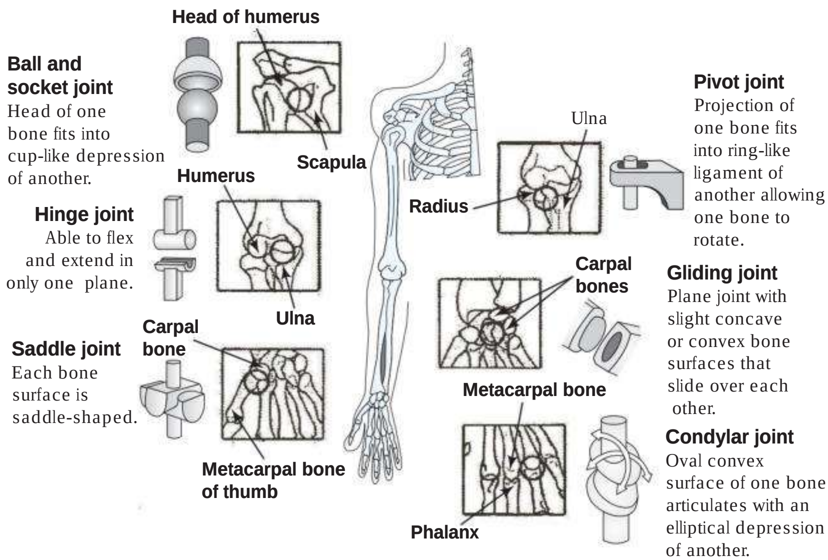
Articular cartilage
A layer of hyaline cartilage, which covers the ends of bones. It is about 2-3 mm thick.

Ligament
It joins the two bones together.

Synovial fluid
Thick sticky fluid rich in albumin and hyaluronic acid. It nourishes articular cartilage and makes the movement at these joints almost friction-free.

Types of Synovial Joint

Various type of synovial joints and their respective position in the body is given in the following figure



Different types of synovial joints in human forelimb

Disorders of Muscular and Skeletal System

1. **Arthritis** It refers to the group of inflammatory and degenerative conditions that cause stiffness, swelling and pain in the joints.

   There are several different types of arthritis, each having different characteristics.

   (i) **Osteoarthritis** It most often involves the knees, hips and hands and usually affects middle-aged and older people.

   (ii) **Rheumatoid arthritis** It is a damaging condition that causes inflammation in joints and in other body tissues, such as heart coverings, lungs and eyes. It affects individual of all age groups.

2. **Bursitis** It is the inflammation of the bursae present within the synovial joints as small membrane bound sockets which hold the synovial fluid. It mainly occurs due to an injury or pressure on a joint for a long duration.

3. **Muscular dystrophy** It is a genetic disease that damages the muscle fibres. Its symptoms include weakness, loss of mobility and lack of coordination. It can occur at any time in a person's life and has no cure.
4. **Myasthenia gravis** It is characterised by weakness and rapid fatigue of skeletal muscles. It is a chronic autoimmune neuromuscular disorder in which the body produces antibodies that block the muscle cells from receiving messages from the nerve cells.
5. **Spondylitis** It is a chronic and developed form of arthritis that affects vertebrae. It is found in a person who keeps bending their neck for several hours.

21

Neural Control and Coordination

Nervous system is the master controlling and communicating system of the body through which the activities of the animal and its awareness and reaction to outside environment are coordinated.

Neurons or nerve cells are the functional unit of nervous system.

Human Neural System

Humans have highly integrated nervous (or neural) system and for the convenience of study it can be divided into two principal parts.

Human Neural System

Central Nervous System
Dorsally placed structure lying along the mid-dorsal axis of the body. It is the integrating and command centre of the nervous system.

Peripheral Nervous System
This system consists of nerves that extend from the brain and spinal cord and known as cranial nerves and spinal nerves, respectively.

Brain
Anterior most part, lodged in the cranial cavity of skull.

Spinal Cord
Posterior part, run mid-dorsally within vertebral column.

Sensory or Afferent Division
Consists of nerve fibres that convey impulses to CNS from sensory receptors located in the body.

Motor or Efferent Division
Consists of nerve fibres that transmit impulses from the CNS to effector organs, i.e., muscles and glands.

Autonomic Nervous System (ANS)
Consists of visceral motor fibres that regulate the activities of smooth muscles, cardiac muscles and glands (involuntary nervous system).

Parasympathetic Nervous System
This system conserves energy and promotes non-emergency functions.

Sympathetic Nervous System
It mobilises body during emergency situations.

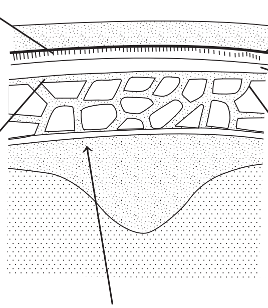
Central Nervous System

It consist two major divisions, i.e., brain and spinal cord.

Brain

It is the highly coordinated centre of the human body which weighs about 1220 to 1400 grams.

The human brain is covered by three membranes or **meninges** (sing. meninx) namely piamater, arachnoid membrane and duramater.



① Duramater
Outer tough, fibrous collagenous layer, inserted in periosteum of cranium.

② Arachnoid Membrane
Middle layer, non-vascularised, also called spider web.

③ Piamater
Innermost layer, highly vascularised, soft of all.

④ Epidural Space
Space between duramater and cranium; contains fatty connective tissue.

⑤ Subdural Space
Space present between duramater and arachnoid. It is filled with fatty connective tissues.

⑥ Subarachnoid Space
Space between arachnoid and piamater;filled with Cerebrospinal Fluid (CSF).

Meninges and spaces of brain : 1, 2, 3 in the figure are meninges and 4, 5, 6 are spaces of brain

The human brain is divisible into three parts as follows

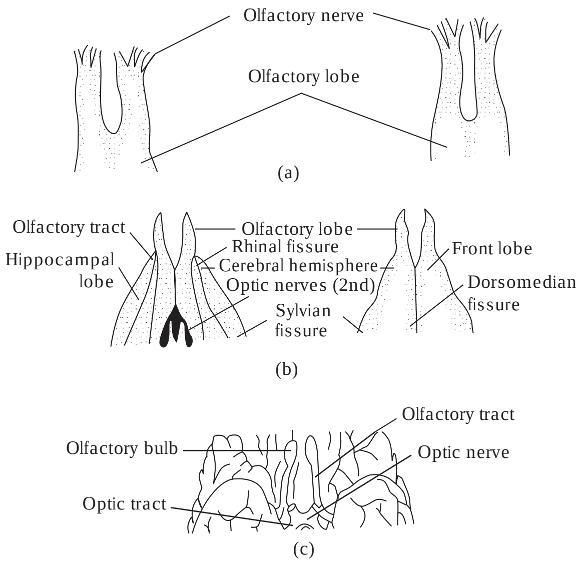
Vertebrate Brain

- **Prosencephalon** or **Forebrain**
  - Rhinencephalon or olfactory lobes
  - Telencephalon or cerebrum
  - Thalmencephalon or diencephalon
- **Mesencephalon** or **Midbrain**
  - Optic lobes
- **Rhombencephalon** or **Hindbrain**
  - Cerbellum
  - Pons Varolii
  - Medulla oblongata

1. Forebrain

(i) **Rhinencephalon** Anterioventral part of forebrain, functionally related to smell, consists of olfactory lobes as paired, fused posterior portion.

The variations in rhinencephalon in different animal groups is shown in the figures below



Olfactory region relatively smaller, major part is formed by olfactory lobes, anterior most portion runs as olfactory nerves into nasal chambers.

Olfactory region relatively larger, lobes are smaller, major part is formed by olfactory tract, a rhynial fissure separates both lobes from cerebral lobes.

Anterior portion is lost, hence the lobes look ventral in position as olfactory bulbs.

Olfactory lobes : (a) Frog, (b) Rabbit (c) Human

(ii) **Telencephalon** Most developed part in humans, performs specialised functions like intelligence, learning skills, memory, speech, etc. It has shown maximum development during evolution, in particular its **roof** (pallium) in vertebrates other than mammals.

Neopallium
Highly developed pallium in mammals containing folds (gyri) and depression (sulci).

Allocortex
Centralised old portion of pallium.

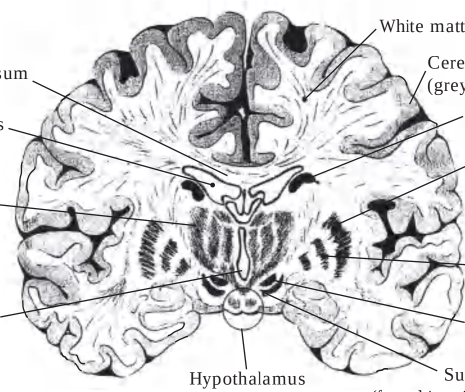
Neocortex
Circumcentric newly developed portion of pallium.

Lobes of Cerebrum

Cerebrum consists of two lobes, **i.e.,** right and left, which are separated by a deep **longitudinal fissure**.

Each hemisphere has a thick central core of **white matter** containing bundles of myelinated axons.

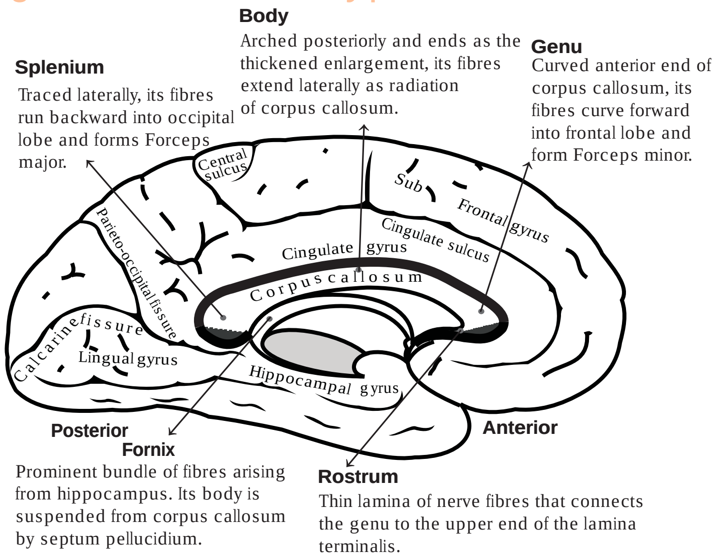
- **Cerebral cortex** forms the thin outer layer of **grey matter**. containing the cell bodies of the neurons.



Transverse section of brain showing white matter, grey matter and components of basal ganglion

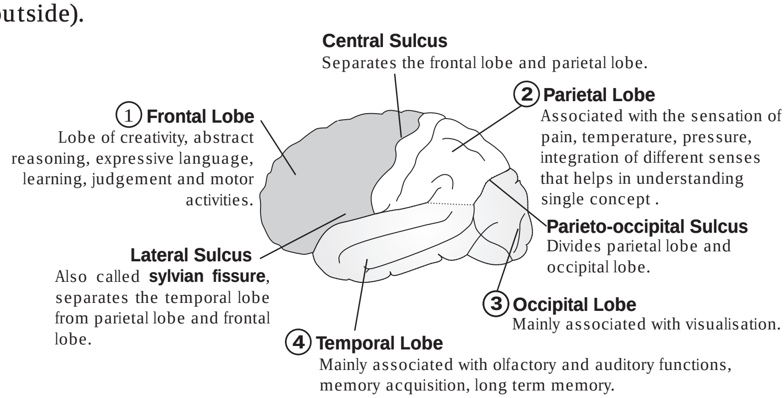
- **Basal ganglion** (or nuclei) These are the scattered masses or bulges of grey matter, which are submerged into the white matter (subcortex) of cerebrum.
  They constitute the five structures namely, **caudate nucleus**, **putamen**, **globus pallidus**, **subthalamic nuclei** and **substantia nigra**. The main function of basal nuclei is to control and regulate stereotypic (3D) movements.
- **Corpus striatum** It is the structure formed by the association of caudate nucleus, putamen and globus pallidus. In mammals, it is present in frontal lobe and both corpora striata are connected with the help of a nerve fibre band called **anterior commissure**.
- **Corpus callosum** It is the largest bundle of fibres which connect the two hemispheres of cerebrum. Most of the fibres of corpus callosum arise from the parts of neocortex of one cerebral hemisphere and terminate in the corresponding parts of the opposite cerebral hemisphere. It is a unique feature of mammals.

It is divided into 4 parts namely rostrum, genu, body (or trunk) and splenium. It is the characteristic feature of mammals only.



Corpus callosum

Each cerebral hemisphere is further divided into five lobes namely **parietal**, **occipital**, **temporal**, **frontal** and **insular** (not visible from outside).



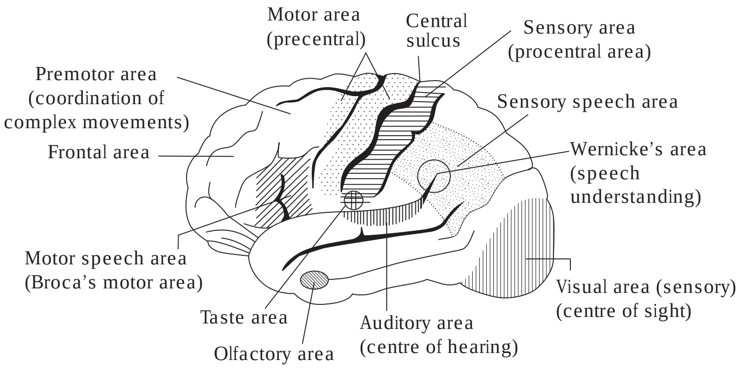
Major lobes and sulcus of brain

Specialised Regions Present in Cerebral Hemisphere

The cerebral cortex has three principal functions

(a) Receiving sensory input
(b) Integrating sensory information
(c) Generating motor responses.

These functions are performed by special areas in cerebrum, which are described in the figure below

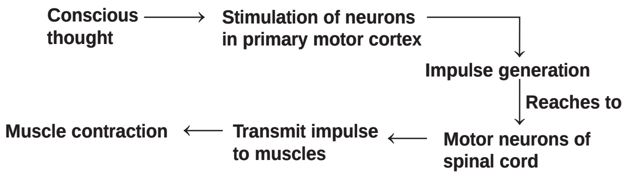


Cerebral hemisphere

The three major specialised regions of the cerebrum are

(a) **The primary motor cortex** It occupies a single ridge on each hemisphere in front of central sulcus.

The pathway of voluntary movements carried out by primary motor cortex is as follows



(b) **The primary sensory cortex** It lies just behind the central sulcus as a ridge of tissue running parallel to the primary motor cortex. It is the final destination of many sensory impulses travelling to the brain. It receives the sensory information from the body.

(c) **Association cortex** It consists of large regions of cerebral cortex where integration occurs. Here, information is interpreted, made sense of, and acted upon. It also carries out more complex functions.

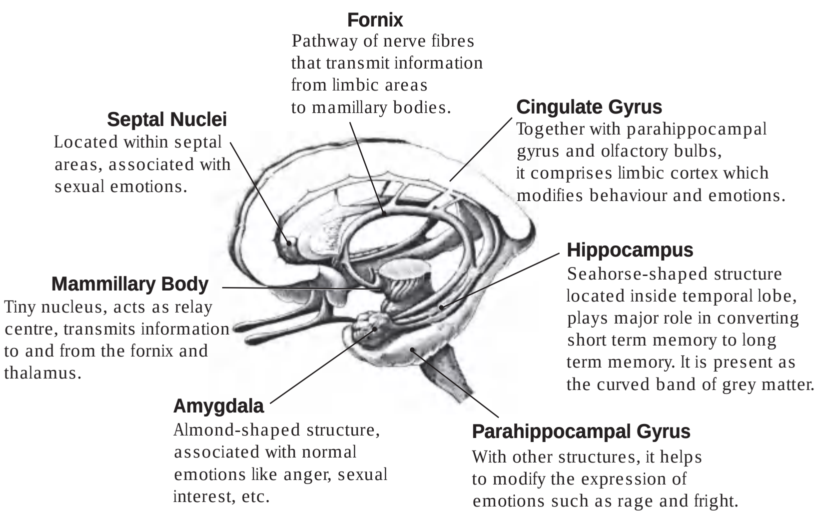
Neuron of Cerebral Cortex

Cerebral cortex is composed of two major types of neurons, i.e.,

Neurons of Cerebral Cortex

- **Stellate Cells**
  They possess spheroidal cell bodies (soma) having dendrite projections in all directions for short distances.
- **Pyramidal Cells**
  They are tall and conical cells having their apex pointed towards the brain surface. They have thick dendrites with many branches and small knobby dendritic spines.

Limbic system The medial border of temporal lobe is called limbic system. It is a loop of cortical structures, surrounding the corpus callosum and thalamus. Its four major components are hippocampus, amygdala, septal nuclei and mammillary bodies.



Limbic system and its associated structures

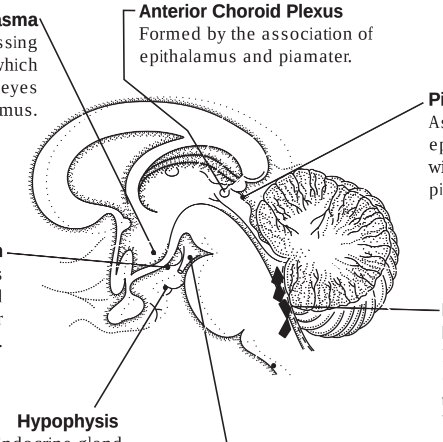
(iii) **Diencephalon** **It is the posterioventral part of the brain and formed by three structures as follows**

Diencephalon

- **Epithalamus** (forms the roof of diencephalon)
- **Optic Thalami** (forms the sides of diencephalon)
- **Hypothalamus** (forms the base of diencephalon)

In case of humans, only two parts of diencephalon are defined

- **Thalamus** includes roof (epithalamus) and upper portion with medial portions of side walls. It is present just beneath the cerebrum. It is a relay centre. It receives all sensory inputs, except for smell and then relays it to the sensory and association cortex.
- **Hypothalamus** includes floor along with lower side walls. It is present beneath the thalamus. It consists of many groups of nerve cells called **nuclei** which control a variety of autonomic functions and helps to maintain homeostasis (such as appetite, body temperature, blood pressure, etc). It also regulates the functioning of pituitary gland.



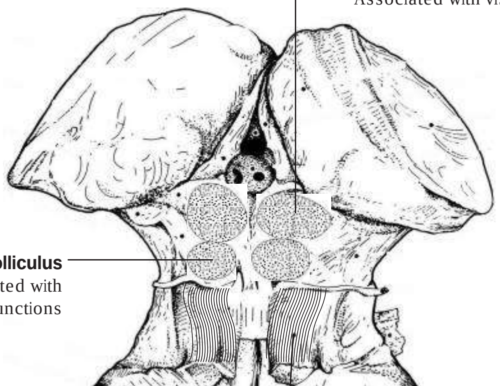
Components of diencephalon

2. Midbrain

The midbrain contains optic lobes. These lobes are two in case of frog and called as **corpora bigemina** (hollow structures).

In case of humans, they are four in number and called as **corpora quadrigemina** (solid structures).

In humans, the four lobes are defined in two pairs as superior and inferior colliculus.



Posterior view of brain showing the components of midbrain

The functions performed by superior and inferior colliculi are originally taken up by cerebrum. Crus cerebri functions to relay impulses back and forth between the cerebrum, cerebellum, pons and medulla.

3. Hindbrain

It basically consists of cerebellum (metencephalon), medulla oblongata (myelencephalon) and pons Varolii. Collectively, these three structures form the **brain stem**.

(i) Cerebellum

It is the second largest part of brain and considered as small brain or little cerebrum. From birth with the age of 2 yrs, it grows faster than the rest of the brain.

It consists of 2 cerebellar hemispheres with a central worm-shaped vermis. **The various structural components of cerebellum are as follows**

(a) **Arbor vitae** It is the tree of life present in the internal region of cerebellum. It is the profuse ramifications of white matter into the grey matter. Externally, its surface contains gyri and sulci.

(b) **Cerebellar peduncles** These are the bundles of fibres connecting the cerebellum with the underlying brainstem. **On the basis of their position, they are of three types**

- **Caudal cerebellar peduncle** Connects cerebellum with medulla, contains afferent and efferent axons, also called restiform bodies.
- **Middle cerebellar peduncle** Connects cerebellum with pons, contains only afferent axons, also called branchia points.
- **Rostral cerebellar peduncle** Connects cerebellum with midbrain, contains predominantly efferent axons, also called branchia conjunctiva.

(c) **Cerebellar cortex** It is the surface grey matter of the cerebellum. **It consists of three layers as follows**

- **Molecular layer** Most superficial, consisting of axons of granule cells and dendrites of Purkinje cells.
- **Purkinje cell layer** Middle layer, consisting of a single layer of large neuronal cell bodies of Purkinje cells.
- **Granule cells layer** Deepest layer next to white matter consisting of small neurons called granule cells.

Cerebellar cortex also contains various cell types as follows

- **Purkinje cells** These are the only output neuron from the cerebellar cortex; it utilises the neurotransmitter GABA (Gamma Amino Butyric Acid) to inhibit neurons in deep cerebellar nuclei. These flask-shaped Purkinje cells are considered as one of the largest and most complex neurons.
- **Granule cells** These are the intrinsic cells of cerebellar cortex; they use glutamate as an excitatory transmitter; they excite Purkinje cells **via** axonal branches called parallel fibres.
- **Basket cells** These are the inhibitory interneurons, they utilise GABA to inhibit Purkinje cells.

Functions

- Maintenance of balance and posture.
- Coordination of voluntary movements by modulating timing and force of muscle groups.
- Motor learning through adaptation and fine-tuning in solving a motor problem.
- Cognitive functions associated with language.

(II) **Pons Varolii**

It is present at the axis of brain in front of cerebellum below the midbrain and above medulla oblongata. It is considered as a link between upper portion of brain and spinal cord through medulla oblongata.

It contains nerve fibres which form a bridge called **pons bridge** in between the two cerebellar hemispheres.

Function

It contains pneumotoxic centre and helps in regulating breathing movements.

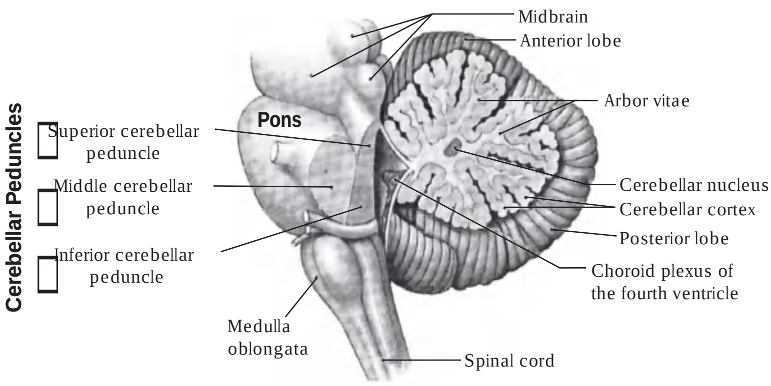
(III) **Medulla Oblongata**

It is the triangular part of the brain. Its roof is associated with overlying piamater to form the posterior choroid plexus.

Functions

(i) It receives and integrates signals from spinal cord and sends them to cerebellum and thalamus.

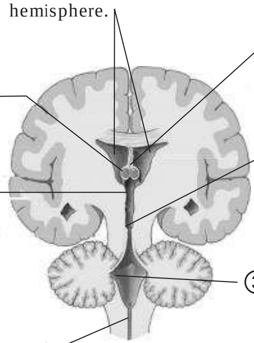
(ii) It regulates heart rate, blood pressure, swallowing, salivation, vomiting and some other involuntary movements.



Lateral view of brain showing the components of hindbrain

Brain Ventricles

The ventricles consist of four hollow, fluid-filled spaces inside the brain. **These are as follows**



Ventricles of brain

Cerebrospinal Fluid (CSF)

It is the watery liquid that is found between the inner and outer layers of meninges. It also fills the internal cavities in the brain and spinal cord. CSF is secreted by anterior and posterior choroid plexus. It is similar in composition to blood plasma and interstitial fluid.

Functions of CSF

(i) **Protection of brain and spinal cord** CSF protects the delicate brain and spinal cord by providing shock-absorbing medium. It acts as **cushion jolts** to the central nervous system.

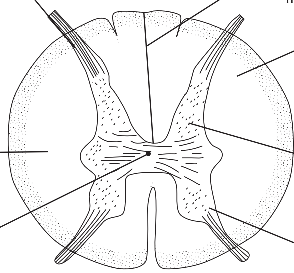
(ii) **Buoyancy to the brain** Since, the brain is immersed in the CSF, the net weight of the brain is reduced from about 1.4 kg to about 0.18 kg. Thus, the pressure at the base is reduced.

(iii) **Excretion** CSF carries harmful metabolic wastes, drugs and other substances from the brain to the blood.

(iv) **Detection of infections** As CSF bathes the CNS, examining small amounts of CSF can provide physicians a means of detecting infections in the brain, spinal cord and meninges. Samples of CSF are obtained by inserting a needle between 3rd and 4th lumbar vertebrae (lumbar puncture).

Spinal Cord

It is the part of dorsal nerve cord present in continuation with brain. It lies in the neural canal of the vertebral column. Like brain, it is also surrounded by 3 meninges namely piamater (inner), arachnoid membrane (middle) and duramater (outer).



TS of spinal cord

Horns These are the projections of grey matter into the white matter and their presence gives a butterfly appearance to the TS of spinal cord.

Conus terminalis or medullaris It is the termination point of the spinal cord. In humans, this point is situated in L-2 region.

Filum terminale It is a long slender filament at the end of the spinal cord in the caudal region. It consists of vascular meninges, **i.e.,** piamater or pia arachnoid matter. It anchors the spinal cord within the vertebral column.

In the TS of spinal cord, certain tracts are also seen. These tracts are meant for the vertical communication of spinal cord with brain. **These are**

(i) **Ascending tracts** They take information to the brain.

(ii) **Descending tracts** They bring information from the brain.

Peripheral Nervous System (PNS)

The PNS transmits information to and from the CNS and plays a major role in regulating movements and internal environment. It consists of cranial and spinal nerves.

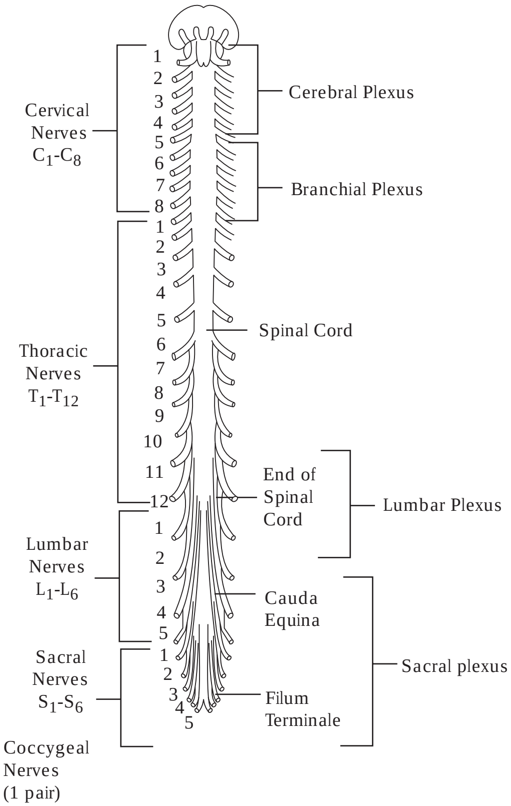
Cranial nerves They originate in the brain and terminate mostly in the organs of the head and upper body. Mammals have 12 pairs of cranial nerves.

Cranial Nerves in Humans

	Types of Cranial Nerves	From	To	Nature
I.	Olfactory	Olfactory lobe	Olfactory epithelium	S
II.	Optic	Optic chiasma	Eye retina	S
III.	Oculomotor	Crus cerebrum	Four muscles of eyeball, iris, ciliary body	Mo
IV.	Trochlear (smallest nerve)	Midbrain	Superior oblique muscles of eye	Mo
V.	Trigeminal (largest nerve)	Pons Varolii		Mix
	V_1- Ophthalmic		Eye, eyelids, snout	S
	V_2- Maxillary		Upper jaw, cheeks and lower eyelids	S
	V_3- Mandibular		Lower jaw, lip, tongue, external ear	Mix
VI.	Abducens	Pons	Lateral rectus muscles of eye	Mo
VII.	Facial	Pons		Mix
	VII_1- Palatinus		Palate	S
	VII_2- Tympani		Tongue, salivary gland, taste buds	S
	VII_3- Hyomandibular		Lower Jaw, pinna, neck, hyoid	Mix
VIII.	Auditory	Medulla		S
	$VIII_1$- Vestibular		Internal ear	S
	$VIII_2$- Cochlear		Cochlea	S
IX.	Glossopharyngeal	Medulla		Mix
	IX_1- Lingual		Tongue, pharynx	Mix
	IX_2- Pharyngeal		Pharynx, salivary gland	Mix
X.	Vagus	Medulla		
	X_1- Superior laryngeal		Laryngeal muscles	Mix
	X_2- Recurrent laryngeal		All muscles of larynx	Mo
	X_3- Cardiac		Cardiac muscles	Mo
	X_4- Pneumogastric		Lungs, oesophagus, stomach, ileum	Mo
	X_5- Depressor		Diaphragm	Mix
XI.	Spinal accessory	Medulla	Pharynx, larynx, neck, shoulder	Mo
XII.	Hypoglossal	Medulla	Tongue, hyoid	Mo

S — Sensory, Mo — Motor, Mix — Mixed.

Spinal Nerves They originate in the spinal cord and extend to the different body parts below the head. There are 31 pairs of spinal nerves in humans. All spinal nerves contain axons of both sensory and motor neurons.



Spinal nerves in human

Autonomic Nervous System (ANS)

The ANS regulates the internal environment of the animal's body by controlling smooth and cardiac muscles and other involuntary actions.

Autonomic Nervous System

Sympathetic Nervous System	Parasympathetic Nervous System
Vasoconstriction in general and vasodilation (brain, heart, lungs and skeletal muscles)	Vasodilation of coronary vessel
Dilates pupil	Constricts pupil
Increases lacrimal gland's secretion	Inhibits lacrimal gland's secretion
Inhibits salivary and digestive glands	Stimulates them
Accelerates heartbeat	Retards heartbeat
Dilates trachea, bronchi, lungs	Constricts these organs
Inhibits gut peristalsis	Stimulates gut peristalsis
Contracts anal sphincter	Relaxes anal sphincter
Relaxes urinary bladder	Contracts urinary bladder

Reflex Action

It is a spontaneous automatic mechanical response to a stimulus involuntarily (without the will).

It is of following types

Simple Reflexes
These are present in an organism starting from birth. Also called unconditioned/inborn reflexes, e.g., sweating, breathing, peristalsis, etc.,

Acquired Reflexes
These develop in an organism after birth through learning, experience, etc., Also called conditioned reflexes, e.g., writing, reading, driving a vehicle, etc.

Reflex Action

Spinal Reflexes
These are controlled by spinal cord.

Cranial Reflexes
These are controlled by brain.

Reflex Arc

It is the pathway covered by nerve impulses (generated at the receptor due to the stimulus) to reach the effector organ during a reflex action.

It has following five components

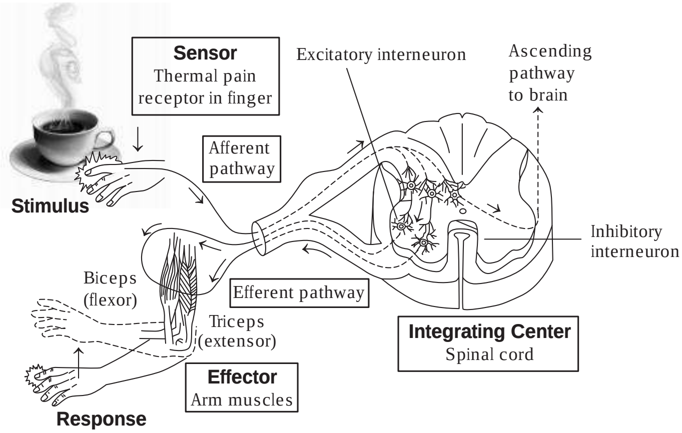
(i) **Receptor** It is a cell/tissue/organ, which receives an external or internal stimulus, **e.g.,** skin, eye, ear.

(ii) **Sensory/Afferent nerve fibres** They carry the sensory nerve impulses generated by the receptor to the central nervous system.

(iii) **Part of central nervous system** It may be spinal cord or brain or ganglion.

(iv) **Motor/Efferent nerve fibres** These carry the motor nerve impulse generated in the CNS to the specific effector organs.

(v) **Effector organ** It may be organ/muscle/gland which on being activated by a motor nerve impulse, helps to deal with the stimulus.



Reflex action and reflex arc

Importance of Reflex Arc

(i) Controls a number of body activities.

(ii) Response to harmful stimulus is fast.

(iii) Response to stimulus is accurate and useful.

(iv) Coordinate body activities.

Nerve Impulse

It may be defined as wave of depolarisation of the membrane of the nerve cell. It travels along a neuron or across a synapse (junction), between one neuron and another, or between a neuron and an effector, such as a muscle or gland.

Membrane Theory of Nerve Impulse

This theory was proposed by English neurophysiologists **Hodgkin** and **Huxley** in the late 1930s. This theory states that electrical events in the nerve fibre are governed by the **differential permeability** of its membrane to sodium and potassium ions and that these permeabilities are regulated by the **electric field** across the membrane.

The interaction of differential permeability and electric field makes a critical threshold of charge essential to excite the nerve fibre.

According to this theory, the process of nerve impulse conduction is divisible into two main phases, **i.e., resting membrane potential of nerve** and **action membrane potential of nerve**.

Membrane Potential

Membrane Potential

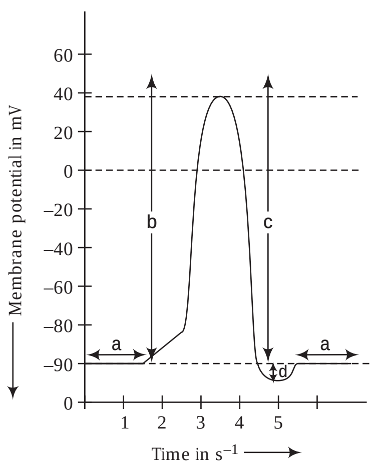
Positive Over Potential
It is the small action potential generated following the termination of spike. It consists of an initial negative deflection followed by a positive deflection both being of smaller amplitude than action potential Represented by 'd' in the graph below.

Resting Membrane Potential
(Polarised state)
It is about 90 mV for a resting large resting nerve fibre, i.e., potential inside the fibre is 90 mV more negative than the potential in the extracellular fluid on the outside of the fibre. Represented by 'a' in the graph below.

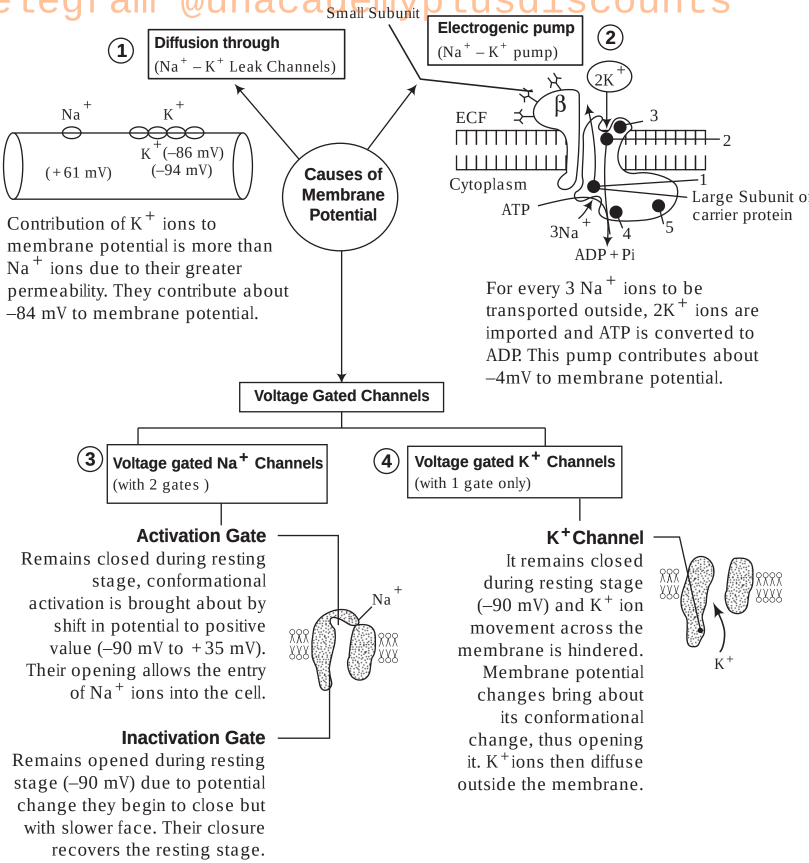
Action Membrane Potential
It is responsible for transmitting the nerve signals. Action potential is generated due to rapid changes in membrane potential when a threshold stimulus is applied. The membrane potential changes from negative to positive.

Depolarisation Stage
Normal 90 mV polarised stage is lost, potential rises rapidly to positive direction due to tremendous inflow of Na^+ ions inside the axion. Represented by 'b' in the graph below.

Repolarisation Stage
Caused due to excessive diffusion of K^+ ions to exterior which establish normal negative resting membrane potential. Represented by 'c' in the graph below.



Causes of Membrane Potential



Causes of membrane potential (1) and (2) for resting potenial (3) and (4) for action potential

Calculation of Nernsth Equation and Nerve Potential

The potential level across the membrane that will exactly prevent net diffusion of an ion in either direction through a membrane is called **Nernst potential of that particular ion**. Its magnitude can be determined by the ratio of ion concentration on the two sides of the membrane.

The following equation called **Nernst equation** is used to calculate the **Nernst potential** for any univalent ion at normal body temperature of 37°C.

$$\text{EMF (milli volts)} = \pm 61 \log \frac{\text{Concentration inside}}{\text{Concentration outside}}$$

When using this formula, it is assumed that the potential outside the membrane always remains exactly at zero and Nernst potential is calculated in the potential membrane.

Diffusion potential occurs when membrane is permeable to several different ions. In this condition, the diffusion potential that develops, depend upon three factors

(i) The polarity of electric charge of each ion.

(ii) The permeability of membrane (P) of each ion.

(iii) The concentration (C) of respective ions on the inside (i) and outside (o) to the membrane.

Thus, the following formula called the **Goldman equation** or **Goldman-Hodgkin-Katz equation** gives the calculated membrane potentials when the Na^+, K^+, Cl– ions are involved. **The equation is**

EMF (milli volts)

$$= -61 \log \frac{C[Na^+]_i \cdot P[Na^+]_i + C[K^+]_i\ P[K^+]_i + C[Cl^-]_O \cdot P[Cl^-]_O}{C[Na^+]_O \cdot P[Na^+]_O + C[K^+]_O \cdot P[K^+]_O + C[Cl^-]_i \cdot P[Cl^-]_i}$$

Here, C is the concentration of respective ion, P is the partial pressure and permeability of concerning ion, i represents inside, o represents outside.

Synapse

It is formed by the membranes of a pre-synaptic neuron and a post-synaptic neuron which may or may not be separated by a gap called **synaptic cleft**. **There are two types of synapses**

(i) At **electrical synapse**, the membranes of pre and post-synaptic neurons are in very close proximity. Electrical current can flow directly from one neuron to the other, across these synapses.

Impulse transmission across an electrical synapse is always faster than that across a chemical synapse. Electrical synapses are rare in our system.

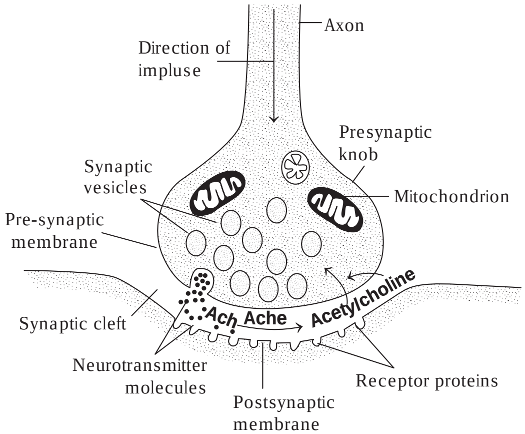
(ii) At **chemical synapse**, the membranes of pre and post-synaptic neurons are separated by a fluid-filled space called as **synaptic cleft**.

Conduction Through Synaptic Cleft

The pre-synaptic neuron synthesises the neurotransmitter and packages it in **synaptic vesicles** which are stored in the neuron's synaptic terminals. Hundreds of synaptic terminals may interact with the cell body and dendrites of a post-synaptic neuron.

When an action potential reaches a synaptic terminal, it depolarises the terminal membrane, opening the **voltage-gated calcium channels** in the membrane. Calcium ions (Ca^{2+}) then diffuse into the terminal and the rise in Ca^{2+} concentration in the terminal causes some of the synaptic vesicles to fuse with the terminal membrane, releasing the **neurotransmitter**.

The neurotransmitter diffuses across the **synaptic cleft**, a narrow gap that separates the pre-synaptic neuron from the post-synaptic neuron. The released neurotransmitter binds to the specific **receptors**, present on the post-synaptic neuron. This binding open the ion channels allowing the entry of ions which can generate a new potential in the post-synaptic neuron.



Transmission of nerve impulse at a chemical synapse

Neurotransmitters

These are **chemical messengers** secreted by the axon terminals for transmitting impulses to the next neuron. At most synapses, information is passed from the transmitting neuron (pre-synaptic cell) to the receiving cell (post-synaptic cell) by neurotransmitters. Each neurotransmitter binds to its own group of receptors. Some neurotransmitters have many different receptors, which can produce different effects in the post-synaptic cell.

Various kinds of neurotransmitters are listed below

(i) **Acetylcholine** is a common neurotransmitter present in the neuromuscular junctions, voluntary neural synapses, synapses of pre-ganglionic nerve fibres, synapses of post-ganglionic parasympathetic nerve fibres. **Cholinergic** nerve fibres release acetylcholine. It has excitatory effect on the skeletal muscles and excitatory or inhibitory effect at other sites.

(ii) **Nor-epinephrine** (nor-adrenaline) is formed at synapses and neuromuscular junctions of the post-ganglionic sympathetic nerve fibres. The nerve fibres are called **adrenergic**. It has excitatory or inhibitory effects.

Peripheral nervous system generally uses acetylcholine, nor-adrenaline and adrenaline.

(iii) **Glycine**, **Dopamine** and **Gamma Amino Butyric Acid** (GABA) are inhibitory transmitters.

(iv) **Glutamate** is excitatory in function.

(v) **Serotonin** inhibits pain pathways of spinal cord. It generally controls mood and induces sleep.

Sense Organs

The human body contains receptors that monitor numerous internal and external stimuli essential for homeostasis and our well-being. These receptors are located in the skin, internal organs, muscles, etc.

They detect stimuli that gives rise to **general senses** like pain, pressure, etc.

The human body is also endowed with five additional **special senses**, **i.e.,** taste, smell, sight, hearing and balance.

General and Special Senses

Sense	Stimulus	Receptor
General senses	Pain	Naked nerve endings
	Light touch	Merkel's discs; naked nerve endings around hair follicles; Meissner's corpuscles; Ruffini's corpuscles, Krause's end-bulbs
	Pressure	Pacinian corpuscles
	Temperature	Naked nerve endings
	Proprioception	Golgi tendor organs; muscle spindles; receptors similar to Meissner's corpuscles in joints
Special senses	Taste	Taste buds
	Smell	Olfactory epithelium
	Sight	Retina
	Hearing	Organ of Corti
	Balance	Crista ampularis in the semicircular canals, maculae in utricle and saccule

Receptors in humans, involved in the general and special senses **fall into five categories as follows**

Receptors

Thermoreceptors
Activated by heat and cold.

Photoreceptors
Activated by light.

Chemoreceptors
Activated by chemicals in the food, air, blood, etc.

Nociceptors
They are pain receptors activated by pinching, tearing or burning.

Mechanoreceptors
Activated by mechanical stimulus like touch or pressure.

Based on kinds of stimulus, the sensory receptors fall into following two categories

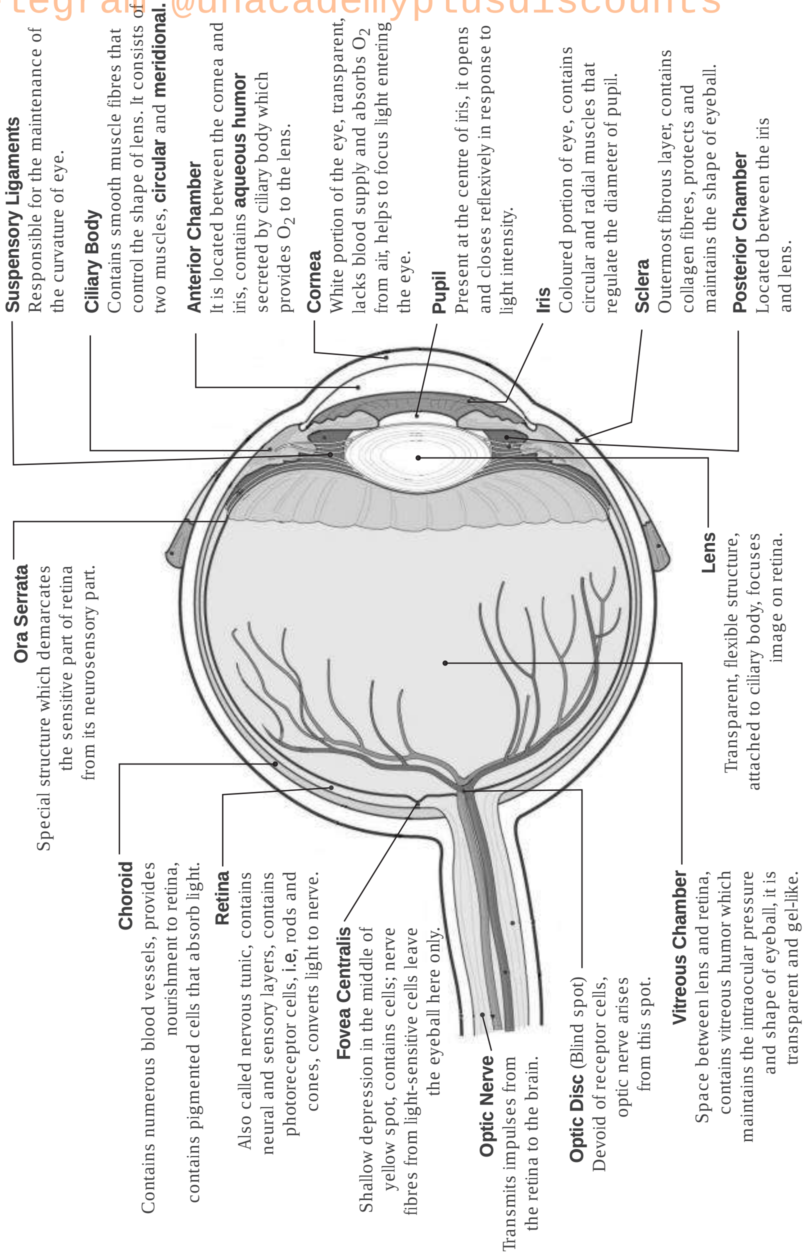
(i) **Exteroceptors** These receive external stimuli.

(ii) **Interoceptors** These receive internal stimuli coming from the internal body organs, changes in muscles and joint movements.

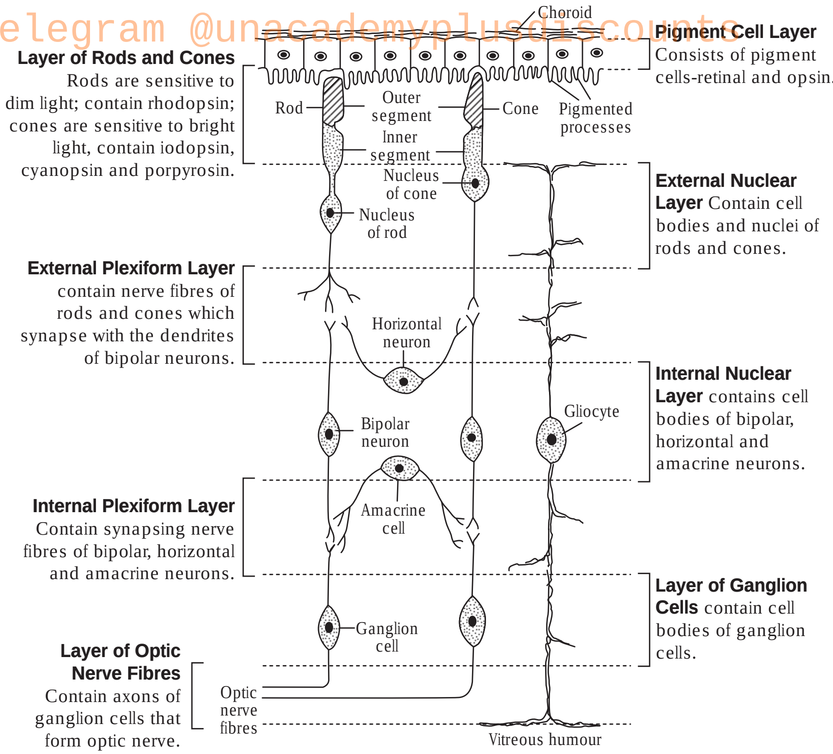
The Visual Sense–The Eye

Human eye is one of the most extraordinary product of evolution. It contains a patch of photoreceptors that permit us to perceive the diverse and colourful environment.

Anatomy of Eye



Various layers of retina are as follows



Layers of retina

- Rhodopsin pigment (visual purple) is formed by combining **retinene** with **scotopsin** in the presence of energy.
- Iodine is the main constituent of iodopsin pigment (visual violet).
- On the basis of sensitivity to a particular colour, **the cones are of three types.**

Cone Cells

Erythrolable Cones
Sensitive to red colour.

Chlorolable Cones
Sensitive to green colour.

Cyanolable Cones
Sensitive to blue colour.

Rest of the colours are detected by the combination of these basic colours.

Few Important Terms Related to Eye

(i) **Uvea** It is the name given to the vascular layer (tunic) of the eye which comprises posterior choriodeal, intermediate ciliary body and an anterior iris, perforated with pupil.

(ii) **Canal of Schlemm** Aqueous humor secreted by ciliary body is continuously drained to anterior part of eye through this canal. Its blockage may cause glucoma or kala motia.

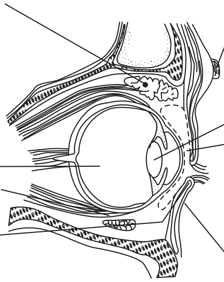
(iii) **Tapetum Lucidum** It is the refractive layer of guanine particles in the iris of many mammals and elasmobranch fishes.

(iv) **Tapetum Fibrosum** It is the tapetum containing glistening white fibres of tendon type in marsupials, elephant, whale and hoofed mammals.

(v) **Tapetum Cellulosum** It is the tapetum composed of cellulose like crystalline material instead of guanine in carnivore mammals, seals and lower primates.

Accessory Organs of the Eye

The eye is a delicate organ which is protected by several structures, **i.e.,** eyebrows, eyelids, eyelashes, lacrimal apparatus, etc.

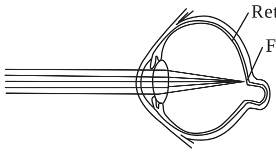
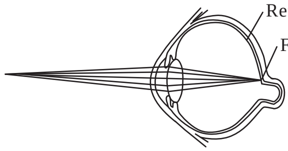


Accessory structures of human eye

Mechanism of Vision

Light rays from outside → Focus on retina → Light induces dissociation of retinal and opsin → Structure of opsin changes → Potential difference is generated in photoreceptor cells. → Action potential is generated in ganglionic cells through bipolar neurons. → Action potential is transmitted to visual cortex in occipital lobe by optic nerve. → Neural impulses are analysed → Image is recognised

Accommodation It is the automatic adjustment in the curvature of lens as it focuses on different objects.

Accommodation for Distant Objects	Accommodation for Near Objects
	
Light rays are parallel from the distant objects when they strike the eye.	Light rays are divergent from the near objects when they strike the light.
Lens is pulled thin.	Lens is allowed to shrink.
Suspensory ligament is stretched tightly.	Suspensory ligament's tension is relaxed.
Ciliary muscles are stretched.	Ciliary muscles are contracted.

Binocular vision When both the eyes can be focused simultaneously on a common object, it is called binocular vision, **e.g.,** humans.

Monocular vision In this vision, eye focuses its own object and both the eyes cannot focus on one object, **e.g.,** rabbit.

Common Diseases of the Eye

(i) **Myopia** It occurs due to the convexity of lens or longer eyeballs, which results in image of distant objects being formed in front of the retina. It can be corrected by wearing concave lenses.

(ii) **Cataract** An eye disease generally occurring in older people (lens becomes opaque). It can be treated by laser treatment, removing opaque lens and wearing spectacles.

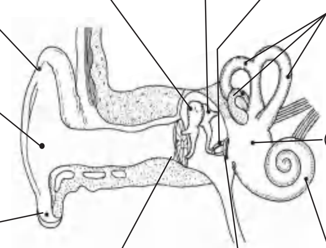
(iii) **Hypermetropia** Also called long-sightedness. The image of nearer objects becomes blurred. It can be corrected by wearing convex lenses.

(iv) **Presbyopia** The loss of elasticity in the eye lense occurs so that near objects are not correctly visible. It can be corrected by bifocal lenses.

Human Ear-Organ of Hearing and Balance

It is an organ of special senses. It serves two functions; it detects sound and enables us to maintain balance.

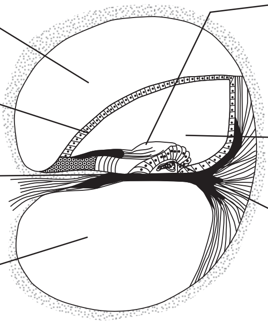
Anatomys of Ear



Human Ear: (1), (2), (3), (4) = External ear; (5), (6), (7) = Middle ear; (8), (9), (10) = Internal ear

Structure and Function of Cochlea

The cochlea is a hollow structure containing 3 fluid-filled canals, sound receptors (organ of Corti) and a basilar membrane.



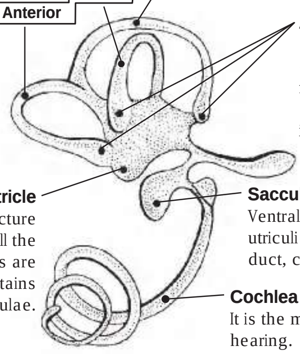
Cross-section through the cochlea

Function It is the main organ of hearing which converts the fluid waves to nerve impulses.

The Vestibular Apparatus

It consists of two parts-the semicircular canals and the vestibule. Both are involved in proprioception.

The semicircular canals The three semicircular canals are filled with a fluid (endolymph). These are anterior, posterior and lateral semicircular canals or ducts.



Membranous labyrinth of internal ear

Maculae It is concerned with the static equilibrium and responds to linear acceleration and tilling of the head.

Mechanism of Hearing

Sound waves from external source. → Reach to tympanic membrane.

↓

Vibration of tympanic membrane transports sound waves to ear ossicles. → Ear ossicles amplify the sound waves and transform them into shorter and powerful movements.

↓

Powerful waves reach the fluid that fills the cochlea. → Pressure waves cause the basilar membrane to vibrate.

↓

Vibrations stimulate hair cells of organ of Corti and contract the tectorial membrane. → All these changes stimulate dendrites at the base of hair cells and a nerve impulse is generated.

↓

Impulse travels to auditory area of brain *via* vestibulocochlear nerve. → Sound is detected by the brain.

Common Diseases of the Ear

(i) **Meniere's syndrome** It is a hearing loss due to the pathological distension of membranous labyrinth.

(ii) **Tympanitis** It is due to the inflammation of eardrum.

(iii) **Otalgia** Pain in the ear.

(iv) **Otitis media** Acute infection in the middle ear.

22

Chemical Coordination and Integration

Glands

They are the group of cells that are specialised for the secretion of a particular substance. **They can be classified as follows**

Types of Glands

1. **Exocrine glands** The secretion of these glands are carried by the ducts to a particular organ, **e.g.,** salivary glands, liver, etc.
2. **Endocrine glands** These glands do not possess ducts and they pour their secretions directly into the blood, **e.g.,** hypothalamus, thyroid, etc.
   (i) **Holocrine glands** They secrete only hormones, **e.g.,** thyroid, adrenal, etc
   (ii) **Heterocrine glands** They have dual functions, **i.e.,** secretion of hormones and other physiological functions, **e.g.,** testes, pancreas, etc.

Hormones (Bayliss and Starling; 1903)

These are the chemical substances that are produced or released by cells or group of cells that form the endocrine (ductless) glands.

Target cells are the cells affected by a hormone. These target cells are selective or exclusive to a hormone due to the presence of protein receptors on them.

Types of Hormones

(i) **Hormones fall into two broad categories**

(a) **Tropic hormones** These hormones stimulate other endocrine glands to produce and secrete hormones, **e.g.,** Thyroid Stimulating Hormone (TSH) produced by pituitary gland stimulates the release of thyroxine hormone from thyroid gland. Thyroxine in turn stimulates metabolism in many types of body cells. Thus, TSH is a tropic hormone (thyroxine is a non-tropic hormone).

(b) **Non-tropic hormones** These hormones stimulate vital cellular processes including metabolism, but do not stimulate the release of other hormones, **e.g.,** prolactin secreted by anterior pituitary stimulates the production of milk in a woman's breast tissue.

(ii) According to their chemical composition, **hormones can be classified into following groups**

(a) **Steroid hormones** Derivative of cholesterol, **e.g.,** aldosterone, cortisol, sex corticoids, oestrogen, etc.

(b) **Proteins and peptide hormones** Largest group of hormones, they are the long chains of amino acids, **e.g.,** insulin, hCG, hypothalamic hormones, GH, etc

(c) **Amine hormones** Smaller molecules derived from amino acid tyrosine, **e.g.,** thyroxine, catecholamines, etc.

(iii) **Local hormones** These are secreted by the cells, but not by glands and widely dispersed in the body. These are considered as tissue hormones or non-endocrine hormones.

Different types of local hormones are as follows

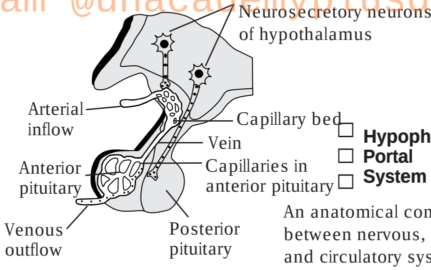
(a) **Histamine** Synthesised by mast cells in tissues and basophils, released in response to inflammation, increases capillary permeability and dilation.

(b) **Leukotrienes** Released from mast cells, assist in promoting allergic response cause vasoconstriction, attract neutrophils to the site of inflammation present in large quantity in rheumatoid joints.

(c) **Cytokines** Polypeptide hormones, help in defence mechanism, elicit effects on same cells and nearby cells, important cytokines are interleukins and interferons.

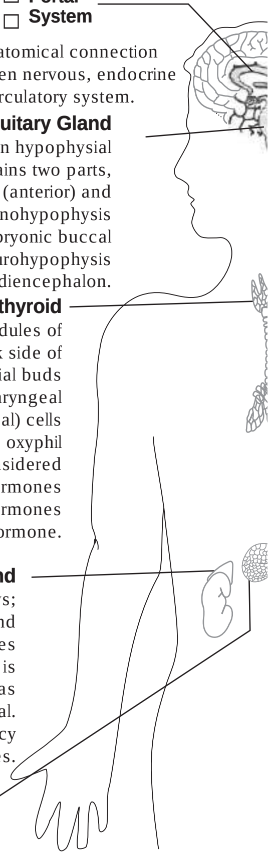
(d) **Thromboxanes** Synthesised by platelets, cause vasoconstriction and platelet aggregation, thus contribute to the process of blood coagulation.

Human Endocrine System



Hypophyseal Portal System

An anatomical connection between nervous, endocrine and circulatory system.



Pituitary Gland

Master gland of the body, lying in hypophysial fossa or sella turcica, contains two parts, i.e., adenohypophysis (anterior) and neurohypophysis (posterior). Adenohypophysis is formed from embryonic buccal cavity (Rathke's pouch) and neurohypophysis develops from diencephalon.

Parathyroid

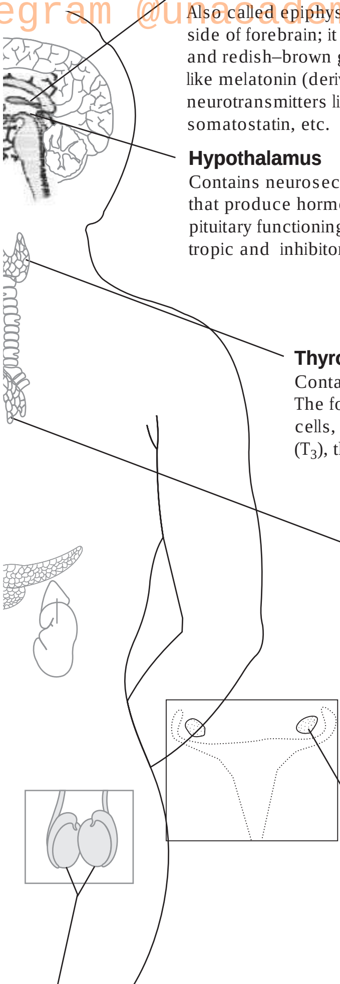
These are the four small nodules of tissue embedded in the back side of thyroid gland; develop as epithelial buds from third and fourth pairs of pharyngeal pouches, contain chief (principal) cells which secrete hormones and oxyphil (eosinophil) cells which are considered as degenerated chief cells. Its hormones are called parathormones or collips hormone.

Adrenal Gland

Perched on top of the kidneys; consists of an inner medulla and outer cortex, each of which releases several hormones. Its cortex region is mesodermal in origin, whereas medulla is ectodermal. Medulla secretes emergency (or flight or fight) hormones.

Pancreas

Dual purpose organ, produces digestive enzymes and hormones, its acini meets the exocrine functions, whereas Islet of Langerhans perform endocrine functions.



Pineal Body
Also called epiphysis,located on the dorsal side of forebrain; it is stalked, small, rounded and redish–brown gland, secretes hormones like melatonin (derivative of tryptophan) and neurotransmitters like serotonin, histamine, somatostatin, etc.

Hypothalamus
Contains neurosecretory cells (nuclei) that produce hormones to control the pituitary functioning. It synthesises both tropic and inhibitory hormones.

Thyroid Gland
Contains follicles which synthesise hormones. The follicles are formed of cuboidal epithelial cells, secrete 3 hormones namely triiodothyronin (T_3), thyroxine (T_4) and calcitonin.

Thymus Gland
Endodermal origin, develops from the epithelium of outer part of third gill pouch, lobular structure lying on dorsal side of the heart and aorta, contains lymphoid tissues that take part in proliferation and maturation of T-lymphocytes and release peptide hormones that are referred to as thymosins (humoral factors) and are important during puberty.

Testes
Male gonad, perform dual functions, i.e., synthesise sperms and release hormone, their hormones are called androgens.

Ovaries
Female gonad, perform dual functions, i.e., production of ova and hormone release.

Major Hormones of Human Endocrine System

Gland	Hormone	Type	Action
Hypothalamus	Oxytocin	Peptide	Moves to posterior pituitary for storage.
	Antidiuretic Hormone (Vasopressin)	Peptide	Moves to posterior pituitary for storage.
	Regulatory Hormones (RH and IH) of anterior pituitary gland		Act on anterior pituitary to stimulate or inhibit the hormone production.
Pituitary gland Anterior			
(i) Pars distalis	Growth Hormone (GH)	Protein	Stimulates body growth.
	Prolactin	Protein	Promotes lactation.
	Follicle-Stimulating Hormone (FSH)	Glycoprotein	Stimulates follicle maturation and production of oestrogen; stimulates sperm production.
	Luteinizing Hormone (LH)	Glycoprotein	Triggers ovulation and production of oestrogen and progesterone by ovary, promotes sperm production.
	Thyroid-Stimulating Hormone (TSH)	Glycoprotein	Stimulates the release of T_3 and T_4.
	Adrenocorticotropic Hormone (ACTH)	Peptide	Promotes the release of glucocorticoids and androgens from adrenal cortex.
(ii) Pars intermedia	Melanocyte-Stimulating Hormone (MSH)	Peptide	Maintenance of lipid content in body.
Posterior	Oxytocin Vasopression (ADH)	Peptide	Initiates labor, initiates milk ejection, controls osmotic concentration of body fluids in particular water reabsorption by kidneys.
Thyroid gland	T_3 (Triiodothyronine)	Amine	Increases metabolism and blood, pressure, regulates tissue growth, five times more potent than T_4.
	T_4 (Thyroxine)	Amine	Increases metabolism and blood pressure, regulates tissue growth.
	Calcitonin	Peptide	Childhood regulation of blood calcium levels through uptake by bone.

Gland	Hormone	Type	Action
Parathyroid gland	Parathyroid hormone (parathormones or collip hormones).	Peptide	Increases blood calcium levels through action on bone, kidneys and intestine.
Pancreas	Insulin (-cells)	Protein	Reduces blood sugar level by regulating cell uptake.
	Glucagon (-cells)	Protein	Increases blood sugar levels.
Adrenal glands Adrenal medulla	Epinephrine (Adrenaline)	Amine	Affects PNS either by stimulating or inhibiting it, increases respiration rate, heart rate and muscle contraction.
	Norepinephrine (Nor-adrenaline)	Amine	Stress hormone, increases blood pressure, heart rate and glucose level.
Adrenal cortex	Glucocorticoids (cortisol)	Steroid	Long-term stress response–increased blood glucose levels, blood volume maintenance, immune suppression.
	Mineralocorticoids (Aldosterone)	Steroid	Long-term stress response-blood volume and pressure maintenance, sodium and water retention by kidneys.
Gonads Testes	Androgens (Testosterone)	Steroid	Reproductive maturation, sperm production.
Ovaries	Oestrogen	Steroid	Stimulates hypothalamus to release GnRH before ovulation, maintains follicular growth.
	Progesterone	Steroid	Maintains pregnancy and uterus wall thickening, inhibits the release of oestrogen.
Pineal gland	Melatonin	Amine	Circadian timing (rhythm).
Thymus	Thymosin	Peptide	Development of T-lymphocytes.

Mechanism of Hormone Action

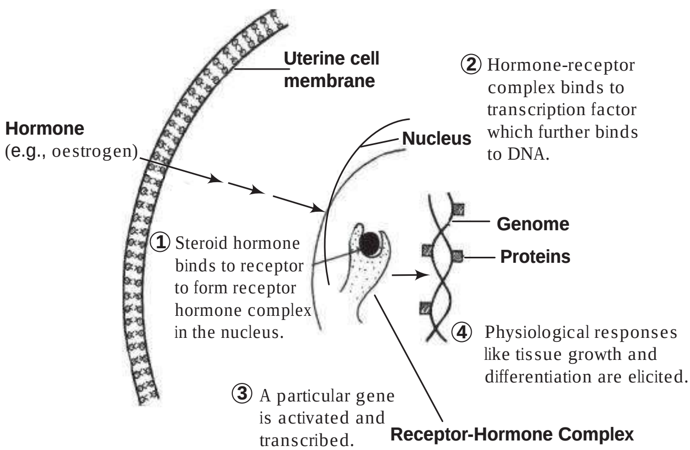
Hormones are mainly of two types, **i.e., water soluble** (**e.g.,** amino acid derivatives, peptide and protein hormones) and **lipid soluble** (**e.g.,** steroid hormones).

Water soluble hormones require extracellular receptors and generate **second messengers** (**e.g., c**AMP) for carrying out their activity.

Lipid soluble hormones can pass through cell membranes and directly enter the cell.

(i) Steroid Hormone Action through Intracellular Receptors

These hormones easily pass through the cell membrane of a target cell and bind to specific intracellular receptors (protein) to form a hormone receptor complex.

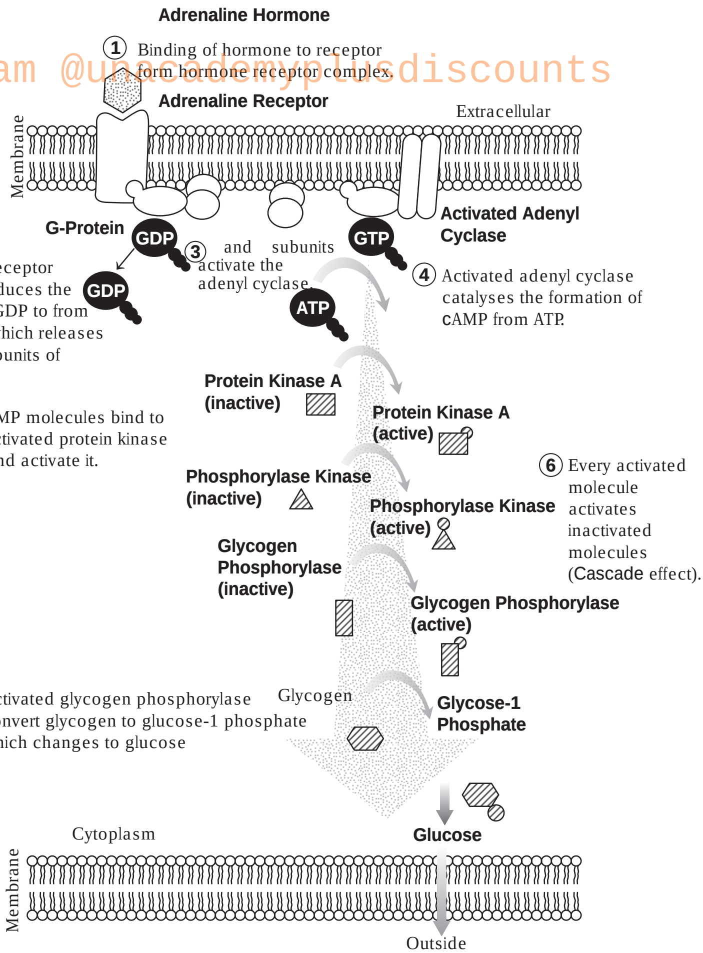


MECHANISM OF STEROID HORMONE ACTION

(ii) Peptide Hormone Action through Extracellular Receptors

These hormones act at the surface of target cell as **primary messengers** and bind to the cell surface receptor forming the **hormone-receptor complex**.

This mechanism was discovered by **EW Sutherland** in 1950 for which he got the Nobel Prize.



MECHANISM OF PROTEIN HORMONE ACTION

Hence, single molecule of adrenaline may lead to the release of 100 million glucose molecules.

Regulation of Hormone Action

Both hypoactivity and hyperactivity of an endocrine gland produces structural or functional abnormalities. Hence, the normal functioning of endocrine glands and the level of hormones in the body needs to be regulated.

This is possible by **feedback mechanisms**. Feedback mechanism works on a simple principle that a hormone will be synthesised only when it is needed. Thus, feedback mechanism may be positive or negative and **may operate in following ways**

1. Feedback Control by Hormones

The hyposecretion of a hormone is sometimes dependent upon the hormones secreted by other glands. For example, hypothalamus is stimulated by some external stimulus and produces releasing hormones.

2. Feedback Control by Metabolites

The levels of metabolites also affect the secretion of certain hormones. For example, after a meal, glucose level of blood rises which stimulates secretion of insulin to act on it.

3. Feedback Control by Nervous System

An emotional stress stimulates the sympathetic nervous system. In turn, sympathetic nerves of adrenal gland stimulate adrenal medulla to produce adrenaline hormone. This leads to increase in blood pressure, heartbeat and rate of respiration.

Control of Hormone Action

Hormones help to control many homeostatic mechanisms. Their production and release are generally controlled by positive or negative feedback loop.

- **In positive feedback loop**, hormones released by one gland stimulate the other gland which further leads to even more significant changes in the same direction. It acts as self-amplifying cycle that accelerates a process.
- While in **negative feedback loop**, the end product of a biochemical process inhibits its own production.

Endocrine Disorders

(i) **Acromegaly** It is caused by the hypersecretion of GH after bone growth has stopped.

Its symptoms include skin and tongue thickening, enlarged hands and feet, facial features become coarse.

(ii) **Addison's disease** It is caused due to the decreased production of hormones from adrenal gland usually due to autoimmune reactions.

Its symptoms include loss of weight and appetite, fatigue, weakness, complete renal failure.

(iii) **Cushing's syndrome** It is caused due to the hyposecretion of hormones from adrenal glands.

In this disease, face and body become fatter, loss of muscle mass, weakness, fatigue, osteoporosis.

(iv) **Cretinism** (Hypothyroidism) The retarded mental and physical development is associated with the hyposecretion of thyroid hormones. The child receives hormones from the mother before birth, so appears normal at first, but within a few weeks or months it becomes evident, the physical and mental development are retarded.

Symptoms are disproportionately short limbs, a large protruding tongue, coarse dry skin, poor abdominal muscle tone and an umbilical hernia.

(v) **Diabetes insipidus** It is caused due to the hyposecretion of ADH and characterised by excessive thirst, urination and constipation.

(vi) **Diabetes mellitus** It is caused due to the insufficient insulin production in body. It can be of two types, **i.e.,** Type 1 or Insulin Dependent Diabetes Mellitus (IDDM) and Type 2 or Non-Insulin Dependent Diabetes Mellitus (NIDDM).

It is characterised by poor wound healing, urinary tract infection, excess glucose in urine, fatigue and apathy.

(vii) **Eunuchoidism** It is a hormonal disorder due to the deficient secretion of testosterone in males. In this case, the secondary male sex organs, such as prostate gland, seminal vesicle and penis are underdeveloped and non-functional. The external male sex characters like beard, moustaches and masculine voice fail to develop, sperms are not formed.

(viii) **Grave's disease** (Hyperthyroidism) It is caused due to the hypersecretion of thyroxine.

Its symptoms include protrusion of eyeballs (exopthalamus), excessive fat near the eyes, weight loss, nervousness, excess sweating.

Toxic nodular goitre (Plummer's Disease) It is caused due to the excess secretion of T_3 and T_4 and is characterised by the presence of glandular tissue in the form of lumps.

Simple goitre It is caused due to the deficient secretion of T_3 and T_4 hormones which results in the enlargement of thyroid gland.

(ix) **Gigantism** It is caused by the excess of growth hormone from early age. It is characterised by large and well-proportioned body.

(x) **Gynaecomastia** It is the development of breast tissue in males. Gynaecomastia occurs mainly due to the disturbance in oestrogen and testosterone ratio.

(xi) **Hyperparathyroidism** It is caused due to the excessive parathromones secretion usually due to tumour in parathyroid gland.

Its symptoms include kidney stones, indigestion, depression, loss of calcium from bones, muscle weakness.

(xii) **Hypoparathyroidism** (Tetany) It is caused due to the hyposecretion of parathyroid hormones.

Its symptoms include muscle spasm, dry skin, numbness in hands and feet.

(xiii) **Hypogonadism** It occurs due to the defect in hypothalamus, pituitary, testes or ovaries. In males, less production of testosterone occurs affecting the development of male secondary sexual features. In females, deficient production of oestrogen occurs resulting in very less development of secondary sex characters.

(xiv) **Simmond's disease** It is caused due to the atrophy or degeneration of anterior lobe of pituitary gland. In this disease, the skin of face becomes dry and wrinkled and shows premature ageing.

23

Reproduction in Organisms

Reproduction is the process of producing offspring similar to itself. It is a characteristic feature of living organisms.

Biologically it means the **multiplication and perpetuation of the species**.

According to the conditions available in environment, organisms have adapted the processes of reproduction. Generally, two types of reproduction mechanisms are present in organisms.

Reproduction

Asexual Reproduction
- Uniparental (single parent involved).
- Gamete formation does not occur.
- Syngamy (gametic fusion) is absent.

Sexual Reproduction
- Biparental (both parents involved).
- Gamete formation always occurs.
- Syngamy characteristically occurs.

Reproduction in Plants

Plants also reproduce by both asexual and sexual methods.

Asexual Reproduction in Plants

The asexual reproduction in plants is also known as **vegetative propagation**.

In both lower and higher plants, **it occurs by following methods**

(i) **Vegetative propagules** There are various vegetative propagules involved in asexual reproduction.These are discussed in chapter 19. These may be tuber, runner, sucker, corm, stolons, offset, bulbil and rhizome, etc.

(ii) **Fragmentation** This method is common in algae, fungi and lichens. The small fragments of plant body led to the formation of new individuals.

(iii) **Fission** This process of reproduction is found in yeast, algae and bacteria. The organism divides into two or more halves.

(iv) **Budding** Mostly occurs in yeasts. Small protruding vegetative outgrowths, develop into new organism after detaching from the mother plant.

(v) **Spores** Algae, fungi, bryophytes and pteridophytes reproduce by this method. Spores are usuallymicroscopic structures.

(vi) **Conidia** Series of rounded structures in several fungi and algae called conidia. After detaching, these germinate into new plants.

Sexual Reproduction in Plants

The plants also reproduce sexually in which fertilisation of male and female gametes takes place and zygote is formed. Gametic cells (**i.e.,** sperm and egg) are produced by the meiotic division.

In lower plants, these gametes fuse directly through their cells and show **isogamy** (fusion between similar gametes), **anisogamy** (fusion between dissimilar gametes) and **oogamy** (fusion between well-defined gametes).

In bryophytes and pteridophytes, these gametes are formed in well-defined structures like antheridia (for male gametes) and archegonia (for female gametes), while in phanerogams, these are situated inside more pronounced structures like androecium (for male gametes) and gynoecium (for female gametes).

Reproduction in Animals

Animals reproduce by both asexual and sexual methods.

Asexual Reproduction in Animals

It is the primary means of reproduction among the **protists, cnidarians** and **tunicates**.

The process of asexual reproduction can occur through following methods

(i) **Regeneration** It is the formation of whole body of an organism from the small fragment of parent body, **e.g.**, **Planaria, Hydra, etc**.

(ii) **Fission** The parent body is divided into two or more daughter cells, which become new individual, **e.g.**, planarians, protozoans, etc.

(iii) **Budding** Small projections or outgrowths in protozoans and sponges. Projection is called bud, later bud develops into new organisms, e.g., yeast and coelenterates.

(vi) **Fragmentation** The parent body breaks into two or more fragments. Each fragment becomes, new organism, **e.g.**, sponges and echinoderms.

(v) **Strobilisation** In this, the ring-like constrictions are developed and organisms look like a pile of minute saucers, **e.g.**, **Aurelia**.

(vi) **Spore formation** The propagules which germinate to form new individual, **e.g.**, **Funaria, Claviceps, Toxoplasma gondii**, etc.

(vii) **Gemmules** These are the asexual? reproductive structures present in several sponges. These are internal buds, **e.g**. **Spongilla lacustris**.

Sexual Reproduction in Animals

In animals, the sexual reproduction occurs by the fertilisation of **haploid sperm** and **haploid egg**, to generate a diploid offspring.

In most individuals (**i.e.**, dioecious), females produce **eggs** (**i.e,** large non-motile cells containing food reserve) and males produce **sperms** (**i.e.**, small, motile cells and have almost no food reserve).

In other individuals (**i.e., monoecious**) such as **earthworm** and **many snails**, single individual produces both sperms and egg. These individuals are called as **hermaphrodite**. The union of sperm and egg occurs in variety of ways depending on the mobility and the breeding environment of individual, **sexual reproduction is of two types**

Sexual Reproduction

- **Syngamy**
  Permanent fusion of male and female gametes.
  - On the basis of no. of parents involved.
    - **Exogamy**
      It is the fusion of gametes produced by two different parents, e.g.,dioecious individuals.
    - **Endogamy**
      It is the fusion of gametes produced by the same parent, e.g.,monoecious individuals.
  - On the basis of structure of fusing gametes.
    - **Isogamy**
      Fusion of morphologically similar gametes, e.g.,Monocystis.
    - **Anisogamy**
      Fusion of two dissimilar gametes, e.g., frog, rabbit, etc.
- **Conjugation**
  Temporary fusion of male and female parents of the same species for exchange of nuclear material, e.g., bacteria and Paramecium.

Other Modes of Sexual Reproduction

(i) **Autogamy** Fusion of male and female gametes produced by same individual, **e.g., Paramecium.**

(ii) **Hologamy** Fusion of entire mating individuals acting as gametes, **e.g., Chlamydomonas**.

(iii) **Paedogamy** Fusion of young individuals, **e.g., Actinosphaerium**.

(iv) **Merogamy** Fusion of small and morphologically dissimilar gametes.

(v) **Macrogamy** Fusion of two macrogametes takes place.

(vi) **Microgamy** Fusion of two microgametes takes place.

(vii) **Cytogamy** Fusion of cytoplasm of two individuals, but no nuclear fusion, **e.g., P. aurelia**.

(viii) **Plasmogamy** Fusion of related cytoplasm, **e.g.,** fungi.

(ix) **Karyogamy** Fusion of nuclei of two gametes, **e.g., Mucor**.

(x) **Automixis** Fusion of gamete nuclei of the same cell, **e.g.,** phasmids.

Events of Sexual Reproduction in Both Plants and Animals

The events of sexual reproduction are though lengthy and complex, but follow a regular sequence. For easy understanding of the process, the process of sexual reproduction (**i.e.**, fertilisation) can be divided into three distinct stages.

These are as follows

(i) Pre-fertilisation events

(ii) Fertilisation

(iii) Post-fertilisation events.

1. Pre-Fertilisation Events

The events which occur before the fertilisation (**i.e.,** gametic fusion) are included in this. These include **gametogenesis** and **gamete transfer**.

Gametogenesis

The process of gamete formation is known as gametogenesis. The gametes are generally of two kinds, **male gametes** and **female gametes.**

In some lower organisms, both male and female gametes are morphologically similar and are called **isogametes** or **homogametes**.

In higher organisms, both male and female gametes are morphologically distinct and are called **heterogametes**.

Heterogametes
- Small—Microgamete/Male gamete—Spermatozoa
- Large— Macrogamete/Female gamete—Ova

The gametes are usually formed by meiotic division, therefore they are haploid in nature.

Gamete Transfer

In most of the organisms, male gamete is motile and the female gamete is non-motile. The male gametes are produced in large number because large number of male gametes are failed to reach female gamete. In flowering plants through the process of **pollination**, male gametes reach to female gamete.

2. Fertilisation Events

In this stage, the most important event is the fusion of gametes (haploid) and formation of diploid **zygote**. This process is called **syngamy** or **fertilisation**.

The process of fertilisation may occur outside the body of organisms, called **external fertilisation** (**e.g.,** algae, amphibians, fishes, etc).
If the syngamy occurs inside the body of organisms, it is called **internal fertilisation** (**e.g.,** fungi, reptiles, birds, higher animals and plants).

In organisms like rotifers, honeybees, lizard and some birds, the female gametes form **new organisms without fertilisation**. This phenomenon is called **parthenogenesis**.

3. Post-Fertilisation Events

These are the events which take place after fertilisation and are majorly described under zygote and embryogenesis.

- **Zygote** The zygote is formed in all sexually reproducing organisms. Further, the development of zygote depends upon the type of life cycle and the environment of organism.
- **Embryogenesis** The process of development of an organism before birth is termed as embryogenesis. It involves gastrulation, formation of primary germinal layers to give rise to the entire body of organisms.
- **Oviparous** Organisms which lay eggs, to hatch out their young one are called oviparous animals, **e.g.,** reptiles, birds, amphibians, etc.
- **Viviparous** Organisms which give birth to newborn young ones are termed as viviparous animals, **e.g.,** primates, non-primates, etc.

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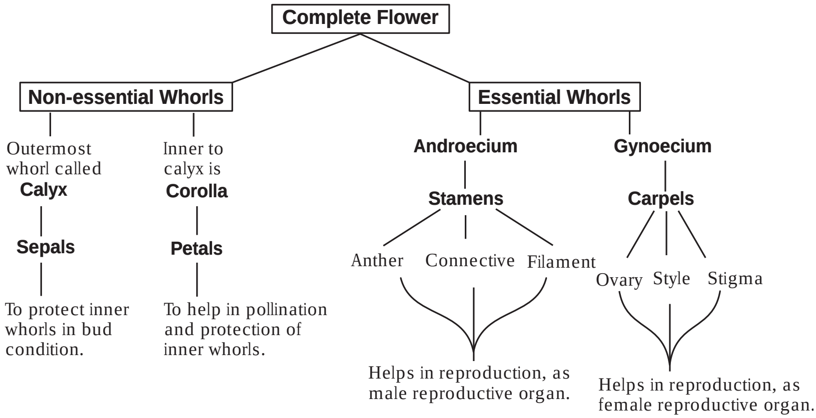
Sexual Reproduction in Flowering Plants

All flowering plants show sexual reproduction and to comply this, they have adopted various features in the form of coloured flowers, minute pollen grains and nector, etc. Before discussing sexual reproduction in flowering plants, we must take a close look of the most pivotal structure for sexual reproduction, **i.e.,** a flower.

Flowers

Flowers are formed in mature plants in response to hormone induced structural and physiological changes on shoot apices.

Following flow chart will provide the detailed information about flower



Floral whorls and their functions

The whole process of sexual reproduction in flowering plants can be divided into following steps

Pre-Fertilisation : Structures and Events

These are discussed below

Male Gametophyte

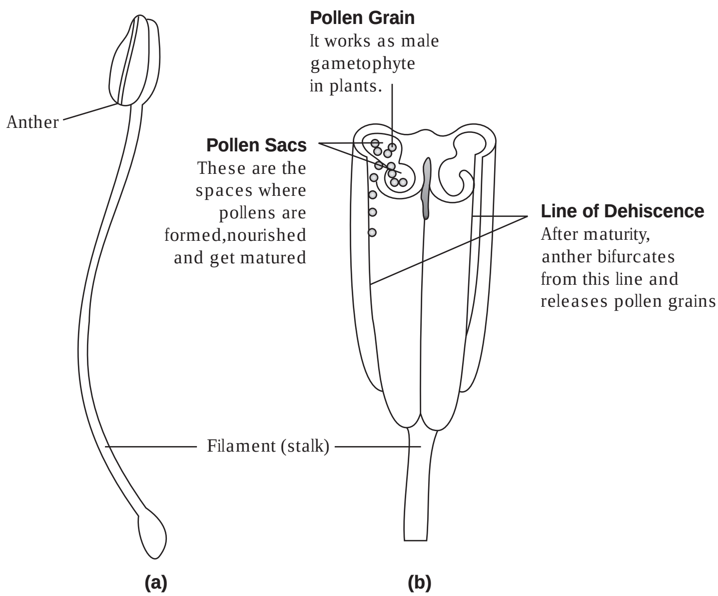
Stamen is male reproductive part of a flower. Each stamen is composed of **anther** and **filament**.

Structure of an Anther

Pollen grains are formed in pollen sacs of anther. The anther is bilobed and the lobe encloses four pollen sacs or **microsporangia**. The four pollen sacs in a dithecous anther appear to lie in its four corners, thus a typical anther is tetrasporangiate.

Anther develops from a homogenous mass of hypodermal cells. These cells contain a prominent nucleus and abundant protoplasm.

These cells are called **archesporial cells**. Archesporial cells divide by **periclinal division** and produce **parietal cells** on outer side and **sporogenous cells** on inner side.



(a) A typical stamen; (b) three-dimensional cut section of an anther

Structure of Microsporangium

It is surrounded by following four layers

Microsporangium

Layers

- **Epidermis** (Single layer, provides protection).
- **Endothecium** (Single layer, cells have fibrous thickenings).
- **Middle layer** (One to three layers).
- **Tapetum** (Single layer, multinucleate cells with dense cytoplasm provides nourishment to developing pollen grains).

Development of Pollen Grain (Male Gametophyte)

Hypodermal Cell of Anther

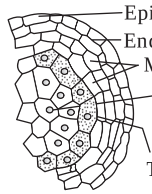
↓ Differentiation/ Specialisation

Archesporial Cell (prominant nucleus and abundent protoplasm)

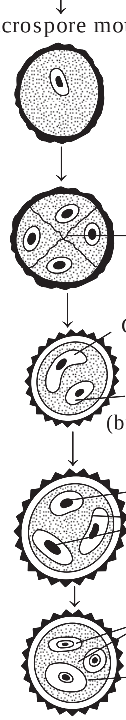
↓ Periclinal division/ Layering division

- Parietal Cells (outer)
  - ↓ Anticlinal division
  - 2-5 layers of anther wall and tapetum
- Sporogenous Cells (inner)
  - ↓ Specialisation
  - Microspore Mother Cells (MMCs) or Pollen Mother Cells (PMCs)
  - ↓ Meiosis
  - Microspore or Pollen Grain (In form of tetrad)
  - ↓ Dehydration
  - Separated Pollen Grain
  - ↓ Mitotic division in generative cell
  - Pollen Grain
  - ↓ Maturation
  - Mature Pollen Grain

Microsporogenesis



Microsporangium (nourishes the developing pollen grain)

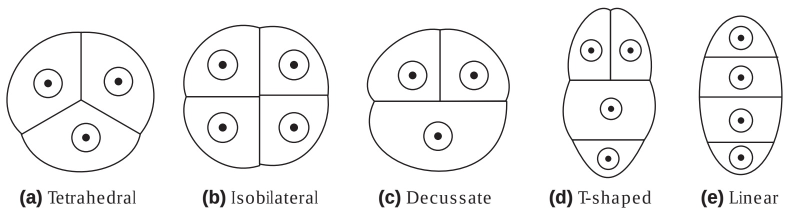


Stages of maturation of microspore into pollen grain

Note About 60% angiosperms shed their pollen in 2-celled stage and remaining shed the pollen in 3-celled stage.

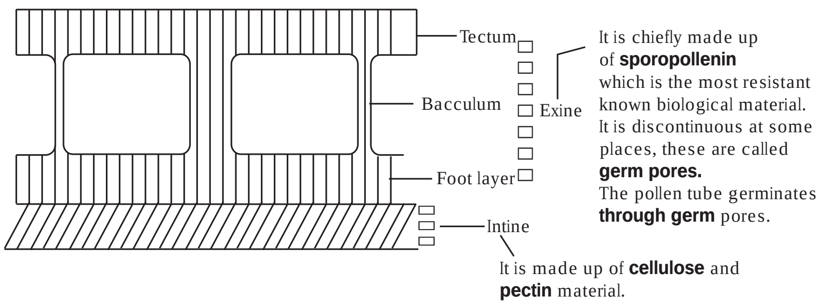
Microspores or Pollen Grains Arrangement

The newly formed microspores are arranged mostly in tetrahedral manner with following arrangements



Different types of microspore tetrads

Pollen Wall



Pollenkitt is the matter produced by tapetal cells, which provide specific colour and odour to pollen grains and help in attracting pollinating insects.

Female Gametophyte

Female reproductive part of a flower is as follows

Pistil/Gynoecium

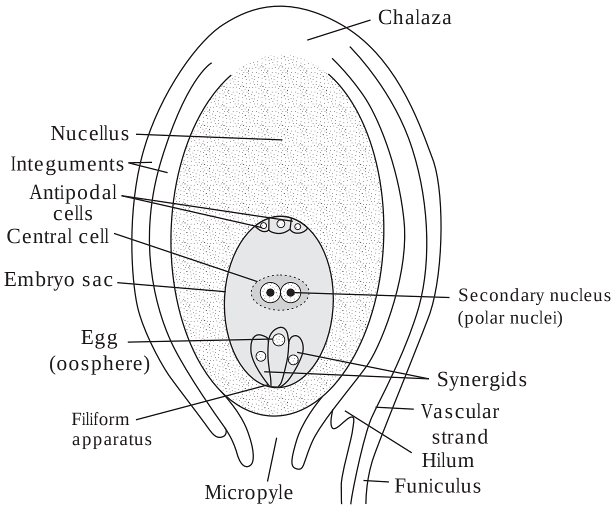
It is the innermost essential whorl of a bisexual flower. **Its main parts are**

- Stigma
- Style
- Ovary

Structure of Megasporangium (Ovule)

An individual ovule comprises of a nucellus invested by one or two **integuments**. They help in encircling the ovule, except the tip at **micropylar end** and a stalk called **funiculus** or **funicle**.

The junction between an ovule and funicle is called **hilum.** The basal part of ovule, just opposite to micropyle is called chalaza.



Structure of a typical ovule

On the basis of relative position of funiculus, chalaza and micropyle, **the ovules can be classified into following six types**

(i) **Atropous** Simple and primitive type, **e.g.,** Gymnosperms, **Piper nigrum, Rumex** and **Polygonum**.

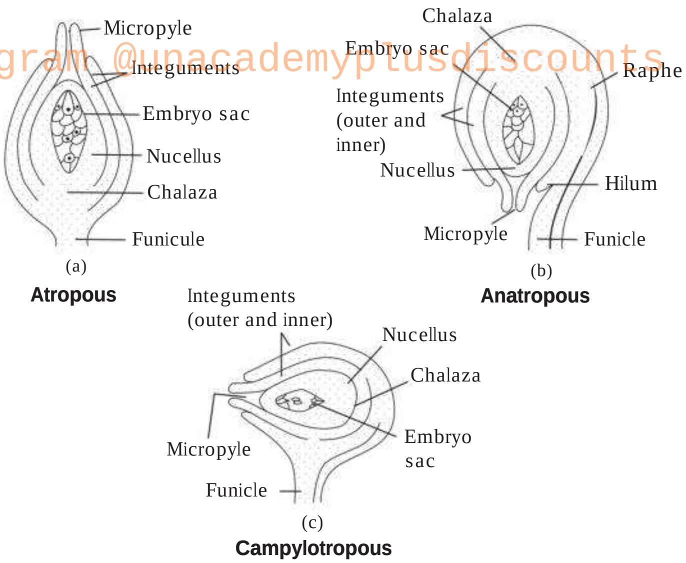
(ii) **Anatropous** The most common type of ovule. The ovule is rotated at 180°, **e g.,** Solanaceae**, etc.**

(iii) **Campylotropous** The body of ovule is more or less at right angle to funicle, **e.g.,** Chenopodiaceae and Capparidiceae.

(iv) **Amphitropous** The curvature is like anatropous ovule but, the embryo sac is horse-shoe-shaped, **e.g.,** Butamaceae and Alismaceae.

(v) **Hemianatropous** Here, body of ovule is turned at 90°, **e.g.,** Primulaceae and Plumbiginaceae.

(vi) **Circinotropous** In this type of ovule, the length of funiculus is increased and covers whole ovule, **e.g.,** Cactaceae, etc.



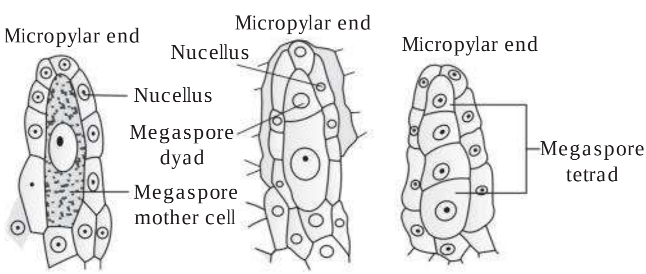
Development of Embryo Sac (FEMALE GAMETOPHYTE)

It is a two step process

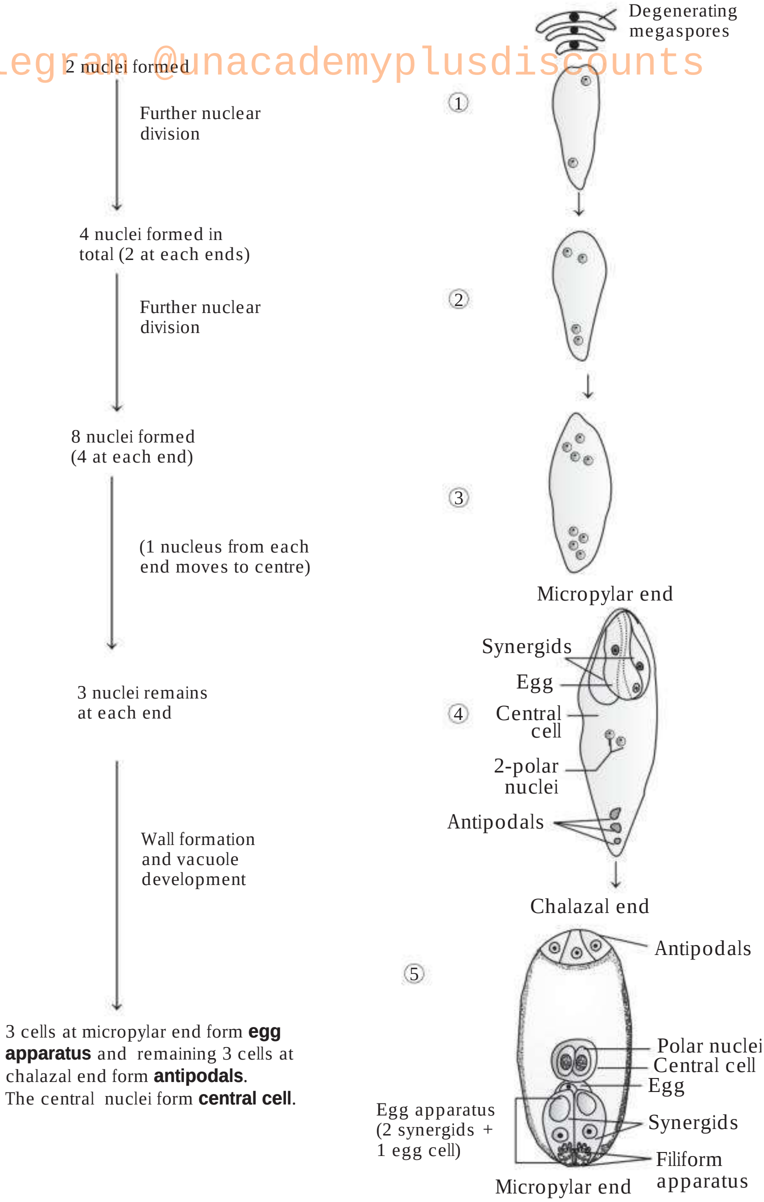
(i) **Megasporogenesis** It is the development of megaspore, **i.e.**, embryo sac, while megagametogenesis is the development of gamete within the megaspore. The development of megaspore takes place from specialised hypodermal cell, called archesporial cell. This cell after various mitotic divisions forms a megaspore tetrad (a cluster of 4 cells) out of which 3 cells degenerate while remaining one develops into functional megaspore or embryo sac.

Further development in embryo sac results into a functional egg.

(ii) **Megagametogenesis The events in this process look like**



Parts of the ovule showing a large megaspore mother cell, a dyad and a tetrad of megaspore



Embryo sac formation

Pollination

It is the transfer of pollen grains from the anther of a flower to the stigma of the same or another flower.

It is of two types

1. Self-pollination
2. Cross-pollination

1. Self-Pollination (AUTOGAMY)

It is the transfer of the pollen grain from the anther of a flower to the stigma of either the same or genetically similar flower.

Adaptations for Self-Pollination

Autogamy	Geitonogamy	Cleistogamy
Transfer of pollen to the stigma occurs in the same flower, **e.g.,** rice.	Pollens of one flower are deposited on the stigma of another flower of the same plant.	Flowers never open. The pollen from anther lobe falls on the stigma of the same flower, **e.g., Commelina bengalensis.**
Direct contact of anther and stigma occurs by bending of filaments and style of the two organs respectively, e.g., **Mirabilis jalapa**.	This transfer involes a pollinator, hence functionally, it is a cross-pollination. Genetically, it is similar to autogamy since the pollen grains come from the same plant.	Anthers do not dehisce; germinated pollen tube pierces anther wall and enter the stigma of same flower.

2. Cross-Pollination (XENOGAMY)

It is the deposition of pollen grain from anther of a flower to the stigma of a genetically different flower of another plant of same or different species. It is also known as allogamy.

Certain adaptations to facilitate xenogamy are as follows

Adaptations for Cross-Pollination (Outbreeding Devices)

Dichogamy	Dicliny	Herkogamy	Self-Sterility or Self-Incompatibility
The condition, where maturation time of stigma and anthers is such that either stigma becomes receptive before anthers get mature (protogyny) or the anthers become ready for the dehiscence before stigma becomes receptive (protandry), e.g., in Aristolochia and Scrophu**laria**, protogyny occurs and in rose, sunflower, **Impatiens**, etc., protandry condition is found.	The presence of only one kind of reproductive whorl in a flower is called dicliny or unisexuality. A plant may be monoecious, **i.e.,** carrying male and female flowers on the same plant. In such case, both cross and self-pollinations can occur. In dioecious plants, **i.e.,** plants either with male or female flowers are borne on different plants, in such a case cross-pollination is the only way of pollination.	In some flowers, a mechanical barrier exists between the compatible pollen and stigma so that self-pollination becomes impossible. Sometimes, a hood-like, covering covers the stigma as in Iris and in **Calotropis**. The pollens are grouped in pollinia and stick to the surface till they are carried away by the insects.	The pollen of a flower has no fertilising effect on the stigma of the same flower, **e.g., Thea sinensis** (tea), **Passiflora**, etc.

Agents of Pollination

The pollination can occur through following agents

Various Agencies of Pollination

Pollinating Agency	Process	Agent	Examples
Abiotic agents	Anemophily	Wind	Grasses, maize and gymnosperms
	Hydrophily	Water	Vallisneria and Hydrilla
Biotic agents	Entomophily	Insects	Rose, poppy and Salvia
	Ornithophily	Birds	Erythrena and Marcgravia
	Cheiropterophily	Bats	Baobab tree (Adansonia)
	Malacophily	Snails	Chrysanthemum and Lemma
	Myrmecophily	Ants	Myrmecophilus acervorum
	Anthrophily	Human	Various ornamental plants

Flowering plants have adapted various features to support their pollinators in the process of pollination as insect pollinating plants have strong nectariferous glands to attract the insects. On the other hand, wind pollinating plants have very light and non-sticky pollen grains to fly freely in air.

Note
- **Pollen-pistil interaction** refers to the events from the deposition of pollen on the stigma till the entry of pollen tube into the ovule. It determines compatibility and incompatibility of pollen and pistil.
- **Artificial hybridisation** has been used by the plant breeders for crop improvement programme. It includes **emasculation** (removal of anther from bud before anther dehisces, if female parent bears bisexual flowers) and **bagging**.

Fertilisation

Through the process of pollination, the pollen lands on the stigma of a female flower. Pollen grain germinates and tube cell elongates and grows down into style towards the ovule in ovary.

Double Fertilisation

It was discovered by Nawaschin in 1898. It is a complex process of fertilisation in flowering plants which involves a female gametophyte and two male gametes.

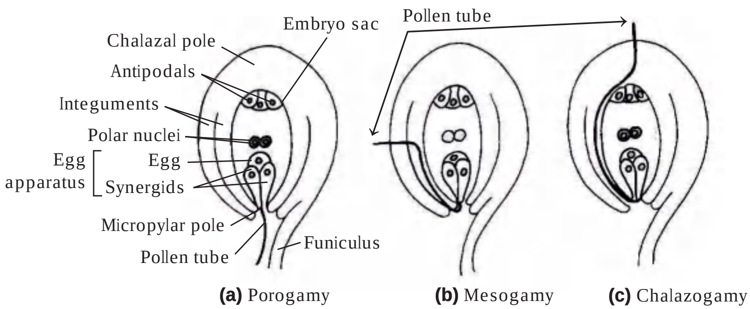
Entry of Pollen Tube into Ovule

The pollen tube can enter in ovule through three alternate ways. **These are**

(i) **Porogamy** Entry through micropyle.

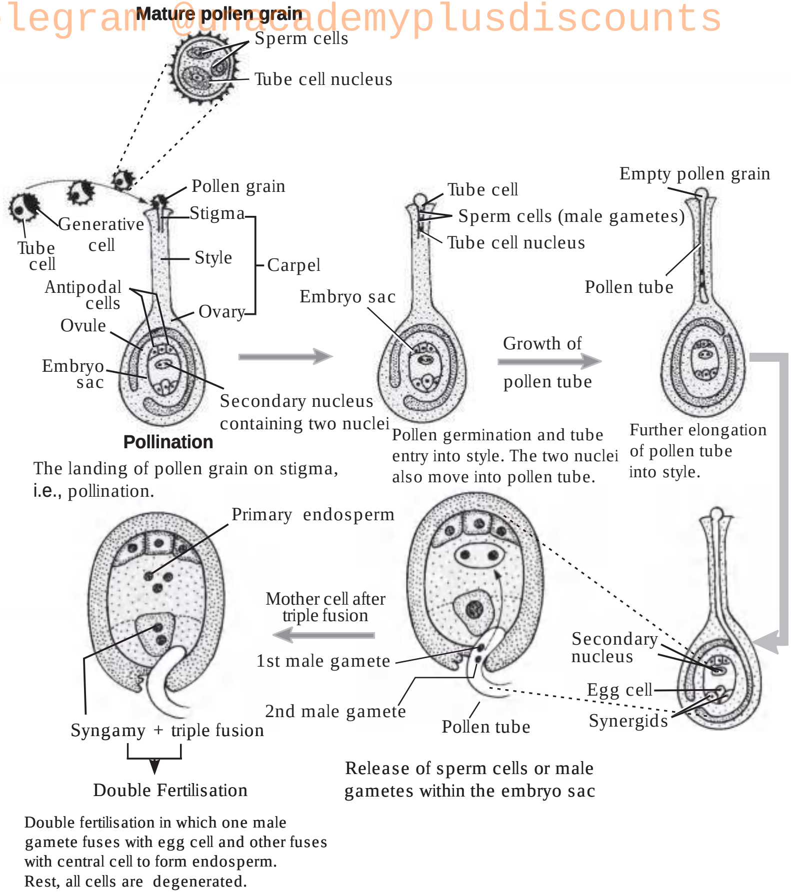
(ii) **Mesogamy** Entry through integuments.

(iii) **Chalazogamy** Entry through chalazal end.



Various routes of pollen tube entry into the ovule

The process of fertilisation is presented diagrammatically below



The process of fertilisation and double fertilisation

Post-Fertilisation Events

The major post-fertilisation events include development of endosperm and embryo, maturation of ovules into seed and ovary in fruit. They take place soon after the double fertilisation.

Development of an Endosperm

As a result of triple fusion, a triploid structure called Primary Endosperm Mother Cell (PEMC) is formed that finally produces a mass of nutritive cell called **endosperm** through **mitotic division**.

On the basis of development, endosperms are of three types

(i) **Cellular endosperm**

Every division of endosperm nucleus is followed by cytokinesis. Occurs in about 72 families, **e.g., Balsam**, **Datura**, **Petunia**, etc.

(ii) **Nuclear endosperm**

It is the most common type of endosperm (about 161 families) Primary endosperm nucleus divides repeatedly without wall formation, hence large number of free nuclei are present, **e.g.,** wheat, maize, rice, etc.

(iii) **Helobial endosperm**

It occurs mostly in monocots. The endosperm is of intermediate type between cellular and nuclear endosperm, **e.g.,** Asphodelus.

Functions of Endosperm

The important function of endosperm is to provide nutrition to the embryo and support its growth.

Development of an Embryo/Embryogenesis

Before going into detail of embryogenesis, we first understand the embryo.

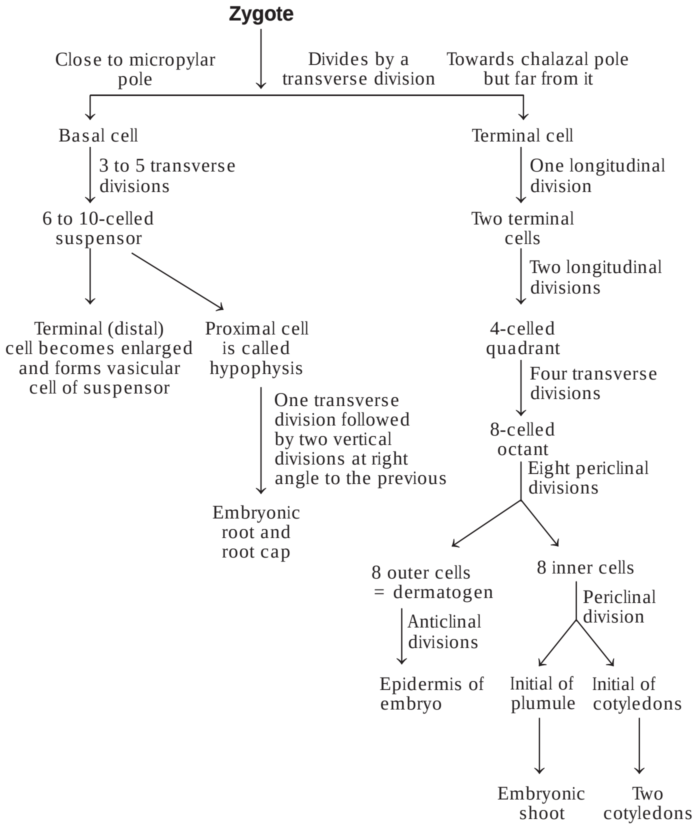
Embryo

The embryo of a plant is a miniature plant tucked into a foetal position in the seed. It is actually one of the earliest stage in the development of a plant, where nutrients which are provided to the seed enable it to germinate into a plant.

Dicot embryo consists of an **embryonal axis** and **two cotyledons.** Embryo of monocots possesses only **one cotyledon** at one end.

The embryogenesis is the series of specialisation and differentiation of cells.

The whole process of embryogenesis can be understood through following flow chart



Embryo development in dicots

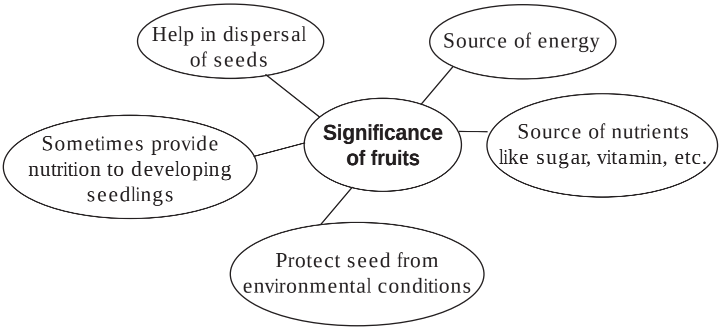
Seed

'A seed typically consists of seed coat, cotyledons and an embryo axis.' In angiosperms, it is the final product of sexual reproduction and they are formed inside fruit.

Although in most of the species, fruits are the result of fertilisation, some species develop fruit without fertilisation. Such fruits are called **parthenocarpic fruits**, **e.g.,** banana.

Fruits

These are mature or ripened ovaries developed after fertilisation, containing seeds inside them.



Post-Fertilisation Changes in Ovary Leading to Fruit and Seed Formation

Ovary	– Fruit	
Ovary wall	– Pericarp	
Ovule	– Seed	
Outer integument	– Testa	Seed coat
Inner integument	– Tegmen	
Synergids	– Degenerate	
Egg cell	– Oospore (embryo)	

Additional Terms

1. Parthenocarpy

It is the process of producing fruits without fertilisation.

On the basis of its causes, it is of three types

(i) **Genetic parthenocarpy** Parthenocarpic fruits are produced because of hybridisation or mutation.

(ii) **Environmental parthenocarpy** The environmental condition like fog, frost, high temperature and freezing led to non-functioning of reproductive organ and results into parthenocarpy.

(iii) **Chemical induced parthenocarpy** The artificial application of IAA, α-NAA, gibberellin leads to production of parthenocarpic fruits.

2. Apomixis

The term 'Apomixis' was introduced by **Winkler** (1908).

'Apomixis is the substitution of sexual reproduction, which does not involve meiosis and syngamy.'

It is of two types

(i) **Vegetative reproduction** It is a type of asexual reproduction, mostly in plants when a plant part is detached and produces new progeny.

(ii) **Agamospermy** Process which involves sex cells but takes place without fertilisation or meiosis.

(a) **Diplospory** $\underset{(2n)}{\text{MMC}} \xrightarrow[\text{division}]{\text{mitotic}} \underset{(2n)}{\text{Embryo sac}} \xrightarrow[\text{division}]{\text{mitotic}} \underset{(2n)}{\text{Embryo}}$

(b) **Adventitive embryony** The nucellar or integumentary cells produce diploid embryo.

(c) **Apospory** Cell, outside the embryo sac produces aposporic embryo sac.

3. Polyembryony

The process of occurrence of more than one embryo in a seed is known as polyembryony. It was first observed by **Antonie van Leeuwenhoek** in 1917 in orange seed.

On the basis of originating cell, it is of two types

(i) **Gametophytic polyembryony** (arises from haploid cells of embryo sac)

(ii) **Sporophytic polyembryony** (embryo arises from diploid structures)

4. Xenia

The term 'Xenia' was coined by **Wilhelm Olbers Focke** in 1881.

It is the effect of pollen on maternal tissues including seed coat and pericarp. When one allele in the pollen is able to mask the effect of double dose of other, the former is called **xenia** over the latter.

5. Metaxenia

It is a condition during hybridisation where the alleles of one locus behave as a double dose for the other and make it as a recessive.

This condition is found in aneuploids where segregation is prevented.

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Human Reproduction

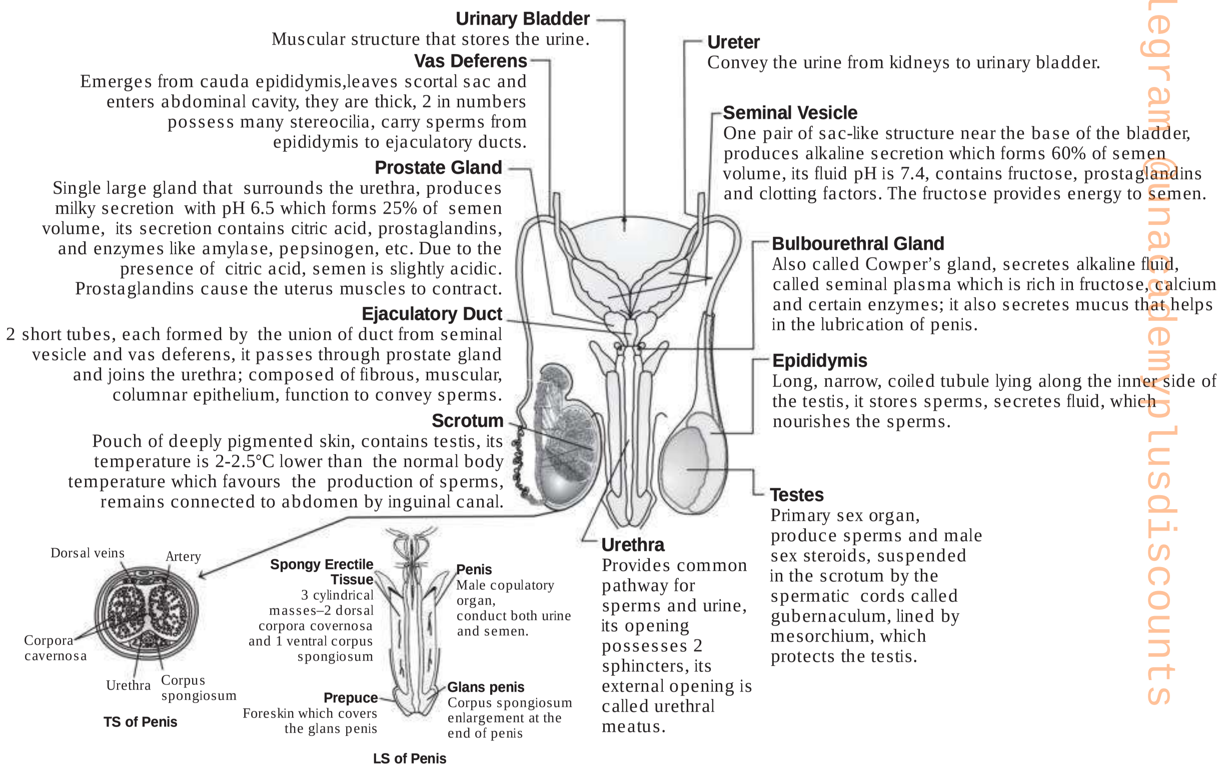
Human beings show sexual reproduction and they have separate sexes (unisexual). As we can identify male and female from their physical appearance means sexual dimorphism is also present. **The secondary sexual characters of man and woman are as follows**

Secondary Sexual Features in Man and Woman

Character	Man	Woman
General build up	More muscular	Less muscular
Aggressiveness	More marked	Less marked
Hair growth		
(i) Facial	Beard, moustache present	Absent
(ii) Axillary	Present	Present
(iii) Pubic	Hair distribution more lateral and upwards towards umbilicus	Upward growth not so marked and is more horizontal
(iv) Chest	Present	Absent
Mammary glands	Undeveloped	Well-developed
Pelvis	Not broad	More broad
Larynx	More apparent	Less apparent
Voice	Low pitched	High pitched
Breathing	Predominantly abdominal	Predominantly thoracic
BMR	High due to greater activity	Not so high as compared to man

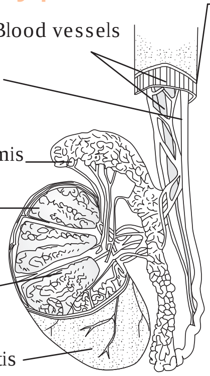
Male Reproductive System

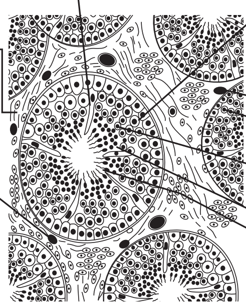
The male has two visible sex organs, the testes and penis, which can be seen from the outside. The testes are the **primary male sexual organ** in males, whereas prostate, seminal vesicles, vas deferentia and penis are the **secondary sexual organs**.



Male reproductive system

The testis in transverse section shows different cell types at various stages.



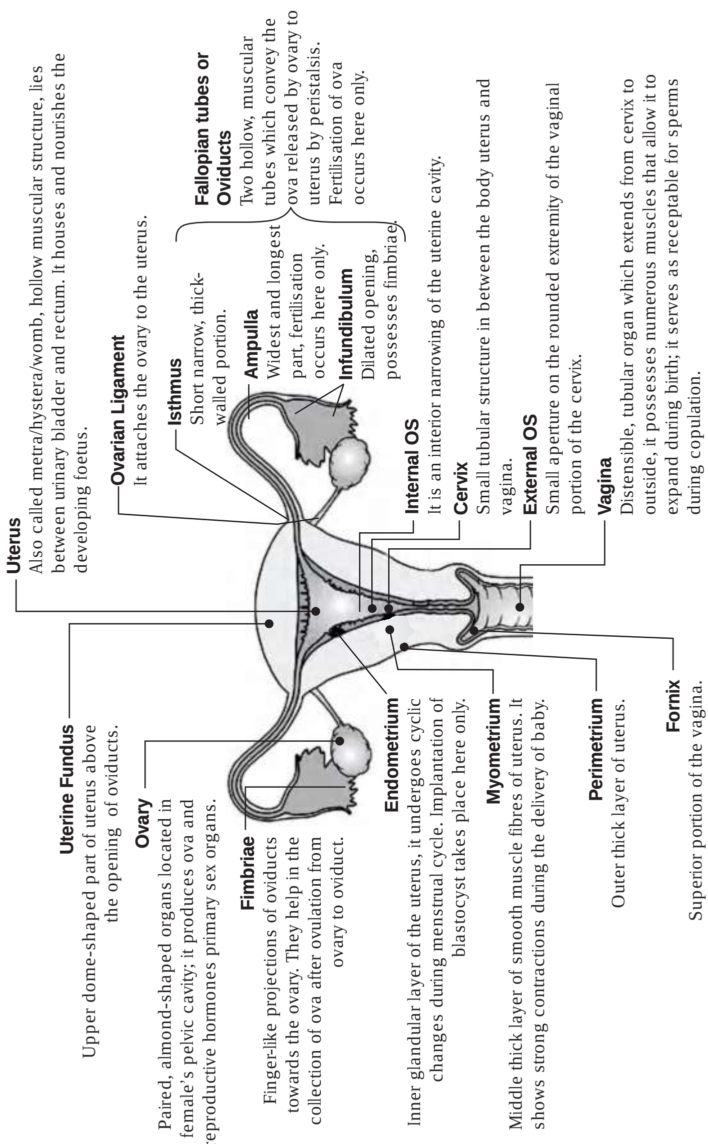


TS of testis

Female Reproductive System

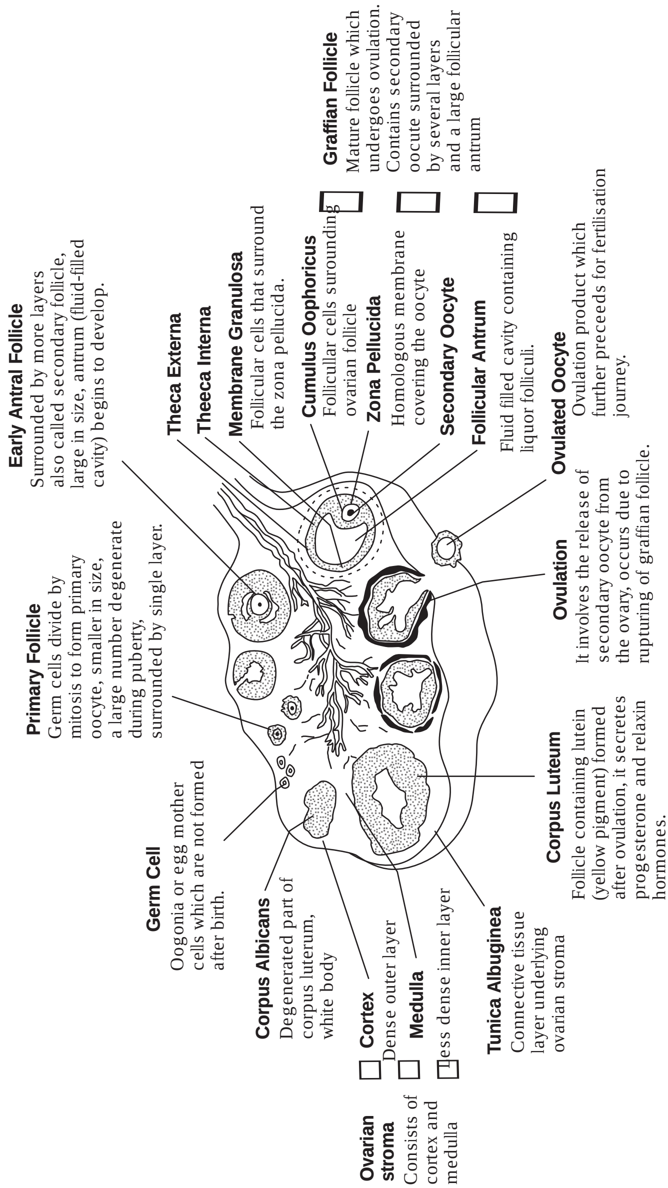
It consists of ovaries which are the primary sex organs in human female. The secondary sex organs in human female are Fallopian tubes (oviducts), uterus, vagina and mammary glands.

Various components of female's internal reproductive system are shown in the given figure



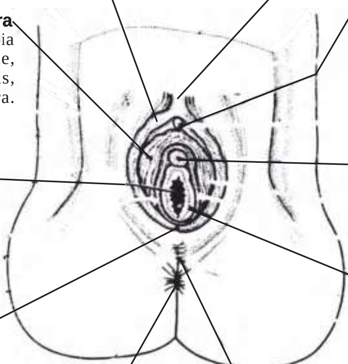
Female reproductive system

The primary sex organs of human females, **i.e.,** ovaries consist of a dense outer layer called **cortex** and a less dense inner portion called **medulla**. A section of ovary shows the growing follicles at different stages.



TS of ovary

The external genitilia or vulva of female consists of following parts.



External genitalia of female

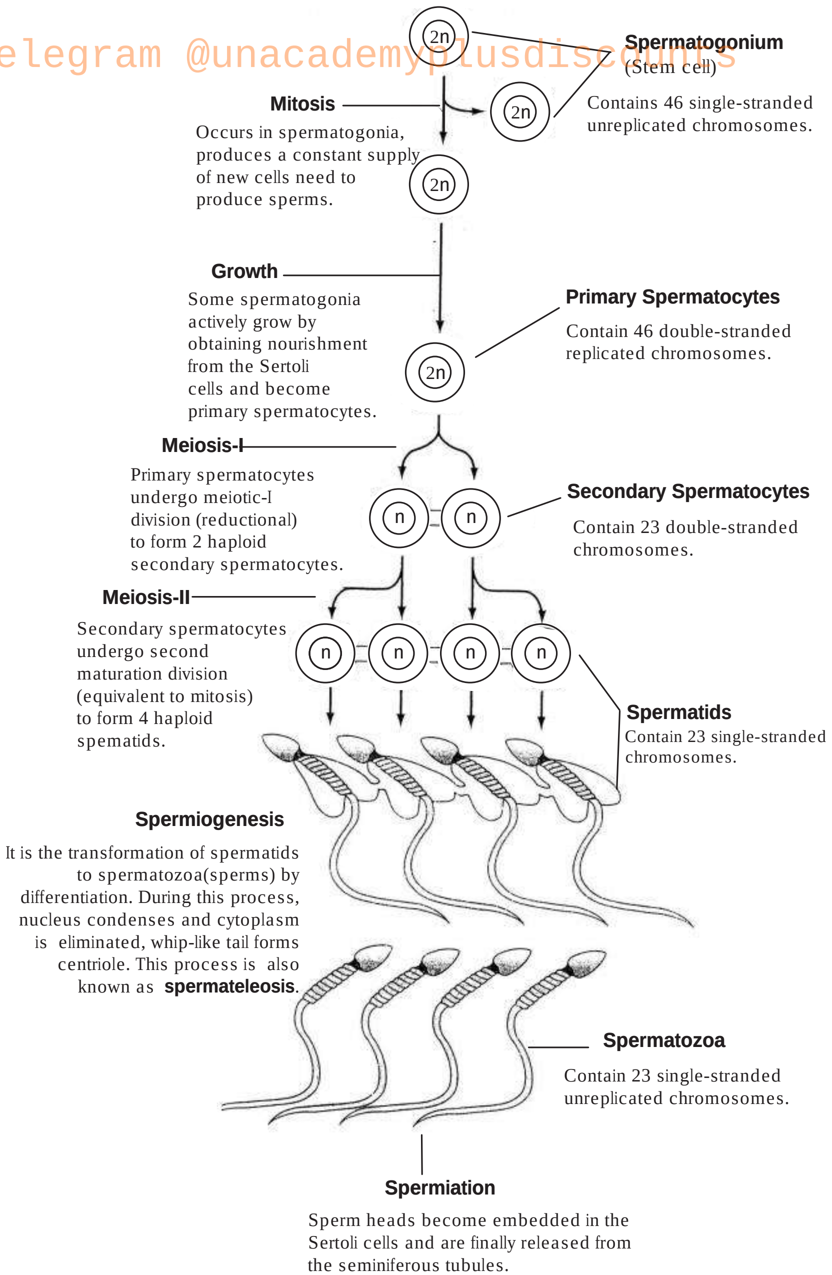
Gametogenesis

It involves the formation of male and female reproductive cells, **i.e.,** sperms and ova under the influence of hormones.

Process of formation of sperms is called spermatogenesis and that of ova is called oogenesis.

Spermatogenesis

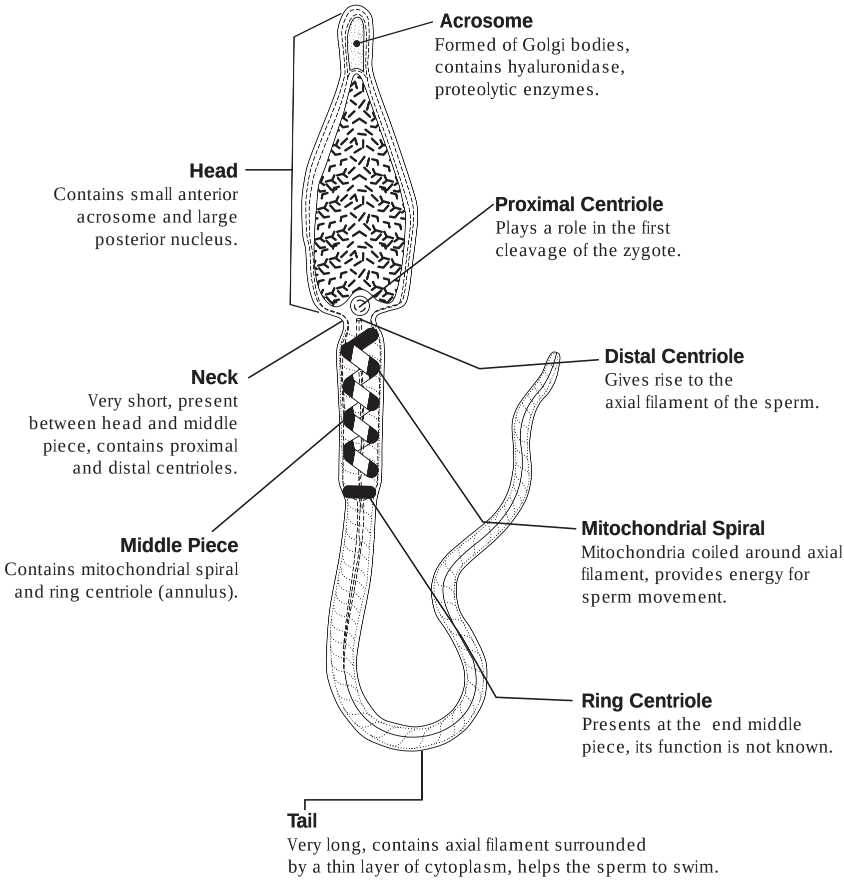
The formation of sperms occurs in the seminiferous tubules of the testis. Sperms are formed from the special cells present in the periphery of tubules, known as spermatogonia.



Stages in spermatogenesis

Structure of Sperm (Spermatozoan)

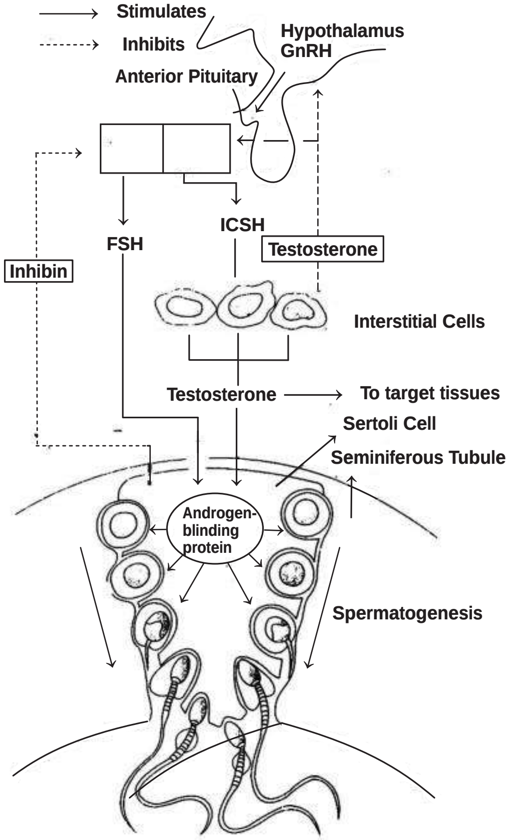
The sperms are microscopic and motile cells. They remain alive and retain their ability to fertilise the ovum from 24 to 48 hours after being entered in the female reproductive tract.



Human sperm

Hormonal Control of Male Reproductive System

The growth, maintenance and functions of male reproductive organs are under the control of steroid hormones–mainly testosterone. These hormones, in turn are controlled by negative feedback mechanisms.



GnRH released from hypothalamus stimulates anterior pituitary to release FSH and LH (ICSH in males). ICSH acts upon interstitial cells to secrete testosterone and FSH acts upon the Sertoli cells. Both FSH and testosterone promote spermatogenesis in seminiferous tubules.

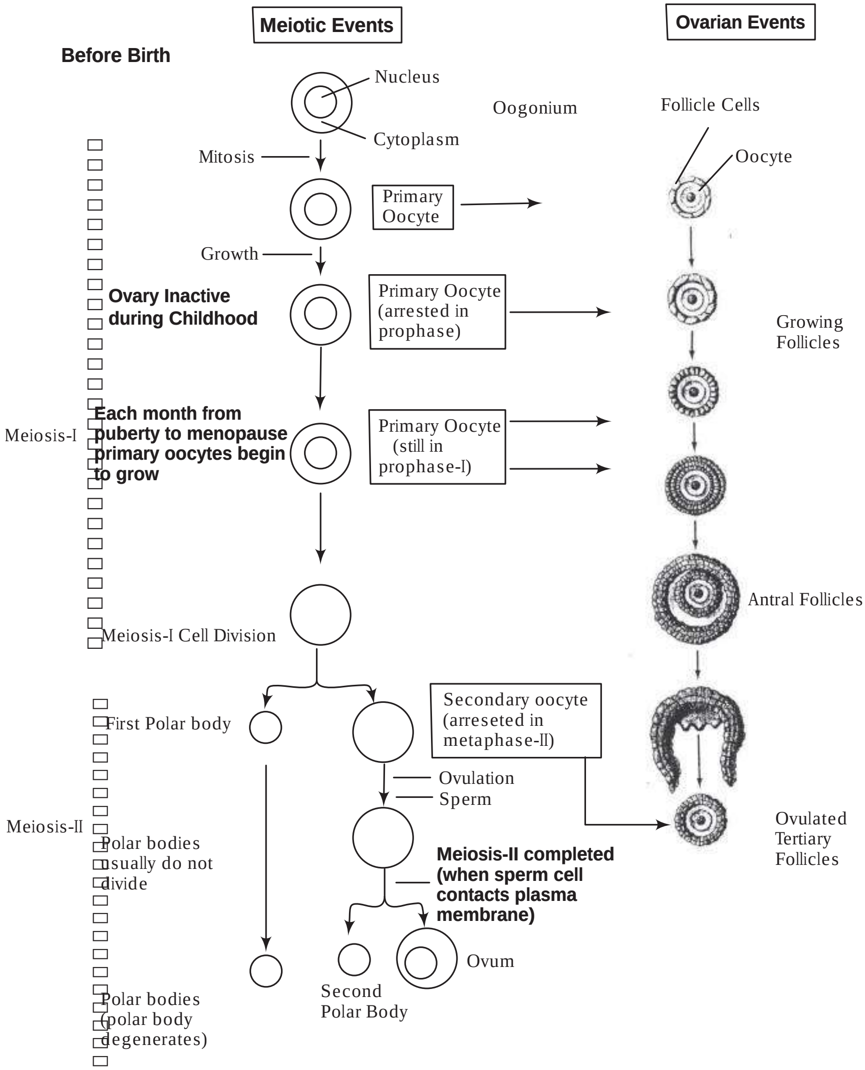
Negative Feedback Control

The secretion of GnRH and ICSH is controlled by the testosterone in a negative feedback loop. Dip in the testosterone level in the blood increases the production of GnRH and ICSH, whereas when the testosterone level becomes normal, GnRH release subsides, as does ICSH level. Similarly, FSH secretion is controlled by inhibin by negative feedback loop. When the excess FSH level is detected in blood, Sertoli cells secrete inhibin which in turn inhibits the release of FSH from anterior pituitary.

Hormonal control of male reproductive system

Oogenesis

It is the process of formation of a mature female gamete (ovum), occurring in the primary female gonads, **i.e.,** ovaries.

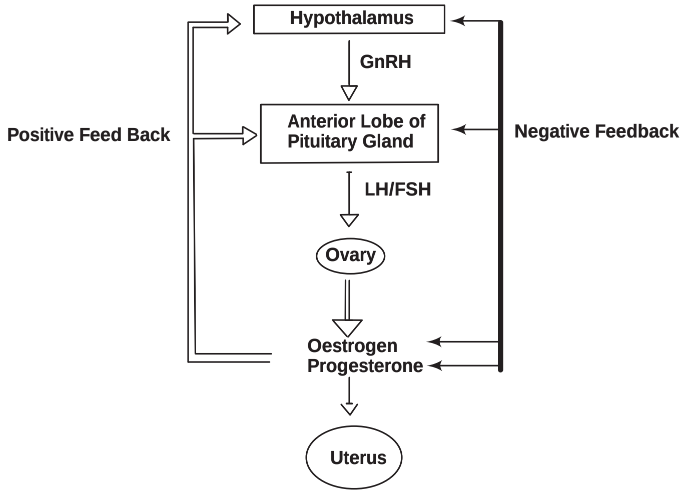


Process of oogenesis

Hormonal Control of Female Reproductive System

The growth, maintenance and functions of the female reproductive organs are under the hormonal control as described below

GnRH is secreted by the hypothalamus which stimulates the anterior lobe of pituitary gland to secrete LH and FSH. FSH stimulates the growth of the ovarian follicles and also increases the development of egg/oocyte within the follicle to complete the meiosis-I to form secondary oocyte. FSH also stimulates the formation of oestrogens. LH stimulates the corpus luteum to secrete progesterone. Rising level of progesterone inhibits the release of GnRH, which in turn, inhibits the production of FSH, LH and progesterone.



Hormonal control of female reproductive system

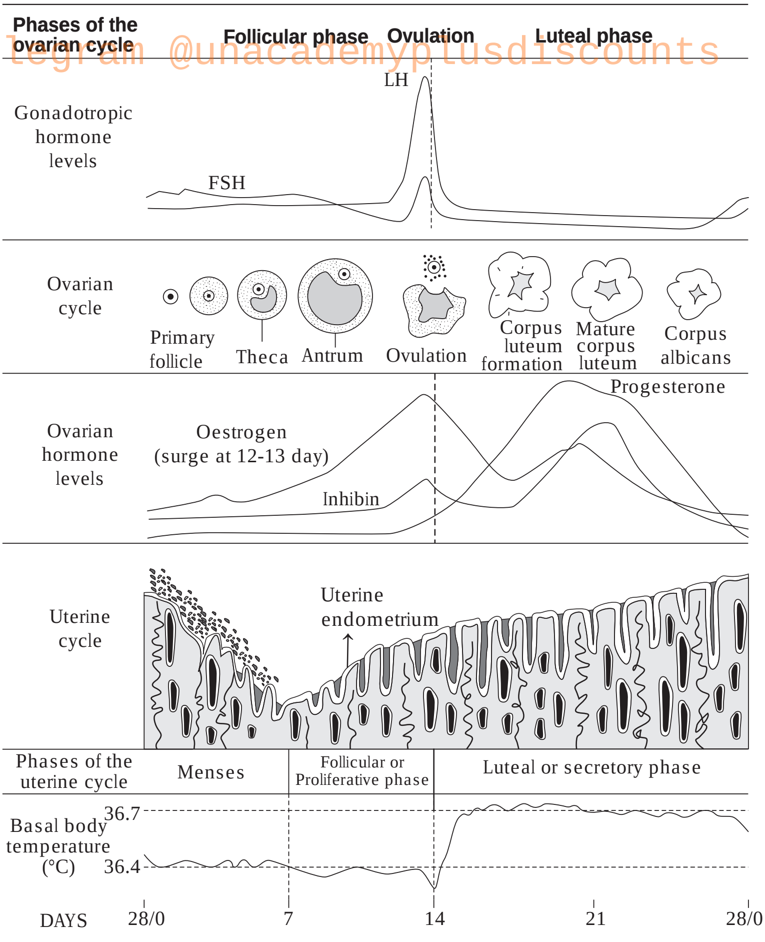
The Menstrual Cycle

Women of reproductive age undergoes a series of anatomical and physiological changes each month known as the **menstrual cycle**.

These changes occur in three areas–hormone levels, ovarian structure and uterine structure.

On average, the menstrual cycle repeats itself every 28 days. Ovulation usually occurs approximately at the midpoint of the 28 day cycle, **i.e.**, at day 14.

The average length of menstrual cycle is 28 days which may vary in different or even in the same women.



The menstrual cycle

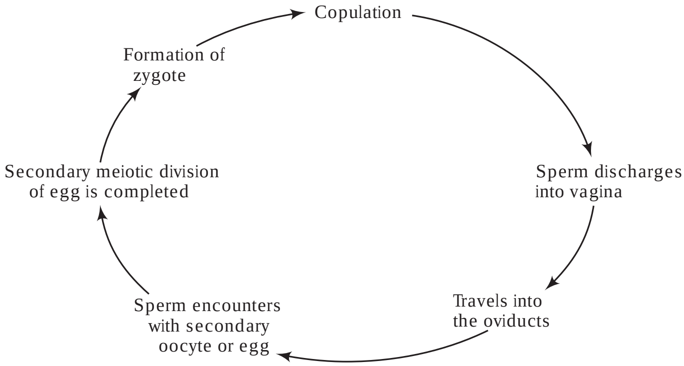
Menopause

It is the complete cessation of the menstrual cycle, which occurs between the age of 40-50. All the follicles present in the ovary gets degenerated or ovulated, decline in oestrogen production and vaginal secretions occur. It results in temporary behavioural changes such as irritability and depression. It can also lead to osteoporosis.

Fertilisation

It is the first step in human development where union of sperm and ova occurs to form a diploid **zygote**.

It occurs in the ampullary-isthmic junction of the oviduct.



Although many millions of sperms are deposited in the vagina, only a tiny fraction makes it into the oviducts. The rest are killed by the acidic secretions of the vagina or fail to find their way into the cervix.

Steps of Fertilisation Process

These are as follows

Sperm Capacitation

It is the process, in which the sperm acquires the capacity to fertilise the egg by the secretions of the female genital tract.

It involves the removal of coating substances present on the surface of sperms, so that the receptor sites on acrosome are exposed and sperm become active to penetrate the egg.

It takes about 5 to 6 hours.

Acrosome Reaction

It involves the release of various chemicals (sperm lysins) contained in the acrosome of capacitated sperm.

Acrosome reaction occurs in three steps which are carried out by three different sperm lysins as follows

(i) **Hyaluronidase** acts on the ground substances of the follicle cells.

(ii) **Corona penetrating enzyme** dissolves the **corona radiata** (radiating crown) cells that surround the female gamete.

(iii) **Zona lysins** (acrosin) digests the **zona pellucida** (the clear zone), a clear gel-like layer immediately surrounding the oocyte.

The Block to Polyspermy

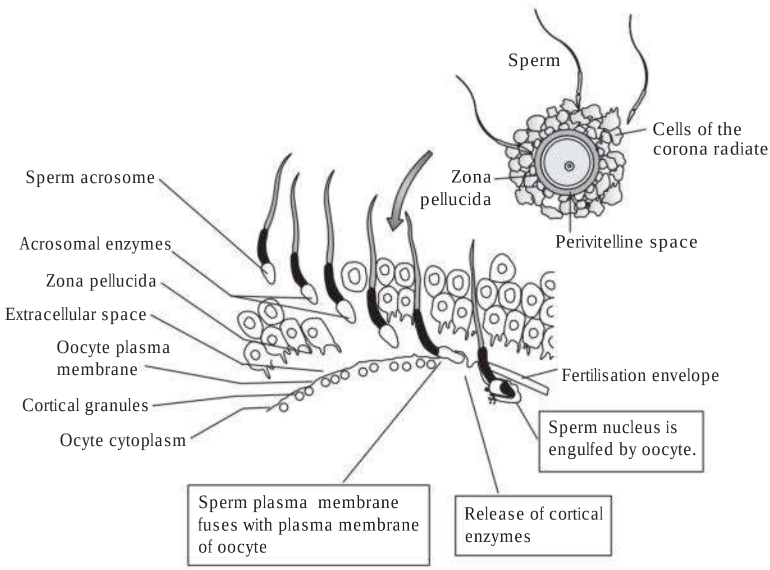
Polyspermy is the entry of more than one sperm into the oocyte.

To prevent polyspermy and to ensure monospermy (entry of one sperm into oocyte), **following events occur**

(i) **Fast block to polyspermy** Rapid depolarisation of the egg's plasma membrane as soon as first sperm contracts the plasma membrane.

(ii) **Slow block to polyspermy** (cortical reaction) Just after the penetration of sperm into egg, cortical granules (present beneath the plasma membrane of egg) fuse with the plasma membrane and release **cortical enzymes**.

These enzymes harden the zona pellucida and converts it into the **fertilisation envelope** hence, blocking other sperm from reaching the oocyte.



Series of events occurring in development of fertilisation envelope

Zygote Formation

Sperm contact with the plasma membrane of the oocyte triggers the second meiotic division and converts the secondary oocyte to **ovum**, which rapidly converts into **zygote** after the entry of the sperm nucleus.

Zygote contains 46 chromosomes, one set from each parent.

Pre-Embryonic Development

It involves all the changes that occur from fertilisation to the time just after an embryo implants in the uterine wall.

This process starts with **cleavage**.

Cleavage

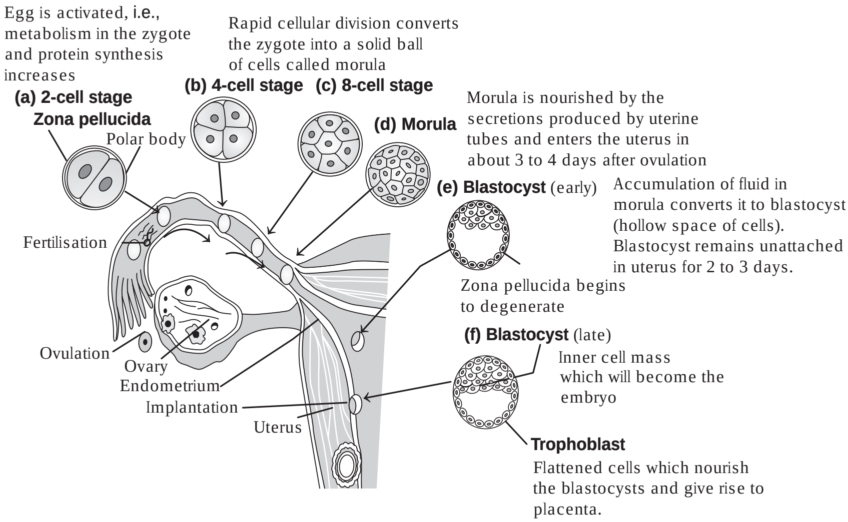
It is a series of rapid mitotic divisions of the zygote which converts the zygote into a multicellular structure (blastocyst or blastula). The pattern of cleavage in human is **holoblastic**.

Significance of Cleavage

(i) Distribution of the cytoplasm amongst the blastomeres and

(ii) Restoration of the cell size and nucleocytoplasmic ratio.

Detailed events occurring in pre-embryonic development are shown below



Development of morula and blastocyst

Implantation

It is the attachment of blastocyst to the uterine lining and digesting its way into the thickened layer of uterine cavity using enzymes released by the cells of blastocyst.

It occurs 6 to 7 days after fertilisation.

The process involves

(a) Cells of trophoblast contact the endometrium, if it is properly primed by oestrogen and progesterone, cells of uterine cavity at the contact point enlarge and thicken. Blastocyst usually implants high on the back wall of the uterus.

(b) Trophoblast cells release enzymes, digest a hole in the thickened endometrial lining and blastocyst bores its way into deeper tissue of uterine cavity. During this process, blastocyst feeds on nutrients released from the cells it digests.

(c) By day 14, the uterine endometrium grows over the blastocyst, enclosing it completely. Endometrial cells produce certain prostaglandins which stimulate the development of uterine blood vessels. Soon after that, placenta develops.

Implantation fails to occur in the following conditions

(i) If endometrium is not properly primed by oestrogen and progesterone.

(ii) If endometrium is not ready or is 'unhealthy' because of the presence of an IUD, use of a "morning after pill" or an endometrial infection.

(iii) If the cells of blastocyst contain certain genetic mutations.

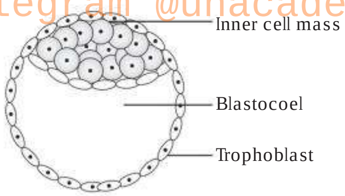
Unimplanted blastocysts are absorbed (phagocytised) by the cells of uterine lining and are expelled during menstruation.

Embryonic Development

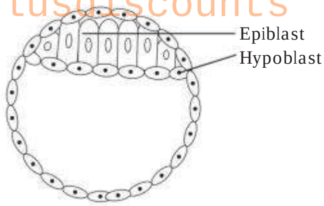
It involves the transformation of the blastocyst into the gastrula by the process called **gastrulation**. The formation of the primary germ layers marks the beginning of embryonic development.

Gastrulation involves the cell movements called **morphogenetic movements** which help the embryo to attain new shape and morphology. These movements result in the formation of three germ layers namely **ectoderm**, **mesoderm** and **endoderm**.

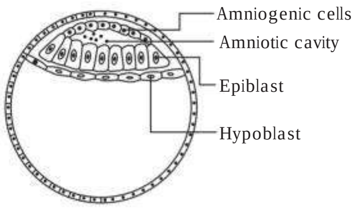
Key events occurring during embryonic development are shown below



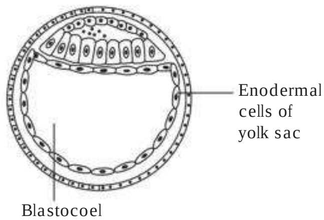
Cells of inner cell mass differentiate into 2 layers around 8 days after fertilisation. These 2 layers are hypoblast (primitive endoderm) and epiblast (primitive ectoderm).



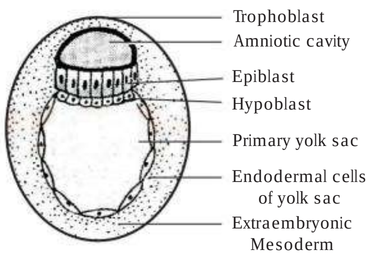
Hypoblast contains columnar cells and epiblast contains cuboidal cells. Together these two layers form the embryonic disc.



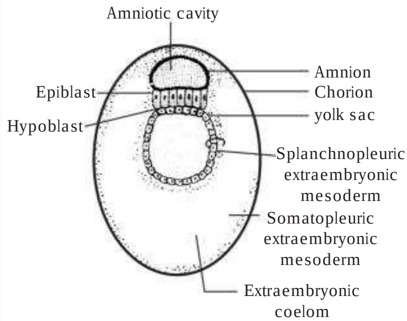
A space called amniotic cavity appears in between epiblast and trophoblast containing amniotic fluid. Cavity's roof is lined by amniogenic cells derived from trophoblast and its base is formed by epiblast.



The cells of trophoblast give rise to the mass of extraembryonic mesoderm cells. It is differentiated into outer somatopleuric and inner splanchnopleuric mesoderm.



Yolk sac is derived from hypoblast cells (primary yolk sac). Later on, due to the appearance of extraembryonic coelom (formed by outer and inner mesoderm), the yolk sac becomes smaller (secondary yolk sac).



The amnion is formed from the inner cell mass, chorion from somatopleuric mesoderm and allantois from trophoblast (inside) and splanchnopleuric mesoderm (outside).

The primary germ layers of the embryo gives rise to the organs in a process called **organogenesis.**

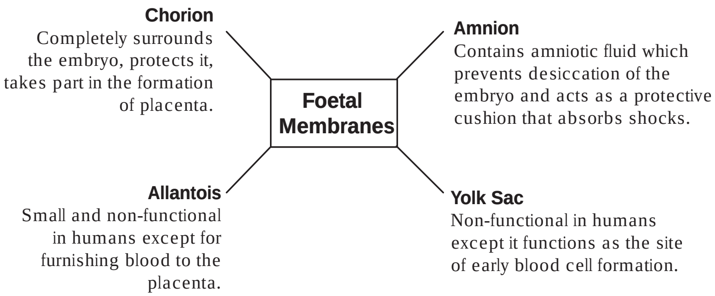
Various organs derived from different germ layers are as follows

End Products of Embryonic Germ Layers

Ectoderm	Mesoderm	Endoderm
Epidermis	Dermis	Lining of the digestive system
Hair, nails, sweat glands	All muscles of the body	Lining of the respiratory system
Brain and spinal cord	Cartilage	Urethra and urinary bladder
Cranial and spinal nerves	Bone	Gall bladder
Retina, lens, and cornea of eye	Blood	Liver and pancreas
Inner ear	All other connective tissues	Thyroid gland
Epithelium of nose, mouth, and anus	Blood vessels	Parathyroid gland
Enamel of teeth	Reproductive organs and kidneys	Thymus

Role of Extraembryonic Membranes (Foetal Membranes)

The growing foetus develops 4 associated membranes called foetal membranes or extraembyonic membranes which are specialised to perform different functions.



Foetal Development

It involves the continued organ development and growth and changes in body proportions. It begins in the eight week of pregnancy and ends during parturition.

Gestation Period and Parturition

Gestation period is the time period during which the foetus remains in the uterus. In humans, this period is about 280 days (38-40 weeks).

Parturition is the process of giving birth to a baby. It begins with mild uterine contractions. During labour pains, contractions increase in strength and frequency until the baby is born.

Following factors play a major role in parturition

(i) Increased level of hormone oxytocin from the foetus and the mother.

(ii) Increase in oxytocin receptors by oestrogen.

(iii) Blocking of calming influence of the progesterone by oestrogen.

(iv) Expansion of cervix by hormone relaxin.

The stepwise approach with oxytocin feed back mechanism in birth is as follows

Step 1. Baby moves further into mother's vagina.

Step 2. Receptors in cervix get excited.

Step 3. Impulses sent to hypothalamus.

Step 4. Hypothalamus sends impulses to posterior pituitary.

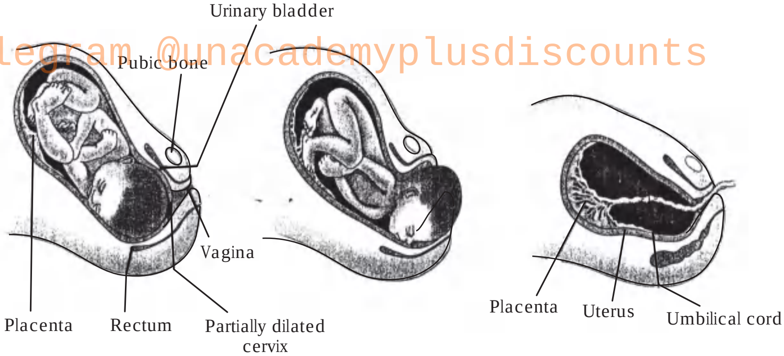
Step 5. Posterior pituitary releases stored oxytocin to blood which stimulates mother's uterine muscles to contract.

Step 6. Uterine contractions become more vigrous (labour pains).

The cyclic mechanism continues until the birth of the baby.

Stages of Childbirth

Childbirth consists of three stages namely, dilation, expulsion and placental stages.



Dilation stage
Uterine contractions push the foetal head lower in the uterus and cause the relaxin–softened cervix to dilate.

Expulsion stage
Foetus is expelled through the cervix and vagina.

Placental stage
Placenta is expelled by uterine contractions usually within 15 mins after childbirth.

Placenta

It is the intimate connection between the foetus and the uterine wall of the mother.

It develops from chorion.

Chorionic villi are the number of finger-like projections which develop from the outer surface of chorion and penetrate the uterine walls to form placenta.

The **foetal part** of placenta is chorion and the **maternal part** is decidua basalis.

Types of Placenta

The placenta can be classified into different types on the following basis

(I) Nature of Contact

On the basis of nature of contact, placenta is of two types **indeciduate** and **deciduate**.

(a) **Indeciduate placenta** Chorionic villi are simple, lie in contact with uterus, they have loose contact, and there is no fusion. At the time of birth, uterus is not damaged, **e.g.,** Ungulates, Cetaceans, Sirenians, Lemurs, etc.

(b) **Deciduate placenta** The allantochorionic villi penetrate into the uterine villi. They are intimately fused. Hence, at the time of birth, the uterus is damaged and bleeding occurs, **e.g.,** Primates, Rodentia, Chiroptera, etc.

(ii) Distribution of Villi

On the basis of villi distribution, placenta is of five types as follows

Placental Types on the Basis of Villi Distribution

Diffused
Villi are distributed uniformly on the blastocyst surface except at extreme ends, e.g., Pig, horse (indeciduate type).

Cotyledonary
Villi are arranged in groups, each group is called cotyledon which fits into the caruncles (maternal contact sites) of uterus, e.g., sheep, cow, deer (indeciduate type).

Zonary
Villi are in the form of transverse bands or zones and penetrate in the uterus wall, e.g., cat, dog, bear, elephant, carnivores. (deciduate type).

Intermediate
Rare type, shows free villi on cotyledons, indeciduate type; e.g., camel, giraffe.

Discoidal
Villi are present as disc on the entire surface of blastocyst when embryo grows, it moves away from the uterus hence, it looks like a disc, deciduate type, e.g., rat, bat, rabbit.

(iii) Histology

Placenta is classified into 5 types on the basis of number of layers present between the foetus and uterus.

The six layers in between foetal and maternal parts are (i) endothelium of mother blood vessel, (ii) maternal syndesmose connective tissue, (iii) maternal epithelium, (iv) chorion of foetus, (v) foetus syndesmose connective tissue, (vi) endothelium of foetal blood vessel.

The five placental types are as follows

Placental Types On the Basis of Histology

Epithelio-chorial
Contains all the six layers, foetal chorion is in contact with uterus epithelium, e.g., pig, horse, lemurs.

Hemoendothelial
Foetus floats in the mother's blood, e.g., rat, rabbit, etc.

Syndesmose-chorial
Allantochorionic villi pierce into uterus and chorion comes in contact with syndesmose of uterus, e.g., sheep, cow.

Hemochorial
Chorion of foetus in the blood pool of mother's uterus, e.g., bat man, primates, etc.

Endothelio-chorial
Chorion of foetus is in contact with the endothelium of uterus, e.g., dog, other carnivores.

Human placenta is deciduate and hemochorial type and it produces various hormones whose functions are as follows

Hormones Produced by the Placenta

Hormone	Function
Human Chorionic Gonadotropin (hCG)	Maintains corpus luteum during pregnancy, stimulates secretion of testosterone by developing testes in XY embryos.
Oestrogen (also secreted by corpus luteum during pregnancy)	Stimulates growth of myometrium, increasing uterine strength for parturition (childbirth). Helps prepare mammary glands for lactation.
Progesterone (also secreted by corpus luteum during pregnancy)	Suppresses uterine contractions to provide quiet environment for foetus. Promotes the formation of cervical mucous plug to prevent uterine contamination. Helps prepare mammary glands for lactation.
Human chorionic somatomammotropin	Helps prepare mammary glands for lactation. Believed to reduce maternal utilisation of glucose so that greater quantities of glucose can be shunted to the foetus.
Relaxin (also secreted by corpus luteum during pregnancy)	Softens cervix in preparation of cervical dilation at parturition. Loosens connective tissue between pelvic bones in the preparation for parturition.

Other functions performed by placenta are listed below

(i) Nutrition It helps to supply all the nutritive elements from the maternal blood to pass into the foetus.

(ii) Excretion The foetal excretory products diffuse into maternal blood through placenta.

(iii) Barrier Placenta serves as an efficient barrier and allows only necessary material to pass into foetal blood.

(iv) Storage Placenta stores glycogen, fat, etc.

Summary of Human Pregnancy from Fertilisation to Birth of the Baby

Week 1	**Week 2**	**Week 3**
Fertilisation, cleavage to form a blastocyst 4-5 days after fertilisation. More than 100 cells. Implantation 6-9 days after fertilisation.	The three basic layers of the embryo develop, namely ectoderm, mesoderm and endoderm. No research allowed on human embryos beyond this stage.	Woman will not have a period. This may be the first sign that she is pregnant. Beginning of the backbone. Neural tube develops, the beginning of the brain and spinal cord (first organs). Embryo about 2 mm long.
Week 4	**Week 5**	**Week 6**
Heart, blood vessels, blood and gut start forming. Umbilical cord developing. Embryo about 5 mm long.	Brain developing. 'Limb buds', small swellings which are the beginnings of the arms and legs. Heart is a large tube and starts to beat, pumping blood. This can be seen on an ultrasound scan. Embryo about 8 mm long.	Eyes and ears start to form.
Week 7	**By Week 12**	**By Week 20**
All major internal organs developing. Face forming. Eyes have some colour. Mouth and tongue. Beginnings of hands and feet. Foetus is 17 mm long.	Foetus fully formed, with all organs, muscles, bones, toes and fingers. Sex organs well-developed. Foetus is moving. For the rest of the gestation period, it is mainly growing in size. Foetus is 56 mm long from head to bottom. Pregnancy may begin to show.	Hair beginning to grow, including eyebrows and eyelashes. Fingerprints developed. Finger nails and toe nails growing. Firm hand grips. Between 16 and 20 weeks baby usually felt moving for first time. Baby is 160 mm long from head to bottom.
Week 24	**By Week 26**	**By Week 28**
Eyelids open. Legal limit for abortion in most circumstances.	Has a good chance of survival, if born prematurely.	Baby moving vigorously. Responds to touch and loud noises. Swallowing amniotic fluid and urinating.
By Week 30	**40 Weeks** (9 months)	
Usually lying head down ready for birth. Baby is 240 mm from head to bottom.	Birth	

Lactation

The production and release of milk after birth by woman is called lactation. The first milk which comes out from the mother's mammary glands just after childbirth is known as colostrum.

Colostrum is rich in proteins and energy along with antibodies that provide passive immunity for the new born infant. Milk synthesis is stimulated by pituitary hormone, prolactin.

The release of milk is stimulated by a rise in the level of oxytocin when the baby begins to nourish. Milk contains inhibitory peptides, which accumulate and inhibit milk production, if the breasts are not fully emptied.

The Lactating Breast

The glandular units enlarge considerably under the influence of progesterone and prolactin. Milk is expelled by contraction of muscle-like cells surrounding the glandular units. Ducts drain the milk to the nipple.

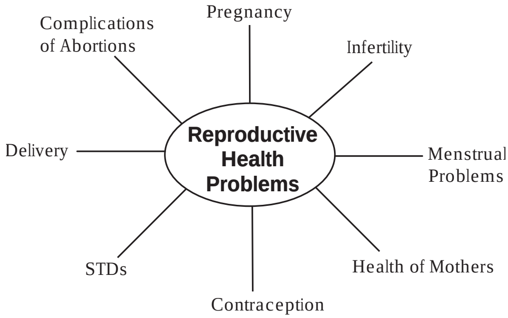
26

Reproductive Health

According to World Health Organisation (WHO), reproductive health means a total well-being in all aspects of reproduction, **i.e.,** physical, emotional, behavioural and social.

Problems Related to Reproductive Health

There are various factors which may lead to reproductive health problems. **These are as follows**



Population Explosion

It is the rapid increase of a population attributed especially to an accelerating birth rate, decrease in infant mortality and an increase in life expectancy.

Reasons for High Population Growth

(i) **Spread of education** People of the country are being educated about the diseases.

(ii) **Control of diseases** Control of various communicable diseases is in practice.

(iii) **Advancement in agriculture** Farmers are educated to develop high yielding crops.

(iv) **Storage facilities** A good quantity of grains can be stored easily.

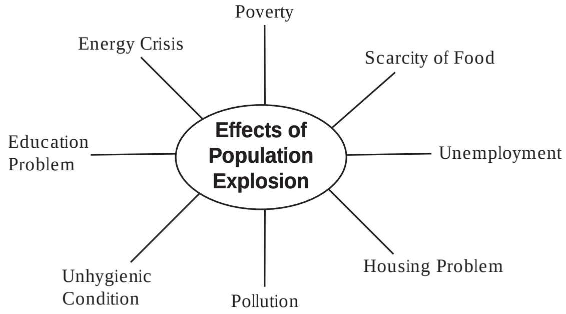
(v) **Better transport** This protects from famines.

(vi) **Protection from natural calamity** It decreases death rate.

(vii) **Government efforts** Government is making efforts to provide maximum informations to the farmers.

Effects of Population Explosion

Overpopulation leads to the number of national and individual family problems. **These are as follows**



It may also lead to socio-economic problems due to the shortage of space, food, educational and medical facilities.

Strategies to Improve Reproductive Health

These are as follows

1. Reproductive and Child Healthcare (RCH) Programmes

They aim to create awareness among people about various reproduction related aspects and provide facilities and support for building up a reproductively healthy society.

This programme is a part of **family planning** programme which was initiated in 1951.

The various parameters of these programmes are as follows

RCH Programmes

Knowledge of Growth of Reproductive Organs and STDs
Proper information about reproductive organs, adolescence, safe and hygienic sexual practices, Sexually Transmitted Diseases (STDs) etc, would help to lead a reproductively healthy life.

Sex Education
It should be introduced in schools and encouraged to provide right information about myths and misconceptions about sex-related aspects.

Medical Facilities
Better awareness about sex related problems, prenatal care of mother, medically assisted deliveries and postnatal care of mother and infant decreases maternal and infant mortality. Better detection and cure of Sexually Transmitted Diseases (STDs) and increased medical facilities for sex-related problems, etc., indicate improved reproductive health of male and female individuals and children.

Prevention of Sex Abuse and Sex Related Crime
Awarness of problems due to uncontrolled population growth, social evils like sex abuse and sex-related crimes, etc., need to be created, so that people should think and take up necessary steps to prevent them and thereby build up a reproductively healthy society.

2. Research in Reproductive Health Area

It should be encouraged and supported to find out new methods. 'Saheli', a new oral contraceptive for the females was developed by our scientists at Central Drug Research Institute (CDRI) in Lucknow, India. It is a non-hormonal contraceptive.

3. Birth Control

It refers to the regulation of conception by preventive methods or devices to limit the number of offsprings.

Contraception It includes the contraceptive methods, **i.e.,** the methods which deliberately prevent fertilisation.

The various methods of birth control are listed in the following table

Methods of Contraception and Birth Control

Methods	Basis of Action	Note on Uses	Relative Disadvantages
Barrier Methods			
Condom	A thin, strong rubber sheath, prevents the sperm to enter the vagina.	Placed over erect penis just before sexual intercourse.	Not as reliable as the pill. Relies on male. May tear or slip off.
Femidom	Female condom-a thin rubber or polyurethane tube with a closed end, which fits inside vagina and open end has two fixable rings, one on each end, to keep it in place.	Inserted before intercourse and removed any time later.	Difficult to insert. Can break or leak. Expensive than male condom.
Diaphragm/Cap	A flexible rubber dome which fits over the cervix and prevents entry of sperm to uterus. Used with a spermicidal cream or jelly (a spermicide is a chemical which kills sperms).	Inserted before intercourse. Must be left in place at least 6 hours after the intercourse.	Suggestion of doctor is must for proper size selection. Its training is required to fit. Occasionally causes abdominal pain. It should not be left for more than 30 hours as it may cause toxic shock syndrome. Examination required after every 6 months that cap is of right size.
Spermicide	Chemical which kills sperm.	Placed in vagina to cover the lining of vagina and cervix. Effective for about 1 hour.	High failure rate, if used on its own.
Sponge	Polyurethane sponge impregnated with spermicide, fits over cervix, disposable.	Fits up to 24 hours before intercourse. Leave in place for at least 6 hours after intercourse.	High failure rate.

Methods	Basis of Action	Note on Uses	Relative Disadvantages
Hormonal Methods			
Pill	Contains the female sex hormones-oestrogen and progesterone. Prevents development of eggs and ovulation by inhibiting the secretion of FSH. Acts on cervical mucus to prevent the penetration of sperm. Prevents the blastocyst implantation.	One taken orally each day during first 3 weeks of cycle. After week 4, menstruation starts and the pill is started again.	Short-term side effects, may include nausea, fluid retention and weight gain. Long-term side effects not fully understood, but increased risk of blood clotting may occur in some women. Not recommended for older women.
Minipill	Contains progesterone only. Ovulation may occur, but cervical mucus is thickened, preventing entry of sperms.	Must be taken within 3 hours after intercourse everyday.	May cause headache, nausea, weight gain.
IUD (Intra-Uterine Device) or Coil	Ist generation (non-medicated, **e.g.,** lippes loops, rings). 2nd generation (copper devices, **e.g.,** copper T-220). 3rd generation (hormonal devices, **e.g.,** progestasert).	It is placed in cervix, acts as spermicide within the uterus.	May cause bleeding and discomfort. IUD may slip out.
Natural Methods (NFP stands for Natural method of Family Planning)			
Abstinence	Avoid sexual intercourse.	—	Restricts emotional development of a relationship.
Rhythm method	Avoid sexual intercourse around the time of ovulation (total abstinence for about 7-14 days).	—	High failure rate, even higher if periods are irregular. Requires good knowledge of body and good record-keeping. Requires a period of abstinence.

Methods	Basis of Action	Note on Uses	Relative Disadvantages
Temperature method	Note the rise in temperature at ovulation (due to rise in progesterone) and avoid sexual intercourse at these times.	—	As above.
Coitus interruptus (withdrawl)	Penis is withdrawn from vagina before ejaculation.	—	HIgh failure rate. Requires much self-discipline. Penis may leak some sperms before ejaculation.
Lactational amenorrhea	Sucking stimulus prevents the generation of normal preovulatory LH surge hence, ovulation does not occur.	Effective only for initial three four months.	—
Sterilisation (Surgical methods)			
Vasectomy	Vas deferens are severed and tied.	—	Very difficult to reverse. Need to use alternative method upto 2 to 3 months after vasectomy
Tubectomy	Both oviducts are severed and tied (now laproscopic method are used).	—	Even more difficult to reverse than vasectomy.
Termination (Its not a part of contraception)			
Morning-after Pill	Contains RU486, an antiprogesterone.	Taken within 3 days of sexual intercourse.	For use only in emergencies. Long-term effects not known.
Abortion (discussed later in this chapter as MTP)	Up to 24 weeks	Premature termination of pregnancy by surgical intervention.	Risk of infertility and other complications. Emotionally difficult and ethically wrong.

Medical Termination of Pregnancy (MTP)

MTP or induced abortion is the termination or removal of embryo from the uterus by using pharmacological or surgical methods. It is considered safe during the first trimester, **i.e.,** up to 12 weeks of pregnancy.

MTP

Significance

- Plays significant role in decreasing human population.
- Helps in getting rid of unwanted and harmful pregnancies.

Drawbacks

- Misused to abort the normal female foetuses.
- Raises many emotional, ethical, religious and social issues.

Sexually Transmitted Diseases (STDs)

These are the diseases or infections which are transmitted through sexual intercourse. They are also called **Veneral Diseases** (VD) or **Reproductive Tract Infections** (RTI).

Various STDs are as follows

(i) **Syphilis** Caused by bacterium Treponema pallidium which grows and multiplies in warm, moist area of reproductive tract, causes skin lesions, swollen joints, heart trouble, etc.

(ii) **Gonorrhoea** Caused by bacterium Neisseria gonorrhoea and mainly affects women, causes pain around genitalia, pus-containing discharge, etc

(iii) **Genital herpes** Caused by Herpes simplex virus, causes vesiculopustular lesions, ulcers over external genitalia, vaginal discharge, etc.

(iv) **Chlamydiasis** Caused by bacterium **Chlamydia trachomatis**, causes inflammation of Fallopian tubes, cervicities, mucopurulent, epididymitis, urethritis, etc.

(v) **Trichomoniasis** Caused by protozoan Trichomonas vaginalis, causes vaginitis, foul smelling and burning sensation in females. Causes urethritis, epididymitis and prostatis in males.

Other STDs are as follows

STDs	Pathogen	Symptoms
Chancroid	**Haemophilus ducreyi** bacterium	Ulcers over external genitalia.
Genital warts	Human Papilloma Virus (HPV)	Warts over external genitalia, vaginal infection.
Hepatitis-B	Hepatitis–B Virus (HBV)	Fatigue, jaundice, cirrhosis, etc.
Candidiasis	**Candida albicans** (vaginal yeast)	Inflammation of vagina, thick, cheesy discharge etc.

Acquired Immuno Deficiency Syndrome (AIDS)

It is a fluid transmitted disease with possibility of transmission through body fluids like blood, semen, etc.

As sexual intercourse is the best suitable mode of fluid transmission that's why it is misleaded to be one of the STDs. Other transmission modes include blood transfusion, use of same syringes and needles, etc.

Preventive Measures (Prophylaxis) of STDs

Prevention of sexually transmitted diseases can be done by the simple practices given below

(i) Avoid sex with unknown partners/multiple partners.

(ii) Always use condoms during coitus.

(iii) Use sterilised needles and syringes.

(iv) Education about the sexually transmitted diseases should be given to the people.

(v) Any genital symptoms such as discharge or burning during urination or unusual sore or rash could be a signal of STDs and the person should seek medical help immediately.

(vi) Screening of blood donors should be mandatory.

Infertility

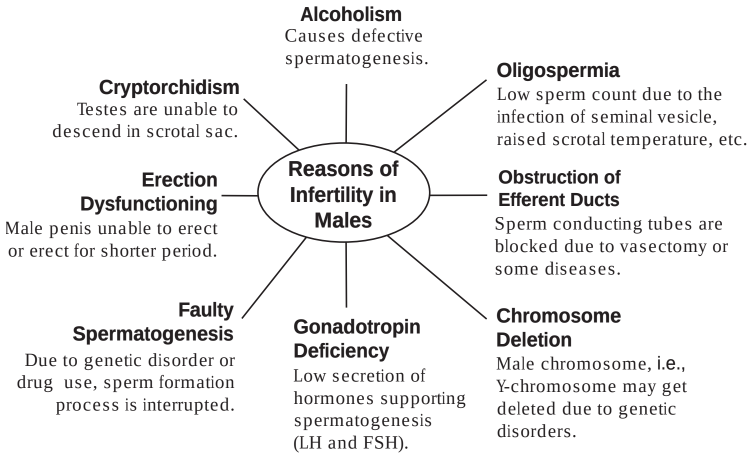
It is the failure to achieve a clinical pregnancy after 12 months or more of regular unprotected sexual intercourse. The reason for this could be physical, congenital diseases, drugs, immunological or psychological.

Primary Infertility

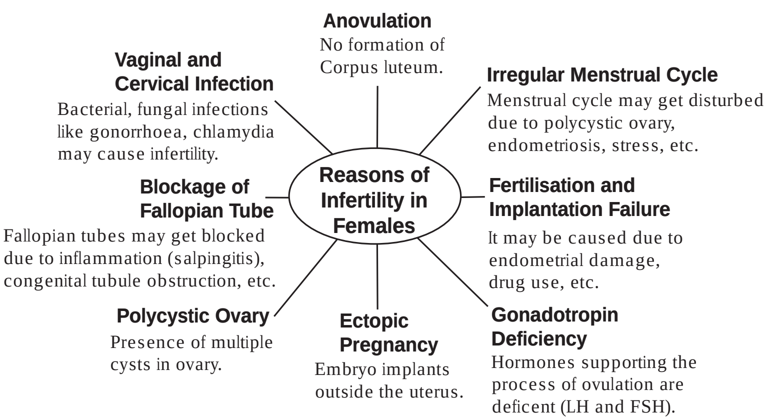
If the conception has never occurred, the condition is called primary infertility.

Secondary Infertility

If the patient fails to conceive after achieving a previous conception, the condition is called secondary fertility.



Reasons of infertility in males



Reasons of infertility in females

Assisted Reproductive Technology (ART)

These are the applications of reproductive technologies to solve infertility problems.

They include the following techniques

1. In Vitro **Fertilisation** (IVF)

It is used as a remedy for infertility. A woman's egg cells are combined with sperm cells outside the body in laboratory conditions to become fertilised. The fertilised egg (zygote) is then transferred to the patient's uterus. Hence, IVF refers to any biological procedure that is performed outside the organism's body.

2. **Intracytoplasmic Sperm Injection** (ICSI)

In this technique, sperm is injected into the cytoplasm of an egg using microinjection. It is effective when sperms are unable to penetrate the egg on its own due to low sperm count, abnormal sperms, etc.

3. **Intra Uterine Transfer** (IUT)

It involves the transfer of an embryo to the uterus when it is with more than 8 blastomeres. Similarly, when the zygote is placed in the Fallopian tube, the technique is known as **Zygote Intra Fallopian Transfer** (ZIFT).

4. **Gamete Intra Fallopian Transfer** (GIFT)

In this technique, eggs are removed from the ovaries and placed in one of the Fallopian tubes along with the sperm. This allows the fertilisation to occur within the woman's body (**in vivo** fertilisation).

5. **Artifcial Insemination** (AI)

In this technique, the semen collected either from husband or a healthy donor is artificially introduced either into the vagina or into the uterus (IUI–Intra-Uterine Insemination) of the female. It is commonly used in cases where male partners are unable to inseminate the female due to very low sperm counts.

Detection of Foetal Disorders During Early Pregnancy

No one wants to pass on any abnormality to the next generation, but all the pregnancies carry some degree of risk. Fortunately, it is now possible to detect hundreds of genetic mutations and chromosomal abnormalities very early in the course of development using invasive and non-invasive techniques.

1. Invasive Techniques

These involves the insertion of an instrument into the body. It involves amniocentesis, Chronic Villi Sampling (CVS), etc. Amniocentesis (also referred to as Amniotic Fluid Test or AFT) is a medical procedure used in prenatal diagnosis of **chromosomal abnormalities** and **foetal infections**. A small amount of amniotic fluid, which contains foetal tissues is extracted from the amnion or amniotic sac surrounding the developing foetus and the foetal DNA is examined for genetic abnormalities. Using this process, the sex of a child can be determined and hence, this procedure has some legal restrictions in some gender biased countries.

2. Non-Invasive Techniques

These techniques do not involve the introduction of any instruments into the body. It involves ultrasound imaging, maternal blood sampling, etc.

In ultrasound imaging, high frequency sound waves are utilised to produce visible images from the pattern of the echos made by different tissues and organs.

Maternal blood sampling technique is based on the fact that few foetal blood cells leak across the placenta into the mother's bloodstream. A blood sample from the mother provides enough foetal cells that can be tested for genetic disorders.

27

Principles of Inheritance and Variation

Through the process of reproduction, all organisms produce offspring like themselves. The transfer of characters from one generation to the next generation is the central idea of this chapter.

Heredity

It is the study of transmission of characters from parents to offspring or from one generation to the next. Thus, the transmission of structural, functional and behavioural characteristics from one generation to another is called heredity.

Basis of Heredity

Mendel (1866) proposed that inheritance is controlled by paired germinal units or **factors**, now called **genes**. These represent small segments of **chromosome.**

The genetic material present in chromosomes is DNA. Genes are segments of DNA, called **cistrons**. Therefore, DNA is regarded as the chemical basis of heredity.

Inheritance

It is the process by which characters or traits pass from one generation to the next. Inheritance is the basis of heredity.

Variations

It is the difference in characteristics shown by the individuals of a species and also by the offspring or siblings of the same parents.

Variations

Somatic or Somatogenic variations

(These variations affect the somatic cells of organisms. These are also known as modifications of acquired characters.)

These can be caused by

- **Environmental factors**
  Environmental factors such as light, temperature and nutrition affect the physical features of both animals and plants.
- **Use and disuse of organs**
  Continuous use and disuse make the body organ stronger and weaker, respectively.
- **Conscious efforts**
  Animals with intelligence show such processes, e.g., education, slim bodies, etc.

Germinal or Blastogenic variations

(These are inheritable variations in germinal cells. These may arise due to mutations.)

These are of two types

- **Continuous**
  These are fluctuating variations, which are caused due to rare variety and species.
- **Discontinuous**
  These are sudden but inheritable changes, originating due to mutation, etc.

Terms Related to Genetics

1. **Characters** It is a well-defined morphological or physiological feature of an organism.
2. **Trait** It is the distinguishing feature of a character.
3. **Gene** Inherited factor that determines the biological character of an organism.
4. **Allele** A pair of contrasting characters is called alleles or alternate forms of genes are called alleles.
5. **Dominant allele** The factor or an allele which can express itself in both homozygous and heterozygous state.
6. **Recessive allele** The factor or allele which can express itself only in homozygous state.
7. **Wild allele** The allele which was originally present in the population and is dominant and widespread.

8. **Homozygous condition** The state in which organism has two similar genes or alleles of a particular character, **e.g.,** TT or tt.
9. **Heterozygous condition** In this, the organism contains two different alleles for a particular character, **e.g.,** Tt.
10. **Monohybrid cross** When only one allelic pair is considered in cross breeding.
11. **Dihybrid cross** When two allelic pairs are used in crossing, it is called dihybrid cross.
12. **Genotype** Genetic constitution of an individual is called genotype.
13. **Phenotype** External features of an organism.
14. **Punnet square** It is a checker board which was invented by RC Punnett and used to show the result of a cross between two organisms.
15. **Polyhybrid cross** Involvement of more than two allelic pairs in a cross is called polyhybrid cross.
16. **F_1 or First Filial generation** The second stage of Mendel's experiment is called F_1-generation.
17. **Hybrid vigour or heterosis** The superiority of hybrid over either of its parents in one or more traits.
18. **Gene pool** All the genotypes of all organisms in a population are combinely called gene pool.
19. **Genome** It is the complete set of chromosomes where every gene is present singly as in gamete.
20. **Pureline or pure breeding line** It is a strain of individuals homozygous for all genes considered. The term was coined by Johannsen.
21. **Haploid, diploid and polyploid cell** A single genome is present in haploid, two in diploid and many genomes are present in polyploid cells.
22. **Test cross** The cross of F_1 offsprings with their recessive parents is called test cross.
23. **Back cross** The cross of an organism with the organism of its previous generation is known as back cross.
24. **Reciprocal cross** A cross in which same two parents are used in such a way that, if in one experiment 'A' is used as female parent and 'B' is used as the male parent, in other experiment 'A' will be used as male parent and 'B' is used as female parent.

Gregor Johann Mendel

He was born on July 22, 1822 in Austria. He graduated from Gymnasium in 1840. In 1843, Mendel was admitted to the Augustinian Monastery at Brunn, where he took the name **Gregor**. From 1851-53 he studied mathematics and natural science.

In spring of 1856, he began experimenting with pea plants. In 1866, his paper 'Experiment on Plant Hybridisation' published in volume IV of the proceedings of the natural society. He died on January 6, 1884 and was buried in Brunn central cemetery.

Mendel's experiments involved four steps

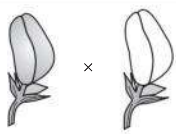
1. **Selection** The selection of characters for hybridisation is the first and an important step.
2. **Hybridisation** The pollination and hybridisation between the individuals of two different /contrasting characteristics.
3. **Selfing** It is the specific hybridisation between the organisms of same origin (siblings).
4. **Calculation** The counting and categorising the products on the basis of character identified takes place in calculation.

Mendel performed his experiments on pea plant and chose seven contrasting characters in it for observation.

These are

(i) Colour of seed
(ii) Shape of seed
(iii) Flower colour
(iv) Colour of pod
(v) Shape of pod
(vi) Position of flower
(vii) Height of plant

These characters and their inheritance patterns are given in the following table

Character or Trait Studied	Parent forms Crossed (F_1 Cross)	F_1 Phenotype	F_2 Products Dominant form, Recessive form	Total	Actual Ratio	Chromosome Location
Colour of seed	 Yellow (cotyledon) × Green	All yellow	6022 yellow, 2001 green	8023	3.01 : 1	1
Shape of seed	 Round × Wrinkled	All round	5474 violet, 1850 wrinkled	7324	2.96 : 1	7
Flower colour	 Violet × White	All violet	705 violet, 224 white	929	3.15 : 1	1
Colour of pod	 Green ×  Yellow	All green	428 green, 152 yellow	580	2.82 : 1	5
Shape of pod	 Inflated ×  Constricted	All inflated	882 inflated, 299 constricted	1181	2.95 : 1	4
Position of flower	 Axial ×  Terminal	All axial	651 axial, 207 terminal	858	3.14 : 1	4
Height of plant	 Tall  Dwarf	All tall	787 tall, 277 dwarf	1064	2.84 : 1	4

Emasculation and Bagging

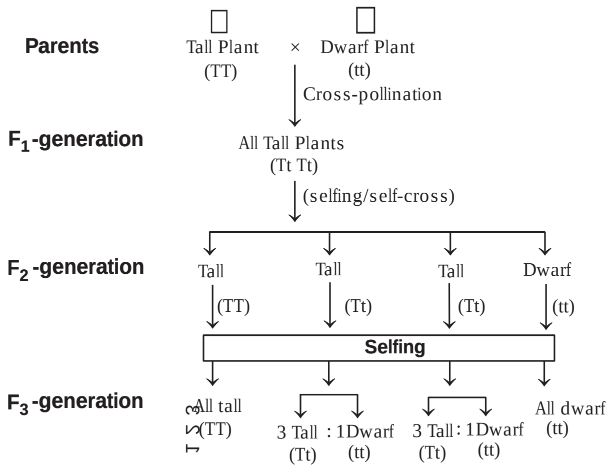
Mendel required both self and cross-fertilisation within the plants for his experiments. Due to its self-fertilising nature, the anthers of pea plants require removal before maturity (emasculation) and the stigma is protected against any foreign pollen (bagging). Through the process of emasculation and bagging, the pollen of only selected parent can be used for cross-fertilisation.

Inheritance of One Gene/Monohybrid Cross

Mendel performed several experiments on pea by considering one character at a time.

It is a cross made to study simultaneous inheritance of a single pair of Mendelian factors.

The schematic presentation of the monohybrid cross is as follows



Monohybrid cross in pea plant

Mendel's Laws of Inheritance

From the three laws of inheritance (**i.e.,** Law of dominance, Law of segregation and Law of independent assortment), the first two laws are based on the monohybrid cross.

These are explained in detail below

1. Law of Dominance

According to this law, 'when a cross is made between two homozygous (pure line) individuals considering contrasting trait of simple character then the trait that appears in F_1 hybrids is called dominant and the other one that remains masked is called recessive trait'.

In pea plant, out of the 7 characters, Mendel studied the dominant and recessive traits. These characters are discussed earlier.

The dominant and recessive traits are also found in other animals, **e.g.,**

Cat	(a) Skin colour	Tabby colour is dominant over black or blue.
	(b) Length of hair	Short hair are dominant over long hair (Angora).
Cattle	(a) Colour of face	White face colour is dominant over coloured face.
	(b) Horn	Polled or hornless are dominant over horned cattle.
Dog	(a) Skin colour	Grey colour is dominant over black colour.
	(b) Tail	Stumpy tail is dominant over normal tail.
Drosophila	(a) Eye colour	Red colour is dominant over white.
	(b) Wings	Flat and yellow wings are dominant over curled and white.
	(c) Body colour	Grey body colour is dominant over white.
Salamander	Body colour	Dark body colour is dominant over light.

The law of dominance explains why individuals of F_1-generation express the trait of only one parent and the reason for occurrence of 3:1 ratio in F_2 individuals.

Exceptions to Law of Dominance

These are as follows

(i) Incomplete Dominance/Blending Inheritance (CORRENS, 1903)

It is also known as **Intermediate** or **Partial** or **Mosaic** inheritance.

When F_1 hybrids exhibit a mixture or blending of characters of two parents, it is termed as blending inheritance.

It simply means that the two genes of allelomorphic pair are not related as dominant or recessive, but each of them expresses themselves partially, **e.g., 4 O'clock plant** (**Mirabilis jalapa**), **snapdragon** (**Antirrhinum**) and **homozygous fowl**. In 4 O'clock plant when a cross is made between dominant (red) and recessive (white) variety, the result of F_2-generation shows deviation from Mendel's predictions.

Here, both phenotypic and genotypic ratios came as 1 : 2 : 1 for Red : Pink : White.

(II) Codominance

The phenomenon of expression of both the alleles in a heterozygote is called **codominance**.

The alleles which do not show dominant-recessive relationship and are able to express themselves independently when present together are called **codominant allele,** e.g., **coat colour in short horned cattles and MN blood group in humans.**

In short horned cattle, when a cross is made between white (dominant) and red (recessive) variety, appearence of all Roan offsprings in F_1-generation and then white, roan and red in 1:2:1 ratio in F_2-generation show codominance of both the colours in roan.

The roan coloured F_2 individuals in above cross have both red and white hairs in the form of patches but no hair is having the intermediate colour.

(III) Pleiotropic Gene

The ability of a gene to have multiple phenotypic effects, because it influences a number of characters simultaneously, is known as pleiotropy and such genes are called pleiotropic genes.

It is not essential that all traits are equally influenced, sometimes it is more evident in case of one trait (major effect) and less evident in other (minor effect), **e.g.,** in garden pea, the gene controlling flower colour, also controls the colour of seed coat and the presence of red spot on leaf axil.

2. Law of Segregation/Law of Purity of Gametes

According to this law, 'In F_1 hybrid, the dominant and recessive characters though remain together for a long time, but do not contaminate or mix with each other and separate or segregate at the time of gamete formation. Thus, the gamete formed receives either dominant or recessive character out of them.'

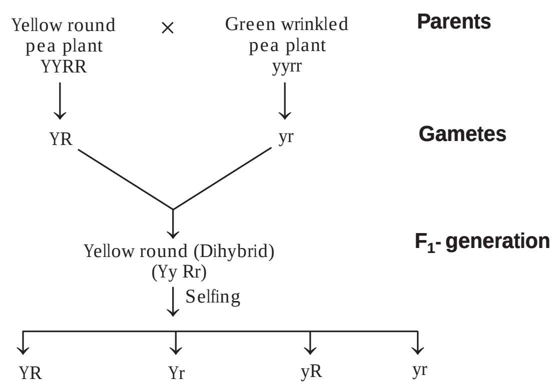
For proper understanding of Mendel's law of segregation, the formation of hybrid is considered from pureline homozygous parents through monohybird cross given before first law.

As the purity of gametes again established in F_2-generation, it is called law of purity of gametes.

Inheritance of Two Genes/Dihybrid Cross

These crosses are made to study the inheritance of two pairs of Mendelian factors or genes.

The schematic representation of the dihybrid cross is as follows



	YR	Yr	yR	yr
YR	YYRR (Yellow round)	YYRr (Yellow round)	YyRR (Yellow round)	YyRr (Yellow round)
Yr	YYRr (Yellow round)	YYrr (Yellow wrinkled)	YyRr (Yellow round)	Yyrr (Yellow wrinkled)
yR	YyRR (Yellow round)	YyRr (Yellow round)	yyRR (Green round)	yyRr (Green round)
yr	YyRr (Yellow round)	Yyrr (Yellow wrinkled)	yyRr (Green round)	yyrr (Green wrinkled)

F_2- generation

Phenotypic ratio

Yellow round : 9
Green round : 3
Yellow wrinkled : 3
Green wrinkled : 1

Dihybrid cross in pea plant

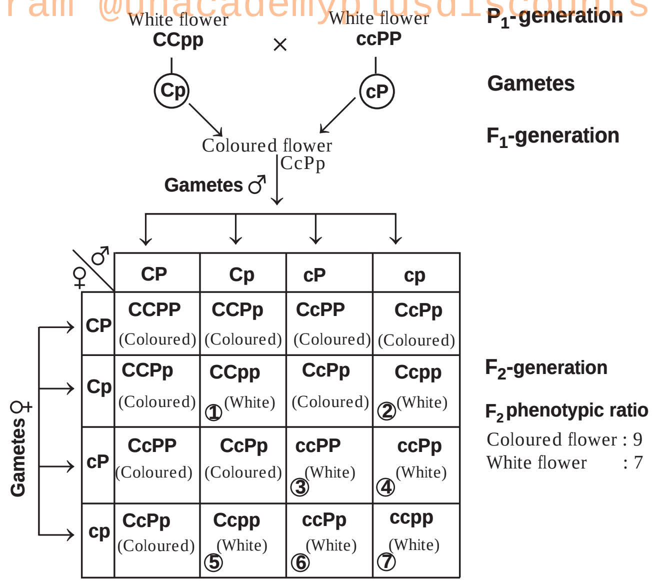
Exceptions to Law of Segregation

These are as follows

(I) Complementary Genes

The two pairs of non-allelic dominant genes, which **interact to produce only one phenotypic trait**, but neither of them (if present alone) produces the trait in the absence of other. It shows the phenotypic ratio of 9 : 7.

This cross is shown as



The results of an experiment to show the operation of complementry genes in the production of flower colour in sweet pea (Lathyrus)

(II) Epistatic Gene or Inhibitory Gene

It is the interaction between two non-allelic genes, in which one gene masks or suppresses the expression of other. The gene which got suppressed is called hypostatic factor and the suppressor gene is called epistatic factor. Such an interaction is called epistasis.

The epistasis may be

(A) Dominant Epistasis

In this, out of two pairs of genes, the dominant one masks the expression of other gene pair.

The ratio obtained in this may be 12 : 3 : 1 or 13 : 3, **e.g.,** coat colour gene in dog.

(B) Recessive Epistasis

In this, out of the two pairs of genes, the recessive epistatic gene masks the activity of dominant gene of the other gene locus. The ratio obtained in this may be 9 : 3 : 4, **e.g.,** coat colour gene in mice.

3. Law of Independent Assortment

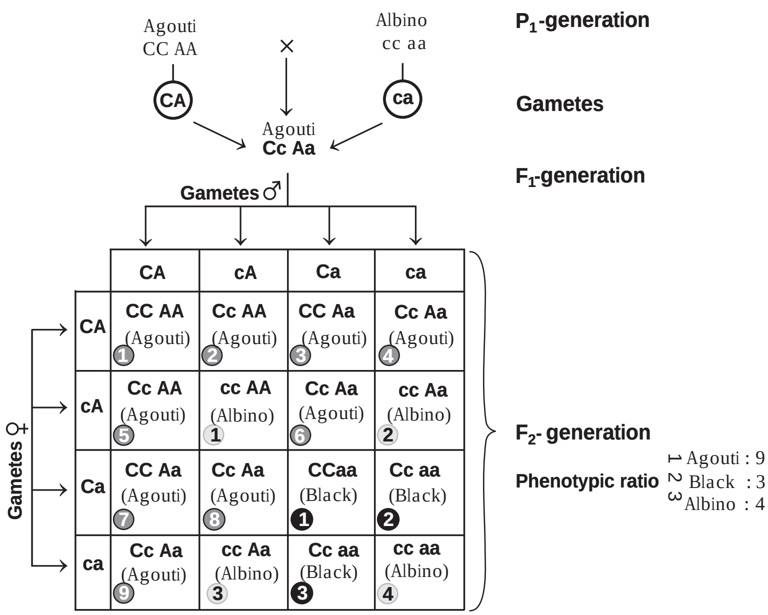
This law states that, 'the inheritance of one character is always independent to the inheritance of other character within the same individual'. The dihybrid cross of Mendel can be a very good example of independent assortment.

Exceptions to Law of Independent Assortment

These are as follows

(I) Supplementary Genes

Two independent dominant gene pairs, which interact in such a way that one dominant gene produces its effect irrespective of the presence or absence of other, **e.g.,** the coat colour in mice. **The cross is represented as**



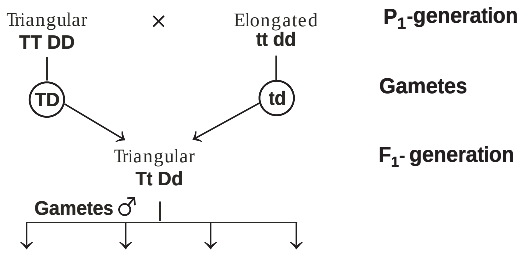
Interaction of supplementary genes in mice for coat colour

Here, the presence of gene C produces black colour which along with gene A changes its expression in agouti colour. Thus in all, combinations with at least one C and one A produce agouti colour.

(II) Duplicate Gene

The two pairs of genes which determine same or nearly same phenotype, hence either of them is able to produce the character. The duplicate genes are also called **pseudoalleles**, **e.g.,** fruit shape in Shepherd's purse.

The inheritance can be seen as



♀ \ ♂	TD	Td	tD	td
TD	TT DD	TT Dd	Tt DD	Tt Dd
Td	TT Dd	TT dd	Tt Dd	Tt dd
tD	Tt DD	Tt Dd	tt DD	tt Dd
td	Tt Dd	Tt dd	tt Dd	tt dd (elongated)

Gametes ♀

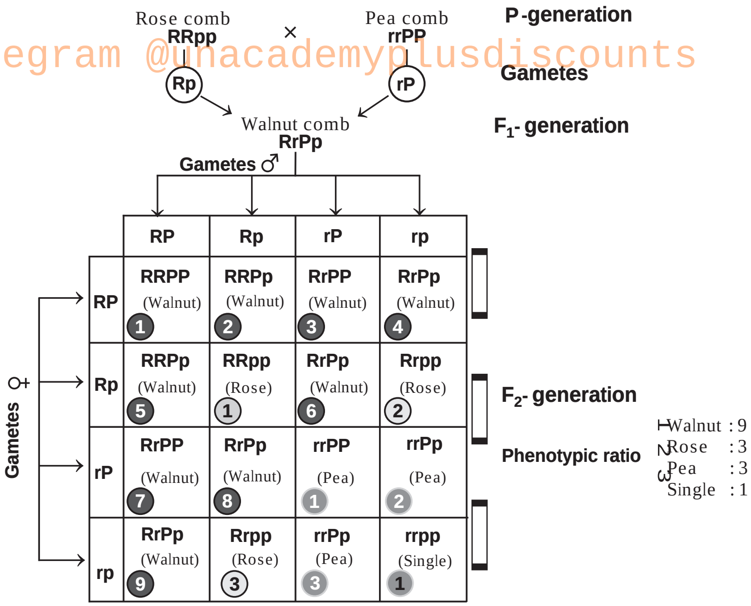
F$_2$- generation

Phenotypic ratio Triangular : 15, Elongated : 1

Interaction of duplicating genes in Shepherd's purse for seed pod's shape

(III) Collaborator Gene

In this, the two gene pairs which are present on separate locus, interact to produce totally new trait or phenotype, **e.g.,** inheritance of comb in poultry.



Inheritance of rose and pea comb in poultry

Multiple Allelism

It is the presence of more than two alleles for a gene, **e.g.,** ABO blood group in human beings is controlled by three alleles, but only two of these are present in an individual.

Polygenic Inheritance

Genes when acting individually have a small effect but that collectively produce a significant phenotypic expression are called **polygenes**, **e.g.**, genes for height or weight. The polygenes show polygenic inheritance.

Chromosomal Theory of Inheritance

Walter Sutton and **Theodore Boveri** in 1902 united the knowledge of chromosomal segregation with Mendelian principles and called it chromosomal theory of inheritance.

According to this theory,

(i) All hereditary characters are carried with sperms and egg cells, as they provide bridge from one generation to the other.

(ii) The hereditary factors are carried in the nucleus.

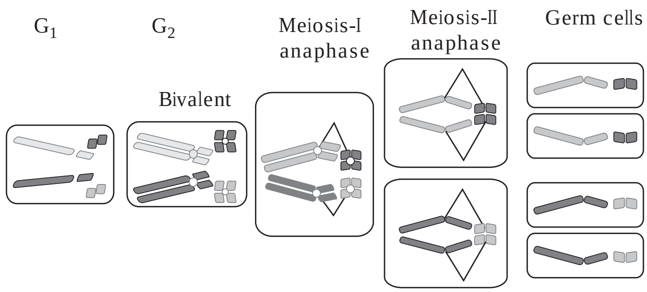
(iii) Chromosomes are also found in pairs like the Mendelian alleles.

(iv) The two alleles of a gene pair are located on homologous sites on the homologous chromosomes.

(v) The sperm and egg have haploid sets of chromosomes, which fuse to re-establish the diploid state.

(vi) The genes are carried on the chromosomes.

(vii) Homologous chromosomes synapse during meiosis and get separated to pass into different cells. This is the basis for segregation and independent assortment.



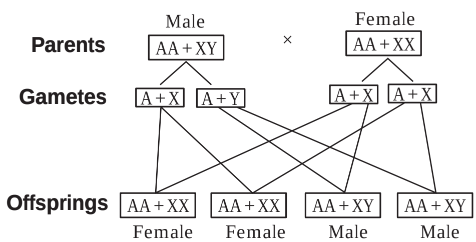
Meiosis and germ cell formation in a cell with four chromosomes

Sex-Determination

It is the method by which the distinction between male and female is established in a species. It is usually under genetic control of specific chromosomes called **sex chromosomes** or **allosomes**.

There are five main genetic mechanisms of sex-determination

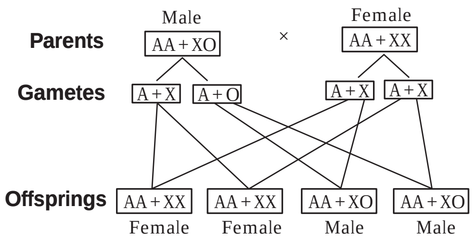
(i) **XX-XY Method**



Examples are mammals (as in humans).

(ii) XX-XO Method

In this, female has XX chromosomes and produces homogametic eggs, while male has only one chromosome and produces two types of sperms, **e.g., gynosperms** (with X) and **androsperms** (without X), **e.g.,** insects and roundworms.



(iii) ZW-ZZ Method

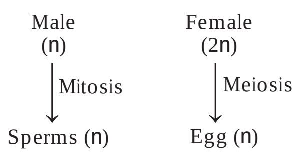
In this, the male is homogametic and female is heterogametic, **e.g.,** certain insects, fishes, reptiles and birds.

(iv) ZO-ZZ Method

In this, female is heterogametic while the male is homogametic, **e.g.,** moths and certain butterflies.

(v) Haploid-Diploid Method

In this method, the unfertilised egg develops into male (Arrhenotoky) while fertilised egg develops into female. This type of sex-determination is the characteristic feature of insects like honeybees, ants, etc.



Sex-Determination in Humans

The human shows XY type of sex-determination. Out of total (23 pairs) chromosomes, 22 pairs are exactly similar in both males and females, known as **autosomes**.

The female contains a pair of X-chromosome and male contains both X and Y-chromosomes. The sex is determined by the genetic make up of sperm.

During spermatogenesis among males, two types of gametes are produced, 50% of the total sperms carry X-chromosomes and the rest 50% carry Y-chromosomes.

Linkage (Exception to Independent Assortment)

It is the phenomenon of certain genes staying together during inheritance through generations without any change or separation. In other words, 'It is the tendency of genes staying together during inheritance.'

Morgan (1910) clearly proved and defined linkage on the basis of his breeding experiments on fruitfly, **Drosophila melanogaster**.

Linked genes are inherited together with the other genes as they are located on the same chromosome.

Linkage group are equal to the number of chromosomes pair present in cells, **e.g.,** humans have 23 linkage groups.

According to Morgan et. al., the linkage can be

(i) **Complete or Perfect** In this, genes remain together for at least two generations.

(ii) **Incomplete or Imperfect** In this, genes remain together within the same chromosome for less than two generations.

Sex-Linked Inheritance

Sex-linked characters are governed by the genes located on sex chromosomes. The phenomenon of the inheritance of such characters is known as sex-linked inheritance, **e.g.,** haemophilia, colour blindness, etc.

The sex-linked genes located on X-chromosomes are called X-linked genes, while these present on Y-chromosomes are called holandric genes.

Few examples of sex-linked inheritance in human beings are given below

(i) **Haemophilia** It is a sex-linked recessive disease. It is transmitted from an unaffected carrier female to some of the male progeny. In this disease, a protein involved in the clotting of blood is affected due to which a small cut results in profuse bleeding and sometimes may lead to death.

A heterozygous female (carrier) for haemophilia may transmit the disease to sons (50% chances), if she marries a normal male. The possibility of female becoming haemophilic is extremely rare because mother of such a female has to be at least carrier and the father should be haemophilic.

(ii) **Colour blindness** It is also a sex-linked recessive disorder. It is due to defect in either red or green cone of eye resulting in failure to discriminate between red and green colour. The defect occurs due to mutation in certain genes present in the X-chromosomes. The son of a woman who is carrier for the disease has 50 per cent chance of being colourblind.

The carrier mother is not colourblind herself because the gene is recessive. The daughter will be colourblind only if the mother is at least carrier and father is colourblind.

(iii) Duchenne Muscular Dystrophy (DMD) is also a sex-linked.

Crossing Over/Recombination

Those genes which show non-linkage, result into non-parental combinations in F_1-generation. Presence of such combinations indicates that in these genes, the process of interchange of alleles within non-sister chromatids of homologous chromosomes takes place, this is known as crossing over.

The crossing over can be of two types

Somatic / Mitotic Crossing Over
- Very rare in occurrence.
- The crossing over which occurs in somatic cells of organisms.
- First reported by **C Stern** in somatic cells of *Drosophila*.

Germinal / Meiotic Crossing Over
- Universal in occurrence.
- The crossing over occurs in germinal cells of organisms during meiosis.

Single Cross Over
Crossing over at only one point.

Double Cross Over
Crossing over at two points.

Multiple Cross Over
Crossing over at many points.

The mechanism of crossing over is explained by various theories, some of them with their propounders are listed below

1. **Copy choice theory** — J Lederberg (1955)
2. **Precocity theory** — C D Darlington (1931)
3. **Belling hypothesis** — Belling
4. **Break and exchange theory** — Stern and Hotta (1969)
5. **Hybrid DNA Model** — R Holliday (1964)

Linkage Maps/Genetic Maps/Chromosomal Maps

'It is the graphic representation of the relative distance between the genes in a linkage group'.

The first linkage map was given by **Sturtevant** and **Morgan** in 1920s. In linkage maps, the intergenic distances can be explained through arbitory unit of measurement called, **map unit** to describe the distance between linked genes.

1 map unit =1% of crossing over

One map unit is now referred as cM (centiMorgan) in the honour of Morgan's contribution.

Steps to Construct Genetic Map

Step 1 Determination of linkage group and total number of genes

By hybridising wild and mutant strains, we can determine the total number of genes and link groups in an organism.

Step 2 Determination of map distance

For determining map distances, the test crosses are performed. The relative distance can be calculated according to the percentage of crossing over, as cross over frequency is directly proportional to the distance between the genes.

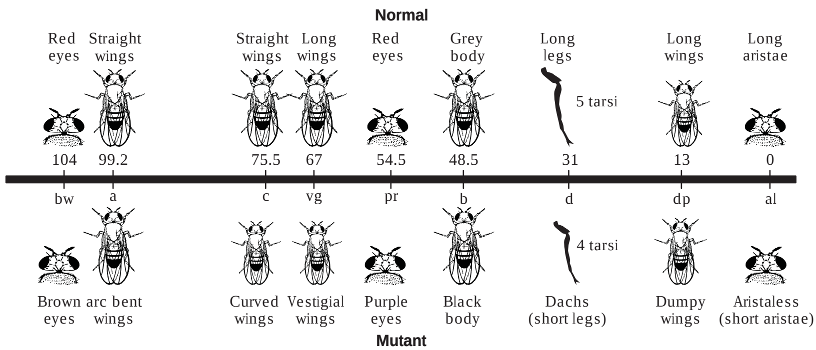
Step 3 Determination of gene order

After determining the relative distance, the genes can be placed in proper linear order.

Step 4 Combining map segments

Finally different segments forming linkage group of a chromosome, are combined to form genetic map.

Thus, **chromosomal map of chromosome number** 2 **of Drosophila melanogaster can be seen as**



The genetic map of chromosome number-2 of Drosophila melanogaster

Cytoplasmic Inheritance/Extranuclear Inheritance

The total self-replicating hereditary material of cytoplasm is called **plasmon** and cytoplasmic units of inheritance are described as plasma genes.

Cytoplasmic inheritance have two distinct features

(i) It is maternal inheritance, **i.e.,** only maternal parent contributes for inheritance.

(ii) The reciprocal crosses are not same due to the participation of female parents only, **e.g.,** sigma particle inheritance in **Drosophila**, Kappa particle inheritance in **Paramecium** and breast tumor in mice, etc.

In **Drosophila,** one strain shows more sensitivity towards CO_2 (these are comparatively easily immobilised by exposing them to CO_2). This more sensitivity was discovered by L Heritier and Teissier. The sensitive trait is regulated by a heat labile substance present in cytoplasm called sigma.

The inheritance of sensitive fly can be seen as

CO_2 sensitive female × Normal male
↓
All sensitive flies

Similarly, Normal female × CO_2 sensitive male
↓
All normal flies

Results of reciprocal crosses clearly indicate the inheritance of more CO_2 sensitivity through females. The mammary cancer or breast tumour in mice has been found to be maternally transmitted. It was noted by **JJ Bitiner**. **He performed following crosses regarding cancer in mice**

Female (with breast cancer) × Male (without breast cancer)
↓
About 90% offsprings susceptible to cancer

Similarly, Female (without breast cancer) × Male (with breast cancer)
↓
All normal offsprings

Such a difference in reciprocal crosses suggests the presence of maternal inheritance.

Mutation (Hugo de Vries; 1901)

A sudden inheritable discontinuous variation which appears in an organism due to permanent change in their genotypes.

Mutation

- **Chromosomal mutation/ Chromosomal aberration**
  Change that occurs in the morphology of chromosomes, resulting in change of number or sequence of gene without change in ploidy.
  - **Change in chromosome number**
    It is called **heteroploidy.**
    - **Monoploidy/Haploidy**
      (organisms contain only one set of chromosomes)
    - **Polyploidy**
      (organisms contain several sets of chromosomes)
      - **Euploidy**
        - **Allopolyploidy**
          The polyploids in which the chromosome sets are non-homologous and are derived from two different species.
        - **Autopolyploidy**
          The polyploid in which all the chromosomes are homologous. These are produced by treating cell with **colchicine**.
      - **Aneuploidy**
        - **Hyperploids**
          (i) Trisomics ($2n+1$)
          (ii) Double Trisomics ($2n+1+1$)
          (iii) Tetrasomic ($2n+2$)
          (iv) Pentasomic ($2n+3$)
        - **Hypopolyploids**
          (i) Monosomic ($2n-1$)
          (ii) Double monosomic ($2n-1-1$)
          (iii) Nullisomic ($2n-2$)
  - **Change in chromosome structure**
    The structure of chromosome is changed because of several reasons.
- **Gene mutation/ Point mutatiion**
  The sudden stable change in the structure of a gene due to change in its nucleotide type or nucleotide sequence is called gene mutation.

Change in Chromosomal Structure

The variations occur due to following four processes

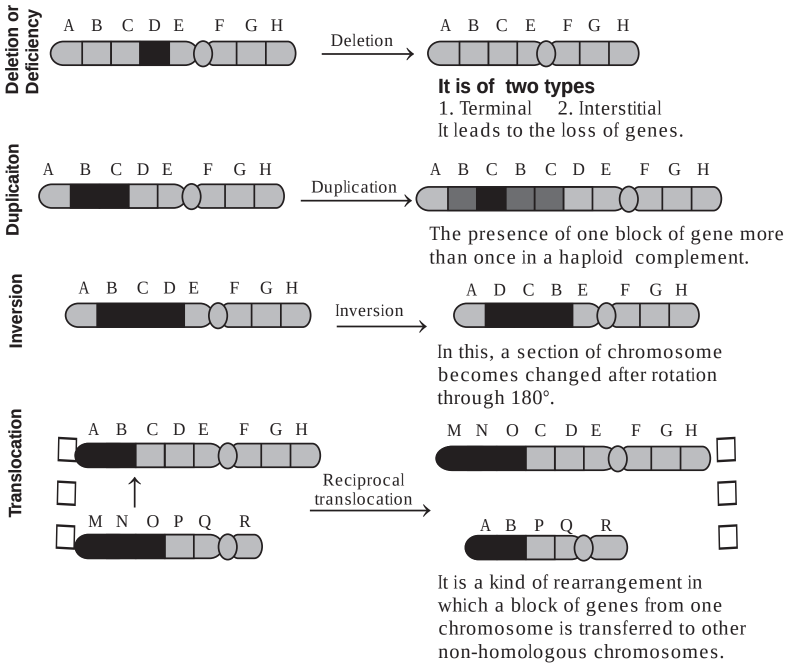


Diagram showing the forms of chromosomal mutations

Gene Mutation

The intragenic or point mutations involve alterations in the structure of gene by altering the structure of DNA. **It is of two types**

Gene Mutation

- **Base pair substitution**
  In which one nitrogenous base is substituted by other.
  - **Transitions**
    In which, the purine base is replaced by another purine and pyrimidine base is replaced by another pyrimidine.
  - **Transversions**
    In which, the purine base is replaced by pyrimidine and vice versa.
- **Frameshift mutation**
  The shift in reading frame occurs, either forward or backward.
  - **Deletion**
    In this, one or more nitrogenous bases are removed hence, the reading frame is shifted towards right.
  - **Insertion**
    Here, the addition of one or more nitrogenous bases takes place and reading frame is shifted to left.

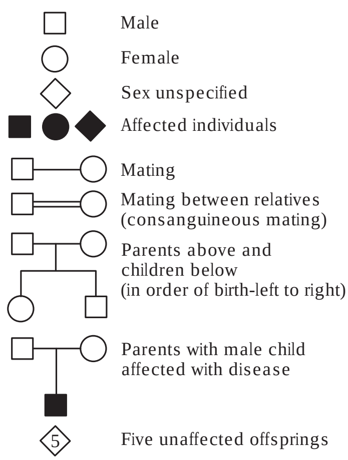
All these mutations cause various genetic disorders. **A list of some important genetic disorders is given below.**

Disorder	Dominant/ Recessive	Autosomal/ Sex linked	Symptom	Effect
Sickle-cell anaemia	Recessive	Autosomal, gene on chromosome 11	Aggregation of erythrocytes, more rapid destruction of erythrocytes leading to anaemia.	Abnormal haemoglobin in RBCs.
Phenylketonuria	Recessive	Autosomal, gene on chromosome 12	Failure of brain to develop in infancy, mental retardation, idiots	Defective form of enzyme phenylalanine hydroxylase.
Cystic Fibrosis (CF)	Recessive	Autosomal, gene on chromosome 7	Excessive thick mucus, clogging in lungs, liver and pancreas anomalies.	Failure of chloride ion transport mechanism through cell membrane.
Huntington's Disease (HD)	Dominant	Autosomal, gene on chromosome 4	Gradual degeneration of brain tissues in middle age, loss of motor control.	Production of an inhibitor of brain cell metabolism.
Haemophilia A/B	Recessive	Sex-linked, gene on X-chromosome	Failure of blood to clot.	Defective form of blood clotting factor VIII/IX
Colour blindness	Recessive	Sex-linked, gene on X-chromosome	Failure to discriminate between red and green colour.	Defect in either red or/ and green cone cells of retina.
Down's syndrome		Autosomal, aneuploidy (trisomy + 21)	Mongolian eyefold (epicanthus), open mouth, protruded tongue, projected lower lip, many loops on finger tips, palm crease	Retarded mental development, IQ below 40.

Disorder	Dominant/ Recessive	Autosomal/ Sex linked	Symptom	Effect
Turner's syndrome		Sex chromosome monosomy 44+X0	Short stature females (<5'), webbed neck, body hair absent, menstrual cycle absent, sparse pubic hair, under developed breasts, narrow lips, puffy fingers.	Sterile, hearing problem
Klinefelter's syndrome		Sex chromosomal aneuploidy (Tri/tetrasomy of X chromosome), **i.e.**, 44+ XXY, 44+XXXY	These males are tall with long legs, testes small, sparse body hair, Barr body present, breast enlargement.	Gynaecomastia, azoospermia, sterile

Pedigree Analysis

Scientists have devised another approach, called pedigree analysis, to study the inheritance of genes in humans. This is also useful while studying the population when progeny data from several generations is limited. It is also useful in studying the species with long generation time. A series of symbols is used to represent different aspects of a pedigree. **These are as follows**



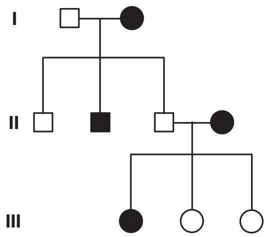
Symbols used in the human pedigree analysis

Once phenotypic data is collected from several generations and the pedigree is drawn, careful analysis will allow you to determine whether the trait is dominant or recessive.

For those traits exhibiting dominant gene action

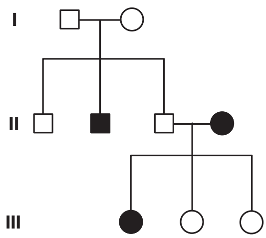
- Affected individuals have at least one affected parent.
- The phenotype generally appears in every generation.
- Two unaffected parents only have unaffected offspring.

It is called dominant pedigree and shown as



Those traits which exhibit recessive gene action

- Unaffected parents can have affected offspring.
- Affected progeny are both male and female and it is called **recessive pedigree** and shown as



In due course of time, the genetics and its principles will help in the solution of several heredity problems.

28

Molecular Basis of Inheritance

Early in 20th century, scientists knew that the genes are situated on chromosomes, but they did not know the composition of genes. The identification of the molecules of inheritance was a major challenge to biologists.

DNA and proteins were the candidate for the genetic material, but protein seems stronger because of its complexity and variety.

The scientists knew that the genetic material should have following characteristics

(i) It should be able to **store information** that pertains to the development, **structure and metabolic activities** of the cells or organisms.

(ii) It should be stable, so that it **can be replicated** with high fidelity during cell division and be **transmitted from generation to generation**.

(iii) It should be able to undergo rare genetic changes called **mutations** that provide the genetic variability **required for evolution** to occur.

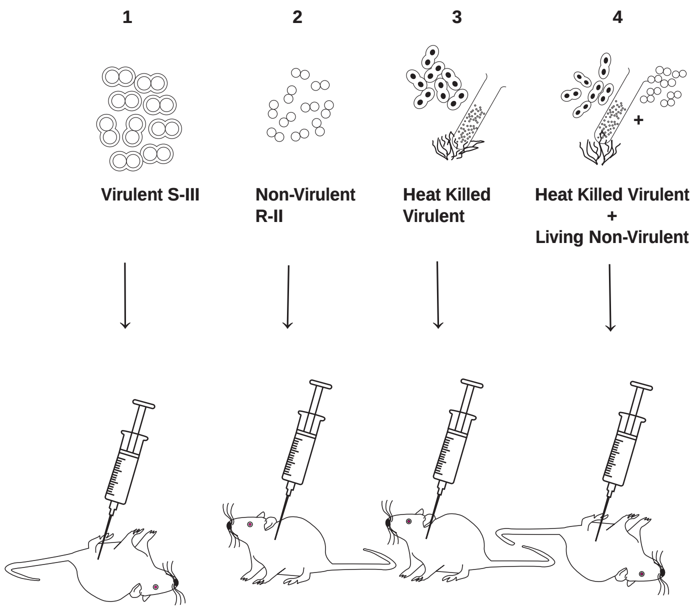
DNA as Genetic Material

The chromosomes, which are described as hereditary vehicles are the condensed form of DNA and proteins.

The characteristics of DNA as genetic material can be proved through following experiments

1. Bacterial Transformation (Frederick Griffith; 1928)

This experiment was performed with two strains of **Streptococcus pneumoniae** (the pneumonia causing bacteria).



Died
Smooth walled encapsulated (virulent) bacteria, when injected into mice, it caused pneumonia and death of mice.

Survived
When non-virulent bacteria were injected into mouse, it caused no harm to mice and mice survived.

Survived
After heat treatment the capsular structure got broken down and the virulent bacteria became non-virulent.

Some Died
After mixing both heat killed virulent and living non-virulent, the genetic material of virulent, transformed the rough walled non-virulents and made them virulent and responsible for killing of mice.

S = Smooth walled
R = Rough walled

Transformation experiment

2. Transformation Experiment

(Avery, Mac Leod and Mc Carty; 1944)

Through this experiment, they showed that the genetic characteristics of bacteria could be altered from one type to another by the treatment with purified DNA.

The experiment can be understood by following cases

(Case-1) R-type + Protein S-type = R-Type

(Case-2) R-type + Carbohydrate S-type = R-Type

(Case-3) R-type + DNA of S-type + DNase = R-Type

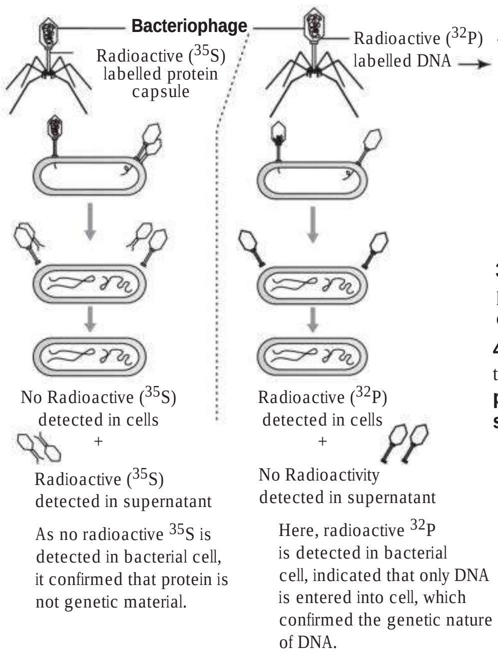
(Case-4) R-Type + DNA of S-type = R-Type + S-Type

The experiment of **Avery**, **Mac Leod** and **Mc Carty** was based on the same principle as Griffith's experiment. R indicates the rough walled bacteria (**i.e.,** avirulent), while S indicates the smooth walled bacteria (virulent). In the experiment, in every case the resultant is modified according to the DNA (**i.e.,** R-type).

3. Blender Experiment

(Alfred Hershey and Martha Chase; 1952)

The diagrammatic representation of this experiment is given below



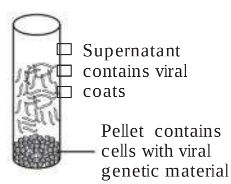
STEPS IN THE EXPERIMENT

1. Radiolabelling Transfer of radioactive ^{35}S to amino acids in protein coat and ^{32}P to the DNA molecule. Radiolabelled viruses can be detected through centrifugation.

2. Infection When virus and bacteria come in contact, virus injects its genetic material into bacteria.

3. Blending This led to the separation of protein coats from bacteria. Empty coats called **viral ghosts.**

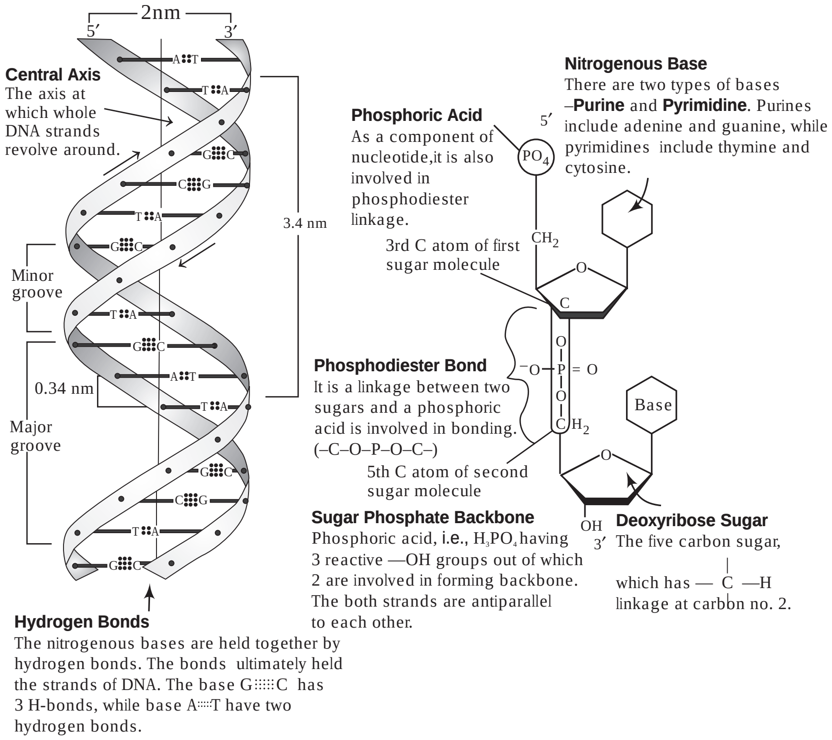
4. Centrifugation After every centrifugation, the bacterial cell with viral particles from **pellet** and viral coat formed the part of **supernatant.**



Blender experiment of Hershey and Chase

DNA

The chromosomes are chemically DNA molecules, which act as the genetic material in most of the organisms. The DNA was discovered by a German chemist, **F Meischer** in 1869. Before discussing the molecular basis of inheritance in detail, we need to understand the structure of DNA molecule.



DNA double helix

The DNA molecule consists of two helically twisted strands connected together by base pairs, which align themselves in such a manner just like the steps of ladder.

The antiparallel polynucleotide chains run in opposite directions. The 5′ end carries phosphate group attached on 5th carbon of sugar and 3′ end carries OH-group attached to 3rd carbon of sugar.

- The joining of bases creates two types of grooves called **major grooves** and **minor grooves**. Each turn of DNA helix accommodates 10 base pairs.
- On the basis of various criteria, there are different types of DNA, **These are given in the following table**

Comparative Structure of DNA

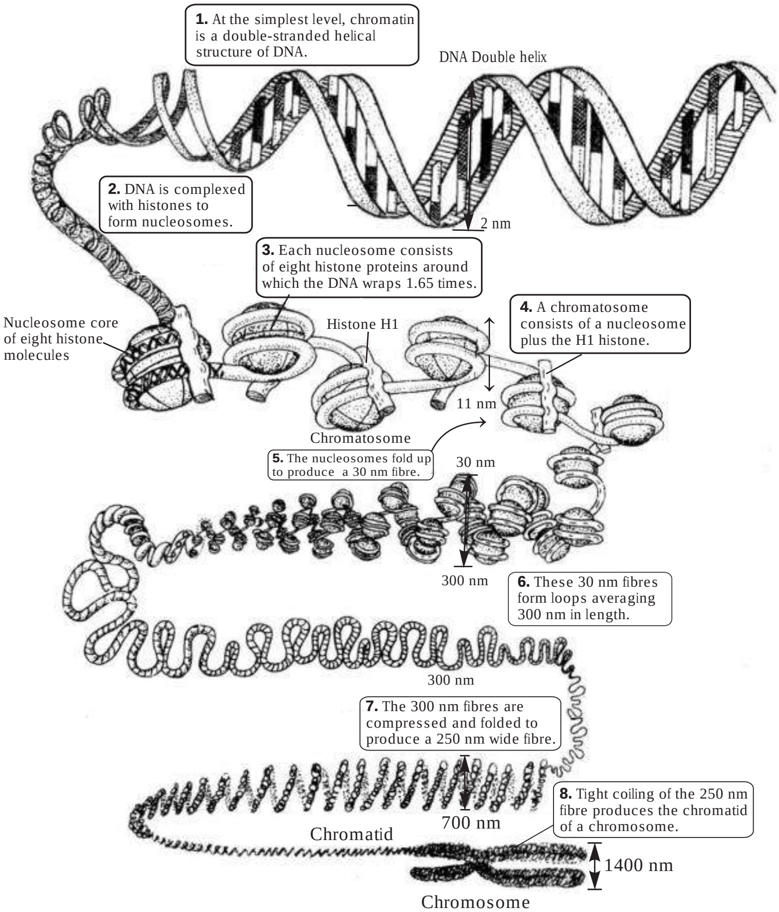
Characters	A	B	C	D	Z
Handedness	Right	Right	Right	Right	Left
Base pairs / Turn	11.0	10.0	9.3	8.0	12.0
Helix diameter (Å)	23	19	19	16.7	18
Helix rise per bp	2.92	3.36	3.32	3.03	3.52-4.13
Occurrence in biological world	Rare	Common	Less common	No	In some cells

Packaging of DNA Helix

The haploid human genome contains approximately 3 billion base pairs of DNA packaged into 23 chromosomes. In a diploid cell, it makes about 6 billion base pairs per cell.

As each pair of base is around 0.34 nm long, each diploid cell therefore contains about 2 metres of DNA $[(0.34 \times 10^{-9}) \times (6 \times 10^{9})]$.

To accommodate such a large amount of DNA in our body the packaging is required, **which can be explained through the following figure**



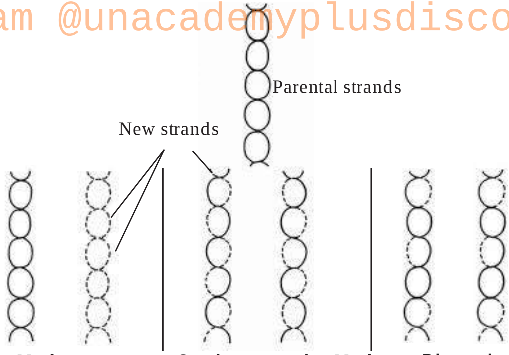
Packaging of DNA at different levels

DNA Replication

The DNA dependent DNA synthesis (**i.e.,** copying) is called DNA replication. It occurs in S-phase of cell cycle.

In DNA, it was found that replication is of semiconservative type, although it can be thought of to operate in conservative or dispertive modes too.

All the three possibilities are given below



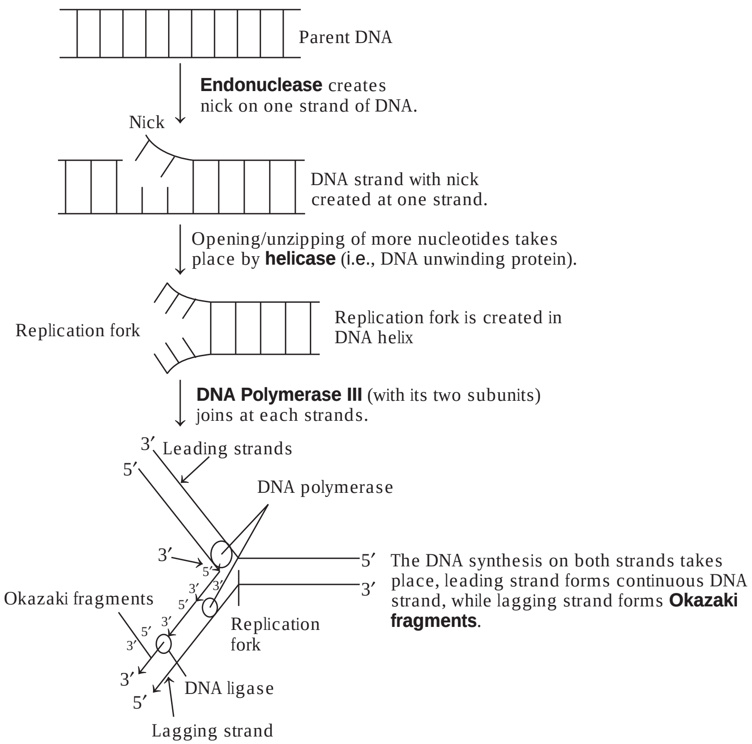
Conservative Mode
Here, out of two daughter DNAs, one is completely new and other one is completely old.

Semiconservative Mode
Both DNAs with one old and one new strand.

Dispersive Mode
Both DNAs with patches of new material in older DNA helixes.

Three modes of DNA replication

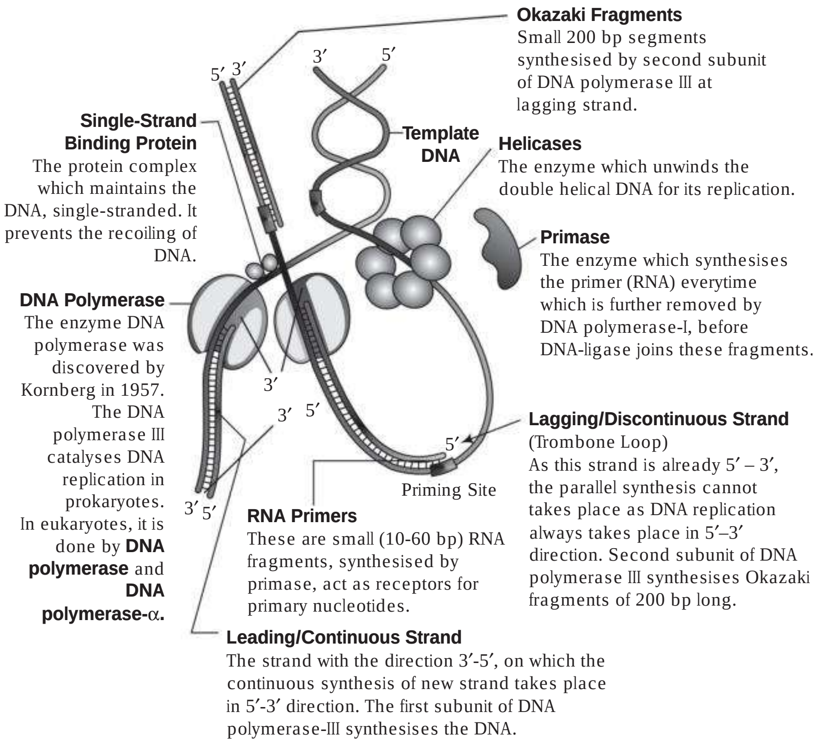
The schematic representation of DNA replication in prokaryotes is given below



Process of DNA replication

As DNA replication can occur only in $5' \rightarrow 3'$ direction, hence it is continuous on one strand (leading) and in the form of small fragments, by forming loop (trombone loop) at another strand (lagging strand).

The DNA synthesis on both the strands can be seen clearly through following figure



Mechinery of DNA replication (clearly showing trombone loop)

RNA

The other nucleic acid present in cell is RNA, **i.e.,** ribonucleic acid. It is present predominantly in cytoplasm and mostly in the form of single strand. The pyrimidine, **thymine of DNA is replaced by uracil in RNA**. All normal RNA chains begin with adenine or guanine.

The RNA can be of following three types

(i) **m**RNA or messenger RNA or template RNA.

(ii) Ribosomal RNA or **r**RNA.

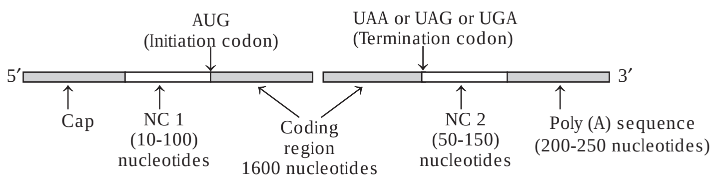
(iii) Soluble RNA or transfer RNA or **t**RNA.

1. Messenger or mRNA or Template RNA

It makes 3 – 5% of total cellular RNA. The sedimentation coefficient of **m**RNA is 8S. The name messenger RNA was proposed by **Jacob** and **Monod** (1961).

The structural components of mRNA include

(i) CAP (at 5′ end)
(ii) Non-coding region-1
(iii) Initiation codon (AUG)
(iv) Coding region
(v) Termination codon
(vi) Non-coding region - 2
(vii) Poly A sequence (at 3′ end)

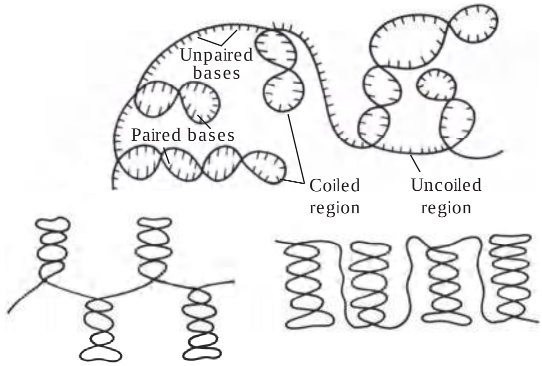


Structure of mRNA

The **m**RNA formed in nucleus, comes out with proteins into cytoplasm and normally swims as spherical balls, known as **informosomes**.

2. Ribosomal RNA or rRNA

It makes about 80% or more of total cellular RNA. It is the basic constituent of ribosomes and developed from the Nucleolar Organiser Region (NOR) of chromosomes in eukaryotes. In prokaryotes, it is developed from **r**DNA.



Structure of ribosomal RNA (schematic)

There are three types of rRNA **present**

(i) High molecular weight **r**RNA (mol. wt > 1 million)
e.g., 21S – 29S **r**RNA.

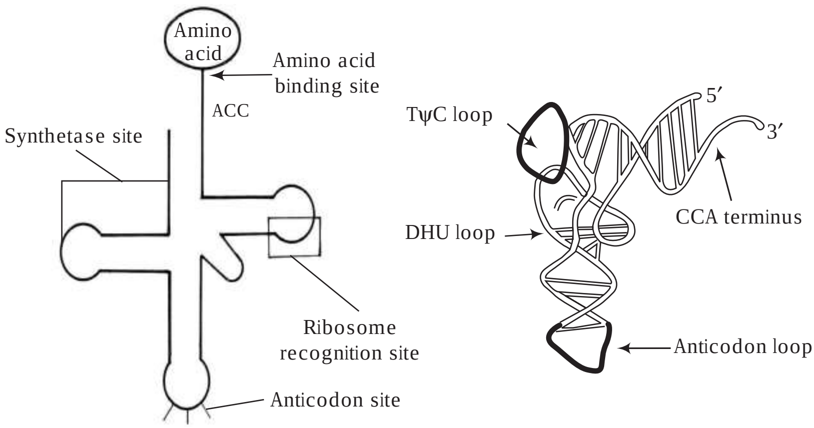
(ii) High molecular weight **r**RNA (mol. wt < 1 million)
e.g., 12S – 18S **r**RNA.

(iii) Low molecular weight **r**RNA (mol. wt ~ 40,000), **e.g.,** 5S **r**RNA.

3. Transfer or tRNA or Soluble RNA

It makes about 10 – 20% of total cellular RNA with sedimentation coefficient of 3.8 S. It contains 73 – 93 nucleotides.

tRNA is synthesised in nucleus on DNA template. About 0.25% of DNA codes for **t**RNA. The chief function of **t**RNA is to carry amino acids to ribosomes for protein synthesis.



(a) (b)

tRNA (a) The binding sites (b) The tertiary structure

Gene Expression

It is the process by which information contained in genes is decoded to produce other molecules that determine the phenotypic traits of organisms.

Central Dogma

Central dogma of molecular biology states that there is one way or unidirectional flow of information from master copy DNA to working copy RNA (transcription) and from working copy RNA to building plan polypeptide (translation).

$$\text{DNA} \xrightarrow{\text{Transcription}} \text{mRNA} \xrightarrow{\text{Translation}} \text{Polypeptide}$$

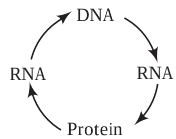
Central dogma of molecular biology was proposed by **Crick** (1958). **It is also written as follows**

$$\text{DNA} \xrightarrow{\text{Replication}} \text{DNA} \xrightarrow{\text{Transcription}} \text{mRNA} \xrightarrow{\text{Translation}} \text{Polypeptide}$$

In this dogma, genetic information is stored in the 4 letters language of DNA and same is transferred during transcription to 4 letters language of messenger.

Commoner (1968) suggested a circular flow of information.

$$\text{DNA} \longrightarrow \text{RNA} \longrightarrow \text{Proteins} \longrightarrow \text{RNA} \longrightarrow \text{DNA}$$



Temin (1970) found that **retroviruses** perform Central Dogma reverse that involves reverse transcription (forming DNA from RNA).

$$\text{DNA} \underset{\text{Reverse Transcription}}{\overset{\text{Transcription}}{\rightleftharpoons}} \text{RNA} \xrightarrow{\text{Translation}} \text{Polypeptide}$$

Transcription or RNA synthesis occurs over DNA. Translation or protein synthesis occurs over ribosomes. These two are separate in time and space. This protects DNA from respiratory enzymes and RNAs from nucleases.

Transcription

The transfer of information from DNA strand to RNA is termed as transcription. It occurs in the nucleus during G_1 and G_2-phases of cell cycle.

Like DNA replication, it also proceeds in $5' \rightarrow 3'$ direction and it requires the enzyme **RNA polymerase**. In prokaryotes, only one RNA polymerase is involved in transcription (with its 5 polypeptide subunits $-\sigma, \beta, \beta'$ AND 2α), while in eukaryotes, **the transcription is performed by three** RNA **polymerases**

(i) **RNA polymerase-I** Synthesises large **r**RNAs.

(ii) **RNA polymerase-II** Synthesises small **r**RNA and **m**RNA.

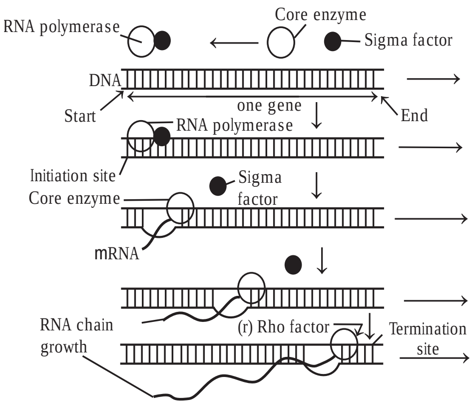
(iii) **RNA polymerase-III** Synthesises small **r**RNA and **t**RNA.

Transcription Unit

The segment of DNA that takes part in transcription is called transcription unit. **It has three components**

1. A promoter 2. The structural gene 3. A terminator

A schematic the representation of the process of transcription is as follows



1. Binding of RNA polymerase with its sigma factor to DNA strand.

2. RNA polymerase reaches to initiation site from where the process of transcription starts.

3. Initiation After uncoiling of DNA strands, a bubble shaped structure called transcription bubble is formed and the synthesis of RNA chain starts.

4. Elongation Further addition of ribonucleotides leads to elongation of RNA chain.

5. Termination The termination factor (ρ = Rho) stops the chain growth and releases RNA from transcription bubble. The DNA recoils and newly synthesised RNA goes for processing.

Outline of transcription process

RNA Processing

In Prokaryotes

In prokaryotes, there are three enzymes, **RNase III, RNAse E** and **RNase P** which are responsible for the most of primary endonucleolytic RNA processing events. The first two are proteins, while RNAse P is a **ribozyme**.

These enzymes have unique functions and in their absence the processing events are not performed. On the other hand, a large **exonuclease** participates in the trimming of the 3' end of **t**RNA precursor molecule.

In Eukaryotes

The initial processing steps involve the addition of a cap at 5′ end and a tail at 3′ end. The primarily synthesised RNA (**i.e.,** Pre **m**RNAs), constitute the group of molecules found only in nucleus, **i.e.,** heterogenous nuclear RNA (**hn**RNA). These RNA molecules, in combination with proteins form heterogenous nuclear ribonucleoprotein particles (**hn**RNPs). In general, any RNA having sedimentation coefficient more than 8 is called **hn**RNA.

Capping involves the **formation of a cap at 5′ end** by the condensation of guanylate residues. **Addition of tail at 3′ end** occurs in the form of adding **polyadenylate sequences**.

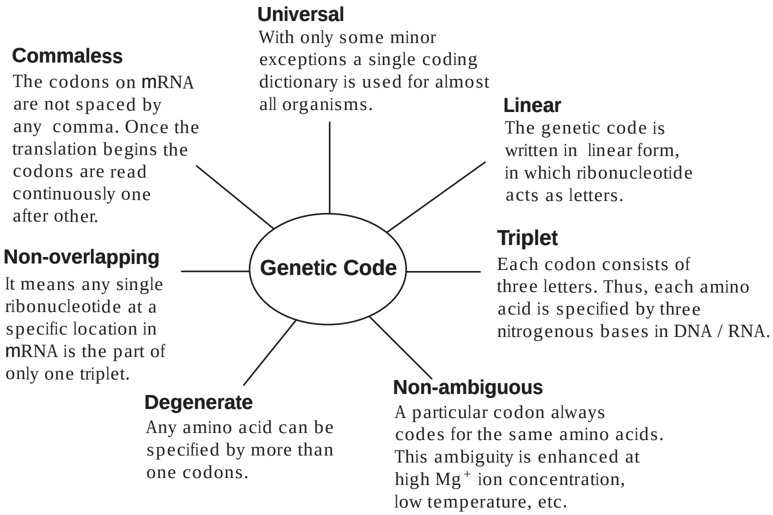
Genetic Code

The genetic code was discovered by **Nirenberg** and **Matthaei** (1961). The 64 distinct triplets determine the sequence of 20 amino acids on polypeptide chains.

It is defined as

'The nucleotide sequence of nitrogenous bases, which specifies the amino acid sequence in a polypeptide molecule'.

Features of Genetic Code



Characteristics of genetic codes

As a result of triplet combination of all ribonucleotides, 64 codons are generated.

Out of these 64 triplet codons, 3 codons are **stop or non-sense codon** (or termination codon). These are nucleotide triplets within the mRNA that signal the termination of translation. **These stop codons are**

UAG (Amber), UAA (Ochre) and UGA (Opal).

Sometimes genetic codons show deviation from their universality. **e.g.,** in **Mycoplasma capricolum**, yeast and humans, the stop codon UGA codes for tryptophan while in several prokaryotes it codes for amino acid **Selenocysteine**. In humans, the codon AGA (for arginine) acts as **stop codon**.

Mostly codons are non-ambiguous (**i.e.,** particular codon codes for same amino acid). However, in certain rare cases, the genetic code is found to be **ambiguous**, **i.e.,** some codons, codes for different amino acids under different conditions, for example, in streptomycin sensistive strain of **E. coli**, the codon UUU, normally codes for phenylalanine but, it may also code for isoleucine, leucine or serine when ribosomes are treated with **streptomycin**. This ambiguity is enhanced, at high Mg ion concentration, low temperature and in the presence of ethyl alcohol.

Wobble Hypothesis (Crick; 1966)

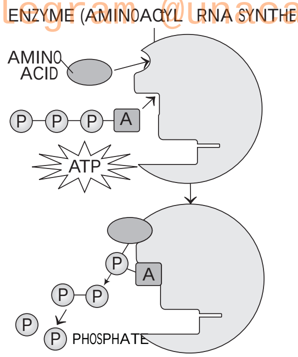
According to this 'the major degeneracy occurs at the third position, while first two bases do not change. The third base is called **Wobble base**.' This wobble base of codon lacks specificity and the base in the first position of anticodon is usually abnormal, **e.g.,** inosine, pseudouridine and tyrosine.

These abnormal bases are able to pair with more than one nitrogenous bases at the same position, **e.g.**, Inosine (I) can pair up with **A**, **C** and **U**. The pairing between unusual bases of **t**RNA and wobble base of **m**RNA is called **wobble pairing**.

Translation

The process in which genetic information present in **m**RNA directs the order of specific amino acids to form a polypeptide chain.

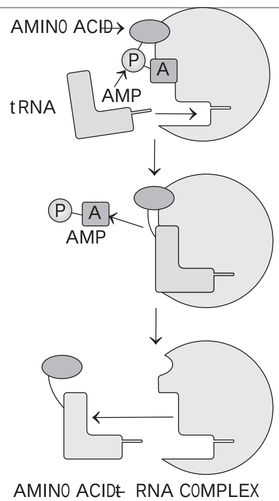
The process of translation can be summarised as



Activation of Amino acids

With the help of enzyme aminoacyl **t**RNA synthetase, the amino acid is activated at its carboxyl group.

Amino acid + ATP + Enzyme $\rightarrow$ Enzyme amino acid – AMP + PPi

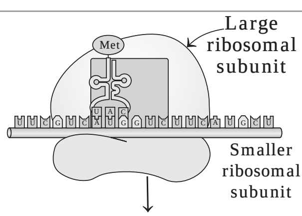


Transfer of active amino acid to **t**RNA

Transfer of amino acid to tRNA

During this process, a high energy ester bond is formed between the carboxyl group (—COOH) of amino acid and 3-hydroxy group of terminal adenosine of **t**RNA.

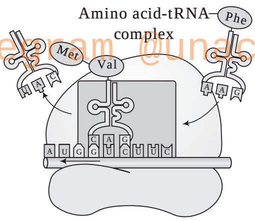
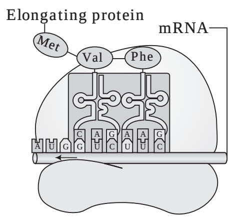
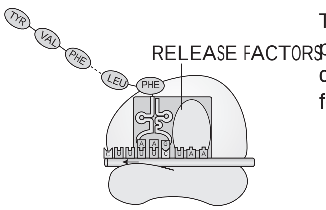
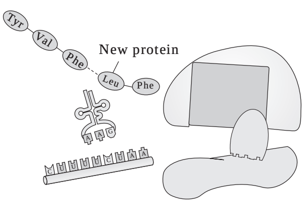
Enzyme–Amino acid – AMP + **t**RNA $\rightarrow$ Amino acid –**t**RNA + AMP + Enzyme.



Joining of larger subunit of ribosome to smaller subunit-initiation complex

Initiation of polypeptide chain synthesis

The initiation is done by the formation of smaller subunit initiation complex by joining of activated amino acid **t**RNA complex with initiation codon. The total complex then joins to large subunit for complete synthesis of initiation complex.

 	Elongation of polypeptide chain	The enzyme which helps in peptide bond formation is peptidyle transferase. After peptide bond formation, translocation occurs, which involves the movement of second amino acid tRNA complex from A-site to P-site.
 	Termination of polypeptide chain formation	Termination codon (UAG, UGA and UAA) reaches the ribosome and terminates the polypeptide synthesis.

Regulation of Gene Expression

Gene regulation is the mechanism of **switching off** and **switching on** of the gene depending upon the requirement of cells and the state of the development.

(A) **Control of Gene Expression in Prokaryotes**

The hypothesis of this regulation was given by **F Jacob** and **J Monad.** This hypothesis is known as **operon model**. The theory was given on the basis of the study of *lac* (lactose) **operon** in **E. coli**.

The operon consists of following components

(i) Regulator gene (ii) Promoter gene
(iii) Operator gene (iv) Structural gene

The first three genes among above genes produce three compounds, **i.e.,** repressor, inducer and corepressor.

Repressor has capacity to bind on operator gene only after activation by **corepressor**. Another protein **inducer** have the capacity to bind on operator as well as **repressor**.

The complete operon looks like

Regulator	Promoter	Operator	Structural Gene		
			Z	*Y*	*A*
1200 bp	30 bp	35 bp	3063 bp	800 bp	800 bp
Regulator is responsible for the synthesis of protein called repressor. The active repressor is seen in inducible system, while inactive repressor is seen in repressible system.	It is the segment at which RNA polymerase binds. It initiates the transcription of structural gene and controls the rate of **m**RNA synthesis.	This segment of DNA imposes control over the transcription. This region works like 'on' and 'off' switch for protein synthesis.	This region of DNA codes for the synthesis of proteins. These determine the primary structure of polypeptide.		

On the basis of their activity principles, the operons are of two types

Operon

Inducible System
(inducer is synthesised by regulator)

Possibilities

Inducer Absent
In this, regulator gene produces active repressor, which binds to operator gene and blocks transcription and protein synthesis.

Inducer Present
Regulator gene produces active repressor, which forms inducer-repressor complex. Thus, it does not bind to operator gene and transcription and translation goes on.

Repressible System
(inactive repressor is synthesised by regulator)

Possibilities

Corepressor Absent
In this, regulator gene produces aporepressor which does not have affinity for operator gene. So, it does not bind to operator to block the transcription and translation.

Corepressor Present
The aporepressor produced combines with corepressor to activate it. Then, this active repressor binds to operator gene and blocks both transcription and translation.

(B) Control of Gene Expression in Eukaryotes

In eukaryotes, the most accepted theory, is **Operon-Operator Model** of **Britton-Davidson** (1969).

According to this model, the eukaryotic operon contains four basic types of genes

(i) **Sensor** These gene segments are sensitive to cellular environment.

(ii) **Interogator** These act as carriers of signal from sensor to receptor.

(iii) **Receptor** The signal is received by these genes. These are associated with produce.

(iv) **Producer** These are output control centre.

The gene regulation can occur at various levels

1. At the level of transcription
2. At the level of RNA processing and splicing
3. At the level of translation

Human Genome Project (HGP)

HGP was the international collaborative research programme, whose goal was the complete mapping and understanding of all the genes of human beings, **i.e.,** genome.

HGP has revealed that there are probably about 20,500 human genes. The completed human gene sequence can now identify their locations. The ultimate result of HGP is 'the detailed information about structure, organisation and function of the complete set of human genes.'

The **International Human Genome Sequencing Consortium** published the first draft of the human genome in the journal **Nature** in February, 2001 with the sequence of the entire genome's 3 billion bp, some 90% complete. The full sequence was completed and published in April, 2003.

Following processes were involved in completion of HGP

- DNA sequencing
- The Employment of Restriction Fragment Length Polymorphism (RFLP)
- Yeast Artificial Chromosome (YAC)
- Bacterial Artificial Chromosome (BAC)
- The Polymerase Chain Reaction (PCR)
- Electrophoresis

DNA Fingerprinting

It involves the identification of differences in repetitive DNA. Repetitive DNA is a specific region in DNA in which a small stretch of DNA is repeated many times. It forms the basis of DNA fingerprinting.

Technique of DNA fingerprinting w-as initially developed by **Alec Jeffreys** to find out markers for inherited diseases.

The technique has the following steps

(i) DNA isolation
(ii) Amplification of DNA
(iii) Digestion of DNA
(iv) Separation of DNA fragments
(v) Blotting
(vi) Hybridisation
(vii) Autoradiography

Applications of DNA Fingerprinting

(i) Used as a tool in forensic investigations.
(ii) To settle paternity disputes.
(iii) To study evolution.

29 Evolution

The term **evolution** is derived from two Latin words, **e** = from; **volvere** = to roll/unfold, and was first used by english philosopher **Herbert Spencer**.

The **principle of evolution** implies 'The development of an entity in the course of time through a gradual sequence of changes, from a simple to more complex state'.

Biopoiesis refers to origin of life from non-living substances, while **biogenesis** is the term used to refer to the origin of life from already existing life forms.

There are **two theories** which have been given to explain the mechanism of origin of life. First is spontaneous generation from the non-living material (abiogenesis) and second is the origin of life from the parental organism by reproduction (biogenesis). Presently the view of biochemical origin of life is widely accepted.

The history of life comprises two events

(i) Origin of life

(ii) Evolution of life

Before discussing above events in detail we must take a close look on the 'origin of universe'.

Origin of Universe

Several theories have been given to explain the origin of universe and the most accepted one is Big-Bang theory.

Big-Bang Theory (Abbe Lemaitre; 1931)

According to this theory, about 15 billion years ago, a fiery explosion took place in the condensed cosmic matter and its fragments got scattered into space at an enormous velocity.

Arno Allan Penzias supported the Big-Bang theory and discovered evidences for this theory. Our **galaxy** (**i.e.,** cluster of stars) contains about **100 billion stars** and called as **Milky way**.

Origin of Life

Ancient Theories of Origin of Life

Theories of Abiogenesis (origin of living organisms from non-living matter)	**Theories of Biogenesis** (origin of living organisms from pre-existing living organisms, non-living matter)
Theory of Special Creation These are mythological theories, with the belief that the life was created by supernatural powers.	Theories of biogenesis were supported by various scientists, through experiments performed by them. **Some of them are discussed here**
Theories of Spontaneous Generation This is also known as autobiogenesis. The theory was supported by Plato, Aristotle, etc. They believed that the snails, fishes, frogs arose spontaneously from mud.	Francesco Redi's Experiment (1668) He placed well-cooked meat in three jars. First jar was uncovered, second by parchment and third was covered by muslin cloth. After some days, he observed that the maggots developed only in uncovered jar.
Theory of Cosmozoic Origin According to this theory, the life is coeternal with matter without any beginning. The living protoplasm reached to Earth from other part of universe.	Lazzaro Spallanzani's Experiment (1767) Spallanzani, taking organic liquid (boiled nutritive broth) in the vessels, then sealed them. But he always found that, if proper care is taken, no living things appear.
Theory of Panspermia Arrhenius (1908) proposed this theory. It also supports the process of coming living material from other planet.	Louis Pasteur's Experiment (1860-1862) He disproved the theory of spontaneous generation by performing a well-designed experiment called swan-necked flask experiment.

Modern Theory of Origin of Life (AI Oparin)

It is also known as **modern theory** or **abiogenic origin** or **naturalistic theory or physicochemical evolution**. It was hypothesised by **AI Oparin** and supported by **JBS Haldane, Miller** and **Urey** and **Sydney F Fox**.

According to this theory, the life was originated in deep sea hydrothermal vents. Through these vents, the sea water seeps through the cracks in bottom, until the water comes close to hot magma.

The **super heated water** expelled forcibly, with variety of compounds such as H_2S, CH_4, iron and **sulphide ions**.

Oparin wrote the book Origin of Life in 1936. In his book, he admitted abiogenesis first, but biogenesis ever since. Therefore, Oparin's theory is also known as **primary abiogenesis.**

The schematic presentation of physicochemical evolution is as follows

Chemical Evolution

Primitive Earth
(Hot revolving ball of the gas) Free atoms like hydrogen, oxygen, carbon, nitrogen, sulphur, phosphorus, etc., are present.

↓

Inorganic Molecules
These molecules are produced by the combination of elements, e.g., H_2, O_2, N_2 etc.

↓

Simple Organic Molecules
Formation of water, methane, ammonia and hydrogen cyanide took place. The environment became reducing.

↓

Complex Organic Molecules
By the **polymerisation** of simple organic molecules, larger organic molecules were formed. These are polypeptide, nucleotides and polysaccharides, etc.

↓

Coacervates
These large organic molecules synthesised abiotically on primitive earth. These form colloidal aggregates due to intermolecular attraction. These colloides were called coacervate by Oparin and microsphere by Sydney F. Fox.

↓

Protobionts
These are also known as protocell or eobiont. These are nucleoproteinoid having free-living gene and were similar to present mycoplasma.

↓

Progenotes
The protobionts give rise to Monera, which in turn gives rise to prokaryotes with naked DNA, protoribosomes, etc.

↓

Algae → Bryophytes → Pteridophytes → Gymnosperms → Angiosperms

Fungi

Bacteria

Protozoans → Lower invertebrates → Higher invertebrates → Vertebrates

Organic Evolution

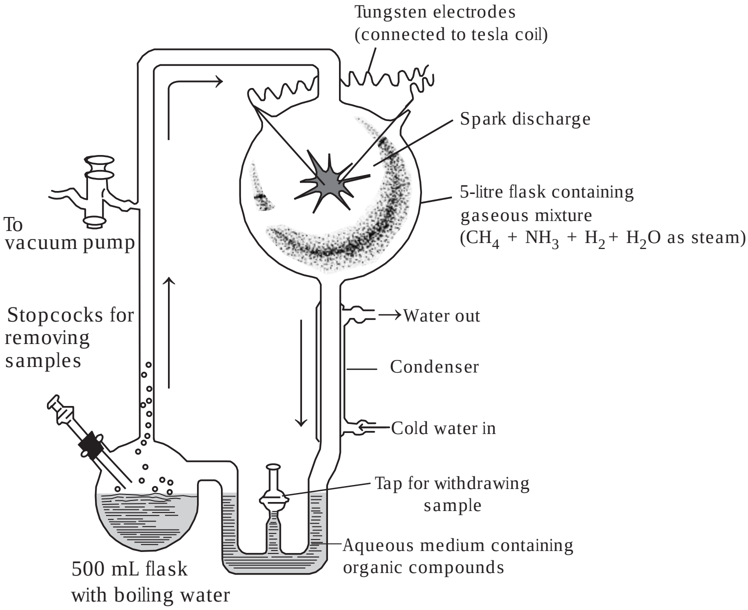
Modern theory of origin of life was supported by **Miller** and **Urey** with their experiment in 1953.

Miller and Urey's Experiment

In 1953, **Miller** built an apparatus of glass tubes and flasks in the laboratory. He created an atmosphere containing hydrogen (H_2), ammonia (NH_3), methane (CH_4) and water vapour (H_2O) in one big flask and allowed the condensed liquid to accumulate in another small flask. The ratio of methane, ammonia and hydrogen in the large flask was 2 : 1 : 2.

Energy was supplied to the apparatus by heating the liquid as well as by electric sparks from tungsten's electrodes in the gaseous flask (larger flask). The conditions of apparatus resembled the atmosphere present on the early earth. The experiment was conducted continuously for about one week and then the chemical composition of the liquid inside the apparatus was analysed.

The diagrammatic representation of Miller's experiment is as follows



Diagrammatic representation of the apparatus Stanley used to demonstrate the synthesis of organic compounds by electrical discharge in a reducing atmosphere.

Following categories of products were formed under the prebiotic conditions in Miller's experiment apparatus.

Some Products Formed Under Prebiotic Conditions

Carboxylic Acids	Nucleic Acid Bases	Amino Acids	Sugars
Formic acid	Adenine	Glycine	Straight and branched pentoses and hexoses
Acetic acid	Guanine	Alanine	
Propionic acid	Xanthine	α-amino butyric acid	
Straight and branched fatty acids ($C_4 - C_{10}$)	Hypoxanthine	Valine	
Glycolic acid	Cytosine	Leucine	
Lactic acid	Uracil	Isoleucine, proline	
Succinic acid		Aspartic acid, serine, threonine	

Which Came First RNA or Protein?

It is a matter of great controversy among biologists to decide that which came first RNA or protein. **There are three views regarding this problem as follows**

(i) **RNA world** (the group of scientists, who focus on RNA as the first molecule) RNA world group feels that without a hereditary molecule, other molecules could not have formed consistently. This view is supported by the discovery of **ribozyme**, a catalytic RNA molecule, which have the ability to act like enzymes.

(ii) **Protein world** (the group of scientists, who focus on protein as the first molecule) The protein group argues that without enzymes (which are proteins), nothing could be replicated at all, or heritable. They are in view that the nucleotide is very complex therefore, it cannot be formed spontaneously.

(iii) **Peptide-Nucleic Acid** (PNA) **world** (the group of scientists, who focus on the combination of RNA and protein.) The PNA world believed that there must have been a pre-RNA world, where the peptide, (nucleic acid) was the basis for life. PNA is simple and able to self-replicate.

Evidences of Evolution

Scientists proposed many evidences through which the evolution of life forms can be proved. Several different lines of evidences convinced **Darwin** and his contemporary scientists that the modern organisms arose by evolution from more ancient forms.

Darwin documented evolutionary evidences mainly on the basis of **geographical distribution of species** and **fossil records.**

Some significant convincing evidences for the occurrence of descent with modification come from

1. Palaeontology
2. Morphology and comparative anatomy
3. Geographical distribution
4. Embryology
5. Taxonomy
6. Connecting links
7. Cytology
8. Biochemistry and Physiology
9. Genetics

1. Evidences from Palaeontology

Palaeontology is the study of fossils of prehistoric life. According to **Charles Lyell**, 'Fossil is any body or trace of body of animals or plants buried and preserved by the natural causes.' Fossils are generally preserved in **sedimentary rocks**, which are formed by the deposition of **silt**, **sand** or **calcium carbonate** over millions of years.

Determination of Age of Fossils

The age of fossils can be determined by following methods

- **Radioactive Carbon** (C^{14}) **Dating Method** This was discovered by **WF Libby**. As the half life of carbon is relatively short, this isotope is only reliable for dating fossils less than 70000 years.
- **Electron Spin Resonance** (ESR) **Method** It is a relatively new, precise and accurate method. It is based on the fact that the background radiation causes electron to dislodge from their normal positions in atoms and trapped in crystalline lattice of material, it is mostly used to date $CaCO_3$ and lime stone.
- **Radioactive Clock Method** This was discovered by **Boltwood** (1907) and based on the disintegrating property of radioactive elements.
- **Potassium-Argon Method** The transformation of potassium into argon; rubidium into strontium has been used for dating fossils bearing rocks of any age and any type.

Geological Time Scale

The evidence of the evolution can also be taken through geological time scale. The complete lifespan of earth (**i.e.,** 4600 million years) is known as geological time, which have been divided into **eras**. Eras are divided into **periods** and periods into **epochs**. An Italian scientist **Giovanni Ardulna**, developed first geological time scale in 1760.

Geological Time Scale with Notes on Events in the Evolution of Life and Environment

Rocky Mountain Revolution (Little Destruction of Fossils)

Era	Period	Epoch	Geological and Climatic Conditions	Flora (Plant Life)	Fauna (Animal Life)
Caenozoic (Age of Mammals)	Quarternary	Recent (Holocene)	End of last ice age; climate warmer; climatic zones distinct.	Dominance of herbs.	Age of man; development of human cultures.
		Pleistocene	Periodic continental glaciers in North.	Increase of herbs, spread of herbs and grassland.	Age of man, extinction of many large mammals.
		Pliocene	Cool and temperate climate away from equator, continuous rise of mountains of Western-North America.	Decline of forests, great decrease of woody plants.	Abundant mammals elephant, horses and camels, humans evolving.
	Tertiary	Miocene	Cooling of climate.	Development of grasses, reduction of forests.	Mammals at height of evolution, first man-like apes.
		Oligocene	Lands lower, climate warmer.	Worldwide tropical forests, rise of monocots and flowering plants.	Archaic mammals extinct, appearance of modern mammals.
		Eocene	Zoned climatic belts well established.	Extension of angiosperms.	Placental mammals, diversified and specialised; hoofed mammals and carnivores established.
		Palaeocene	Development of climatic belts.	Modernisation of angiosperms.	Evolutionary explosion of mammals.

Era	Period	Epoch	Geological and Climatic Conditions	Flora (Plant Life)	Fauna (Animal Life)
Rocky Mountain Revolution (Little Destruction of Fossils)					
Mesozoic (Age of Reptiles)	Cretaceous	—	Birth of modern reptiles, development of climatic diversity.	Rise of flowiering plants especially monocotyledons, decrease of gymnosperms.	Dinosaurs become extinct, toothed birds became extinct; beginning of toteost fishes and modern birds; archaic mammals common.
	Jurassic	—	Culmination of worldwide warm climates.	Cycades and conifers common; appearance of first known flowering plants.	Dominance of dinosaurs, appearance of first toothed birds; rise of insectivorous marsupials.
	Triassic	—	Continents exposed, world subtropical climates.	Gymnosperms dominant, declining towards the end extinction of seed fern.	Transaction of reptiles to mammals, rise of progressive reptiles and egg laying mammals, extinction of primitive amphibians.
Appalachian Revolution (Some Loss of Fossils)					
	Permian	—	Rise of continents; climate became arid and varied, glaciation in Southern hemisphere.	Dwindling of ancient plants, decline of lycopods and horse tails.	Extinction of ammonites and trilobites, abundance of primitives reptiles; appearance of mammals-like reptiles, decline of amphibians.
	Pennsylvanian	—	Uniform climate throughout world.	Great forests of seed-ferns and gymnosperms (great tropical coal forests).	Amphibians dominant on land, insects common, appearance of first reptiles.

Era	Period	Epoch	Geological and Climatic Conditions	Flora (Plant life)	Fauna (Animal life)
	Mississippian (Carboniferous)	—	Climate uniform, humid at first cooler later as land rose; spread of tropical seas.	Mosses and seed ferns dominant, gymnosperms increasingly widespread (early coal forest).	Rise of insects, sea lilies at peak, spread of ancient sharks.
	Devonian	—	Broad distribution of uniform climates; increased temperature.	First forests, first gymnosperms and first known liverworts, horsetails and ferns.	Diversification in fishes; sharks and lung fishes abundant, evolution of amphibians.
	Silurian	—	Slight climate cooling extensive continental seas.	First known land plants club mosses, algae dominant.	Wide expansion of invertebrates, first insects, rise of fishes.
	Cambrian	—	Warm climate, great submergence of land.	Land plants probably first appeared, marine algae abundant.	First indication of fishes, corals and trilobites abundant, diversified molluscs.
	Ordovician	—	Climate became progressively warmer.	Algae, fungi and bacteria; first fossils of plant life.	Invertebrates numerous and varied, most modern phyla established.
Protero-zoic		—	Cool climate, volcanic eruptions, repeated glaciating.	Primitive aquatic plants algae, fungi and bacteria.	Shelled protozoans, coelenterates, flatworms, primitive annelids.
Archae-ozoic		—	Great volcanic activities, no recognisable fossils, indirect evidence of living things from some sedimentary deposits of organic material in rocks, **e.g., Eubacterium isolatum**, **Archaeospheroides barbertonis**.		

2. Evidences from Biogeography

Biogeography is the study of distribution of animals and plants.

According to **continental drift** or **plate tectonics theory** given by **Alfred L Wegener** (1912), the total landmass of modern world is originated from a large mass called **Pangea**.

This separation was started in **carboniferous period** and ended till **mesozoic era**. The shape of coastal areas and the species of plants and animals present in different continents supports the theory. The continental drift theory is also known as **Jigsaw fit theory**.

3. Evidences from Morphology and Comparative Anatomy

These include followings

(i) Homology and Homologous Organs

Those organs which have the **same embryonic origin** and **basic structure**, though they may or may not perform the same function.

This is the result of **divergence** due to **adaptive radiation**. **On the basis of its occurrence, homology is of following types**

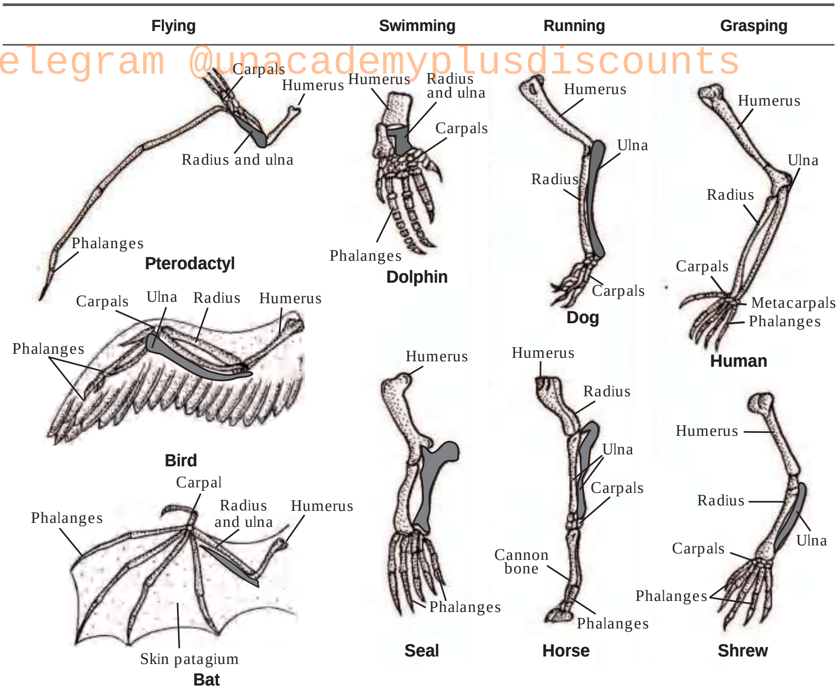
Various examples of homologous organs are given with their function in following diagram

Homology

Phylogenetic Homology
(Homology between different species.), e.g., pentadactyl limbs of air breathing vertebrates.

Sexual Homology
(Homology between two sexes of same species.), e.g., testes of man and ovaries of woman.

Serial Homology
(Homology exists between two organs of same individual), e.g., arm and leg of man.



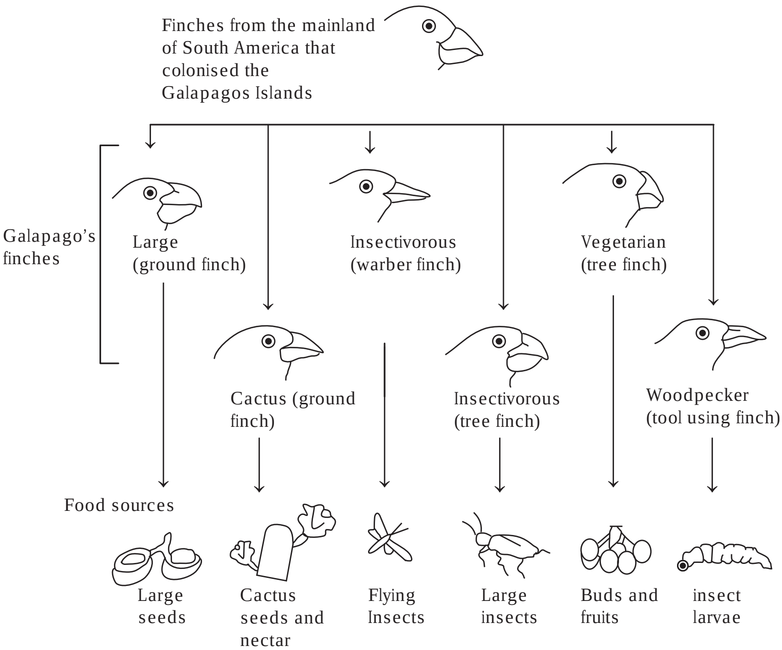
Homology of forelimbs in vertebrates

Adaptive Radiation

HF Osborn (1898) developed the concept of **adaptive radiation** or **divergent evolution**, **i.e.,** the development of different functional structures from a common ancestral form.

The significance of adaptive radiation is that, it leads to the modification of homologous structures which ultimately results into divergent evolution.

Following figure of adaptive radiation in Darwin's finches clearly indicates the process of divergent evolution



Adaptive radiation in Darwin's finches

(ii) **Analogy or Analogous Organs**

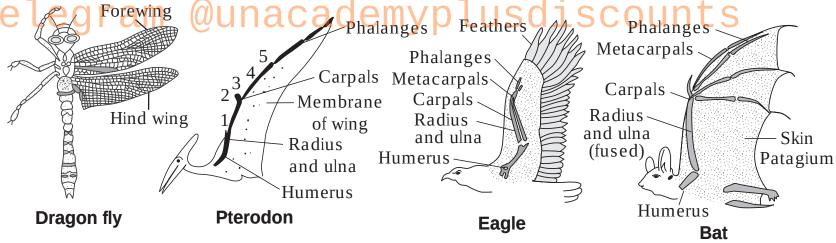
These are the structures which are different in their basic structure and developmental origin, but appear and perform similar functions. This relationship between structure and function is known as **analogy** or **convergent evolution**.

Adaptive Convergence (Convergent Evolution)

In adaptive convergence, separate lineages show similar morphology under the influence of similar environmental factors.

'When a species of distinct lineages closely resemble on overall morphology it is called as **homeomorphs**', **e.g.,** wings of birds, insects and bats are homeomorphs.

Analogy in the wings is shown in the following diagram



Analogy in the wings

(iii) Vestigial Organs

These are non-functional organs, which were functional in their ancestors.

There are more than 90 vestigial organs in the human body. Some examples are **coccyx** (tailbone), **nictitating membrane** (3rd eyelid), caecum, vermiform appendix, canines, wisdom teeth, body hair, auricular muscles, mammary glands in males, etc.

Vestigial organs are also present in some other animals, **e.g.,** splint bones in horse, hindlimbs and pelvic girdle in python, wings and feathers in flightless birds, etc.

Atavism or Reversion

It is the sudden reappearance or refunctioning of some ancestral organs, which have either completely disappeared or are present as vestigial organ, **e.g.,**

- Long and dense hair
- Birth of human baby with small tail.
- Development of power of moving pinna in some individuals.

4. Evidences from Embryology

Through the comparative study of life histories of individuals, the evidences of evolution can be collected.

A comparative study of the ontogeny of various forms of animals reveals the phylogenetic relationship and thus confirms evolution. To varify this, following points can be considered

(i) The zygote of all metazoans are single-celled and similar to the body of protozoans.

(ii) The stages of embryonic development, **i.e.**, **morula, blastula** and **gastrula** are basically similar in all **metazoans**.

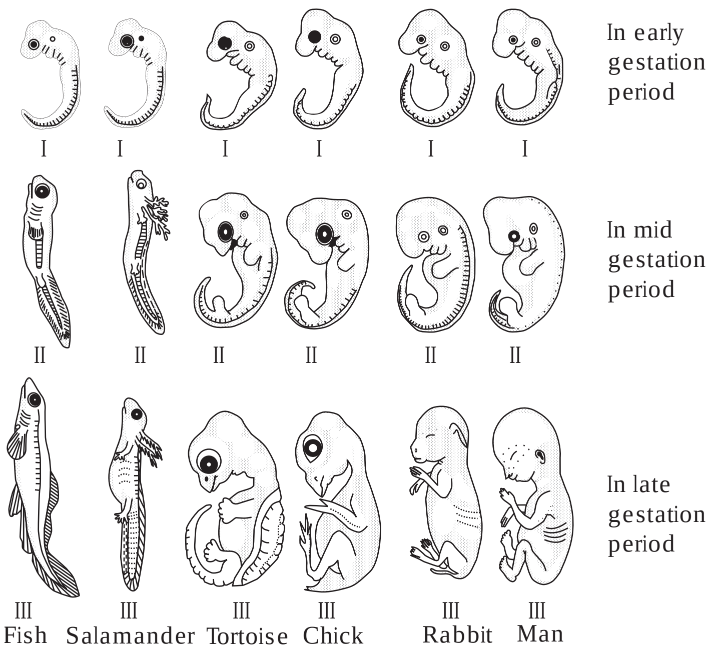
(iii) In fishes, the young individuals develop from gastrulas is almost like the adult, but the tadpole of amphibians is similar to young fishes.

(iv) The early postgastrula stages are quite similar in the members of all the different **classes viz**-fishes, amphibians, reptiles, birds and mammals.

(v) Possession of **pharyngeal gill slits** and **gill pouches** are one of the three diagnostic characters of all chordates.

Due to the similarity among early embryos of all vertebrates, it is very difficult to differentiate a human embryo from embryo of other vertebrates.

The comparative account of several vertebrate embryos is given as follows



Depicting the remarkable similarity in the early embryos of some vertebrates

Recapitulation Theory or Biogenetic Law

It states that **Ontology recapitulates phylogeny**, **i.e., ontogeny** (development of the embryo) is the **recapitulation of phylogeny** (the ancestral sequences).

For example,

(i) Presence of fish-like characters (**i.e.,** gills, gill slits, tail, tail fin, lateral line and sense organs) in tadpole larva of frog.

(ii) Presence of filamentous green algae-like structure, **protonema** during the development of **Funaria** (moss).

5. Evidences from Connecting Links

A connecting link demonstrates the characteristics of more than one group. These organisms indicate the transition of characters from one to another group of organisms.

Following table gives the number of organisms (**i.e.,** links) and their disputed positions between groups.

S.No.	Link	Between the Groups
1.	Virus	Living and non-living
2.	**Peripatus** (walking worm)	Annelida and Arthropoda
3.	**Balanoglossus**	Chordates and Non-chordates
4.	**Archaeopteryx**	Reptiles and Birds
5.	**Cycas**	Pteridophytes and Gymnosperms
6.	Echidna (spiny anteater)	Reptiles and Mammals
7.	**Euglena**	Animals and Plants
8.	**Gnetum**	Gymnosperms and Angiosperms
9.	Hornworts	Protista and Fungi
10.	**Neopilina**	Annelida and Mollusca
11.	**Ornithorhynchus** (duck-billed platypus)	Reptiles and Mammals
12.	**Proterospongia**	Annelida and Arthropoda
13.	**Protopterus** (lung fishes)	Bony fishes and Amphibia
14.	**Xenoturbella**	Protozoa and Metazoa
15.	Trochophore larva	Annelida and Mollusca
16.	Tornaria larva	Echinodermata and Chordata
17.	**Sphenodon** (living fossil lizard)	Amphibia and Reptilia
18.	**Seymouria**	Amphibia and Reptiles
19.	**Latimeria**	Pisces and Amphibia
20.	Myxomycetes	Protista and Fungi
21.	**Actinomyces rickettsia**	Bacteria and Fungi
22.	**Chimaera** (rabbit fish/rat fish)	Cartilaginous and Bony fishes
23.	Club moss	Bryophytes and Pteridophytes
24.	**Ctenophora**	Coelenterates and Platyhelminthes

6. Evidences from Taxonomy

During classification, organisms are grouped according to their resemblance and placed from simple organisms towards the complexity.

There was no difference among animals and plants during the origin of unicellular stage of organisms. Thus, **Euglena** is a common ancestor of both plants and animals.

7. Other Evidences

Several other evidences also support the process of evolution. These may by of **biochemical or physiological** (**i.e.,** study of different products and physiology among organisms), **cytological** (**i.e.,** deep observation of cellular composition among related organisms) and **genetical** (**i.e.,** have the **mutation** and **variation** as their theme for evolution) nature.

Theories of Evolution

Organic evolution implies that 'present day organisms are modified, but lineal descendents of species that lived in former geological time, and the more complex and highly differentiated forms have evolved from the simpler organisms by gradual modifications'.

Lamarckism

It is the first theory of evolution which was proposed by **Jean Baptiste de Lamarck** (1744-1829), a French biologist.

It was published in 1809 in his book '**Philosophie Zoologique**'.

Central Idea The characteristics that are acquired by organisms during their lifetimes in response to environmental conditions are passed on to their offsprings.

Four Basic Propositions of Lamarck

Lamarckism includes four basic propositions

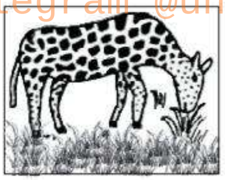
(i) Internal vital force

(ii) Effect of environment and new needs.

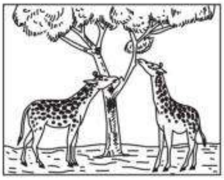
(iii) Use and disuse of organs.

(iv) Inheritance of acquired characters.

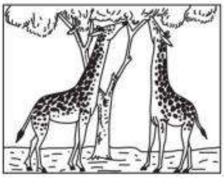
The diagrammatic representation of Lamarck's theory is as follows



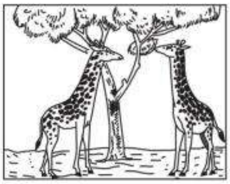
The ancestors of giraffe were bearing small neck and forelimbs and were like horses. These have internal vital force to increase their size and become relatively large in due course of time.



Probably, due to some reasons, the surface vegetation was removed which lead to the stretching of neck to reach to the branches of trees. This stretching is induced by the scarcity of food in environment and need for the food. The changing environmental conditions always generate new needs. To fulfil new needs, an organism needs to make some changes in their structure.



As the neck is comprehensively used to reach to the branches of trees, the elongation takes place. This is based on the proposition of use and disuse of organs the other organs of body say tail is not used so much hence, reduced or become unchanged. The continuous stretching of neck led to permanent elongation and character is acquired.



The acquired character (**i.e.,** long neck) is transmitted in next generation as the inheritance of acquired character is given by Lamarck. After several generations, the variations/modifications are accumulated upto such extent that they give rise to new species. This process of new species formation is called speciation.

Criticism of Lamarckism

(Evidences against the inheritance of acquired characters)

Mendel's laws of inheritance and **Weismann's theory of continuity of germplasm** (1892) discarded the Lamarck's concept of inheritance of acquired characters.

Theory of continuity of germplasm (August Weismann, 1834-1914) According to Weismann, 'the characters influencing the germ cells are only inherited'.

There is a **continuity of germplasm** (protoplasm of germ cells), but the **somatoplasm (protoplasm of somatic cells) is not transmitted** to the next generation. He cut the tails of rats for as many as 22 generations and allowed them to breed, but tail-less mice were never born.

Neo-Lamarckism

In full agreement with Weismann's theory, neo-Lamarckism proposes that

(i) Environment influences an organism and changes its heredity.

(ii) Some of the acquired variations can be passed on to the offspring.

(iii) **Internal vital force** and **appetency** (**i.e.,** a desire) do not play any role in evolution.

(iv) Only those variations are passed on to next generation, which also affect **germ cells.**

Darwinism (Charles Robert Darwin; 1809-1882)

The second most famous theory of evolution was given by **Charles Robert Darwin**. It was published in 1859 in his book "**Origin of Species by Means of Natural Selection" or the Preservation of Favoured Races in the Struggle for Life".**

Five Basic Propositions of Darwinism

Darwinism includes five basic propositions

(i) Rapid multiplication/overproduction

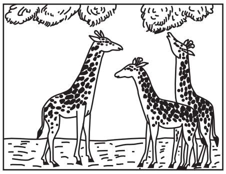
(ii) Limited resources

(iii) Variations

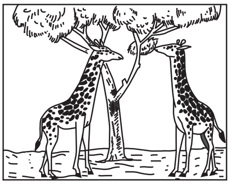
(iv) Natural selection

(v) New species formation

The diagrammatic presentation of five propositions are given in following figure

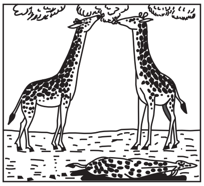


The multiplication of individual of a species occurs in a geometric proportion. Due to this tendency of multiplication, in a very short time the earth would be overcrowded. Despite having the rapid rate of reproduction by a species, its number remains about constant under fairly stable environment.



Due to this geometric population growth and their demands, the resources got depleted rapidly and lead to deficiency. As most of the natural resources are limited, it led to the adjustment among organisms for their needs. **The struggle for resources occurs at three levels**

1. Intraspecific struggle Struggle among individuals of same species. It is most intense.
2. Interspecific struggle Struggle between the individuals of two different species.
3. Struggle with environment It is the struggle of living forms against the environment.

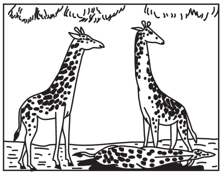


Variations are the differences among the individuals. These variations can help to adjust with the environment.

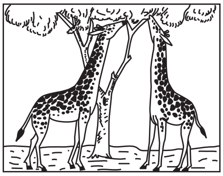
There are two types of variations

1. Continuous variation It shows the whole range of variation among particular character.
2. Discontinuous variation These appear suddenly and show no gradation.

Variations can be conclusively termed as environment induced adaptation by an individual.



The organisms which adapt useful variation successfully survive in changing environment and those which fail to put those changes are not selected and stunted or removed from the population after death. This process is termed as natural selection by Darwin. The giraffes with small neck failed to survive and died. The phrase survival of the fittest was given by Herbert Spencer.



The survived population radiated in different environment and established as different species with changed/modified characters. This process of establishment of new species is called as speciation by Darwin. The new species is originated by combination of struggle for existence, continuous variation and inheritance.

Criticism of Darwin's Natural Selection Theory

Following are the criticisms against Darwin's theory

(i) Darwin emphasised on **inheritance of small variations** which are non-inheritable and useless for evolution.

(ii) Darwin failed to explain the survival of the fittest.

(iii) Darwin failed to differentiate between **somatic** and **germinal variations**.

(iv) Natural selection does not explain the **coordinated development** and **coadaptation**.

(v) Darwin failed to explain the occurrence of vestigial organs.

Neo-Darwinism

It may be defined as the theory of organic evolution by the natural selection of inherited characteristics.

The theory of evolution given by **Darwin** and **Wallace** has been modified in the light of modern studies like genetics, molecular biology, palaeontology and ecology, etc.

Postulates of Neo-Darwinism

These are as follows

(i) Neo-Darwinism distinguished between the germplasm and somatoplasm.

(ii) Neo-Darwinism explained that the adaptations result from the multiple forces and natural selection is one of them.

(iii) As per Darwinism, characters are not inherited as such, instead there are character determiners which control the development.

(iv) The characters are the result of determiner's (genes) of organisms and the environment during its development.

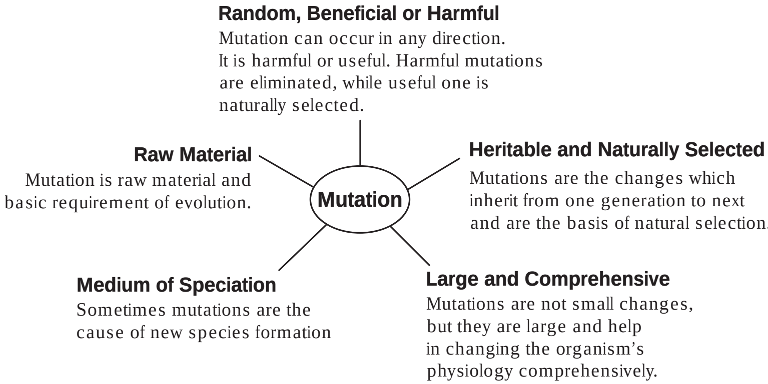
Mutation Theory (Hugo de Vries, 1848-1935)

To explain the process of evolution, **Hugo de Vries** proposed mutation theory, which was published in 1901 in his book **'Die Mutation Theorie'.**

He gave much importance to the **discontinuous variations** or **saltatory variations**. He coined the term **mutation** for suddenly appearing saltatory variations.

Main Features of Mutation Theory

As the mutation theory is more emphasised on mutation's features, it **can be diagrammaticaly represented as**



Criticism Against Mutation Theory

(i) The Oenothera lamarckiana of **Hugo De Vries** was not a normal plant, but a complex heterozygous form with chromosome aberrations.

(ii) Natural mutations are not the common phenomenon.

(iii) Most mutations are **recessive** and **retrogressive**.

(iv) Mutation theory fails to explain the role of nature in the process of evolution.

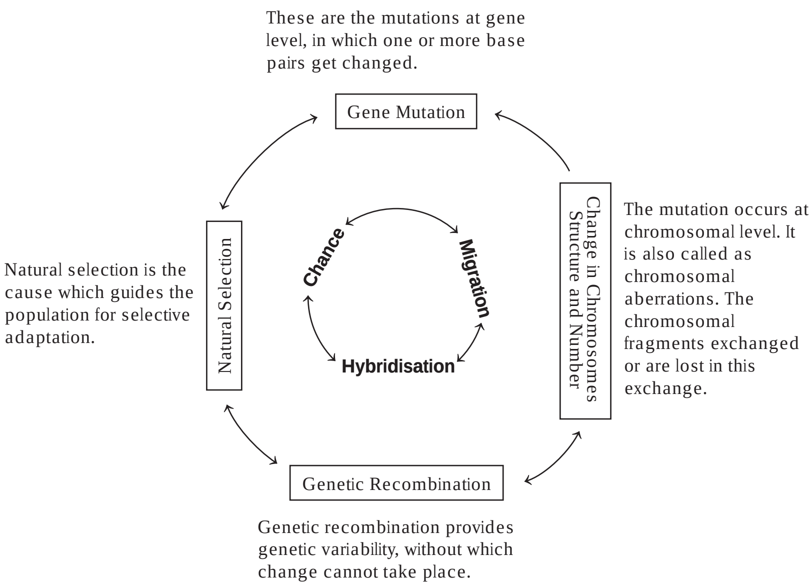
Modern Synthetic Theory of Evolution

The modern theory of origin of species or evolution is known as **modern synthetic theory** of evolution.

The modern synthetic theory of evolution evolved in 1937, with the publication of Dobzhansky's Genetics and the Origin of Species which was supported by **Huxley** (1942), **Mayr** (1942) and **Stebbins** (1950), etc.

Main Postulates of Modern Synthetic Theory of Evolution

This theory has four basic types of processes, this can be represented diagrammatically as following



Causes and processes of evolution (causes with bold and processes in boxes)

Mechanism of Evolution

Evolution is a change in a populations alleles and genotype from generation to generation. There are four basic mechanisms by which evolution takes place. These include **mutation**, **migration**, **genetic drift** and **natural selection**.

Agents of evolutionary change Various agents of evolutionary changes are as follows

Mutation

It is **sudden** and **heritable change** in an organism, which is generally due to change in the base sequence of nucleic acid in the genome of the organisms. It is the ultimate source of variations.

Mutation may be harmful or beneficial for the organism. It helps in the accumulation of variations, which later results in large variations and new species formation.

Gene Migration (Gene Flow)

The movement of individuals from one place to another is called **migration**. It can be a powerful agent of change because the **members** of two different populations may exchange genetic material.

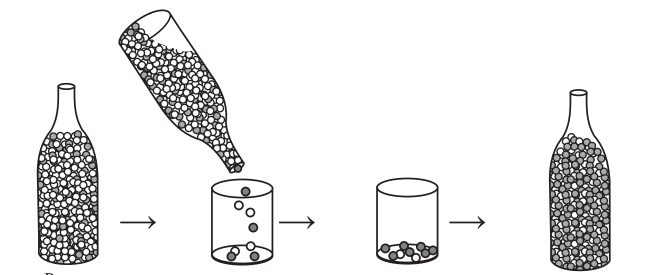
Sometimes **gene flow** is obvious when an animal moves from one place to another. When a newcomer individual have unique gene combination and is well-adapted, it alters the genetic composition of receiving population.

Genetic Drift or Random Drift

In small population, frequencies of particular allele may change drastically by chance alone. Such change in allele frequencies occurs randomly as if the frequencies were drifting and are thus known as **genetic drift**. It continues until genetic combination is fixed and another is completely eliminated.

There are two special cases of genetic drift

1. **Founder effect/founder principle** It is noted that when a small group of people called founders, leave their place of origin and find new settlements, the population in the new settlement may have unique genotypic frequency from that of the parent population. Formation of a different genotype in new settlement is called **founder effect.**
2. **Bottleneck effect** Due to several natural causes, the population declines even if the organisms do not move from one place to another. A few surviving individuals may constitute a random genetic sample of the original population. The resultant alterations and loss of genetic variability has been termed as **bottleneck effect**.



Parent Population (more white individuals as compared to the black ones) → Bottleneck (drastic reduction in population) → Note that the surviving individuals have more amount of black balls. → Next generation with larger proportion of black individuals in comparison to white individuals.

Selection

Darwin and Wallace explained the differential reproduction as the result of selection. **It is of two types**

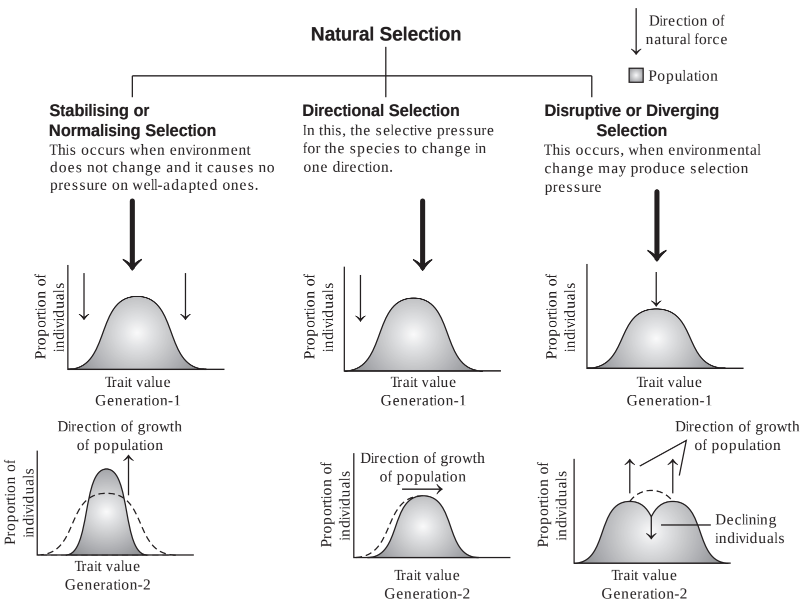
1. Artificial selection

In this, the breeder selects for the desired characteristics.

2. Natural selection

Environmental conditions determine that which individual in population produces the maximum number of offspring.

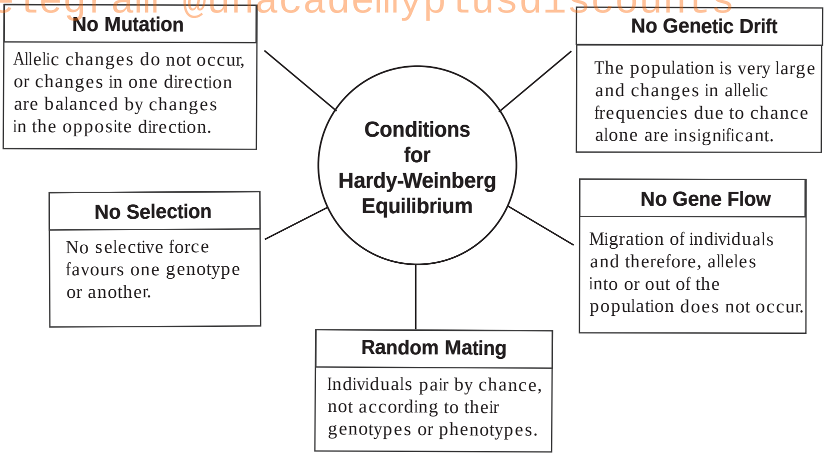
On the basis of environmental conditions, natural selection can be categorised as follows



Hardy-Weinberg Law

It is the fundamental law which provides the basis for studying the **Mendelian populations**. It was developed by **GH Hardy** and **G Weinberg** in 1908. It states that 'The gene and genotypic frequencies in Mendelian population remain constant, generation after generation, if there is no selection, migration, mutation and random drift takes place.'

Followings are the conditions for **Hardy-Weinberg equilibrium.**



Hardy-Weinberg principle is a tool to determine when evolution is occurring. To estimate the frequency of alleles in a population, we can use the Hardy-Weinberg equation.

According to this equation,

p = the frequency of the dominant allele (represented here by A)

q = the frequency of the recessive allele (represented here by a)

For a population in genetic equilibrium,

$\mathbf{p} + \mathbf{q} = 1.0$ (The sum of the frequencies of both alleles is 100%)

$(\mathbf{p} + \mathbf{q})^2 = 1$

So, $\mathbf{p}^2 + 2\,\mathbf{pq} + \mathbf{q}^2 = 1$

The three terms of this binomial expansion indicate the frequencies of the three genotypes

$\mathbf{p}^2$ = frequency of AA (homozygous dominant)

$2\,\mathbf{pq}$ = frequency of Aa (heterozygous)

$\mathbf{q}^2$ = frequency of **aa** (homozygous recessive)

Evolution of Human

Human beings belong to a single family–**Hominidae**,which includes a single genus **Homo** which have a single living species **sapiens** and a single living subspecies **sapiens**. All the racial groups **Mongoloid**, **Negroid**, **Caucasoid** and **Australoid** are the types of **Homo sapiens sapiens.**

The detailed classification of human with their general characteristics are mentioned in following table

Classification of Human

Kingdom	Animalia	Absence of chlorophyll, cell wall, presence of locomotion and intake of complex food.
Phylum	Chordata	Presence of notochord and dorsal hollow central nervous system.
Sub-phylum	Vertebrata (Craniata)	Presence of vertebral column and cranium (brain box).
Section	Gnathostomata	Jaws are present.
Super-class	Tetrapoda	Forelimbs are present.
Class	Mammalia	Mammary glands, ear pinna and hair are present.
Sub-class	Theria	Viviparous.
Infraclass	Eutheria	Presence of true placenta.
Order	Primata	Presence of nails over the digits.
Sub-order	Anthropoidea	Facial muscles are present for the emotional expression.
Family	Hominidae	Posture is erect and bipedal locomotion.
Genus	**Homo**	Man
Species	**sapiens**	Wise
Sub-species	**sapiens**	Most wise

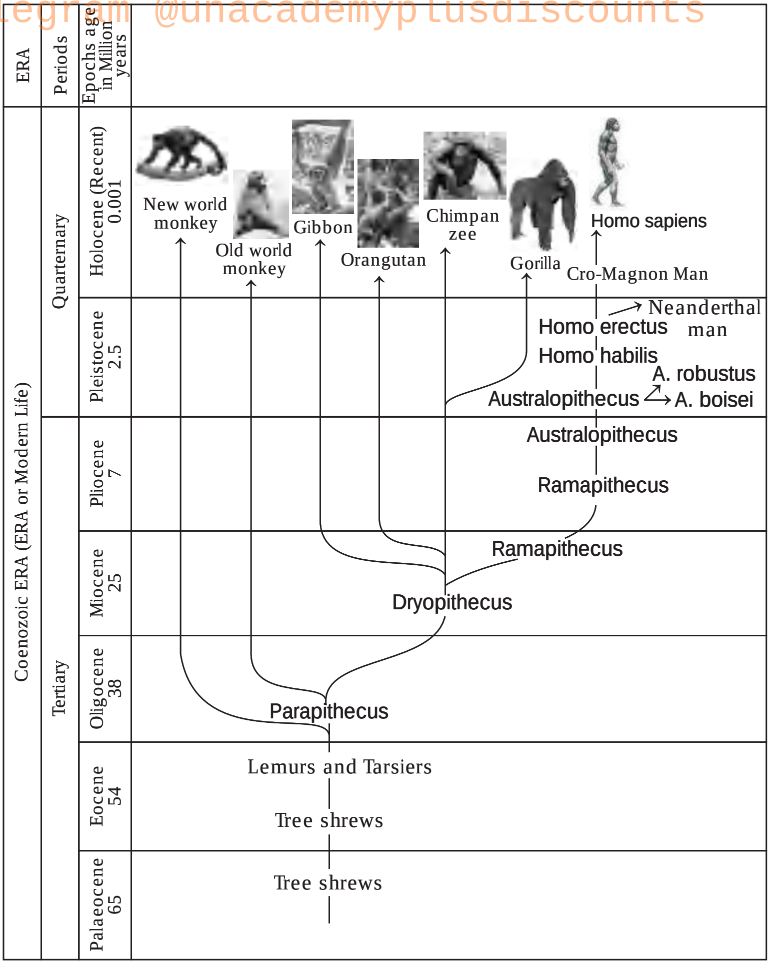
Human and Other Primates

The primates originated in the beginning of the tertiary period (Palaeocene epoch) about 65 million years ago from a small terrestrial shrew-like **insectivore**.

The beginning of primate evolution is presumed in Eocene of Tertiary period (75-60 million years ago) in evergreen forests. The place of origin of human is great controversy.

The fossils of humans were obtained from Africa, Asia and Europe, but most probably the origin of human occurred in Central Asia, China, Java and India (Shivalik hills).

Following primate trees throw a light on human evolution

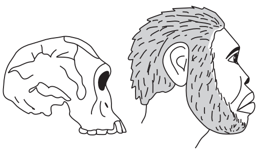
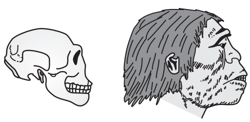


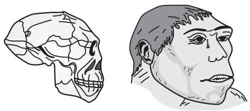
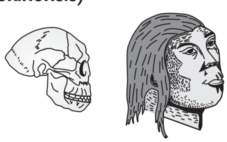
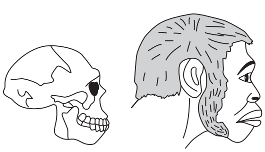
Human evolution can be explained through the series of following intermediates of early humans. From the earliest ape-like ancestors to the modern man, the evolution is slow and dynamic process.

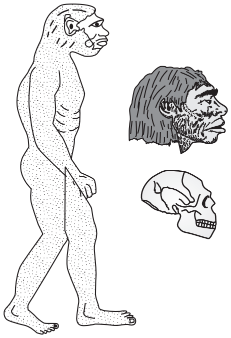
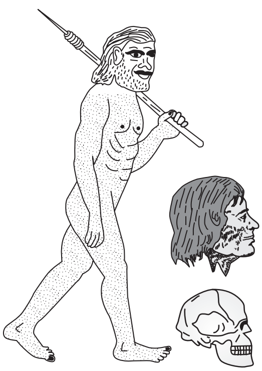
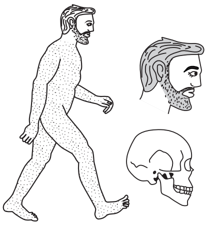
The common ancestry of both **ape** and **human** got differentiated after **Dryopithecus** and the first man-like primate was **Ramapithecus**, it was the oldest man's ancestor and the first hominoid.

Australopithecus, constitutes the first **ape man**, which had both man and ape characters. **Australopithecus** gave rise to **Homo habilis** approximately 2 million years ago.

Prior to ape man

Homo habilis (handy man or able man or skillful man or the tool maker) 	Discovery • Mary Leakey (1961) obtained the fossils of **Homo habilis** from Pleistocene rocks of Olduvi Gorge in East Africa. • Richard Leakey (1972) also obtained fossils of **Homo habilis** from East side of Lake Turkana in Kenya Characteristics • **Homo habilis** man was about 1.2 to 1.5m tall. • Its cranial capacity was 700-800 cc, which lived in Africa about two million years ago. • **Homo habilis** was carnivorous and had begun hunting for meat. • **Homo habilis** lived in small community or groups in caves. • Perhaps they showed sexual division of labour and communicated with visual signals and simple audible sounds.
Homo erectus (erect man) 	Discovery • Fossils of **Homo erectus** obtained from diverse sites from Olduvai Gorge in Africa to Java, Algeria, Germany, Hungary and China. • Fossils were 8,00,000 to 30,000 years ago. • **Homo erectus** is considered as the direct ancestor of modern man. It evolved from **H. habilis** about 1.7 million years ago in the Pleistocene. • **Homo erectus** species includes the fossils of Java man, Peking man, Heidelberg man, Algerian of Atlantic man. Characteristics • They were the oldest known early human to have modern human-like body proportion. • They were the first human species to have fleshy nose. They had flat skull with prominent ridges over the brow. • They had short arm and long legs. The short arms depict that the tree climbing ability was lost completely in them. The long legs depict that they are better suited for long distance migrations. • They were the first one to walk upright and stood erect thus, named so. Also, known as **Homo ergaster**. • They were the first hominid to live in hunter-gatherer society.

Java man or Pithecanthropus erectus or Homo erectus (ape man that walks erect) 	Discovery • In 1891, Eugene Dubois obtained fossils (some teeth, skull cap and femur bone) from Pleistocene deposits (500000-1500000 years back) in Central Java (an island of Indonesia). • It was named **Pithecanthropus erectus** (ape man that can walk erect) by Eugene Dubois and **Homo erectus** by Mayer (1950). Characteristics • Java man was more than 25 feet tall and weighted about 70 kg. • Its legs were thin and erect, but body slightly bent during movement. • Java man was the first pre-historic man, who began the use of fire for cooking, defence and hunting. • Its cranial cavity was 940 cc, which is about intermediate between **Australopithecus** (600-700cc) and modern man (1400-1600cc).
Peking man (**Homo erectus Pekinensis** or **Pithecanthropus pekinensis** or **Sinanthropus pekinensis**) 	Discovery • The fossils (skulls, jaws and post cranial bony fragments) of Peking man were discovered by WC Pai (1924) from the limestone caves of Choukoutien near Peking (Peking is the former name of China's capital Beijing). • These fossils of Peking man were about six lakh years old. Characteristics • Peking man was 1.55 to 1.60m tall, **i.e.,** slightly shorter, lighter and weaker than java man. • The cranial cavity of Peking man was 850-1200cc that is more than Java man.
Heidelberg man **(Homo erectus heidelbergensis)** 	Discovery • The fossil of Heidelberg man is represented by lower jaw, which was found from the middle Pleistocene rocks of Heidelberg (Germany). • Credit for the discovery of Heidelberg man goes to Otto Schoetensack. Characteristics • It had ape-like lower jaw with all the teeth. The teeth were human-like. • The jaw was large, heavy and lack a chin. • Its cranial cavity was probably about 1300cc, intermediate between erect man (**H. erectus**) and Neanderthal man (**H. sapiens neanderthalensis**). • Heidelberg man is regarded as an ancestor to Neanderthal man and contemporary to **Homo erectus**.

Neanderthal man **(Homo sapiens neanderthalensis)** 	Discovery • Fossils of Neanderthal man was discovered by C Fuhlrott (1856) from Neander valley in Germany. • Neanderthal man arose about 1,50,000 years ago and flourished in Asia, Europe and North Africa. Neanderthal man extinct about 25000 years ago. **Characteristics** • Neanderthal man existed in the late Pleistocene period. • Neanderthal walked upright with bipedal movement. • Cro-Magnon man (**Homo sapiens fossilis**) or fossil man closest to modern man or direct ancestor of living modern man.
Cro-Magnon man 	Discovery • Mac Gregor discovered the fossil of cro-Magnon man from Cro-Magnon rocks of France in 1868. Characteristics • Cro-Magnon man was almost similar to modern man with about 1.8m height. Orthognathous face, broad and arched forehead, strong jaws, elevated nose and well-developed chin as well as dentition. • Cranial capacity was about 1650cc, **i.e.,** much more than modern man (1450cc). • Probably they succeeded from Neanderthal man and distributed in Africa, Europe and Middle East. • Cro-Magnon lived during old stone age which is also known as Palaeolithic (began more than 2 million years ago).
Modern man **(Homo sapiens sapiens)** 	Discovery • It is believed that living modern man first appeared about 10,000 years ago in the regions of Caspian sea and Mediterranean sea. Characteristics • Its cranial capacity is average 1450cc, which is lesser than cro-Magnon. • It is distinguished from cro-Magnon merely by slight raising of skull cap, reduction in volume of cranial cavity (1,300-1,600cc) thinning of skull bones and formation of four curves in the vertebral column. • Human species (**sapiens**) have white or caucaroid, mongoloid and black or negroid races.

Future Man (Homo sapiens futuris)

The organic evolution is a continuous process of nature, which is still continued at present and probably will remain in future too. It is believed that in future, human could change as a result of the factors like **gene mutation**, **gene recombination** and **natural selection**.

An American anthropologist **HL Sapiro** named the future man, (**Homo sapiens futuris which may possess following characteristics**

(i) Height will be higher.

(ii) Hair will reduce and skull may become dome-shaped.

(iii) Body and cranium will be more developed.

(iv) The fifth finger may reduce.

(v) The age will increase.

30

Human Health and Diseases

Human Health

It is defined as a state of complete physical, mental and social well-being. It is not merely the absence of disease or infirmity.

Balanced or good health is a state of **optimum physical fitness**, **mental maturity, alertness**, **freedom from anxiety** and **social well-being** with freedom from social tensions.

Health can be affected by the following factors

(i) **Lifestyle related problems** These are habit and food related problems. These include diabetes, obesity, etc. Such problems affect the health reversibly.

(ii) **Genetic disorders** These include deficiencies or defects with which the child born, it means these are inherited from parents. These are also called inborn errors.

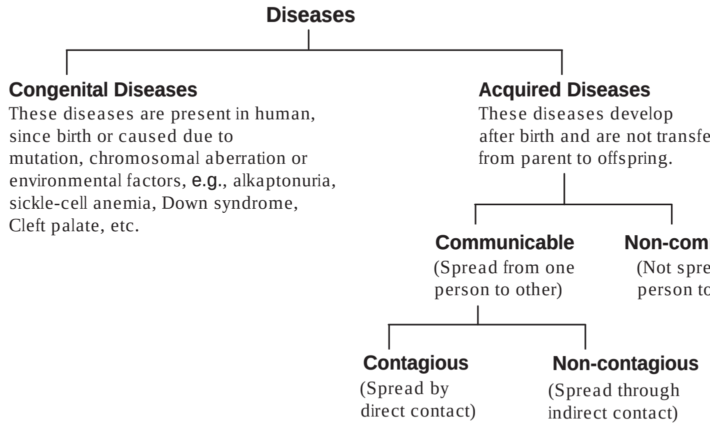
(iii) **Infections** These are health problems caused by infection from disease causing pathogens.

Healthy people are more efficient at work with increased longevity. This leads to reduced **Infant Mortality Rate** (IMR) and **Maternal Mortality Rate** (MMR). There are some other factors also, which have major impact on our health, such as awareness about diseases and their effects on different functions of body, vaccination against infectious diseases, proper disposal of waste, maintenance of hygienic food and water resources.

Common Diseases in Humans

Any deviation from normal state of health is called **disease**, in which the functioning of an organ or body got disturbed or deranged.

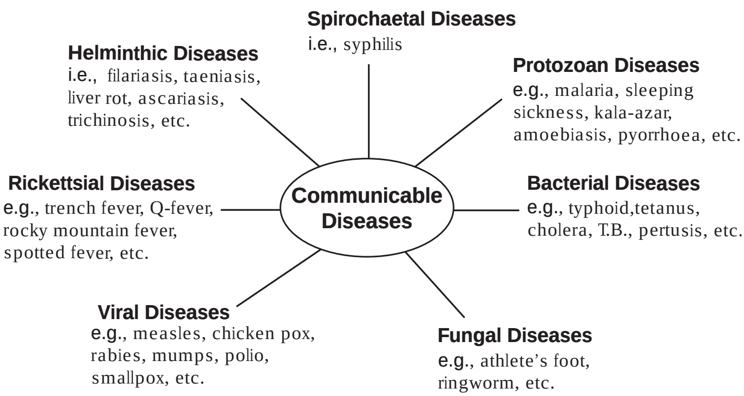
These diseases are caused by microorganisms like bacteria, virus, fungi, protozoans, worms, etc. These diseases causing organism are called as **pathogens**. **Diseases can be classified as**



The detailed accounts of these diseases are as follows

Communicable or Infectious Diseases

These are transferred from one person to another. **On the basis of types of causative agent (pathogen), communicable diseases are of following types**



Communicable diseases

Non-Communicable or Non-Infectious Diseases

These diseases are not transferred from an affected person to healthy person. Among non-infectious diseases, cancer is the major cause of death.

Non-communicable diseases can be categorised as follows

Non-Communicable Diseases

Hormonal Diseases These diseases occur due to defects in the production of hormones. These are
- **Cretinism** (due to the deficiency of thyroxine)
- **Diabetes** (due to the deficiency of insulin)
- **Dwarfism** (due to the hypoactivity of pituitary gland)
- **Gigantism** (due to the hyperactivity of pituitary gland)

Disease of Malfunctioning
Diseases caused by malfunctioning of organs are cardiac failure, kidney failure, osteoporosis, myopia, cataract and cancer, etc.

Allergic Diseases
These are caused due to the overactive response of immune system towards certain things like dust, serum, drugs, fabric and pollens, etc, e.g., sneezing, irritation, itching, rashes, etc.

Disease Caused by Addictive Substances
These are the diseases or symptoms caused by the addiction of certain substances like alcohol, narcotic drugs, tobacco and certain psychological factors, e.g., liver damage, reduce alertness, etc.

Ageing and Degenerative Diseases
Degeneration of body tissue results in disease. e.g., weakening of eye muscles, arteriosclerosis, and arthritis (Joint and bone diseases).

Mental Illness
These are mental disorders originated due to any problem, e.g., schizophrenia, etc.

Deficiency Diseases
These diseases are related to the deficiency of nutrients in diet. These may be
Protein deficiency Kwashiorkor, marasmus, etc.
Vitamin deficiency Pellagra, scurvy, etc.
Mineral deficiency Rickets, etc.
Iodine deficiency Goitre, etc.

Non-communicable diseases

Immunity and Immune System

Immunity can be defined as

'The self-preparedness (of the body) against invasion by microbes. It also includes defense against non-microbial antigens and malignancy.'

Antigens

These are the substances, which evoke an immune response when introduced in the body.

Criterias for Antigenicity

(i) Molecular size should be > 5000 daltons.
(ii) Chemical nature (usually protein and polysaccharide).
(iii) Susceptibility to tissue enzyme.

(iv) Foreignness.

(v) Iso and autospecificity (except lens protein and sperm).

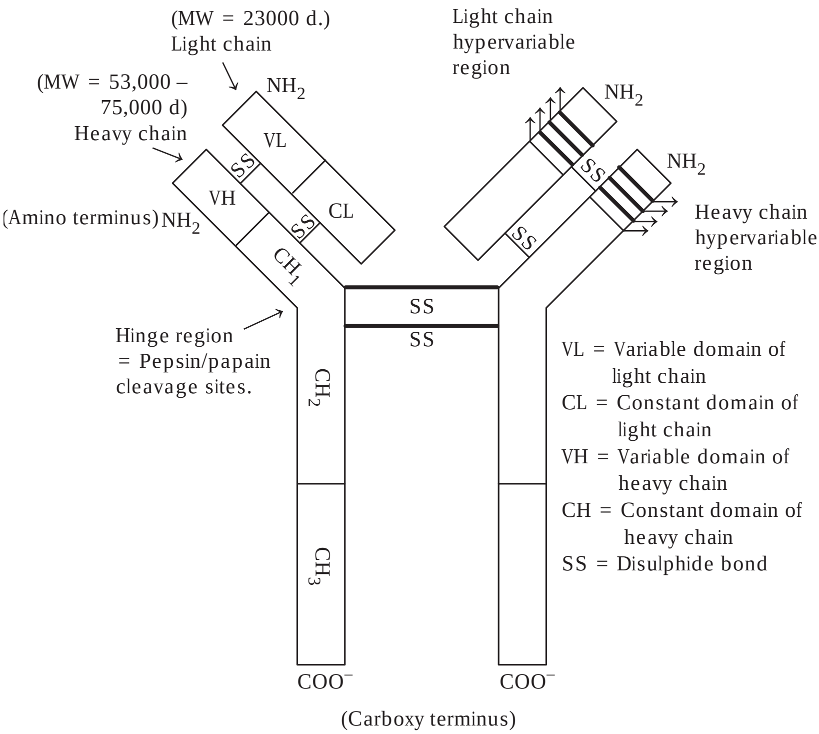
Antibodies

These are proteins produced within the body by the plasma cells against antigens.

Structure of Antibodies

The basic unit of all immunoglobulin (Ig) molecules consists of four polypeptide chains linked by disulphide bonds.

The structure is represented diagrammatically as

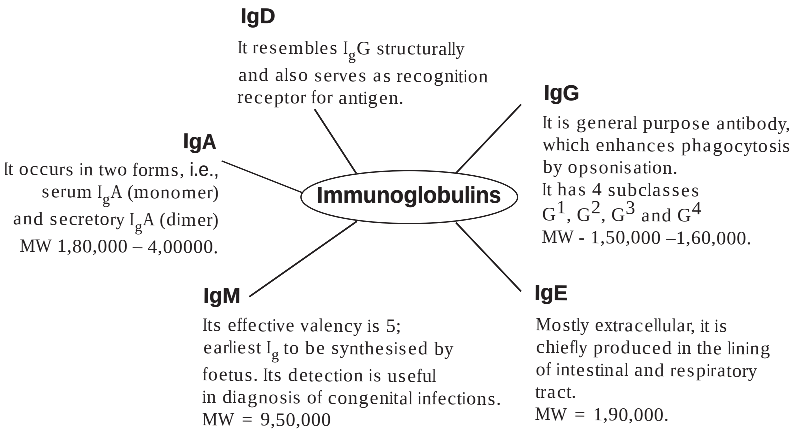


Antibody structure

Most of the antibodies are **euglobulin** and is usually **gamma** (γ) **globulin**. All antibodies are immunoglobulins, but all immunoglobulins may not be antibodies. Immunoglobulins constitute 20-25% of total serum proteins.

Classes of Immunoglobulins

There are five classes of immunoglobulins. These are described as follows



Types of immunoglobulins

Note

IgG protects body fluids.

IgA protects body surface.

IgM protects the bloodstream.

The action/response of antibodies against antigens is known as immune response or **immunity**. **Classically, it is divided into two categories**

(a) Non-specific or Innate Immunity

It is not affected by the prior contact with the antigen and effective against all without recognising the specific identities of the enemies, **e.g.,** skin, sebum, sweat, mucus and acids in stomach are non-specifically protective.

(b) Specific or Acquired Immunity

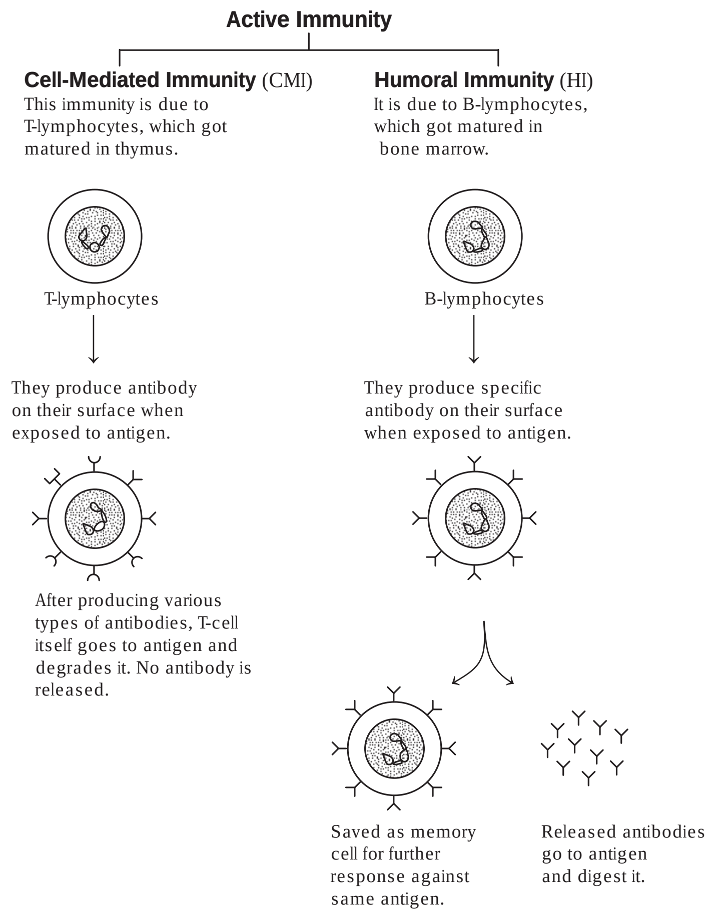
This immunity is the primary function of the lymphocytes which is carried out by other cells also. It has separate mechanisms for each and every enemy. To develop immunity, the prior contact with the specific antigen is essential. It develops against only to those antigens, which are not recognised as self.

The specific immunity may be active **or** passive**.**

(i) Active Immunity

It is developed within the body by the introduction of attenuated (heat suppressed) antigens, which are against lymphocytes. It can also be activated through vaccination, **e.g.,** polio vaccine, tetanus vaccine, etc.

On the basis of action of responding cell, active immunity is of two types



Demonstration of active immunity in organisms

(ii) **Passive Immunity**

It occurs due to the transfer or introduction of antibodies (immunoglobulins) from outside, **e.g.,** injection of serum against specific antibodies as Anti-Tetanus Serum (ATS), Anti-Venom Serum (AVS), etc.

During this, readymade antibodies are directly given to protect the body against foreign agents. The yellowish fluid colostrum secreted by mother during the initial days of lactation has abundant antibodies (**i.e.,** IgA) to protect the infant.

The foetus also receives some antibodies from their mother through the placenta during pregnancy. This is also an example of passive immunity.

Immune system is biologically, reticuloendothelial system.

The detailed description of reticuloendothelial system is as follows

Reticulo Endothelial System (RES)

Lymphoid System
It consists of various cells and organs.

Reticular System
It consists of phagocytic cells that are concerned with scavanging function.

Lymphoid Cells
- Lymphocytes
- Plasma cells

Lymphoid Organs

Central (primary) **Lymphoid Organ**
Organs in which precursor lymphocytes proliferate, develop and mature.
- Thymus
- Bone marrow

Peripheral (secondary) **Lymphoid Organ**
Organs in which lymphocytes store, act and recycled.
- Lymph nodes
- Spleen (largest lymphoid organ)
- Mucosa-Associated Lymphoid Tissue (MALT)

Components of reticuloendothelial system

Cells of Immune System

The various cells performing different functions constitute the immune system.

A close look of structure and functions of these cells are described below

Cells of Immune System

Dendritic cells
These are Antigen Presenting Cells (APCs). These process antigens and present them to T-cell during primary immune response.
They are bone marrow derived cells.
These have little or no phagocytic activity.
These are of three types
(i) Interdigitating dendritic cells.
(ii) Langerhans cell.
(iii) Follicular dendritic cell.

Null Cell or LGL
(Large Granular Lymphocyte)
They do not bear surface Ig, non-adherent and non-phagocytic with macrophage, they constitute innate immunity.

Phagocytic Cells
These are of two types
(i) **Mononuclear macrophages of blood and tissue**
These are the largest lymphoid cells with half life of 1 day, while lifespan of tissue macrophage is ~7 months. These are important for chronic inflammation and cell-mediated immunity.
(ii) **Microphages**
These are polymorphonuclear leucocytes of blood neutrophil, eosinophil and basophil.
They do not have any role in specific immune process.

Lymphocyte
Human body contains about 10^{12} lymphocytes, out of which 10^9 are re-newed daily.
They are of two types
(i) **T-lymphocyte**
Thymus derived and constitutes about 60-70% of peripheral lymphocytes.
It is present in paracortical area of lymph nodes and periarteriolar sheath of spleen.
(ii) **B-lymphocyte**
10-20% of peripheral lymphocytes, responsible for humoral immunity.
In spleen and lymph node, they form lymphoid follicles.

Major Histocompatibility Complex (MHC)

- Gene for MHC located on short arm of **chromosome six**, which code for histocompatibility (transplantation) antigen.
- Main function of MHC molecule is to bind peptide fragments of foreign proteins for presentation to antigen specific **T-cells**.

MHC **gene products are classified as**

Class-I Antigen	Class-II Antigen	Class-III Antigen
It is glycoproteins expressed in all nucleated cells. It is the principle antigen involved in graft rejection and cell mediated cytolysis.	It is glycoproteins restricted to antigen presenting cell only. It is responsible for graft versus host response and Mixed Leucocyte Reaction (MLR).	It is soluble proteins of complement system, **e.g.**, heat shock protein and TNF (α and β).

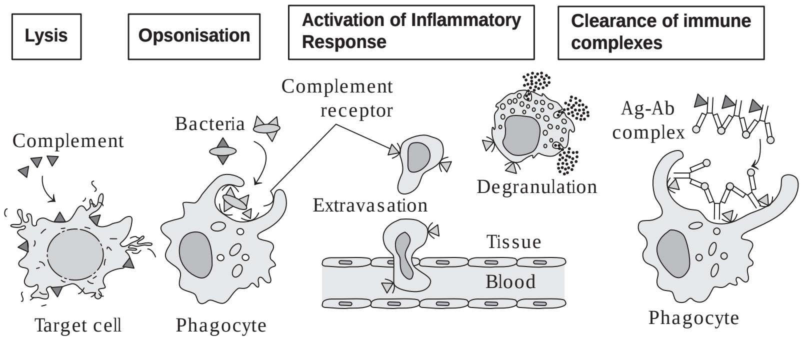
Complement System

It is an enzyme cascade that helps to defend against infections. Many complement proteins (C1-C9) occur in serum as inactive precursors (zymogens). At the sites of infection, these zymogens are activated locally and trigger a series of potent inflammatory events.

Activities of Complement System

The complement system shows various activities to digest the antigens. Phagocytes have important role in this system.

These activities are shown in following figure



Activities of complement system

Vaccination and Immunisation

It is based on the property of the memory of the immune system.

During vaccination, a preparation of antigenic protein or pathogen or inactivated/weakened pathogen is introduced into the body.

Memory B-cell and T-cell are generated by vaccines that recognise the pathogen quickly on further contact and digest the invaders with a massive production of antibodies. If the preformed antibodies against any antigen are introduced into the body, it is called **passive immunisation**.

Allergies

The exaggerated or overactive response of immune system to certain antigen or pathogen is called **allergy**. The substances which cause such immune response are called **allergens**.

During allergies from pollens, animal dander and mites in dust, etc., the IgE type of antibodies are produced. The use of drugs like anti-histamine, adrenaline and steroids helps in reducing such allergic response.

Autoimmunity

Sometimes due to genetic or other reasons, the immune system of body is unable to differentiate between self and foreign substance and start killing the self tissues or cells. This is called autoimmune disease, **e.g,.** rheumatoid arthritis, etc.

Acquired Immuno Deficiency Syndrome (AIDS)

AIDS is a cell-mediated immune disorder caused by Human Immunodeficiency Virus (HIV). HIV causes reduction in the number of **helper T-cells,** which stimulate the antibody production by B-cell and ultimately reduce the natural defence against viral infections.

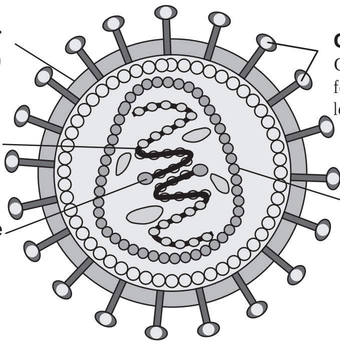
First incidence of AIDS was reported from California, USA (1981). **Prof. Luc Montagnier** isolated HIV in 1983 at Pasteur Institute, Paris.

Various names are given to AIDS **causing agent by different scientist as**

- **LAV-II** (Lymphadenopathy-Associated Virus-II) by **Luc Montagnier** (1983) France.
- **HTLV-III** (Human T-lymphotropic Virus III) by **Dr RC Gallo** (1984) USA.
- **HIV** (Human Immunodeficiency Virus) common name for LAV and HTLV by international committee of viral nomenclature (1986) (WHO).

Structure of HIV

HIV belongs to retrovirus (RNA containing) family of viruses. **The detailed description of the structure of virus is as follows**



Structure of HIV

Transmission of HIV

AIDS is a fluid transmitted disease.

The modes of transmission of HIV can be pointed as

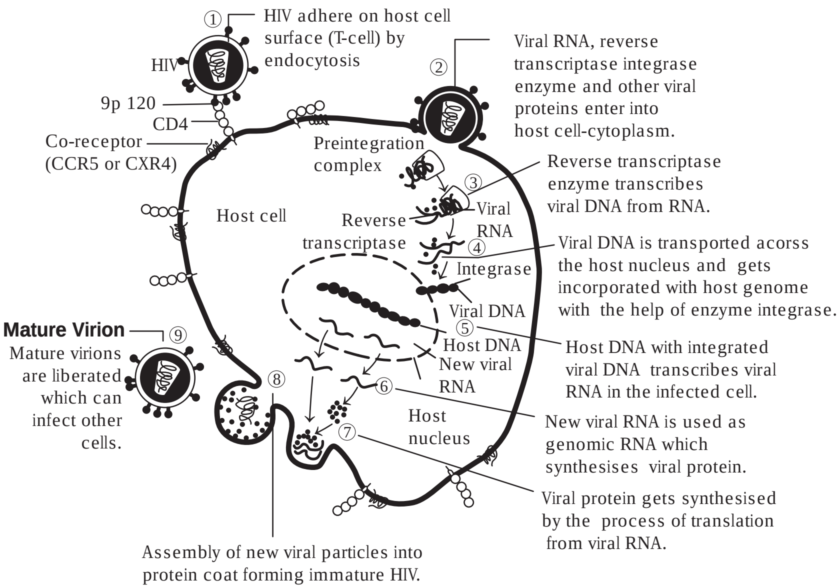
(i) Unprotected sexual intercourse.
(ii) Use of contaminated needles or syringe.
(iii) Use of contaminated razors.
(iv) Transfusion of infected blood.
(v) Artificial insemination.
(vi) Prenatal transmission from mother to baby.

HIV is found in blood and semen, but it is not transmitted through

(i) Mosquito bites.
(ii) Shaking hands with AIDS patients.
(iii) Sharing meals towels and toilets.
(iv) Hugging or dry kissing with patients.

Mechanism of HIV Infection

Mechanism of HIV infection can be described diagrammatically as follows



Steps in HIV infections

Incubation period It ranges from 6 months to 10 years. Average timing is 28 months.

Symptoms Chief symptoms include fever, lethargy, pharyngitis, nausea headache, rashes, etc.

Treatment Although, there is no cure for AIDS, it can be manifested in two major ways,

(i) **Antiviral therapy** Drugs against causative agent.

Azithmidine and **ribovirin** are the drugs, which seems to be promising against AIDS. **Zidovudine** or AZT was the first drug used for the treatment of AIDS. **Didanosine** (dideoxyionosine-DDI) is another drug employed to treat AIDS.

(ii) **Immunostimulative therapy** Increases the number of resistance providing cells in the body.

Prevention

Following steps may help in the prevention of AIDS as there is no vaccine against AIDS.

(i) Health education–people should be educated about AIDS transmission. **December 1st** is celebrated as World's AIDS Day to spread the information about AIDS.

(ii) Use of disposable needles and syringes.

(iii) Blood should be quarantined or screened before transfusion.

(iv) Use of sterilised equipments must be insisted, while getting dental treatment.

(v) In sexual relationship, one should be monogamous or safe sexual practices should be done.

(vi) Avoid use of common blades at barber's shop.

Cancer

It is defined as an uncontrolled proliferation of cells without any differentiation. It is a group of more than 200 different diseases, where malignant growth or enlargement of tissue occurs due to unlimited and uncontrolled mitotic division of certain cells and invades surrounding tissues, forming **tumours**. Simply, cancer can be defined as **mitosis run amok**.

Characteristics of Cancerous Cell

Following are the characteristics of cancerous cells

- Self-sufficiency in growth signaling.
- Insensitivity to antigrowth signals.
- Evasion of apoptosis.
- Limitless replicative potential.
- Induction and sustainment of angiogenesis.
- Activation of metastasis and invasion of tissue.

Types of Tumours

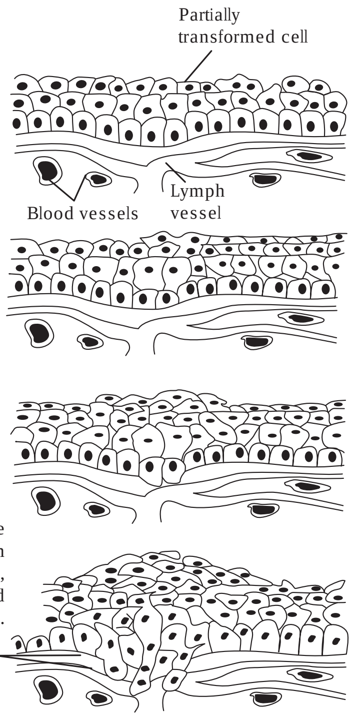
There are two types of tumours

(i) Benign Tumours or Non-Malignant Tumours

These remain confined to the site of its origin, do not spread to other parts of body, grow slow and cause limited damage to the body. It is non-cancerous.

(ii) **Malignant Tumour or Cancerous Tumour**

It contains cancerous cells which break away from their site and can spread to the other part of the body through the blood stream and lymphatic system by the process called metastasis. It grows fast.



1. An epithelial cell becomes partially formed.

2. This cell multiplies forming a mass of dysplastic cells

3. These dysplastic cells grow rapidly, forming a localised cancerous tumour.

4. The cancer cells secrete chemicals that allow them access to other tissues, the lymphatic system and the bloodstream.

Cancer cell secretions

Cancer growth and metastasis

Cancers grow by cell division. Cells can break free from the tumour and lymphatic systems to other parts of the body, where they establish secondary tumours. Secondary tumours often develop in the liver, lungs and lymph nodes.

Types of Cancer

On the basis of its origin, cancer is of following types

Cancer

Leukaemia
Caused due to the excessive WBCs formation in bone marrow and lymphatic nodes. Includes gilomas (cancer of glial cells), melanomas (cancer of pigment cells), etc.

Sarcoma
Cancer of lymphoid tissues (lymphoma), connective tissue (fibrosarcoma, chondrosarcoma), and muscles (leiomyosarcoma in smooth muscles and rhabdomyosarcoma in stripped muscles).

Carcinoma
Cancer of epithelial cells (squamous carcinoma), and glandular tissues (adenocarcinoma). Includes lung cancer, breast cancer, etc.

Theories Related to Causes of Cancer

(i) Mutation Theory

This theory explains that the accumulation of mutation over years may produce cancer.

(ii) Selective Gene Activation Theory

This theory explains that certain genes that are not normally expressed, suddenly become active and their product causes cancer.

Oncogenes that functions normally are called **proto-oncogenes** or **cellular oncogenes** (C-onc), which under normal conditions, code for protein that are necessary for cell growth.

Mutation in proto-oncogene changes its activity and they loose the control on growth and division and continuously divide giving rise to a mass of cells called tumours.

Carcinogens are the agents that cause cancer. They can be physical, chemical or biological.

Different carcinogens are as follows

Carcinogens

Physical Carcinogens
They include ionising (X-ray, γ-ray) and non-ionising (UV) radiations.

Chemical Carcinogens
Include caffeine, nicotine, pesticides, combustion products of coal and petrol.

Biological Carcinogens
Include viruses like HPV causing cervical cancer, epstein-barr virus causing Burkitt's lymphoma.

Cancer Detection and Diagnosis

Successful treatment of cancer requires early detection of the disease. Histopathological studies of the tissue and blood, bone marrow tests for increased cell counts and biopsy are the methods for detecting cancer. Besides these radiography, Computed Tomography (CT) (generates 3-D image of internal organs by using X-rays) and Magnetic Resonance Imaging (MRI) are used to detect cancer of internal organs.

Treatment of Cancer

Surgery, radiation therapy, chemotherapy are the common treatments of cancer.

1. **Radiation Therapy** Exposure of cancerous parts to X-rays, which destroy rapidly growing cells. Radioisotopes like Radon (Rn-220), cobalt (Co-60) and iodine (I-131) are used in it.
2. **Immunotherapy** It involves natural anticancer immunological defence mechanism. Monoclonal antibodies are used in it, **e.g.,** radioimmunotherapy.
3. **Chemotherapy** Involves the administration of certain anticancer drugs, which check cell division. These drugs have side effects like hair loss, anaemia, etc. Patients are given substances called biological response modifiers (**e.g.,** interferon), which activate immune system and destroy tumour.

Drugs

These are the chemicals used in the diagnosis, prevention, treatment and cure of diseases. They change the working style of the body. These are also called **addictive substances** or **habituating substances**.

World Health Organisation (WHO) **defines drugs as follows**

'Drug is any substance or product that is used or is intended to be used to modify or explore physiological systems or pathological states for the benefit of the recipient'.

Drugs can be classified into two major categories as follows

(i) **Psychotropic drugs** Mood altering drugs, affect behaviour and mental activity of a person.

(ii) **Psychedelic drugs** Hallucinogens, produce dream like state with deorientation and loss of true sensory stimulus. They often make users of **see sound** and **hear colour**. These are also called **vision producing drugs** as they produce false imagination.

Psychotropic Drugs

These are classified into four major categories, **i.e.,** tranquillisers, sedative and hypnotics, opiate narcotics and stimulants.

Psychotropic Drugs

Tranquillizers
Decrease tension and anxiety, produce feeling of calmness without inducing sleep.

- **Phenothiazines**
  Major tranquillizers, antipsychotic, reduce aggressiveness, e.g., reserpine, chlorpromazine, etc.
- **Benzodiazepines**
  Minor tranquillizers, antianxiety drug, reduces sleep, e.g. valium, flur zepam, etc.

Sedative and Hypnotics
Reduce excitement, induce sleep, depress CNS.

- **Barbiturates**
  General depressants, reduce anxiety, known as sleeping pills, e.g., phenobarbitone, mephobarbitone, etc.
- **Benzodiazepines**
  Antianxiety as well as sedative.

Opiate Narcotics
Derived from opium, relieve pain (analgesic).

- **Morphine**
  Principal opium alkaloid, strong analgesic, depresses respiratory centre, results in constipation, causes addiction.
- **Codeine**
  It is methyl-opium, mild analgesic, does not cause addiction, used in cough syrups.
- **Smack**
  Crude byproduct of heroin, known as **brown sugar**, stronger analgesic than heroin.
- **Pethidine**
  Sedative and euphoriant, causes less histamine release, local anaesthetic action, also called meperidine, safer in asthmatics.
- **Heroin**
  It is dimorphine or diacetylmorphine, three times more potent than morphine, depressant and dangerous opiate, induces drowsiness and lethargy.

Stimulants
Stimulate nervous system, make the person alert and active.

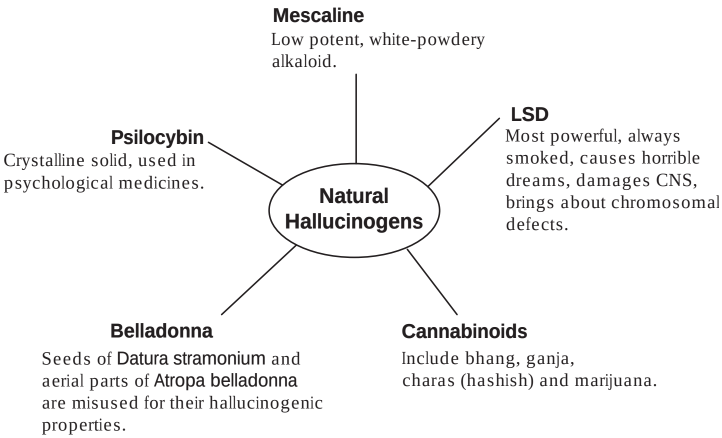
- **Caffeine**
  It is 1, 3, 7 trimethylxanthine, white crystalline bitter alkaloid, CNS stimulant, increases Basal Metabolic Rate (BMR), inhibits the release of histamine.
- **Crack**
  Derivative of cocaine, causes mental and heart problems.
- **Betal Nut**
  Mild CNS stimulant, stains teeth, contains alkaloid arecoline and a red tannin.
- **Amphetamines**
  Synthetic drug, also called pep-pills, CNS stimulant, causes wakefulness, used in dope-test for athletes.
- **Cocaine**
  Natural coca-alkaloid, commonly called coke, posseses vasoconstrictor properties, powerful CNS stimulant, delays fatigue.

Psychedelic Drugs

They are broadly classified into two groups

(i) Natural Hallucinogens

They include Lysergic acid Diethylamine (LSD), mescaline, psilocybin, cannabinoids and belladonna (**Datura**).



(ii) Synthetic Hallucinogens

They include Phencyclidine Piperidine (PCP) and Methylenedioxy Methamphetamine (MDMA).

(a) **PCP** (Phencyclidine Piperidine) It is widely used in veterinary medicine to briefly immobilise large animals. It is available to addicts as angel dust (white granular powder).

It has stimulant, depressant, hallucinogenic and analgesic properties. Higher dose of PCP may produce hypersalivation, vomiting, fever and even coma.

(b) **Methylenedioxy Methamphetamine** (MDMA) It has CNS-excitant and hallucinogenic properties. It has become popular in students under the name ‘ecstasy’ drug.

Some Drug Yielding Plants

Common Name	Botanical Name	Parts of the Plant from which the Product is Obtained	Product Obtained
Hemp plant	**Cannabis sativa** or **Cannabis indica** (cannabinoid)	Leaves and flowers	Hallucinogenic products Bhang from fresh/dried leaves and flowering shoots of both male and female plants. Ganja from unfertilised female inflorescence. Charas from flowering tops of generally female plants. Marijuana from dried flowering plants.
Poppy plant (opium poppy)	**Papaver somniferum**	Unripe capsules (fruits)	Opium (afeem) and its derivatives, (**e.g.,** morphine, codeine, heroin, pethidine and methadone.)
Ergot fungus	**Claviceps purpurea**	Fruiting bodies	LSD
Mexican mushroom	**Psilocybe mexicana**	Fruiting bodies	Psilocybin (Psilocybine)
Tea plant (a shrub)	**Thea sinensis**	Dried leaves	Tea
Coffee plant	**Coffea arabica**	Dried seeds	Coffee
Cocoa plant	**Theobroma cacao**	Dried seeds	Cocoa
Coca plant (cocaine plant)	**Erythroxylon coca**	Leaves and young twigs	Cocaine (Commonly called coke and crack)
Spineless cactus (peyote cactus)	**Lophophora williamsii**	Dried tops (called mescals)	Mescalin (mescaline)

Addiction

It is the continued repetition of a behaviour despite of its adverse consequences. Addiction to any substance is a disease and is difficult to beat.

Drug/Alcohol Addiction (or Abuse)

It is the state of periodic or chronic intoxication or dependency of a person on the regular consumption of drugs and alcohol either in low or high concentration.

Reasons of Drug/Alcohol Addiction

There are various reasons causing drug/alcohol addiction. **They include**

(i) **Peer pressure** If friends describe about the good feeling of alcohol or drugs, such inspiration from peer groups acts as a pressure to start with the drugs.

(ii) **Frustation or depression** People start taking drugs or alcohol to get solace or relief from personal problems

(iii) **Family history** Examples of parents or members of the family using these substances act as the natural stimulant.

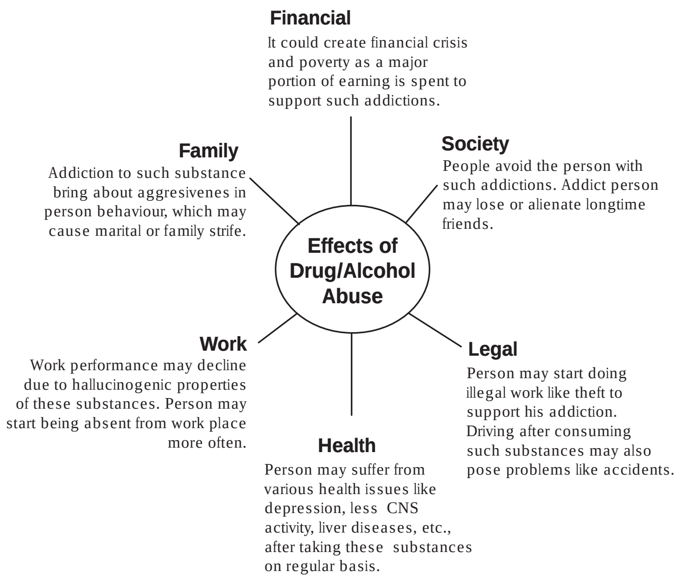
(iv) **Desire to do more physical or mental work** Some people think that the use of such substances provide them mental relief and increase their working power.

(v) **Apathy** Lack of interest in day to day activities of an individual may lead to such addictions.

(vi) **Excitement or adventure** Young blood look for some exciting work and these addictive substances attract them for such tasks.

Effects of Drug/Alcohol Abuse

Drug/alcohol addiction is a sign of disgrace in society. The addicts are not liked by friends, colleagues and family.



Effects of drug/alcohol abuse

Withdrawal Symptoms Include anxiety, nervousness, irritability, depression, insomnia, dryness of throat, disturbed bowels, lack of concentration, increased appetite and craving for tobacco.

De-addiction

Addiction to drugs or alcohol vary widely according to the types of drugs involved, amount of drugs or alcohol used, duration of the drug alcohol addiction, medical complications and the social needs of the individual.

The following four ways can cure the drug/alcohol addicts

(i) Addiction treatment is a methodical and slow process, **e.g.,** if an addict is used to smoke fifteen cigarettes a day, make sure that he/she reduces three cigarettes by the end of the month. This is because his body would not be able to bear the strain of more cigarettes. This may lead to serious complications.

(ii) Addiction rehabilitation centre can provide a temporary relief to the addicts problems.

(iii) De-addiction help can be provided through the means of friends and family members. Active interest in de-addiction process can help the addict tremendously by means of counselling.

(iv) There are many natural therapies available to cure the patient. These therapies are permanent. These therapies work well in the mindset of an addict. Once the patient's mindset is changed, he can take control of his life without any external assistance.

Adolescence

World Health Organisation (WHO) defines adolescence as the period of life between 12 and 19 yrs of age. It is the formative period of both physical and psychological health and is the preparatory phase for the adult life. That's why a healthy adolescence is a critical juncture for a healthy adulthood.

Characteristics of Adolescence

- **Imaginary Audience** False belief in adolescents that other are intensely interested in their appearance and judge their every move.
- **Metacognition** Also called introspection. It is the capacity to reflect on our own thoughts and behaviour.
- **Egocentrism** Lack of differentiation between some aspects of self and other, unpleasant behaviours.
- **Personal Fables** Belief in adolescents that they are highly special and destined to live a heroic or legendary life.

Adolescence and Drug/Alcohol Abuse

It is accompanied by several biological and behavioural changes.

Curiosity, need for adventure and excitement and experimentation may constitute the common causes, which motivate adolescents to start taking drugs and alcohol.

Other causes include peer pressure, family history, media, etc.

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Strategies for Enhancement in Food Production

According to the theory given by **TR Malthus**, the world's population is increasing geometrically, **i.e.,** 2, 4, 8, so on. As the cropping area is not increasing significantly, the search for alternate food resources and strategies for enhancement in food production plays an important role.

The advanced techniques in **animal husbandry** and **plant breeding** play an important role in enhanced food production. Several methods of enhanced food production and their detailed descriptions are given here.

Animal Husbandry

It is the science of rearing, caring, feeding, breed improvement and utilisation of domesticated animals. It deals with the raising of livestock, poultry farming, fisheries, sericulture, apiculture and lac culture. The animals used for transport, milk, meat and agriculture are collectively called **livestock**.

Despite having large portion of livestock population, India contributes only 25% of world's farm produce, it means that the productivity per unit area is very low.

Management of Farms and Farm Animals

In farm management, we deal with the processes and systems that increase the yield and improve the quality of products.

Better yield primarily depends upon the quality of breed in the farm. For the yield, potential have to be realised and the farm animals have to be well-looked after. **Following things should be kept in mind for proper farm management**.

- Farm animals should be housed well.
- They should have proper, scientific diet.
- Farm animals must avail adequate water.
- They should be maintained disease-free.
- Proper maintenance of hygiene and sanitation.

Even after ensuring above measures, a farm should be inspected in regular intervals and the record keeping of these inspections should be maintained.

Livestock

The term 'livestock' is used for domesticated animals and it is a part of modern agriculture. **On the basis of utilities, livestock can be categorised into**

(a) **Milk yielding animals** Cows, buffaloes and goats provide us milk, which are used to obtain animal protein and serve as a perfect natural diet.

(b) **Meat and egg yielding animals** Sheep, goat, pigs, ducks and fowls provide us meat and eggs.

(c) **Animals utilised as motive power** Buffaloes, horses, donkeys, bullocks, camels and elephants are used in transport and ploughing the fields.

(d) **Wool giving animals** Sheep are reared for obtaining wool from their hide.

(e) **Miscellaneous uses** The hides of cattle are used for making a variety of leather goods.

Examples of Some Domesticated Animals

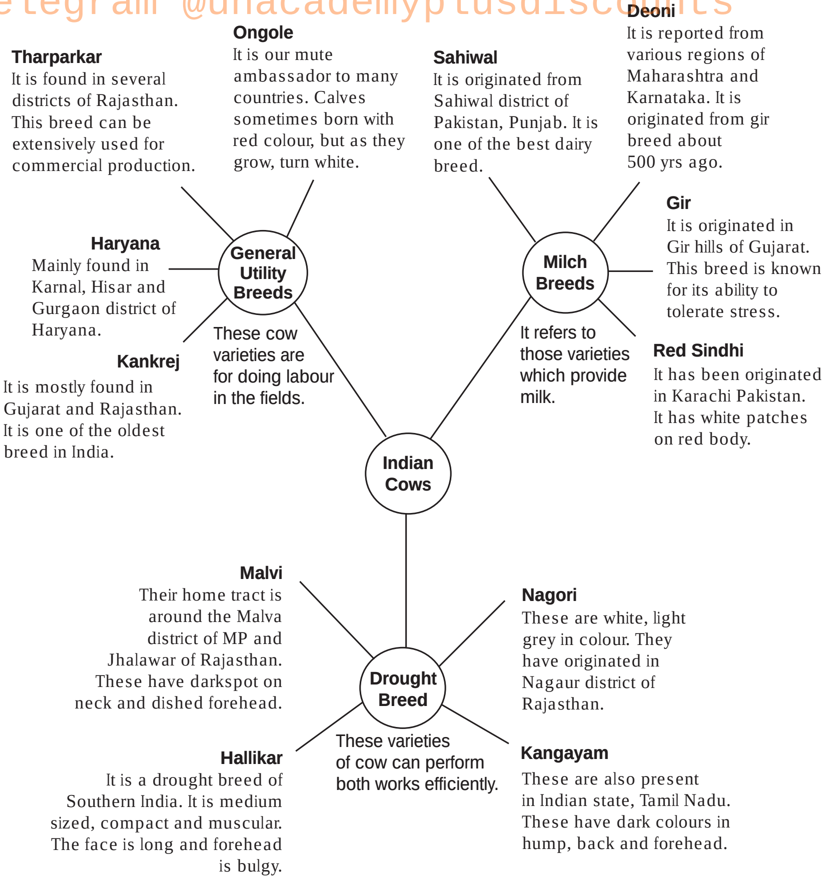
Here, several animals of livestock category are described with their detailed descriptions here.

Cow or Zebu (Bos indicus)

It is sometimes known as **humped cattle**. Cow (**Bos indicus**) is one of the most important milk yielding cattle in the country.

The castrated male cows, **i.e.** bullocks are used in **farm practices** and **drawing carts**.

The important Indian breeds and their related aspects are as follows

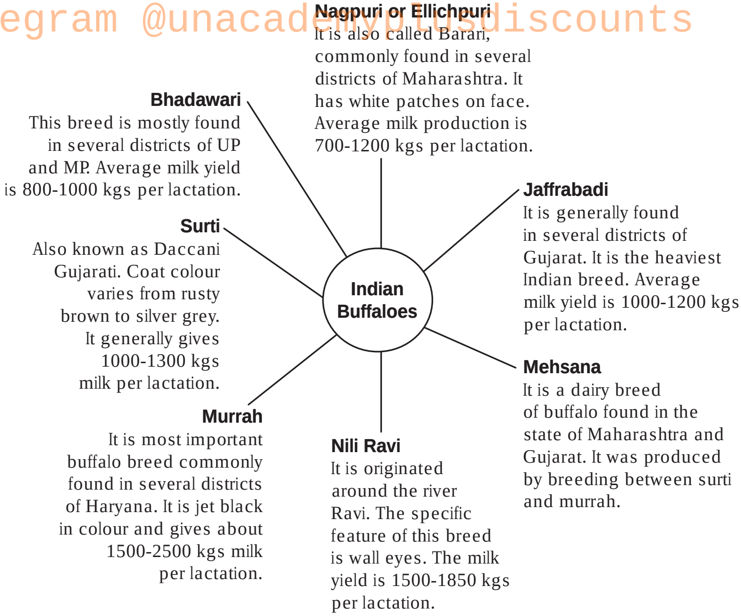


Various cow varieties in India

Buffalo (Bubalus bubalis)

Indian buffalo is a major cattle raised for milk production. 26 breeds of buffalo are found in India.

The important Indian breeds are



Various buffalo varieties in India

Horse (Equus caballus)

It is the first beast of burden. Physically, it is firm footed, strong, fast runner, intelligent and barns easily. Breeds of Indian horses and the regions in which, **they are found is shown in the following table**

Breeds of Indian Horses

Name	Regions
Manipuri	North-Eastern mountains
Marwari	Rajasthan
Zanskari	Ladakh
Kathiawari	Rajasthan and Gujarat
Bhutia	Punjab and Bhutan
Spiti	Himachal Pradesh

Sheep (Ovis aries)

It is reared for wool and mutton. It is herbivorous in nature and feeds on farm-waste, oil cake and other cattle feeds.

Important Indian sheep breeds are as follows

Breeds of Indian Sheep

Breed	Distribution	Uses
Bhakarwal	Jammu and Kashmir	Undercoat used for high quality woollen shawls
Lohi	Punjab, Rajasthan	Good quality wool, milk
Deccani	Karnataka	Mutton, no wool
Rampur-Bushair	Uttar Pradesh, Himachal Pradesh	Brown-coloured wool
Marwari	Gujarat	Coarse wool
Nali	Haryana, Punjab, Rajasthan	Superior carpet wool
Patanwad	Gujarat	Wool for army hosiery
Nellore	Maharashtra	Mutton, no wool

Camel

It is mostly used in deserts and commonly known as 'ship of deserts'. Its main uses are transport, ploughing and drawing water, etc. Some of the species of camels are **Camelus dromdarius** (Arabian camel), **Camelus ferus** (Bactrian camel), etc.

Improvement of Animals through Breeding

Scientific methods are used for the improvement of animals, **some of these scientific methods are as fallows**

Breeding

Breeding is the cross between animals of two breeds (**i.e.,** a group of animals related by descent and similar in most characters).

It can be sub-categorised as

Breeding

Inbreeding

It is the mating of closely related individuals for 4-6 generations. Increasing homozygosity leads to the loss of variation and stabilisation of pureline. Continued inbreeding results into the loss of productivity i.e., inbreeding depression.

Outbreeding

The mating between two unrelated individuals.

Outcrossing

It is mating between unrelated **members of same breed, but have no common ancestors in 4-6 generations.** The resultant individual is known as outcross.

Cross Breeding

It refers to the cross of superior male of one breed with superior female of another breed, e.g., Bikaneri (ewes) X Merino (rams) Hisardale (sheep).

Interspecific Hybridisation

It refers to the crossing between male and female animals of two different species, e.g., Mule and Hinny.

Advanced Methods of Breeding

There are three following advanced methods of breeding

(i) **Artificial Insemination** (AI)

It is a method of controlled breeding in which semen from the selected male parent is injected into the reproductive tract of selected female parent.

Advantages of artificial insemination are

(a) Semen collected can be frozen for later use.
(b) Semen collected can be transported in frozen form.
(c) Help us to overcome several problems of normal mating.

(ii) **Multiple Ovulation Embryo Transfer Technology** (MOET)

It is a programme for herd improvement in animals like cattle, sheep, etc. In this method, the hormones like FSH activity are injected into female to promote super ovulation which can be fertilised by either superior male or artificial insemination. The fertilised egg of 8-32 cells can be transferred to receptive **surrogate mothers**.

(iii) **Transgenesis**

It involves the transfer of gene into special cell or embryos. In this case, the unfertilised egg is enucleated by treating it with **cytochalasin-B** and the blastula stage nuclei are obtained from embryo donor.

Livestock Diseases

There are several infectious diseases that commonly affect the livestock animals. Some of these are listed in the table below

Disease	Pathogen	Affected Livestock
Foot mouth disease	Virus (RNA Amphthovirus)	Cattles-sheep, goat, pigs
Rinderpest (cattle plaque)	Rinderpest virus	Cattle-buffaloes, sheep, goat
Cowpox	Cowpox virus	Cows (and even humans)
Anthrax (splenic fever)	Bacillus anthracis	Cattle-camel, sheep, goat
Pneumonia	Streptococcus/Diplococcus pneumoniae	Cattles
Mastitis	Corynebacterium pyogenes	Cattles
Tick fever	Babesia bigemina	Cattles-buffaloes
Coccidiosis	Eimeria, Isospora	Poultry, cattle-sheep, swine
Ascariasis	Ascaris	Cattle-pig, sheep
Fascioliasis (liver rot)	Fasciola hepatica, Fasciola gigantica	Cattle-sheep, goat.

Pisciculture/Fish Farming/Culture Fishery

It can be defined as

'The scientific rearing and management of fishes in water bodies under controlled conditions'. It is established to capture, preserve, exploit and utilises various types of fishes, prawns, lobsters, crabs, oysters, other molluscs, etc.

Fishery can be categorised into

Fishery

- **On the basis of products**
  - **Fin Fishery** It is the culture and management of cartilaginous and bonyfishes.
  - **Shell Fishery** It is the culture and production of crustaceans and molluscs.
- **On the basis of mode of obtaining fishes**
  - **Capture Fishery** The fish is caught from natural water, both marine and inland.
  - **Culture Fishery** Growing various types of aquatic organisms in water bodies is called culture fishery.
- **On the basis of water source of fish production**
  - **Marine Fishery** This includes capture fisheries in ocean and seas.
  - **Freshwater Fishery** Fish culture in river, canal, lakes, resevoir, tank, ponds, and paddy fields.
  - **Brackish Water Fishery** Fish culture in slightly salty habitat as estuary.

Steps used in Pisciculture

The following steps are used in fish farming or pisciculture

Breeding ⟶ It is first step of pisciculture and divided into two types, i.e.,
Natural breeding Fishes allowed to breed naturally and eggs collected manually.
Induced breeding The sperm and ova collected separately to allow desired fusion.

↓

Hatching ⟶ **Fertilised eggs** are kept in hatching pits. After few days small (4-5 mm), fish fries originate.

↓

Nursery Ponds ⟶ **Fish fries** transferred to ponds contain natural zooplankton and phytoplankton. Fish fries live here for 15-30 days, to grow into **fingerlings**.

↓

Rearing Ponds ⟶ Fingerlings transferred in large tanks for 2-3 months, untill they attain size of about 20 cm.

↓

Stocking Ponds ⟶ Now, these fishes are transferred in large ponds till maturity.

↓

Harvesting ⟶ The big sized fishes are captured for marketing and smaller one again released into stocking ponds.

Fishes are used as food, in controlling diseases and in the production of fish oils (cod-liver oil is rich in vitamin-A and D), fish manure (bones of fishes), fish glue, shagreen (sharp placoid scales of shark used for polishing), leather (skin of sharks) and artificial pearl.

Poultry

The term Poultry refers to rearing of fowl, geese, ducks, turkeys and some variety of pigeons, but more often it is used for fowl rearing. Fowls are reared for food or for their eggs.

- Poultry birds reared for meat are called **broilers**.
- Female fowls raised for egg production are called **layers.**
- **Cockerel** is a young male fowl and **rooster** is mature male fowl.

The hens normally start laying eggs from February and continue till August. The average production by an Indian breed is about 60 eggs per annum.

Poultry Feed

It includes bajra, jowar, barley, maize, wheat, rice bran, oil-cake, fish meal, bread, green residue of vegetables, salt, vitamins and minerals. Now-a-days, readymade poultry feed is also available in the market.

Poultry Products

The fowls are reared to obtain following useful products for human

(i) **Eggs** These are the rich source of easily digestable animal protein. These are the good sources of calcium, protein, iron, vitamins and a moderate amount of fat. Each egg consists of shell and shell membranes (12%), albumin and chalaza (56%) and yolk (32%).

(ii) **Poultry Meat** It is a good source of nutrition for non-vegetarians.

(iii) **Feathers** They are used for the commercial purposes such as for making pillows and quilts.

(iv) **Manure** It is obtained from excreta of poultry birds and is highly valuable for field crops.

Some indigenous breeds of fowls include

- **Assel** (best table bird) It has high endurance and fighting qualities.
- **Chittagong or Malay** It grows faster and have good taste.
- **Ghagus** Big and hardy breed found in South India.
- **Bustra** It is minor breed found in Gujarat and Maharashtra.

Large increase in the egg production in India has been named as **silver revolution**.

Apiculture/Bee-Farming

'Apiculture is the rearing, management and care of honeybees for the obtaining honey, wax and other substances'.

For apiculture large places called **apiaries** or **bee farms** are established scientifically.

The Khadi and Village Industries Commission (KVIC) and the Indian Council of Agricultural Research (ICAR) are making efforts to raise the commercial production of honeybees products.

Species of Honeybees

Four species of honeybees are reported in different parts of India, **which are as follows**

(i) *Apis florea* F. (Little bee) Docile bee rarely stings and can be easily used for honey extraction.

(ii) *Apis indica* F. (Indian bee) It can be easily domesticated and is most commonly used for the honey production. Therefore, it is reared in artificial hives.

(iii) *Apis dorsata* F. (Rock bee) It is a giant bee and yields maximum honey.

(iv) *Apis mellifera* F. (European bee) Best species from commercial point of view.

Products Obtained from Apiculture

Products of Apiculture

Beeswax
It is yellowish or greyish brown-coloured waxy substance. It is completely insoluble in water, but completely soluble in organic solvents as ether. It is secreted by wax glands of worker bees.

Honey
It is white to black in colour and sweet in taste. Its pH is 3.9. It is good blood purifier and curative for ulcers on tongue and alimentary canal.
Chemical composition of honey is
(a) Ash 1.00%
(b) Enzyme and pigments 2.21%
(c) Maltose and other sugar 8.81%
(d) Water 17.20%
(e) Dextrose 21.28%
(f) Levulose 38.90%
(g) Iron, calcium and sodium

Propolis
Propolis and balm are other substances. They are used in repairing and fastening of combs.

Bee venom
It is used in various ayurvedic medicines used for arthritis and snake bites.

Colony and Castes/Social Organisation of Honeybees

Honeybees are social and polymorphic insects, live in highly organised colonies. An ordinary colony has about 40-50 thousand individuals, **consisting of three** main types.

1. Queen

The queen is large-sized bee, responsible for laying eggs. She lays up to 2000 eggs everyday of each season. Queen lays both fertilised (2**n**) and unfertilised (**n**) egg. The workers and queen originate from fertilised egg, while drones originate from unfertilised egg.

2. Drone

It is haploid fertile male. Drones are larger than workers and are quite noisy. They fail to collect food, but eat voraciously. These are stingless and their main role is to mate with queen.

3. Workers

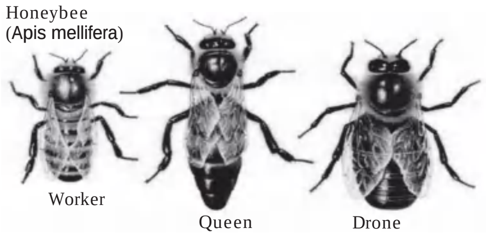
These are diploid, sterile female. Their size is the smallest among all castes.

Total indoor and outdoor activities are performed by workers only. **For this purpose, they have been provided with some specific features such as**

(a) They have a powerful sting for defence.
(b) They have long proboscis for sucking the nectar.
(c) They have strong wings for fanning.
(d) For collection of pollens, they have pollen baskets.
(e) They have four pairs of pocket like **wax** secreting glands on ventral surface of second to fifth abdominal segment.

Workers live for 3-12 months. The function of workers changes with age. During first half of their life-they remain engaged in indoor duties as scavangers, nurse bees, fanner bees and guard bees.

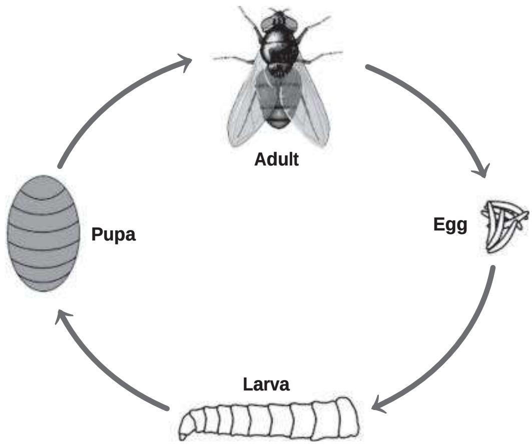
During the second half of their life**,** they perform outside duties as scout bees and forager bees.



Colony members of honeybees

Life Cycle of Honeybees

The life cycle of honeybees have 4 prominent stages. The eggs layed by queen hatches into larva within 24 hrs of formation. The larvagets metamorphosed into pupa which later matures into adult bee. **The diagrammatic representation of life cycle of honeybee is as follows**



Life cycle of honeybees

Sericulture

It is the production of raw silk on commercial scale by rearing practice of the silkworm.

Silk

It is a pasty secretion of caterpillar of silkworm during cocoon formation. It is secreted from the salivary glands of silkworms.

Silk is composed of following two types of proteins

(i) **Fibroin** Constitutes 80% of the silk thread.

(ii) **Sericin** Constitutes 20% of the silk thread.

Four types of silk are produced in India. These are **mulberry silk** (contributes about 91.7%), **eri silk** (contributes about 6.4%), **tasar silk** (contributes about 1.4%) and **muga silk** (contributes about 0.5%).

Species of Silkworm

Some species of silkworm are as follows

(i) **Mulberry silkworm (Bombyx mori)** It belongs to family–Bombycidae, native to China, but now it has been introduced in different countries.

(ii) **Tasar silkworm (Antheraea paphia)** It is found in China, India and Sri Lanka. Caterpillars of this silkworm feed on oak, sal, ber and fig plants. It belongs to the family–Saturniidae.

(iii) **Muga silkworm** (**Antheraea assama**) Native to Asom (India), and it belongs to family–Saturniidae. Caterpillars feed on **Machilus** and **Cinnamon** plants. Silk produced by this moth is known as muga silk.

(iv) **Eri silkworm** (**Attacus ricinii**) It feeds on castor leaf and belongs to family–Saturniidae. Life history of this worm resembles with that of mulberry worm.

(v) **Oak silkworm** (**Antheraea pernyi**) Oak silkworm is found in Japan and China and feeds on oak plant. It also belongs to the family–Saturniidae.

(vi) **Giant silkworm (Attacus altas)** This worm is found in India and Malaysia and is the largest of living insects.

Process of Sericulture

The sericulture includes following steps

Stifling It is the killing of cocoons through hot water, dry heat, sun exposure (3 days) and fumigation.

↓

Reeling It means removal of silk threads from the killed cocoons. The removed silk is called raw silk.

↓

Spinning Twisting of several threads of raw silk to get fibre silk is called spinning.

Lac Culture

The lac is obtained from the **Indian lac insect Laccifer lacca** (**Tachardia lacca**).

The lac insect feeds on the sap of the host tree (palash).

Chemical Composition of Lac

It contains large amount of resins, sugar, water and other alkaline substances.

Resin	68 to 90%
Dye	2 to 10%
Wax	6%
Albuminous matter	5 to 10%
Mineral matter	3 to 7%
Water	3%

Shell lac is used in the preparation of varnishes, paints and polishes and is also used in making gramophone records, printing ink, buttons and pots and in filling ornaments such as bangles and bracelets. It is also used as insulating material.

Plant Breeding

It is purposeful manipulation of plant species in order to create desired plant types that are better suited for cultivation, give better yield and are disease resistant. Plant breeding programmes are carried out in systematic way worldwide.

The main steps in breeding a new genetic variety of a crop are

Collection of variability ↓	For effective exploitation of natural genes available in the population, the collection and preservation of all the different wild varieties, species and relatives of the cultivated species is done. The collection is called germplasm collection.
Evaluation and selection of parents ↓	The germplasm is evaluated to identify the parent with desirable characters, which is further used in the process of fertilisation.
Cross hybridisation among the selected parents ↓	The set of different desired characters can be combined through hybridising these parents. It is very time consuming and tedious process. One among several progeny individual is true hybrid.
Screening and testing of superior recombinants ↓	It is the process of selection of hybrid with desired character combination. It is crucial process and requires careful scientific evaluation of the progeny.
Testing, release and commercialisation of new cultivers.	The newly selected variety is evaluated on the basis of various performance parameters in varied conditions. Later, these are released as the product in market for commercial purpose.

Mutation Breeding

When mutations are artificially induced in a crop for crop improvement, it is known as mutation breeding. Mutations can be artificially induced by certain agents called **mutagens**, **e.g.,** X-rays, β-rays, γ-rays, UV-rays, nitrous acid, maleic hydrazide, hydrazine, Methyl Methane Sulphonate (MMS), Ethyl Methane Sulphonate (EMS), etc.

Like Sharbati Sonora was produced from Sonora 64, some new crop varieties are also developed by mutation breeding **viz.** NP-386 (wheat), Jagannath (rice), Arunna (castor), Mu-7 and Indore 2 (cotton), Pusa Lal Meeruti (tomato), Primex (white mustard), etc.

Indian Hybrid Crops of High Yielding Varieties (HYVs)

With the development and advancement in the agricultural techniques during Green Revolution, several high yielding varieties of crops were introduced in India. It includes the semidwarf varieties of rice (**e.g.** Jaya and Ratna) and wheat; high yielding and disease resistant varieties of wheat (e.g. Sonalika and Kalyan Sona), etc.

Green Revolution

A series of research, development and technology transfer initiatives occurrring between the 1940s and the late 1970s that increased agriculture production worldwide is called **Green Revolution**. The initiatives led by **Norman E Borlaug**, the Father of Green Revolution is credited with saving over billion people from starvation.

This revolution is credited with the development of high yielding varieties and modernisation of management techniques, by the use of synthetic fertilisers and pesticides by the farmers.

Plant Breeding for Disease Resistance

Resistance of the host plant for diseases, is the ability to prevent the pathogens from causing diseases and is determined by the genetic constitution of the host plant.

The disease resistance can be developed in plants through conventional breeding technique or mutation breeding.

During conventional breeding technique, **the following steps take place**

1. Screening the germplasm for resistance resource.
2. Hybridisation of the selected parent.
3. Selection and evaluation of the hybrids.
4. Testing and release of new varieties.

The plant variety of various crops and their disease resistance is shown in the following table

Disease Resistant Varieties

Crop	Variety	Resistance to Diseases
Wheat	Himgiri	Leaf and stripe rust, hill bunt
Brassica	Pusa Swarnim (Karan rai)	White rust
Cauliflower	Pusa Shubhra, Pusa Snowball K-1	Black rot and Curl blight black rot
Cowpea	Pusa Komal	Bacterial blight
Chilli	Pusa Sadabahar	Chilly mosaic virus, tobacco mosaic vrius and leaf curl

Plant Breeding for Resistance Against Insect Pests

For the development of insect pest resistance, the similar steps are taken such as the collection of resistant gene from the cultivated or wild varieties and transfer of these genes to targeted host.

Some released crop varieties bred by hybridisation and selection for insect pest-resistance are given below

Insect Resistant Crops

Crop	Variety	Insect Pests
Brassica (rapeseed mustard)	Pusa Gaurav	Aphids
Flat bean	Pusa Sem 2, Pusa Sem 3	Jassids, aphids and fruit borer
Okra (Bhindi)	Pusa Sawani Pusa A-4	Shoot and fruit borer

Plant Breeding for Improved Food Quality

According to a survey, about 840 million people in the world do not have adequate food to meet their daily requirements. A far greater number, **i.e.,** about 3 billion people suffer from deficiency of micronutrients, vitamin and proteins. This deficiency is called **hidden hunger**. Diet lacking micronutrients increase the risk for diseases, reduced lifespan and mental disabilities.

Biofortification

The breeding methods have been used to produce crops with high levels of vitamins, proteins and minerals, to improve the public health. **Breeding for improved nutritional quality is undertaken with the objectives of improving**

(i) Protein content and quality
(ii) Oil content and quality
(iii) Vitamin content
(iv) Micronutrient and mineral content

In 2000, maize hybrids that had twice the amount of the amino acids, lysine and tryptophan, compared to existing maize hybrids were developed. Wheat variety **Atlas-66** having a high protein content has been used as a donor for improving cultivated wheat.

Single Cell Protein (SCP)

Conventional agricultural production of cereals, pulses, vegetables, fruits etc., may not be able to meet the demand of food with the rate at which human and animal population is increasing.

The shift from grain to meat diets also creates more demand for cereals as it takes 3-10 kg of grain to produce 1 kg of meat by animal farming. One of the alternate sources of proteins for animal and human nutrition is **Single Cell Protein** (SCP). Microbes are being grown on industrial scale as a source of good protein.

Microbes like **Spirulina** can be grown easily on materials like waste water from potato processing plants (containing starch), straw, molasses, animal manure and even sewage to produce large quantities and can serve as food rich in protein, minerals, fats, carbohydrate and vitamins.

Such utilisation also reduces environmental pollution. It has been estimated that in a day, 250 g of microorganisms like **Methylophilus methylotrophus,** because of its high rate of biomass production and growth can be expected to produce 25 tonnes of protein.

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Microbes in Human Welfare

A large variety of microorganisms constitute the major component of biological system, as they are present everywhere like soil, water, air, inside our bodies and of animals and plants.

The branch of science which deals with the study of different aspects of microorganisms is known as **microbiology** and **Louis Pasteur** is considered as **Father of Modern Microbiology**.

Various microorganisms can tolerate extreme conditions like **high salinity** (halophiles), **deep inside temperature** (thermophiles) and in **highly acidic atmosphere** (thermoacidophiles).

By infecting the living organisms, microorganisms cause serious diseases in plants, animals and humans. Thus, microorganisms affect human beings both directly and indirectly.

Many microorganisms are also very useful to human beings. We use several microbial products almost everyday.

The uses of microorganisms in various fields are discussed here

Microbes in Household Products

(Domestic Microbiology)

The microbes have been used to make several products such as curd, cheese, butter, vinegar, etc.

Some important products produced by microorganisms are mentioned below

Microorganism in Households

Vinegar
It is produced by fermentation process induced by *Acetobacter aceti*.

Curd
Lactic Acid Bacteria (LAB) grows in milk and converts it into curd.

Fibre Separation
Bacteria are used in separation of fibre such as flax, hemp and jute.

Dosa, Idli, Toddy
The dough and plant sap are used (after fermentation) in making these products.

Butter
The sweet and sour cream is churned in the presence of organisms like *Streptococcus lactis* and *Leuconostoc citrivorumare* to produce butter.

Cheese
It is a microbial product of milk. Various types of cheese are produced by several organisms.

Bread/Dough
Common yeast *Saccharomyces cerevisiae* is used as leavening agent in baking industry.

Household applications of microbes

Microbes in Industrial Products
(Industrial Microbiology)

Microorganisms such as bacteria, fungi, yeasts, etc., are now used in a wide range of industrial processes. The study of microorganisms in industrial production processes is known as **industrial microbiology**.

The microorganisms are usually cultured in large fermentation chambers called as **fermentors**, under controlled conditions.

Following are the products synthesised industrially through microbes

(i) **Antibiotics** These are chemical substances which are produced by microorganisms and can kill or inhibit the growth of other disease causing microorganisms.

A microorganism which produces antibiotic is called **antibiont**. The term '**antibiotic**' was first defined by **Waksmann** in 1942.

The first antibiotic was **penicillin** (wonder drug), isolated from **Penicillium notatum** (a mould), by **Alexander Fleming** in 1928.

Chief antibiotics and their source organisms are given in following table

Antibiotics and Their Source

Antibiotic	Source
Penicillin	**Penicillium notatum** and **P. chrysogenum**
Streptomycin	**Streptomyces griesus**
Erythromycin	**S. erythreus**
Viomycin	**S. floridae**
Chlorotetracycliin	**S. aurofaciens**
Terramycin	**S. rimosus**

(ii) **Alcohols** The most important alcohol, **i.e.,** ethanol or ethyl alcohol, (CH_3CH_2OH) is used as solvent, a germicide, a beverage, an antifreeze, a fuel, a depressant and is a versatile chemical intermediate for other chemicals.

The most widely used sugar for ethanol fermentation is **blackstrap molasses**, contains about 35-40% sucrose, 15-20% invert sugars such as glucose and fructose and 28-35% of non-sugar solids. The whole process of ethanol production can be summarised as follows

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + \text{Yeast} \rightarrow \underset{\text{Ethanol}}{2C_2H_5OH} + CO_2 + \text{Energy}$$

Several organisms like **yeast** (**i.e., Saccharomyces cerevisiae, S. uvarum**) and **bacteria** (**i.e., Clostridium sporogenes**, **C. indolis, C. sphenoides**, **Zygomonas mobilis** and **Leuconostoc mesentroides**, etc.) are involved in ethanol production, industrially.

(iii) **Nutritional supplements** Microorganisms are also used as a source of several nutritional supplements.

These are given in following table

Microbes as Food Supplements

Product	Microbe	Use (s)
Amino acids		
Glutamic acid	**Corynebacterium glutamicum**	Flavour enhancer (monosodium glutamate)
Lysine and methionine	**Brevibacterium flavum**	Cereal food supplement
Phenylalanine and aspartic acid	**Corynebacterium** sp. and **E.coli**	Ingredients of an artificial sweetener aspartame (nutrasweet)
Vitamins		
Vitamin-B_{12}	**Pseudomonas** sp.	Health supplement
Riboflavin (B_2)	**Ashbya gossypii**	Health supplement
Vitamin-C	**Acetobacter** sp.	Health supplement
Proteins	**Chlorella**, **Spirulina**	Food additive

(iv) **Organic acids** Several organic acids are produced by microorganisms.

Organic Acids Produced by Microorganisms

Citric Acid
It is first isolated in 1784 by **Carl Wilhelm Sheele** from lemon juice. Industrially, the fungus Aspergillus niger produces citric acid.

Lactic Acid
The first organic acid is produced by fermentation process. It is produced by Streptococcus lactis, Lactobacillus sp. and Rhizopus.

Kojic Acid
It is produced industrially by Aspergillus oryzae. It is used as **skin whitener** and **flavour enhancers**.

Acetic Acid (vinegar)
It is produced in two steps
(i) Conversion of sugar into alcohol by yeast.
(ii) Conversion of alcohol to acetic acid by bacteria, Acetobacter sp.

Gluconic Acid
It is produced industrially by Aspergillus niger. It is used in **metal cleaning** and therepy for calcium and iron deficiencies.

Some Other Organic Acids Synthesised by Various Microbes

Organic Acids	Microorganism
Propionic acid	**Propionibacterium**
Butyric acid	**Clostridium acetobutyricum**
Oxalic acid	**Aspergillus** sp.
Gallic acid	**Aspergillus niger**
Itaconic acid	**A. terreus**

(v) **Enzymes** Microbes synthesise large number of enzymes, which have significant economic importance. **Some of these enzymes are given in the following table with their source organisms and uses**

Enzyme Producing Microorganisms

Enzymes	Organisms	Uses
α-amylase	**Aspergillus** sp.	Laundry detergent
β-amylase	**Bacillus subtilis**	Brewing
Cellulase	**Trichoderma viride**	Fruit juices, coffee, paper
Invertase	**S. cerevisiae**	Sweet manufacture
Lactase	**S. fragilis**	Digestive aid, sweet manufacture
Oxidases	**Aspergillus niger**	Paper and fabric bleaching
Lipase	**A. niger**	Washing powders, leather tanning, cheese production
Pectinase	**A. niger**	Fruit juice
Proteases	**A. oryzae**	Meat tenderiser, leather tanning
Rennin (chymosin)	**Mucor** and **E. coli**	Cheese production

Microbes in Healthcare and Medicine
(Medical Microbiology)

Microbes are used to produce **insulin**, **growth hormones** and **antibodies**. They are also helpful in the treatment of diseases such as cancer. Research shows that Clostridia can selectively target cancer cells.

Various strains of non-pathogenic Clostridia have shown to infiltrate and replicate within solid tumours. Clostridia, therefore have the potential to deliver therapeutic proteins to tumours.

Lactobacillus species has therapeutic properties including **anti-inflammatory** and **anticancer** activities.

Serum and **vaccines** produced by various microorganisms are used to induce immunity among human beings.

The alkaloid released from **Claviceps purpurea** called ergotinine, stimulates the muscles of uterus and is used to assist childbirth and controls uterine haemorrhage.

Some Other Important Products of Microorganisms

Products	Microorganisms
Cyclosporin-A 11-membered cyclic oligopeptide, an immunosuppressive that inhibits activation of T-cell response to transplanted organs.	**Trichoderma polysporum** and **Tolypocladium inflatum**.
Statins Inhibitor of enzyme HMG Co-A reductase of liver, lowers LDL cholesterol level.	Yeast–**Monascus perpureus**.

Microbes as Biofertilisers and Biocontrol Agents (Agricultural Microbiology)

To protect the environment and control soil pollution, the biofertilisers and manures are used in modern agriculture, termed as **organic farming**.

Biofertilisers

These are the nutrient materials obtained from the living organisms or their remains, used for enhancing the fertility of soil.

Biofertilisers contain some organisms which can bring about nutrient availability to the crop plants.

The main sources of biofertilisers are

(i) Nitrogen-fixing bacteria (free-living and symbiotic)

(ii) Nitrogen-fixing cyanobacteria (free-living and symbiotic)

(iii) Mycorrhizal fungi

Note

- Natural processes fix about 190×10^{12} g per year of nitrogen through lightning (8%) photochemical reactions (2%) and biological nitrogen-fixation (90%). Biological nitrogen-fixation provides about 1,750 million tonnes of nitrogen, free of cost naturally in the form of biofertilisers.
- N_2 fertilisers are often not required for rice cultivation as the fern Azolla has Anabaena azollae as symbiont, which fixes N_2 and grows thickly into rice fields.

Nitrogen-fixation in plants with their symbiotic host is given in following table

Some Symbiotic Nitrogen-fixing Organisms

Host Plants	Nitrogen-fixing Symbionts
Leguminous Legumes and **Parasponia**	**Azorhizobium, Bradyrhizobium, Photorhizobium, Rhizobium** and **Sinorhizobium**
Actinorhizal **Alder** (tree), **Ceanothus** (shrub), **Casuarina** (tree) and **Datisca** (shrub)	**Frankia**
Gunnera	**Nostoc**
Azolla (water fern)	**Anabaena**
Sugarcane	**Acetobacter diazotrophs**

Biopesticides

Microorganisms such as bacteria, fungi, viruses, protozoan, etc., and their products are which used to control the pests are known as biopesticides.

These biopesticides can be of following types

Bacterial — **e.g., Bacillus thuringiensis**

Fungal — **e.g., Metarhizium**, **Beauveria** and **Verticillium**

Protozoan — **e.g., Schizogregrine**

Viral — **e.g.,** Nuclear Polyhedrosis Virus (NPV) and Granulosis Virus (GV).

Bioherbicides

These are the organisms and their products which destroy weeds without harming the useful plants. The first bioherbicide was a **mycoherbicide**, which was based on a fungus **Phytophthora palmivora**.

Bioherbicides can be categorised as

Bioherbicides

Smoother Crops
The crops which do not allow any weed to grow near by its vicinity (place) are called smoother crops. e.g., sweet clover, soya bean, alfalfa.

Predator Herbivore
In this, some insects like beetles, etc., are used to control weeds, e.g., Cactoblastis cactrorum and Chrysolina beetles.

Mycoherbicides
Devine and **collego** are fungal spores, which are sprayed over weeds to kill it.

Vegetables
Certain weeds, sush as Amaranthus and Chenopodium can be used as fodder or vegetable.

Transgenic Plants
Through the gene transfer, the resulted genetically engineered plants develop resistance against pests.

Bioinsecticides

Living organisms and their products used for insect control are called bioinsecticides. These include **pathogens /parasites** and **predators.**

Some important bioinsecticide are as follows

(i) **Sporeine** First commercial bioinsecticide obtained from **Bacillus thruingiensis**.

(ii) **Doom** It is the mixture of **Bacillus papillae** and **Bacillus lentiborbus**, which has been used to control Japanese beetles papillae.

(iii) **Ladybug** (lady bird beetle) and praying mantis can control scale insect or aphid pests of vegetables, cotton and apple.

(iv) **Vedalian Beetle** (**Radiola cardinalis**) has been found effective against cottony cushion scale (**Icerya purchasi**).

(v) **Mycar** is a product obtained from the fungus **Hirrutella thompsoni** and used to control citrus rust mite.

(vi) **Predator bug** (**Cystorhinus mundulus**) has been successfully used to control sugarcane leaf hopper in Hawaii.

(vii) **Bacillus sphaericus** is toxic to larva of **Anopheles** mosquito.

(viii) **Boverin** is obtained from a fungus **Beauveria bassiana** and used for controlling colorado potato beetle (**Leptinotarsa decemlineata**) and codling moth.

(ix) **The fungus Entomophthora ignobilis** may be used for controlling green peach aphid.

(x) **The fungus Coelomomyces** is useful to control mosquito larvae.

Some of the natural insecticides are listed below

Natural Insecticides and Their Sources

Natural insecticides	Sources
Rotenones	Roots of **Derris elliptica** and **Lonchocarpus**
Nicotine	From tobacco (**Nicotiana tabacum**)
Salanin, azadirachtin, meliantiol	From neem (**Azadirachta indica**)
Pyrethrin and cineria	From capitulum of pyrethrum (**Chrysanthemum cinerarifolium**, **C. coccineum** and **C. marashalli**)
Ryania	Roots and stem of **Ryania speciosa**

Microbes in Sewage Treatment
(Environmental Microbiology)

Municipal waste water is called sewage. It contains large amount of organic matter and microbes. Treatment of waste water is done by the **heterotrophic microbes** which are naturally present in the sewage.

The treatment of sewage is carried out in following two stages

1. Primary Treatment

In involves the **physical removal of large and small particles** from the sewage through **filtration** and **sedimentation**.

2. Secondary or Biological Treatment

The primary effluent is aerated in large tanks. Through this aeration, the Biological Oxygen Demand (BOD) of water increases (dissolved oxygen levels got decreased by growing microbes).

Microbes in Biofuels

Biofuels are fuel of biological origin which are used for the production of heat and other forms of energy. The energy derived from biofuels is called **bioenergy**.

The biofuels offer following advantages

(i) These are renewable energy resources.

(ii) They release relatively low greenhouse gases including carbon dioxide emission than fossil fuels.

(iii) The raw materials used in biofuel production are often wastes, including municipal waste. Therefore, it helps in pollution control.

Various biofuels, their substrate and microorganisms from which they are produced are given in following table

Biofuels and Related Microorganisms

Biofuels	Substrate	Microorganisms
Bioethanol	Starch, sugar crops	**Bacillus licheniformis** (amylase activity)
	Cellulosic wastes	**Saccharomyces cerevisiae**, **Zymomonas** (sugar fermentation)
	(a) Enzyme hydrolysis	**Trichoderma reesei** (cellulase)
		S. cerevisiae (hexose fermentation)
		Recombinant **E. coli** (pentose fermenation)
		Clostridium sp., **Fusarium oxysporum** (consolidated processing)
	(b) Acid hydrolysis	S. **cerevisiae**, **Zymomonas** (for fermentation) and **Clostridium lzungdahlii**
Methane	Farm and human wastes, municipal solid wastes, effluents from food and dairy industries, etc.	A group of anaerobic microorganisms (methanogens)
Butanol	Soluble carbohydrates	**Clostridium acetobutylicum**, **C. beijerinckii**
Hydrogen	Sunlight, water sugars and fatty acids (from starch, cellulose)	**Chlamydomonas reinhardtii**, **C. moewusii** anerobic bacteria like **Clostridium**
Biodiesel	Sunlight and carbon dioxide	**Monoraphidium minutum**, **Cyclotella cryticum**, **Euphorbia** plants, **Copaifera** tree, etc.

Microorganisms with their large population provide the products of several categories to serve human kind. Despite having the list of large number of products, the field remains unexplored in several ways.

The ultimate list of products and services will be different through which the humanity can be served in better ways. The combination of microbiology with biotechnology would be the lead outcome in this field.

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Biotechnology : Principles and Processes

Biotechnology is the scientific technology which uses living organisms in the systems or processes for the manufacturing of useful products/services for human beings.

The term **biotechnology** was coined in 1917 by **Karl Ereky** to describe a process for large scale production of pigs.

Principles of Biotechnology

Among many, the two core techniques that enabled the birth of modern biotechnology are

(i) Alternation of constituents of genetic material (DNA or RNA) to change the phenotype of resultant organisms.

(ii) Production of the large number of microbes/eukaryotic cells in controlled environment to manufacture various products.

Research Areas of Biotechnology

1. Production of improved organisms or pure enzymes.
2. Creating optimal conditions for a catalyst to act.
3. Technologies to purify proteins, organic compounds, etc.

Genetic Engineering or Recombinant DNA Technology

It is the technology involved in the synthesis of artificial genes, repair of genes and for manipulation in genes and genomes of any organism.

The method of genetic engineering is completed in following stages / steps

(i) Isolation of a particular gene segment or DNA from an organism.

(ii) Introduction of isolated DNA into vector DNA to form **r**DNA.

(iii) Introduction of **r**DNA into host.

(iv) Selection of host progeny in which **r**DNA is present (**i.e.,** selection of hybrids).

(v) Formation of multiple copies of these hybrids (**i.e.,** cloning).

For the isolation of particular gene or DNA, specific enzymes, called **endonucleases** are used. The obtained fragments may be **blunt** or **sticky ended**.

For the transfer of the desired DNA from one organism to other, it should be **added with the microbial vector**. As a result of integration of vector DNA and desired DNA, **r**DNA is produced. These **r**DNAs are formed primarily in vectors.

Through vectors, these **r**DNAs are transferred to host where they integrate with the host DNA and are copied several times. Among the total progeny organisms, only some of the organisms cells have **r**DNA present in them, called **hybrids.**

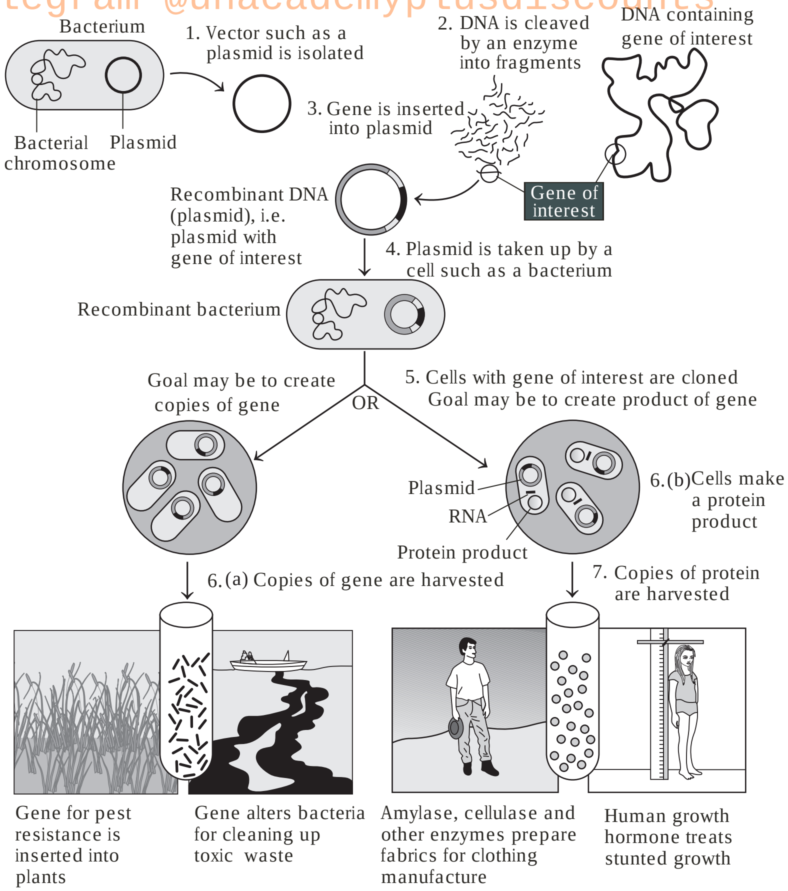
After selecting these hybrids, the process of cloning takes place in which several copies of the same genetic constituents are produced, called **clones**. As a result of insertion of these **r**DNA, the **desired phenotypes/products** can be obtained.

A large number of products of various categories and applications are obtained from biotechnological processes. These products are used in various fields as agriculture therapeutics, textiles, environmental management, etc.

Gene Cloning

It is the process of producing exact copies (clones) of a particular gene or DNA sequence using genetic engineering techniques.

Diagrammatic presentation of process of gene cloning is given below



Basic steps in biotechnology

Tools of rDNA Technology

1. Restriction Endonucleases

The most important tools in biotechnology are restriction enzymes. These belong to the large family of enzymes, called **nucleases**. These were discovered by **Arber** in 1962.

These enzymes have the ability to recognise the certain nucleotide sequence and make 4-8 bp long cuts on these sequences. They were named **restriction endonuclease** because they have the ability to **restrict phage infection among bacteria**. Due to their function, they are also **known as molecular scissors** or **chemical scalpals**.

W Arber, **H Smith** and **D Nathans** in 1978, were awarded with Nobel Prize in medicine and physiology for their pioneering work in the study of restriction endonucleases.

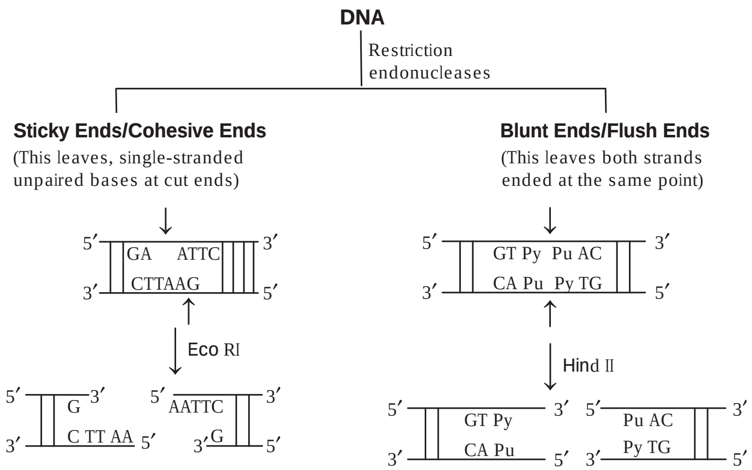
The restriction enzymes can be of 3 types, on the basis of their chemical and physiological properties.

The comparative account of these enzymes is given in the following table

Features	Type I Enzyme	Type II Enzyme	Type III Enzyme
Protein structure	Bifunctional enzyme with 3 subunits	Separate endonuclease and methylase	Bifunctional enzyme with 2 subunits
Recognition site	Bipartite and asymmetrical (**e.g.,** TGAC and TGCT)	Short sequence (4-6 bp), often Palindromic	Asymmetrical sequence of 5-7 bp
Cleavage site	Non-specific >1000 bp from recognition site	Same as or close to recognition site	24-26 bp down stream of recognition site
Restriction and methylation	Mutually exclusive	Separate reactions	Simultaneous
ATP needed for restriction	Yes	No	Yes
Mg^{2+} needed for restriction	Yes	Yes	Yes
Commonly used in	Random cutting and fragments making	Gene manipulation	Gene cloning

Note A palindromic sequence is a nucleic acid sequence that is the same whether read from 5' to 3' end of one strand or 5' to 3' on complementary strand.

As a result of treatment with restriction endonucleases, **two types of DNA fragments are produced.**



Nomenclature of Restriction Endonucleases

The name of the enzyme is derived from the name of organism from which it is isolated.

(i) The first letter of the genus becomes the first letter of the name (written in capital letter).

(ii) First two letters of the species make second and third letter of the enzyme (written in small letters).

(iii) All these three letters are written in italics.

(iv) The fourth letter of the name of enzyme is the first letter of strain (written in capital letter).

(v) The Roman number written at the end of the name indicates the order of discovery of enzyme from that strain.

2. Exonucleases

These enzymes remove nucleotides from the terminal ends (either 5′ or 3′) of DNA in one strand of duplex.

3. Lysing Enzymes

These enzymes are used for the isolation of DNA from cells, **e.g.,** lysozyme is used to digest the bacterial cell wall for the extraction of cellular DNA. Protease, lipase and other degrading enzymes come in this category.

4. Synthesising Enzymes

With the help of these enzymes, the synthesis of DNA takes place on the suitable templates. **They are of two types**

Synthesising Enzymes

Reverse Transcriptase
Synthesis of complementary DNA takes place on RNA template.

DNA Polymerase
Synthesis of DNA takes place on DNA template itself.

This enzyme helps in **in vitro** synthesis of complementary DNA (**c**DNA) strand on DNA templates.

5. DNA Ligase/Sealing Enzyme/Joining Enzyme

These enzymes help in sealing the gaps in DNA fragments, which are joined by complementary base pairing. They act as **molecular glue**, join DNA fragments by **forming phosphodiester bonds**, **e.g.,** T_4-ligase of bacteriophage. It can join both cohesive and blunt ended fragments, hence useful in DNA cloning. The ligase of **E. coli** is ineffective to join blunt end DNA, hence, it is not used in gene cloning.

6. Alkaline Phosphatase

This enzyme phosphate group from the 5′ end of a DNA and thus modify the terminal of DNA.

$$\begin{array}{l} 5'\,G_{OH}\;3' \\ 3'\,C_p\,T_p\,T_p\,A_p\,A_p\;5' \end{array} \xrightarrow{\text{Alkaline Phosphatase}} \begin{array}{l} 5'\,G_{OH}\;3' \\ 3'\,C_p\,T_p\,T_p\,A_p\,\boxed{A_{OH}}\;5' \end{array}$$

After the treatment of alkaline phosphatase to the DNA, both **recircularisation** and **plasmid dimer formation** can be prevented as DNA ligase cannot join the ends.

7. S_1- Nuclease

This enzyme converts cohesive ends of the duplex DNA to blunt or flush ends by trimming away the single strand.

8. Linkers and Adapters

- **Linkers** are **single-stranded**, synthetic oligonucleotides which self associate to form symmetrical double-stranded molecule containing the recognition sequence for a restriction enzyme.
- **Adaptor** molecules are chemically synthesised DNA molecules. They are used in 5′ hydroxyl form to prevent self-polymerisation.

9. **Vectors** (VEHICLE DNA)

It is defined as a DNA molecule that can be used to carry a DNA segment (gene) to be cloned.

Types of vectors are

(i) **Plasmid Vector**

Plasmids are **double-stranded**, closed **circular** DNA molecules which exist in the cell as **extrachromosomal units**. They are self-replicating and found in bacterial species.

There are three general classes of plasmids

(a) **Virulence plasmids** Encode toxic genes.
(b) **Drug resistant plasmids** Provide resistance.
(c) **Conjugation related plasmids** Encode genes for bacterial conjugation.

It was discovered by **William Hayes** and **Joshua Lederberg** in 1952. Plasmids range in size from 1-200kb and depend on the host protein for their maintenance and replication function.

(ii) **Bacteriophage**

Plasmid vectors normally used to clone DNA segments of small size, **i.e.,** up to 10 kb. However, when the size of gene of interest is more than 10 kb, vectors based on bacteriophage are used, **e.g.,** M13, λ (lambda) phage, etc.

(iii) **Cosmid Vector**

Cosmids are formed by the combination of plasmids and **'cos'** sites of phage lambda (λ). It has the capacity to transfer the DNA of up to 45 kbp. This vector can be packaged into λ-phage. This is more efficient than plasmid transformation.

A typical plasmid vector contains

(a) A plasmid origin of replication
(b) Selectable markers
(c) Suitable restriction enzyme sites.
(d) Lambda (λ) **'cos'** site.

(iv) **Phagemid Vectors**

It is a composite structure made up of bacteriophage and plasmids. These have the capacity to carry larger DNA molecules.

(v) **Shuttle Vectors**

Plasmid vectors can replicate only in **E. coli**. The cloning vectors which can propagate in two different hosts are called shuttle vectors.

(vi) **Ti plasmid**

These are found in **Agrobacterium tumefaciens**, bacteria infecting dicot plants. The part of Ti plasmid transferred in the plant cell DNA is T-DNA.

(vii) **Artificial Cloning Vectors**

These vectors are artificially constructed.

Following are some artificial cloning vectors

(a) pBR 322 **vector** This was the first artificial cloning vector constructed in 1977 by **Boliver** and **Rodriguez**.

It possesses following characteristics

- **Size** 4.36 kb (double stranded cloning vector)
- Contains two antibiotic resistant genes
  Ampicillin resistance (**amp**^{R})
  Tetracycline resistance (**tet**^{R})

It contains 20 unique recognition sites for restriction endonucleases.

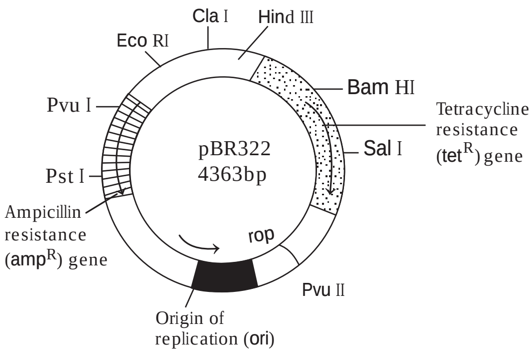


Diagram showing essential features of plasmid pBR 322

(b) **Bacterial Artificial Chromosome** (BAC) This vector is based on **f**-factor of **E. coli**. It can accommodate up to 300-350 kbp of foreign DNA and it can also be used in genome sequencing projects. It contains genes for **replication** and **maintenance of F-factor**.

(c) **Yeast Artificial Chromosomes** (YAC) These vectors **contain telomeric sequences**, the centromere and the autonomously replicating sequence from yeast chromosomes. It is used to clone the DNA fragments of 500 kb in size.

(viii) **Transposons as Vectors**

These are the DNA sequences which can change their location in the genome and hence, known as **mobile DNA** or transposons. The activator (Ac) and dissociation (Ds) elements are the popular transposable controlling elements of maize which are also called **Ac-Ds elements**. The transposons of **Drosophila** are known as **P-elements**. They can be used as vectors.

Characteristics of a Cloning Vector

The following features are essential to facilitate cloning into a vector

(i) A vector should contain a **replicon** that enables replication in the host cells.

(ii) It should have several **marker gene**s.

(iii) It should have a unique **cleavage site** within one of the marker gene.

(iv) For the expression of cloned DNA, the vector DNA should contain **suitable control elements** such as promoter, terminators and ribosome binding sites.

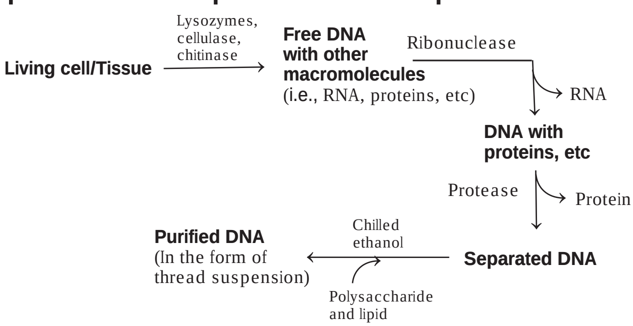
Processes of Genetic Engineering/rDNA Technology

Genetic engineering is a complex process which can be studied in following steps

1. Isolation of Genetic Material

This can be achieved by treating the bacterial cells/plant/animal tissues with enzymes such as lysozyme (bacterial), cellulase (plant cells) and chitinase (fungus), etc.

The complete schematic representation of the process is as follows



Method to isolate DNA

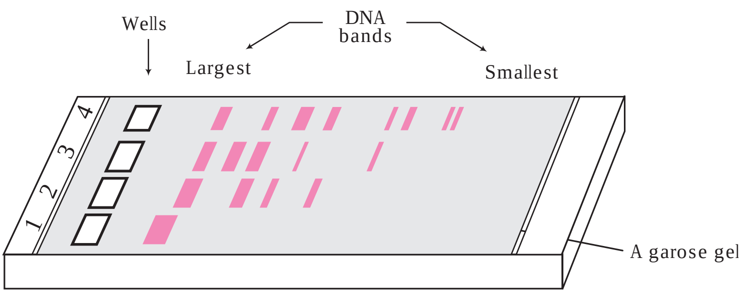
In order to cut the DNA with restriction enzyme, it should be in pure form.

2. Cutting of DNA at Specific Location

The purified DNA fragments are treated with restriction enzyme at optimal conditions of that enzyme. After certain period, **agarose gel electrophoresis** is employed to check the progression of restriction enzyme digestion and separation of DNA fragments.

Gel Electrophoresis

Electrophoresis is a technique of separation of charged molecules like DNA under the influence of an electric field so that, they (DNA) migrate in the direction of positive electrode (anode) through a medium/matrix.



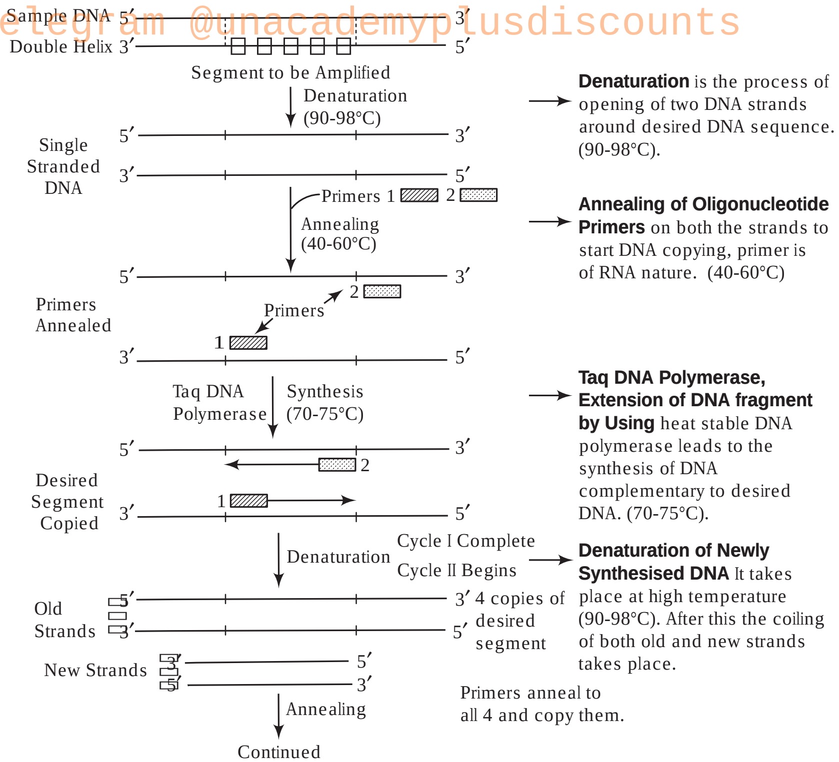
A typical gel electrophoresis showing undigested and digested DNA fragments.

The smaller fragments of DNA settle down fast towards the anode while the larger DNA fragments which remain undigested appear at the topmost region of the agarose gel column.

3. Amplification/Copying of Gene of Interest Using PCR

Polymerase Chain Reaction (PCR) is a technique of synthesising multiple copies of the desired gene (or DNA) **in vitro**. This was developed by **Kary Mullis** in 1985.

The procedure of this reaction is as follows

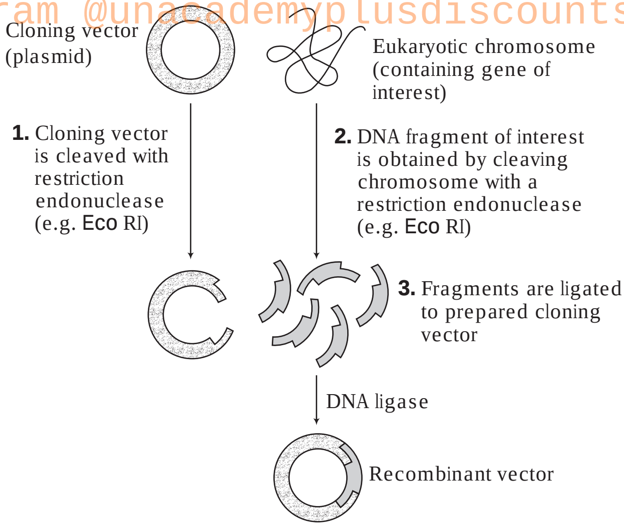


PCR Technique

4. Ligation of DNA Fragment into Vector DNA to form rDNA

After the isolation of target DNA fragment, DNA ligase can be used to join it to a vector digested by the same restriction endonuclease, **e.g.,** a fragment generated by **Eco** RI only joins with the cloning vector digested by **Eco** RI, and not with the cloning vector generated by **Bam** HI.

The complete process looks like



The process of formation of rDNA

5. **Insertion of** r**DNA into Host Cells/Organisms**

The **r**DNA can be inserted into the host cell through various methods. **Broadly these can be categorised into**

(a) Vector-mediated gene transfer

(b) Vectorless gene transfer

Gene transfer

Vector-Mediated Gene Transfer

Agrobacterium **Mediated**
This is the first successful gene transfer method. Various species of Agrobacterium are used to provide natural gene transfer and expression in plant systems, e.g., A. rhizogenes, A. radiobactor

Virus-Mediated
As many viral infections are systemic hence virus can be used to transfer desired genes to host. **Caulimovirus**, **Gemini virus** and some **other RNA viruse** are used to transfer the genes.

Vectorless Gene Transfer

Physical Gene Transfer Methods.

- **Electroporation** Here high electrical impulses (1-1.5 kV) are used to insert the rDNA into host.
- **Particle Bombardment/Biolistics**
  In this, the rDNA coated on gold or tungsten is fired on host through gene gun.
- **Microinjection**
  It is the direct mechanical introduction of rDNA into the target cell.
- **Liposome-Mediated Transformation**
  Artificial lipid vesicles are used to transfer rDNA to host.
- **Silicon Carbide Fibre-Mediated Transformation**
  The fibres of 10-80 μm length are used to deliver rDNA into target cells.
- **Ultrasound-Mediated Transformation**
  An acoustic intensity of 0.5 W/cm^2 for 30 mins. is sufficient to take foreign rDNA by protoplast.
- **Pollen-Mediated Transformation**
  The introduction of rDNA into gametes can occur through this method.

Chemical Gene Transfer Methods PEG

- (Poly Ethylene Glycol-mediated transfer) The first integration of isolated Ti-plasmid DNA into plant protoplast was reported in the Petunia and **tobacco** in the presence of **PEG**. The 40% solution of PEG creates small pores in the plasma membrane which helps in the integration of linear DNA on random sites into host DNA.
- **Calcium Phosphate Coprecipitation**
  In this, the DNA $CaPO_4$ complex is added to dividing cells to transfer rDNA.
- **Polycation, DMSO Technique**
  it involves use of polycation to increase adsorption of DNA by host cell.
- **DEAE Dextran Procedure**
  Here rDNA is complexed with diethyl amino ethyl to inject it into the host. This method does not produce stable transformants.

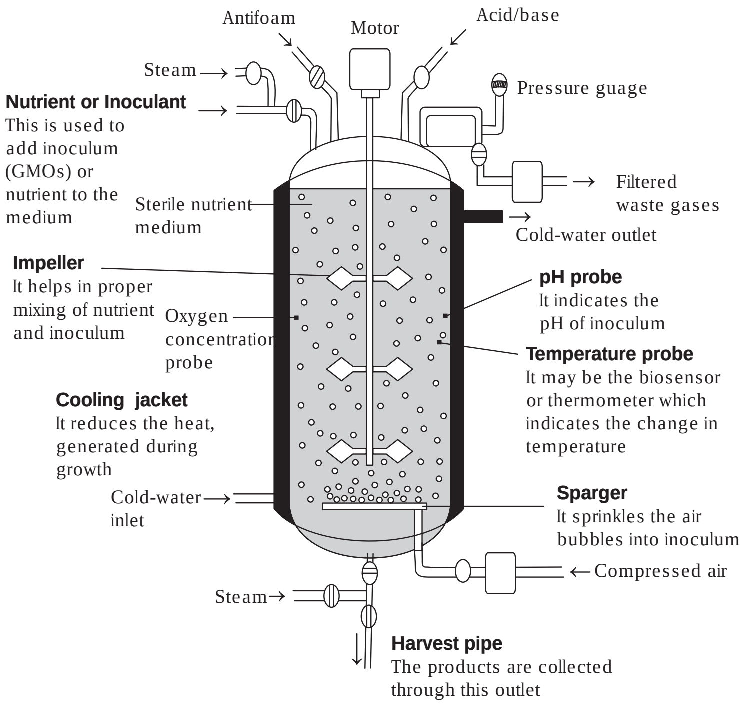
6. Selection/Screening of Hybrids

The selection of hybrids with **r**DNA can be made by the treatment of antibiotics (the resistant gene of antibiotic is already inserted in **r**DNA). All the hybrids will die which do not contain **r**DNA and only recombinant hybrids will be reported in the resultant solution.

Bioreactors (Fermenters)

These are the vessels in which raw materials are biologically converted into specific products by microbes, plant and animal cells in a controlled way.

Following figure will give the idea about the structure and operation of a typical bioreactor



A typical bioreactor

Downstream Processing

It is the process of separation and **purification** to make a biotechnological product ready for marketing.

After the purification, the product is mixed with certain preservative and taken for comprehensive trials on target individuals.

Before **releasing into the market**, every product has to take the approval by Genetic Engineering Approval Committee (GEAC).

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Biotechnology and Its Applications

Biotechnology is the application of biological system in technology that can only be achieved through the integration of biological, physical and engineering sciences. Biotechnology has tremendous applications in certain areas like healthcare, agriculture, industries, etc.

Types of Biotechnology

On the basis of its applications, biotechnology is of following types

(i) **Red biotechnology** It is medical biotechnology, applied in designing organisms used to produce antibiotics or genetic cure products through genomic manipulation.

(ii) **White biotechnology** It is the industrial use of biotechnology.

(iii) **Green biotechnology** It is the agricultural use of biotechnology.

(iv) **Grey biotechnology** It includes all those applications of biotechnology that are directly related to the environment.

(v) **Blue biotechnology** It is based on the exploitation of sea resources to create products and application of industrial interest.

Applications of Biotechnology in Crop Improvement

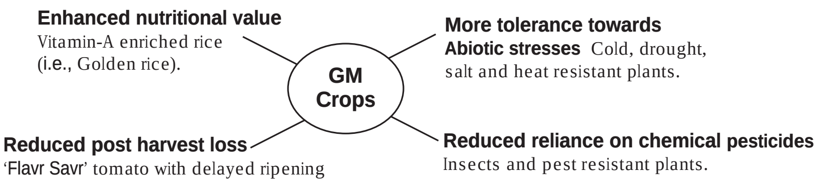
There are mainly three benefits of biotechnology to agriculture

1. Reduction of the duration of breeding period.
2. New methods of hybridisation.
3. Application of **r**DNA technology in agriculture.

Transgenic Crops or GM Crops

It is a crop which contains and expresses a transgene. A more popular term for transgenic crops is **Genetically Modified crops** or **GM crops**.

The genetic modification may lead to following changes in crops



After its integration into host DNA, transgene can perform one of the following functions

(i) **Produces a protein of interest** The gene which produces the protein of our interest is inserted into other organism. **e.g.,** hirudin, a protein that prevents blood clotting. The gene producing hirudin is inserted into the plant **Brassica napus** where the hirudin is synthesised and stored in seeds.

(ii) **Produces a desired phenotype** It produces a protein that, on its own produces the desired phenotype, **e.g.,** crystal (**cry**) protein produced by **Bacillus thuringiensis** (**Bt**) in plants is toxic to the larvae of certain insects.

(iii) **Modifies an existing biosynthetic pathway** By this modification, a new end product is obtained. **e.g.,** transgenic rice and transgenic potatoes produce higher content of vitamin-A and protein, respectively.

(iv) **It masks the expression of native gene** A protein expression masks the existing native gene. **e.g.,** in the tomato variety '**Flavr Savr**', the function of the gene producing **polygalacturonase** (pectin degrading enzyme) is blocked which results in the delayed ripening and better nutrient quality.

Examples of GM crops are

1. Bt **cotton** Pest resistant, herbicide tolerant and high yielding plant. It is also resistant to bollworm infestations.
2. **Golden rice** Vitamin-A rich rice.
3. **Potato** With higher protein content.
4. **Corn, brinjal** Insect resistance.
5. **Soybean**, **maize** Herbicide resistance.

Genetically Modified Organisms (GMOs)

The GMOs have various modifications in their metabolism and may have altered phenotypes.

Following table describes the detailed information about several GMOs

Some Genetically Modified Organisms

Organism	Modification
Long life tomatoes	There are two well-known projects, both affecting the gene for the enzyme polygalacturonase (PG), a pectinase that softens fruits as they ripen. Tomatoes that make less PG, ripen more slowly and retain more flavour. The American '**Flavr Savr**' tomato used antisense technology to silence the gene, while the British Zeneca tomato disrupted the gene. Both were successful and were on sale for a few years, but neither is produced any more.
Insect-resistant crops	Genes for various powerful protein toxins have been transferred from the bacterium **Bacillus thuringiensis** to crop plants including maize, rice and potatoes. These **Bt** toxins are thousands times more powerful than chemical insecticides, and since they are built-in to the crops, insecticide spraying (which is non-specific and damages the environment) is not necessary.
Virus-resistant crops	Gene for virus coat protein has been cloned and inserted into tobacco, potato and tomato plants. The coat protein seems to 'immunise' the plants which are much more resistant to viral attack.
Herbicide-resistant crops	The gene for resistance to the herbicide basta has been transferred from **Streptomyces** bacteria to tomato, potato, corn and wheat plants making them resistant to basta. Fields can safely be sprayed with this herbicide, which will kill all weeds, but not the crops.
Pest-resistant legumes	The gene for an enzyme that synthesises a chemical toxic to weevils has been transferred from **Bacillus** bacteria to the **Rhizobium** bacteria that live in the root nodules of legume plants. These root nodules are now resistant to attack by weevils.
Nitrogen-fixing crops	This is a huge project, which aims to transfer about 15 or more genes required for nitrogen-fixation from the nitrogen-fixing bacteria **Rhizobium** into cereals and other crop plants. These crops would then be able to fix their own atmospheric nitrogen and will not need any fertiliser. However, the process is extremely complex.
Crop improvement	Proteins in some crop plants, including wheat, are often deficient in essential amino acids (that's why vegetarians have to watch their diet so carefully). So the protein genes are being altered to improve their composition for human consumption.

Organism	Modification
Mastitis-resistant cattle	The gene for the enzyme lactoferrin, which helps to resist the infection that causes the udder disease mastitis, has been introduced to Herman-the first transgenic bull. Herman's offsprings inherit this gene and do not get mastitis hence, produce more milk.
Tick-resistant sheep	The gene for the enzyme chitinase, which kills ticks by digesting their exoskeleton has been transferred from plants to sheep. These sheep are immune to tick parasites and do not need sheep dip.
Fast-growing sheep	The human growth hormone gene has been transferred to sheep, so that they produce human growth hormone and grow more quickly. However, they are more prone to infection and the females are infertile.
Fast-growing fish	A number of fish species, including salmon, trout and carp, have been given a gene from another fish (the ocean pout) which activates the fish's own growth hormone gene so that, they grow larger and more quickly. Salmon grows to 30 times their normal mass at 10 times more than the normal rate.
Environment cleaning microbes	Genes for enzymes that digest many different hydrocarbons found in crude oil have been transferred to **Pseudomonas** bacteria so that they can clean up oil spills.

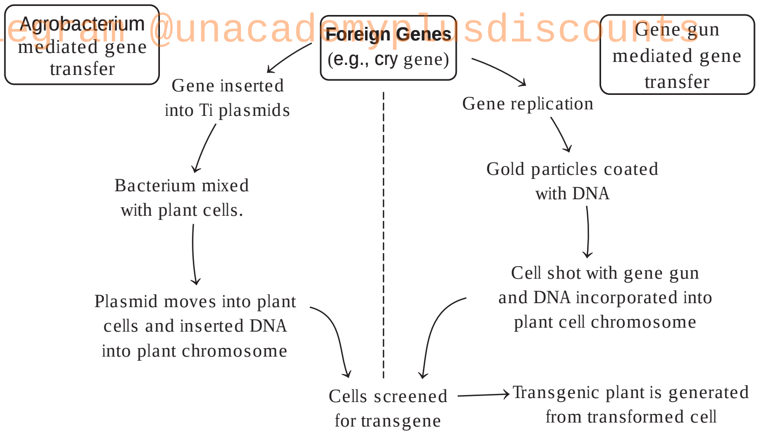
Bt **Cotton** (Insect Resistant Cotton)

The bacterium **Bacillus thuringiensis** (**Bt**) naturally produce chemicals which are harmful to certain insects (**e.g.,** larvae of moths, cotton bollworm and flies) and are harmless to other forms of life.

The **Bt** cotton variety, contains a foreign gene obtained from **Bacillus thuringiensis**. This gene protects the plants from bollworm by producing **Bt** toxin. This **Bt** toxin does not kill the **Bacillus** because it exists as inactive protoxin in its body. Once an insect ingests the inactive toxin, it gets exposed to the alkaline pH of the gut, which solubilises the crystals and converts it into active form. The activated toxin binds to the surface of midgut epithelial cells and creates pores that cause cell swelling and lysis and eventually causes death of the insect.

Farmers who grew **Bt** variety, obtained 25-75% more cotton than those who grew the normal variety. The inserted foreign genes are cry**I Ac** and cry **IIAb** (control the bollworm) and cry **IAb** (controls the corn borer).

There are two methods to introduce cry genes into target cells



Generation of Bt cotton

Applications of Biotechnology in Plant Tissue Culture

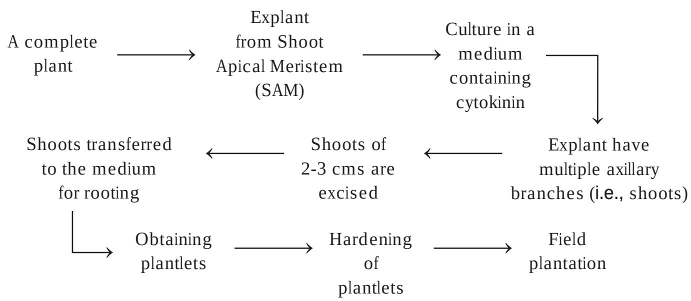
Plant tissue culture is a novel and innovative technique to grow high quality, disease-free plants quickly and in a large quantity by culturing various plant parts. This method is used mostly when the planting material is in scarce amount.

Following are the methods used in plant tissue culture

1. Meristem Culture

It is the method of cultivation of axillary or apical shoot meristem. It involves the development of an already existing shoot meristem and subsequently the regeneration of adventitious roots from the developed shoot.

The process of meristem culture is shown in the following flow chart



Steps in meristem culture

Meristem culture is used for

- Rapid clonal multiplication
- Production of virus-free plants
- Germplasm conservation
- Production of transgenic plants

2. Embryo Culture

In this method, the embryos removed from the developing seeds are placed on a suitable medium to obtain seedlings.

Embryo culture can be applied for

- Recovery of interspecific hybrids.
- Propagation of orchids.
- Overcoming dormancy.
- Anther culture and haploid production.

Embryo-nurse Endosperm Technique

The embryos from mature seeds are cultured **in vitro** on developing endosperm. The fresh endosperm is the primary requirement of the developing embryo.

3. Protoplast Culture and Somatic Hybridisation

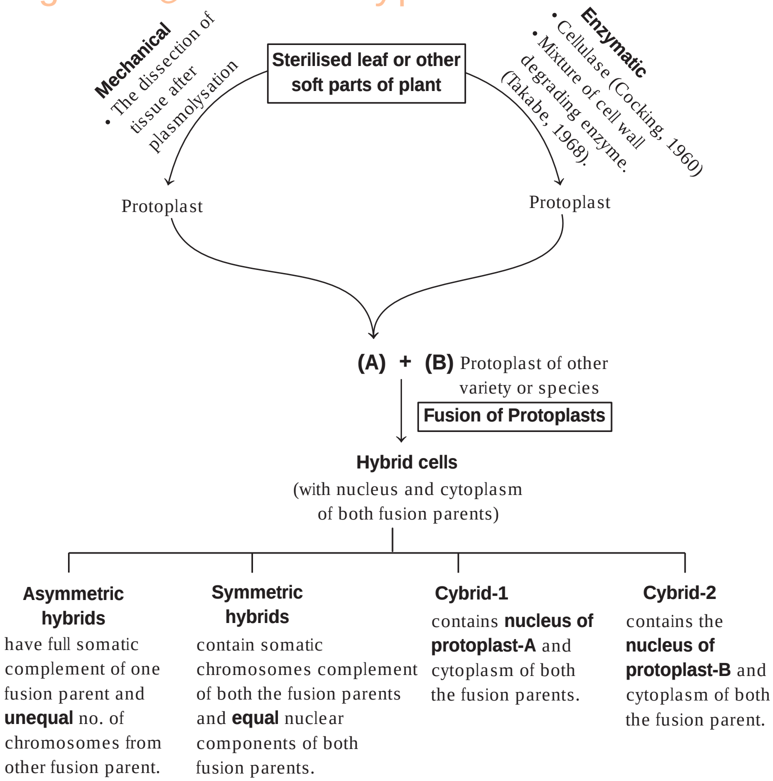
The production of hybrid plants through the fusion of protoplasts of two different plant species is called **somatic hybridisation** and the produced hybrids are known as **somatic hybrids** or **cybrids.**

Protoplast, also known as **naked plant cell** refers to all the components of a plant cell excluding the cell wall.

The technique of somatic hybridisation has following four steps

- Isolation of protoplasts
- Fusion of the protoplasts
- Selection of hybrid cells
- Culture of hybrid cells (regeneration of hybrid plants).

The diagrammatic representation of the process of somatic hybridisation is as follows



Somatic hybrids have following uses

- Used for gene transfer and transfer of cytoplasm.
- Used in the production of useful polyploids.
- In the development of new crop plants, **e.g.,** pomato (hybrid of potato and tomato), rabbage (hybrid of radish and cabbage), etc.

Applications of Biotechnology in Medicine

With the help of following services, biotechnology imposes immense impact on healthcare sector. **It helps in**

(i) Enabling mass production of safe and more effective therapeutic drugs.

(ii) The early diagnosis of diseases for their effective treatment.

The biotechnological applications can be categorised into two groups

1. Gene products
2. Gene therapy

1. Gene Products

Description of some genetically engineered products is as follows

(i) **Human insulin** (humulin) The pancreas produces insulin in humans to regulate the blood sugar concentration. In the absence of enough insulin, the patient develops **wasting symptoms** and **eventually dies**.

Humulin is synthesised for the management of **adult-onset diabetes**. In 1983, an American company **Eli Lily produced first genetically engineered insulin** by synthesising two DNA sequences corresponding to A and B chains of insulin.

This DNA fuses with the plasmid of **E. coli** where both the chains are produced separately. These chains are joined by disulphide bonds and **humulin** is produced.

(ii) **Human Growth Hormone** (hGH) The hGH gene is cloned into **E. coli**, which helps in the treatment of dwarfism in humans. This is synthesised by adding a single sequence which causes the gene to be translated and secreted from the cell.

(iii) **Tissue Plasminogen Activator** (TPA) A clot dissolving protein can now be produced by recombinant mammalian cells.

(iv) **Interferon** It is an antiviral protein produced by **E. coli** and used to fight certain cancers and skin diseases.

(v) α-1 **Antitrypsin** (AAT) The AAT protein inhibits protease enzymes like trypsin and elastase. Because of mutation (base substitution), the **AAT fails to inhibit elastase** hence, elastase digests the elastic tissues of alveoli and causes **emphysema**.

AAT is now produced in GM sheep where the gene for AAT is coupled with milk producing gene. The AAT is purified from the milk of **GM sheep** (**i.e.**, Tracy).

(vi) **Vaccines** These represent another application of **r**DNA technology. The hepatitis-B vaccine (now in use) is composed of viral particles manufactured by yeast cells and recombined with viral genes.

(vii) **Antibiotics** These are produced by fungi such as **Penicillium** and **Cephalosporium** etc., to treat infections caused by bacteria and certain other parasites.

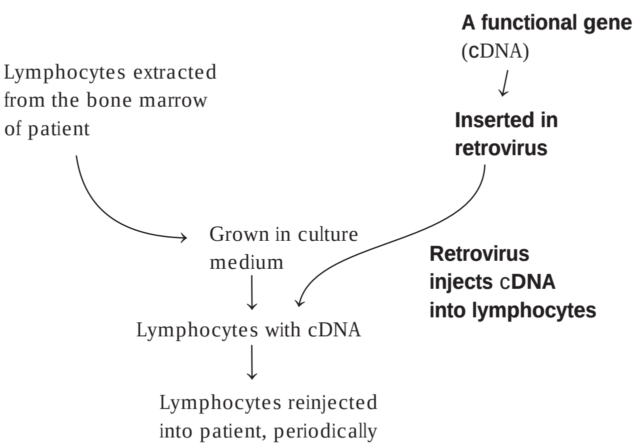
(viii) **Biochips** These are single-stranded DNA chains or repeated DNA segments which firmly struck to silica (glass chips) for matching and studying DNA components of unknown composition.

2. Gene Therapy

It is the technique of genetic engineering in which we **replace a faulty gene by a normal healthy functional gene**. This therapy has been tried for sickle-cell anaemia and **Severe Combined Immunodeficiency Disesae** (SCID).

The first clinical gene therapy was performed on a 4-year-old girl with Adenosine Deaminase (ADA) deficiency in 1990.

Gene therapy can be visualised in following flow chart



Schematic representation of gene therapy

Cystic Fibrosis

It is the most common genetic disease caused by the mutation in the gene for protein called CFTR (Cystic Fibrosis Transmembrane Regulator).

The gene for CFTR was identified in 1989 and soon after that a **c**DNA clone was made. This **c**DNA cloned gene is delivered to epithelial cells of the lungs, where they get incorporated into nuclear DNA and make functional CFTR chloride channels.

Stem Cell Technology

It is rapidly developing field for the treatment of a variety of malignant and non-malignant diseases by using stem cells.

Stem cells are present in multicellular organisms that can divide through mitotic division and differentiate into specialised cells. **These are of two types**

(i) **Embryonic stem cells** These cells can differentiate into all the specialised cells, called pleuripotent cells. These regenerate blood, skin or intestinal tissues.

(ii) **Adult stem cells** In adult organisms, stem cell and progenitor cell act as a repair system for the body.

The potential applications of stem cell include organ and tissue regeneration, brain disease treatment, cell deficiency therapy, cardiovascular disease treatment.

Molecular Diagnostics

It includes all the tests and methods to identify a disease analysing DNA or RNA of an organism, **e.g., r**DNA technology, PCR, ELISA etc.

ELISA (Enzyme Linked Immunosorbent Assay) It uses an enzyme conjugated to an antibody for the detection of specific antigen/antibody based on antigen-antibody interaction.

Applications of Biotechnology in Industries

The industrial applications of biotechnology can be explained by the following presentation

Biotechnology in Industry

Enzymes
Various enzymes are produced at industrial level such as amylase, used in **brewing**, **baking** and **textile industry**. Other enzyme is protease, which is used in **meat**, **leather** and **detergent** industries.

Other Food Items
A food product, sauerkraut (sour cabbage) is produced by the microbial action of Leuconostoc and Lactobacillus bacteria. Some microbes are also used in pickles.

Miscellaneous
Amino acids, nucleotides, vitamins and organic acids are also produced by the microbial action. **Lysine** (used to treat Herpes simplex infection) is a product of the bacterium Corynebacterium glutamicum. **Viatmin-B_{12}** and **B_2** are produced by **bacterium** and **mould** respectively. **Xanthan** (used to stabilise and thicken food is produced by Xanthomonas.

Mining
Microorganisms are highly important to leach low grade ores, to extract their valuable metals. For example, **copper** and **uranium** can be extracted by Trichobacillus.

Beverages Wine
It is the aged product of alcoholic fermentation of fruits. The crushed fruit is combined with the Saccharomyces. Fermentation takes several days and produces alcoholic product called wine. The **beer** is produced by soaking grains with Saccharomyces. The other beverages are vodka, whisky, rum, sake, etc.

Bakery Industry
It this, the flour, water, salt and yeast are used to make the dough. Saccharomyces cerevisiae is used to ferment carbohydrate present in the dough and produces CO_2, which creates the soft texture of bread.

Dairy industry

Cheese
The protein portion of the milk, **casein** is used to produce cheese and cheese products. The **protein curd** which is precipitated from milk is an **unripened cheese**

Buttermilk
The dairy product that results from the souring of low fat milk by lactic acid. The flavour is due to substance such as **diacetyl** and **acetaldehyde**. It is produced by Streptococcus, Leuconostoc and Lactobacillus,

Yogurt
It is a fermented milk product with pudding-like consistency. It is produced by Streptococcus thermophilus and Lactobacillus bulgaricus.

Cheese Product
- **Soft cheese** Such as camembert is a product of growth of the fungus Penicillium camemberti.
- **Hard cheese** Have less water and ripened by bacteria or fungi.
- **Swiss cheese** It is ripened by various bacteria such as Propionibacterium which produce gas holes in the cheese.
- **Blue cheese** It is produced by Penicillium roqueforti which produces veins in the cheese.

Applications of Biotechnology in Environment

Biotechnology has tremendous potential for unique, efficient, eco-friendly and economically viable options for waste treatment and degradation of hazardous waste into relatively less harmful products. Following biotechnological products help in the protection of environment.

(i) **Biosurfactants** These are **surface active substances** synthesised by several microorganisms like bacteria and yeast. These have the property to **reduce surface tension**, stabilise emulsions and **promote foaming**.

Biosurfactants have the potential to solubilise hydrocarbon contaminants and increase their availability for microbial degradation. In some bacterial species such as **Pseudomonas neruginosa**, biosurfactants are also involved in a group motility behaviour called **swarming motility.**

(ii) **Superbug** It is a modified strain of **oil eating bacteria** which was developed by **Prof. Anand Mohan Chakraborty**. The process of working through which GMOs cleanup several environmental contaminants is known as **bioremediation**. A more general approach to cleanup oil spills is by the addition of fertilisers to facilitate the decomposition of crude oil by bacteria.

(iii) **Mycofiltration** It is the process of using fungal mycelia to filtre the toxic waste.

(iv) **Phytoremediation** It refers to the natural ability of certain plants called **hyperaccumulators** to bioaccumulate, degrade or render harmless contaminants in soil water or air, **e.g.,** mustard plants, pigweeds, etc.

(v) **Biosensors** These are referred to engineered organisms (usually a bacterium) that are **capable of reporting some environmental phenomena** like presence of heavy metals or toxins.

(vi) **Biofuels** There are a wide range of fuels, which are in someway derived from biomass. Biofuels are gaining increased public and scientific attention driven by factors such as high fuel prices, need for increased energy security and concern over greenhouse gas emission from fossil fuels.

These fuels can be categorised as

Biofuel

- **Primary**
  Firewood, wood chips, pellets, animal waste. crop residues, landfill gases, etc.
- **Secondary**
  - **1st generation**
    Made from sugar. starch and vegetable oil. e.g., bioalcohol, biodiesel, green diesel, etc.
  - **2nd generation**
    Made from non-food crops. e.g., biogas, syngas, etc.
  - **3rd generation**
    Made from algae. e.g., bioethanol, hydrogen fuel.

Ethical Issues in Biotechnology

The manipulation of living organisms by the human race needs some regulation on both **ethical** and **moral grounds** as genetic modification of organisms can have unpredictable results when such organisms are introduced into the ecosystem.

(i) **Biopatent** A patent is the right granted by the government, to an inventor to prevent others to make commercial use of one's invention. The patents granted for biological entities and products derived from them are called as biopatents.

(ii) **Biopiracy** is the term used to refer the use of bioresources by companies and other organisations without proper authorisation from the countries and people concerned without compensatory payment.

(iii) **Biowar** The war, which is fought with the help of biological weapons against humans, their crops and animals is called a biowar. In biowar, viruses, bacteria and some other harmful organisms are used and are called as bioweapons in biowar.

(iv) **Bioethics** It is a branch of ethics, philosophy and social commentary that deals with the biological sciences and their potential impact on society.

Biotechnology provides several products of high utility values. Major part of applied biotechnology still remains unexplored which surely will provide the solution to various problems related to humans and their environment.

35

Organisms and Population

An isolated, biological entity (**e.g.,** unicellular or multicellular) which is able to perform biological processes independently called as **organism**. Individual organism is the basic unit of ecological hierarchy.

Organism and its Environment

Organism's life exists not just in a few favourable habitats, but even in extreme and harsh conditions, **e.g.,** desert, rainforests, deep ocean and other unique habitats.

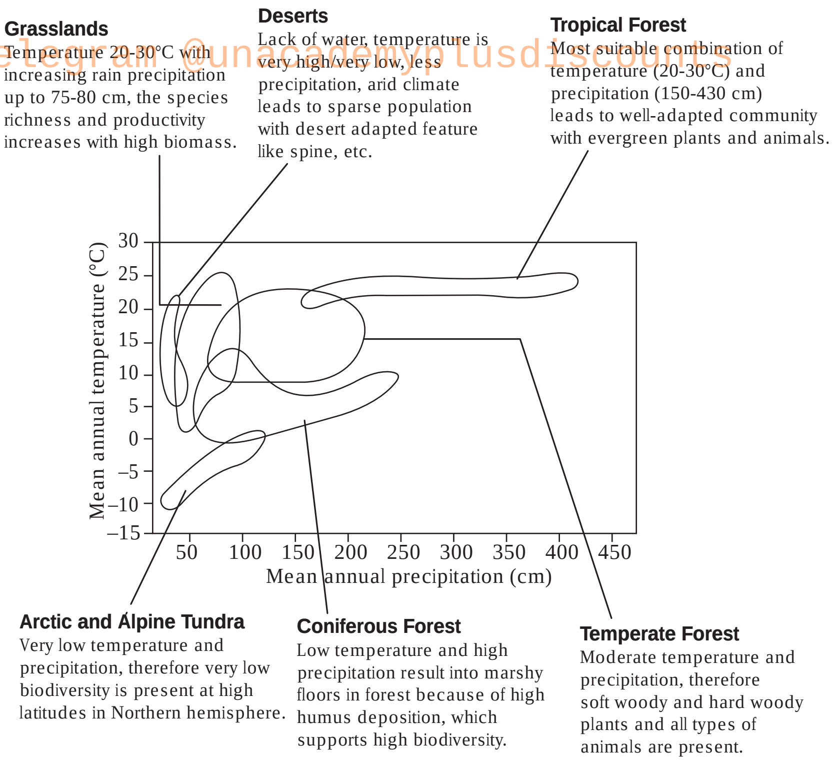
The suitability of environment directly affects the growth of residing population and manifests in the form of various biological communities.

Components of Environment

The surface of the earth consists of three elements, **i.e.,** land, sea and air. On the basis of three elements, it is divided into hydrosphere (water), lithosphere (land), atmosphere (air) and pedosphere (composed of disintegrating compounds of rock and stone forming soil).

Biomes

A large regional unit characterised by a major vegetation type and associated fauna found in a specific climatic zone is referred to as biome.



Different types of biomes of the world

Habitat and Microhabitat

The natural abode of air organism including its total environment is called its **habitat**.

Microhabitat is a small part of a habitat with its own characteristic environmental features, **e.g.,** forest floors, tree canopies, etc.

Niche/Ecological Niche

It refers to the functional role of species in its habitat and more precisely in its microhabitat.

Responses to Abiotic Factors

Organisms cope up with the stressful conditions or possibilities to manage with the adverse situation.

With following modifications, an organism can stabilise its relationship with environment.

Regulate

Some organisms are able to maintain a constant body temperature and constant osmotic concentration despite changes in the external environment, **e.g., thermoregulation**. Human is an isothermic organism, it regulates the temperature in summers by sweating and in winters by shivering. The process of regulation mostly occurs in birds and higher animals.

Conform

It is the strategy of adjustment of organisms towards environmental conditions. In this, an organism controls its physiology in the tune of environmental conditions, **e.g.,** poikilotherms. These organisms fail to maintain their body temperature and change it with the environment, **e.g.,** fishes.

Migrate

It is the movement of an organism from less favourable conditions to more favourable conditions.

On the basis of driving factors of migration, it is of following four types

(i) **Diurnal migration** When migration is controlled by the cycle of day and night, **e.g.,** the movement of planktons towards the surface of aquatic bodies during night and descent to depth during day.

(ii) **Metamorphic migration** This type of migration is controlled by stage of life, **e.g.,** salmon fishes living in Pacific ocean ascend freshwater stream once in life for spawning and after laying eggs, they die. Offsprings return back to the ocean to develop for the period of years before they again repeat the event.

(iii) **Periodic migration** These migrations are controlled by size and population, **e.g.,** several insects migrate from their place of origin, when population increases beyond carrying capacity of that place.

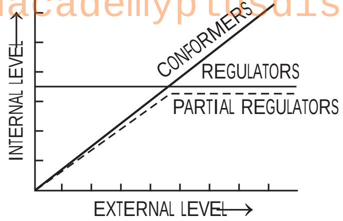
(iv) **Annual migration** This migration is regulated by the time of year, **e.g.,** Siberian Cranes migrate to India at specific period (July to September month).

Suspend

During unfavourable conditions, organisms slow down their metabolic process, **e.g.,**

(i) Lower plants produce spores with thick covering to sustain unfavourable conditions and germinate in favourable conditions.

(ii) Polar bears undergo **hibernation** during winters.



Diagrammatic representation of organismic response

Adaptations

Organisms are adapted morphologically, physiologically, behaviourally to survive and reproduce in their habitat by making adjustments with environment.

Adaptations are of two types

Types of Adaptations

Genotypic Adaptations

- Genetic variations which enable a sub-population to adapt itself to a particular habitat and environmental conditions.
- Genotypic variants in a population or individual species due to change in environment are called **ecotypes**.

Phenotypic Adaptations

- It involves physiological, and morphological modification.
- Phenotype variants formed in a population due to change in environment are called **ecophenes** or **ecads**

Strategic Adaptations in Plants

1. Plant Adaptations to Light Regime

(i) Heliophytes/Sun Loving Plants

(a) Stem with short internodes, leaves thicker and bladed, phototropism.

(b) High respiration rate. 'These plants grow in bright light, but some heliophytes can grow in partial shade, **e.g.,** sugarcane, sunflower, maize and **Bougainvillea etc**.

(ii) Sciophytes/Shade Loving Plants

Stem thin, long internode, sparsely branched, poorly developed conducting and mechanical tissue.

- These plants grow in partial shade or low light, but some sciophytes are not damaged by bright light, **e.g., Drosera**, **Nepenthese**, birch, spruce, etc.
- These are aerobic, show low rate of respiration.

(iii) **Stratification**

In a forest, plants get arranged in various strata (layers/ arrangement according to their size, **i.e.,** grasses, herbs, shurbs and trees) according to their **shade tolerance**, it is called as **stratification**.

2. **Plant Adaptations to Aquatic Environments**

The plants growing in aquatic habitat are called as **hydrophytes** or **aquatic plants**. **Hydrophytes are of five types**

(i) **Emergent Hydrophytes** (Amphibious Plants)

- Plants grow in shallow water of marshy area/swamps.
- Long shoot, aerial leaves with stomata, root well-developed, rhizome present.
- Cuticle present to avoid dessication, developed vascular bundles, **e.g.,**Ranunculus.

(ii) **Submerged Hydrophytes**

- Poorly developed roots.
- Thin leaves, stomata are absent.
- Leaves are finely dissected.
- Stem soft, flexible, spongy with no cuticle layer in epidermal cells.
- Aerenchyma occurs in the roots and stem. Vascular tissues are reduced. **e.g., Hydrilla**, **Vallisneria**.

(iii) **Suspended Hydrophytes**

- Roots are absent.
- Never come in contact with the bottom.
- In all characters, they resemble with the submerged hydrophytes, **e.g.,** Utricularia, Lemna species.

(iv) **Free-floating Hydrophytes**

- Plants are free floating in water, no connection with bottom.
- Plants have air storing organs (**e.g.,** inflated petiole in Eichhornia).
- Roots help in balancing and root tips are covered by root pockets.
- Stomata are present on the upper surface of leaves, **e.g.,** Azolla, Trappa, Eichhornia etc.

(v) **Anchored Hydrophytes with Floating Leaves**

- These plants float on surface but rooted at bottom of shallow water body.
- Large leaves, long petiole, vascular system is well-developed.
- Large air cavities, leaves with wax to avoid wetting.
- Stomata present on upper surface of leaves **e.g., Nymphoides, Potamogeton** species.

3. Plant Adaptations to Water Scarcity and Heat

Xerophytic plants which live in dry conditions and show high rate of transpiration than absorption of water. Deep root system, woody stem, green photosynthetic leaves reduced to spine to prevent water loss.

There are mainly four types of xerophytic plants which are discussed below

(i) Ephemerals or Drought Escapers

- These plants live for a brief period during the rain.
- Small size and larger shoots and roots.
- They are generally found in arid zone, **e.g.**, **Euphorbia** species, **Solanum**, **Argemone mexicana**.

(ii) Annuals or Drought Evaders

- These plants live for a few month even after stoppage of rain.
- They need small quantity of water for their growth and development.
- Similar to ephemeral xerophytes, but grow for longer periods, **e.g.**, **Echinops echinatus** and **Solanum surattense**.

(iii) Succulent or Drought Resistant

- These plants store water and mucilage in fleshy organs.
- They have water storage region made up of thin-walled parenchymatous cells.
- Stem is green, photosynthetic and have thick cuticle.
- They are called **phylloclades** (stems of indefinite growth) and **cladodes** (1-2 internode long stems), **e.g.**, **Opuntia** and **Euphorbia**.

(iv) Non-Succulent Perennial Xerophytes or Drought Endurers

- These are true xerophytes or euxerophytes.
- They have smaller shoot system and very extensive root.
- Leaflets of leaves are often small, vertical, thick and leathery, **e.g.**, **Nerium** and **Calotropis procera**.

4. Plant Adaptations to Saline Environment (Halophytes)

Halophytes show following characteristics as their adaptations

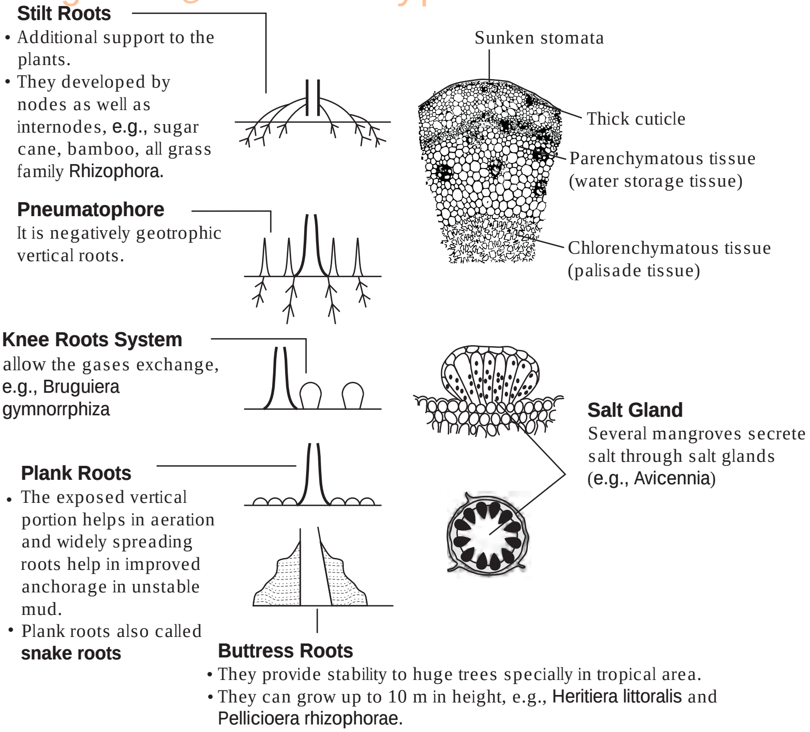
(i) **Accumulation of Several Compounds** — Growing with NaCl, $MgCl_2$ and high concentration of salt.

(ii) **Maintain High Osmotic Pressure** — They have a high osmotic pressure (minimum of 40 bars).

(iii) **Structural Adaptations** — Succulent leaves, stem or both, thick cuticle, sunken stomata. These have substances like tannins and other wax substances to reduce insolation and prevent desiccation.

(iv) **Secretion of Some Products** — They secrete salt like atriplex, spartina through **chalk** or **salt glands**

Halophytic adaptations including structural and physiological modifications can be explained through the example of **mangroves**.



Structural modifications in plants to saline environment

5. Plant Adaptations to Oligotropic Soils

- Oligotropic soils are **poor in nutrients**.
- One such type of soil, which supports dense vegetation is the one found in tropical rainforests.
- Top soil of oligotropic region has shallow while subsoil has dense clay mixed with Fe-Al (iron-aluminium) compounds.
- Major adaptation of tropical plants is the presence of **mycorrhizae** (plant roots with fungi).

Mycorrhizae are of two types

(i) **Ectomycorrhiza** When the fungal hyphae present outside the host cell, it is called ectomycorrhiza.

(ii) **Endomycorrhiza** When the fungal hyphae present inside the host cell, it is called endomycorrhiza.

Strategic Adaptations in Animals

- Animals also develop strategies to live better in their environment.
- **Animal adaptations may be of two types**
  (i) **Short term** It is temporary like increase of heartbeat.
  (ii) **Long term** It is permanent in nature like typical type of beak, claw, etc.
- In animal, most adaptations occur against environmental changes and stress conditions. These may be physiological and behavioural adaptations, **e.g.,** migration, hibernation, aestivation, camouflage, mimicry, echolocation, water scarcity and prevention of freezing.

1. Adaptations to Cold Environment

Some animals protect themselves from excessive cold by developing hard covering as they cannot undergo hibernation and cannot migrate, **e.g.,** barnacles and molluscs of intertidal zone of cold areas, several insects and spiders.

Some animals are adapted to colder environment by developing extra solutes in their body fluids and special ice nucleating proteins in the extracellular spaces.

These extra solutes which prevent freezing, are glycerol and antifreeze proteins. Ice fish (**Chaenocephalus**) or Antarctic fish (**Trematomus**) remain active even in extremely cold sea water due to this hardness.

Mammals from colder climates generally have shorter ears and limbs to minimise heat loss. This is called **Allen's rule**.

2. Adaptations to Water Scarcity

- Animals face water scarcity in desert areas. They show two types of adaptations for reducing water loss and ability to tolerate arid conditions. Camel has a number of adaptations to desert conditions like water consumption, tolerance with temperature, etc.
- The animal produces dry faeces and urine.
- Camel can rehydrate itself quickly. Its storage capacity of water is about 80 litres.

3. Adaptations to Environmental Stress

These are of three types

(i) **Hibernation and aestivation** Hibernation or winter sleep and aestivation or summer sleep are quite common in ectothermal animals.

(ii) **Acclimatisation** It is the development of a favourable morphological and physiological response to a change in the environment.

(iii) **Migration** It is the movement of an animal to other places for food, climate and other reasons.

4. **Adaptations for Protection from Predators**

Camouflage

It is the ability of an organism to blend with the surrounding or background. Organisms use camouflage to mask their **location**, **identity** and **movement**, **e.g.,** many insects, reptiles and mammals (like military colouration dress), insects (like butterfly).

Mimicry

- It is the resemblance of a species with another species in order to obtain advantage, especially against predation.
- The species which is copied is called **model**, while the animals which copy are known as a **mimic** or **mimictic**.

These are of two types

(i) **Batesian mimicry** In this mimicry, the **mimic is defenceless**, **e.g.,** viceroy butterfly mimics unpalatable toxic monarch butterfly.

(ii) **Mullerian mimicry** In this mimicry, there is a resemblance between two animal species, especially insects to their mutual benefit, **e.g.,** monarch butterfly and queen butterfly.

Warning Colouration

Dart frogs (**Phyllobates bicolor, Dendrobates pumilio**) found in tropical rainforests of South America are highly poisonous as well as brightly coloured to be easily noticed. Predators usually avoid them.

Population and Community

As combination of several populations in an area makes community, the relationship between these two is established. **The comparative account of both population and community is given below.**

Differences between Community and Population

Community	Population
It is a grouping of individuals of different species found in an area.	It is a grouping of individuals of a single species in an area.
Interbreeding is absent amongst different members of a community.	Individuals interbreed freely.
Different members of a community are morphologically and behaviourly dissimilar.	Morphologically and behaviourly similar species are found in a population.
It is a large unit of organisation.	It is a small unit of organisation.
In a biotic community, there is often a relationship of eating and being eaten.	There is no relationship of eating and being eaten.

Characteristics of Population

Characteristics of Population

Dispersal

Emigration
Exit of individuals from population.

Immigration
Entry of individuals into population.

Density
Density is the number of individuals per unit area or volume. Density is represented as

$D = \frac{N}{S}$

N = Total number of individuals,
S = Space/Area

Natality (Birth rate)
Natality is the rate of production of new individuals per unit of population per unit time.
Natality is expressed as
$\Delta N_n/\Delta t$ = Absolute natality rate
$\Delta N_n/N\Delta t$ = Specific natality rate
(i.e. Natality rate per unit of population)
Where,
N = Initial number of organisms
n = New individuals in the population
t = Time

Dispersion
It indicates how the individuals of a population are distributed in space and time. Three possible ways of dispersion are uniform, random and clumped.

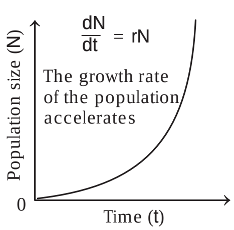
Biotic Potential
It is the maximum reproduction capacity of a population, under optimum environmental conditions.
Vital index = Number of birth/ Number of death
It is the highest possible vital index of a species, therefore when the species has its highest birth rate and lowest mortality.

Mortality (Death rate)
It is the rate of loss of individuals per unit time due to death
(i) **Specific Mortality**
Minimum death rate under ideal conditions due to natural processes.
(ii) **Realised Mortality**
Actual death rate due to abnormal conditions like disease, natural hazards.

Age Distribution
The ratio of various age groups is very important for future aspects of population.
(i) **Pre-reproductive**
Juvenile or dependent phase
(ii) **Reproductive**
Adult phase
(iii) **Post-reproductive**
Old age.

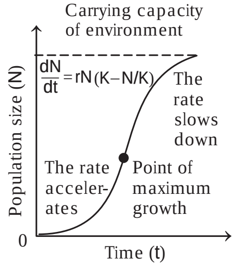
Population Growth Curves

J-shaped

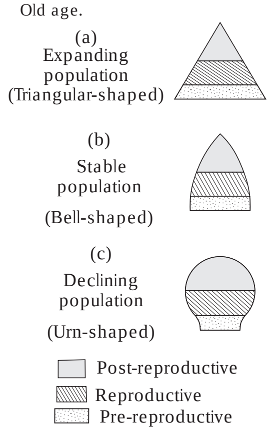


(a) Exponential (unrestricted) **growth**

S-shaped



(b) Logistic (restricted) **growth**



Population Interactions

Organisms belonging to different populations interact for their necessities

Population Interaction (on the basis of species involved)

1. **Intraspecific** (within the species)
2. **Interspecific** (between species) **These are of two types**
   - (i) **Antagonism** (one species or both may be harmed), **e.g.,** Coytes kill and ingest gray fox in South California.
   - (ii) **Symbiosis** (one species or both may be benefitted), **e.g.,** Mycorrhizal roots.

Population interactions can also be categorised on the basis of its nature.

Population Interactions

(on the basis of interaction of nature)

- **Positive Interaction** (one or both may be benefitted)
  - **Mutualism** The association is obligatory, e.g., roots of some leguminous plants and N_2-fixing bacteria.
  - **Proto-cooperation** No obligatory in nature but both the partners get benefitted, e.g., sea anemone and hermit crab.
  - **Commensalism** Only one might be benefitted but other is not affected, e.g., epiphytes.
- **Negative Interaction** (one or both may be affected)
  - **Competition** It is presumed that the superior competitor eliminates the inferior one. It is of two types
    - (i) Intraspecific competition
    - (ii) Interspecific competition

    Gause's competitive exclusion principle states that the two closely related species competing for the same resources cannot co-exist indefinitely and the competitively inferior one will be eliminated eventually.
  - **Parasitism** It is an interaction between two individuals, where the parasite gets the benefit at the expense of the host. It is of different categories
    - (i) **Ectoparasites** e.g.,human body lice.
    - (ii) **Endoparasites** e.g., Plasmodium malariae.
    - (iii) **Facultative parasites** e.g., Oyster prawn.
    - (iv) **Obligate parasites** e.g.,Taenia solium.
  - **Predation** It is the eating of one species by another. Predators consume other living animals, e.g., Nepenthes.

Interaction and adaptation of organisms into their environment can be accomplished by various strategies. These strategies ultimately help in the establishment of new communities. Detailed study of these processes of establishments throws light on several new fields of environmental studies.

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Ecosystem

An **ecosystem** consists of biological community that occurs in some local and the physical and chemical factors that make up its non-living or abiotic environment.

Ecosystem

'Ecosystem is normally an **open system** because there is a continuous entry and loss of energy and materials'.

The term **ecosystem** was first used by **AG Tansley** in 1935 to describe the whole complex of living organisms living together as a sociological unit and their habitats.

The ecosystem is also called as **biocoenosis** (Mobius; 1877), **microcosm** (Forbes; 1887) and **biogeocoenosis** (Sukachey).

It is also known as **ecocosm** or **biosystem**.

Types of Ecosystem

On the basis of origin, the ecosystem can be of following types

Ecosystem

- **Natural Ecosystem**
  The ecosystems which are capable of operating and maintaining themselves.
  It is further classified as
  - **Terrestrial Ecosystem**
    e.g, forest, desert, grassland, etc.
  - **Aquatic Ecosystem**
    e.g., pond, lake, river, etc.
- **Artificial Ecosystem**
  These systems are maintained and manipulated by men for different purposes, e.g., croplands, township, etc.

Components of Ecosystem

Eugene P Odum explained the components of ecosystem on the basis of trophic levels **which are as follows**

- **Abiotic Components**
  - **Inorganic Substances**
    Carbon, nitrogen, sulphur, potassium, carbon dioxide, water, etc.
  - **Organic Substances**
    Proteins, carbohydrates, lipid, etc.
  - **Climatic Regime**
    Temperature, humidity, soil, light, pressure, etc.
- **Biotic Components**
  - **Producers** (autotrophic component)
    Autotrophic organisms, i.e., plants (green) and photosynthetic bacteria
  - **Macroconsumers** (heterotrophic components)
    Phagotrophs or heterotrophs, i.e., animals and non-green plants
  - **Microconsumers** (decomposers)
    Transformers or decomposers, i.e., bacteria and fungi

Components of ecosystem

Abiotic Components

Abiotic components of an ecosystem consist of two things, **i.e., materials** (**e.g.,** water, minerals, gases, etc.) and **energy**.

The important abiotic components include temperature, wind, light, water, soil and minerals, etc.

1. Temperature

It is the most ecologically relevant environmental factor. **Latitude**, **altitude**, **topography**, **vegetation** and **slope aspects** are some factors which influence the temperature.

Temperature regulated periodic activities are reported from animals, **e.g., diurnal** (active during day), **nocturnal** (active during night), **auroral** (active at dawn), **vesperal** (active during evening) and **crepuscular** (active in twilight).

2. **Water**

It is the most important factor for all living processes. Infact the life on earth originated in water and without water, it is unsustainable.

Water constitutes the most part of our body and blood. On the basis of water availability in plants, they are grouped into three communities namely **hydrophytes**, **mesophytes** and **xerophytes**.

3. **Light**

Light with wavelength between 400–760 nm is the **visible light**. The part of light which is effective in photosynthesis (**i.e.,** 400-700 nm) is termed as Photosynthetically Active Radiation (PAR).

This band of energy provides radiant energy for photosynthesis and thus **supports all autotrophic organisms**.

4. **Soil**

It is weathered top surface of earth's crust constituted by **mineral matters** (sand, silt and clay), **organic matter** (humus) and **microorganisms** (bacteria, fungi, etc).

Soil is the medium of anchorage and supply of **nutrients** and **water** to plants and plants are the ultimate source of energy for animals and humans. Hence, soil constitutes the important life support component of the biosphere.

Biotic Components

The biotic components are divided into following categories

(i) **Autotrophic components** (producers) Living organisms **which fix light energy** to manufacture the complex organic food from simple inorganic substances, **e.g.**, green plants.

(ii) **Heterotrophic components** (macroconsumers) Living organisms **that ingest other organisms** and are therefore called **heterotrophs**. They derive their food directly or indirectly through green plants, **e.g.**, animals, etc.

(iii) **Decomposers** (microconsumers) Decomposers are also called as **saprobes** or **saprophytes** or **mineralisers**, as they release minerals trapped in organic substances, **e.g.**, fungi, mould, bacteria, etc.

On the basis of their role in trophic structure, macroconsumers or consumers are categorised as

Consumers

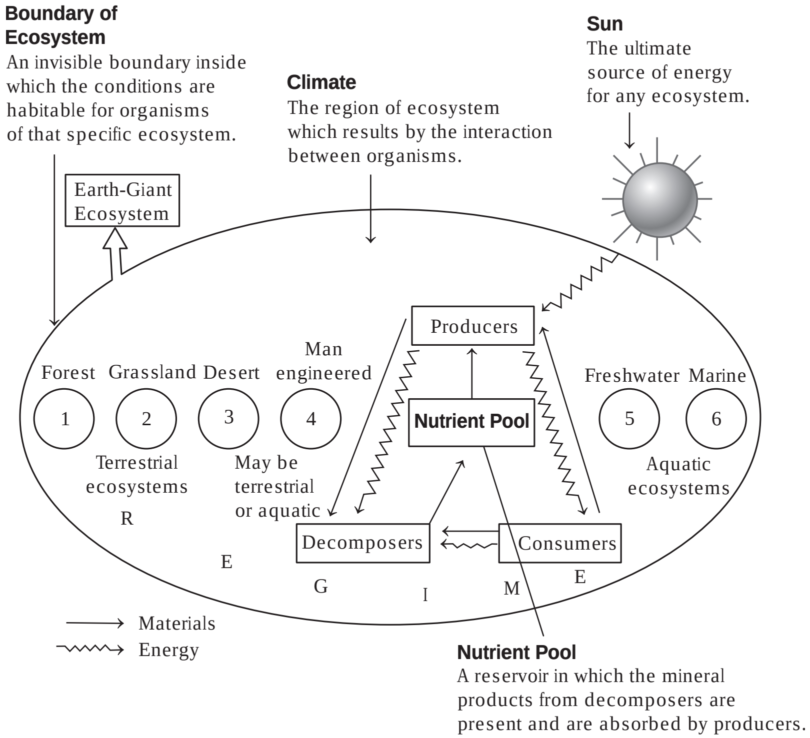
(i) **Primary consumers** (herbivores) These organisms feed directly on producers. These are also known as key industry animals, **e.g.,** protozoans (pond ecosystem), deer (forest ecosystem), etc.

(ii) **Secondary consumers** (carnivores) The group of organisms which feed on primary consumers, **e.g.,** insects, game fishes, etc.

(iii) **Tertiary consumers** (top carnivores) These animals eat other carnivores. Some ecosystems have top carnivores like lion and vulture.

Note **Detritivores** These organisms depend on the organic detritus left by decomposers (bacteria and fungi), e.g., earthworms.

Ecosystem : Structure and Characteristics



Structure of an ecosystem (generalised)

Features of Ecosystem

A comparative account of several ecosystems is given in the following table

Comparative Summary of Marine, Grassland, Forest and Desert Ecosystems

Component	Marine Ecosystem	Grassland Ecosystem	Forest Ecosystem	Desert Ecosystem
Abiotic components	Temperature zones, air, O_2, mineral rich salts, etc.	CO_2, H_2O, nitrate, phosphate and sulphates, roughly 19% of the earth's crust.	Soil and atmosphere.	Rainfall less than 25 cm, extreme of temperature and cold.
Biotic components	Phytoplanktons, diatoms and dinoflagellates.	**Dichanthium** and **Cynodon**.	Mainly trees like teak, sal.	Shrubs, bushes, some grasses and very few trees.
Producers	Microscopic algae, members of Phaeophyta and Rhodophyta.	**Digitaria, Dactyloctenium, Setaria** and also few shrubs.	**Quercus** in temperate forest, **Pinus, Abies, Cedrus, Juniperus** and **Rhododendron.**	Cycads, cacti, palm, coconut, etc.
Macroconsumers				
Primary	Crustaceans, molluscs and fishes.	Deer, sheep, cow, buffaloes, rabbit, mouse. Also some insects, termites and millipedes.	Leafhoppers, flies, beetle, bugs, spider, deer, mouse and moles.	Animals, insects, some reptiles and camel.
Secondary	Carnivorous fishes.	Fox, jackal, snake, frogs, lizards and birds.	Lizard, fox, snake and birds.	Reptiles
Tertiary	Herring, shad and mackerel carnivore fishes like cod, haddock, halibut, etc.	Hawk and vulture.	Lion, tiger, wild cats, etc.	Vultures
Microconsumers				
Decomposers	Chiefly bacteria and fungi.	**Mucor, Aspergillus, Penicillium, Fusarium, Cladosporium** and **Rhizopus**.	Mostly fungi **Aspergillus**, **Polyporus**, **Fusarium**, etc. Bacteria **Bacillus**, **Clostridium** and **Streptomyces**.	Fungi and bacteria which are thermophilic.

Functions of Ecosystem

Following are the important functional aspects of the ecosystem

1. Productivity
2. Energy flow
3. Development and stabilisation
4. Decomposition
5. Nutrient cycle

Before going in detail about the functional aspects of ecosystem, we need the better understanding of **food chain** and **food web**.

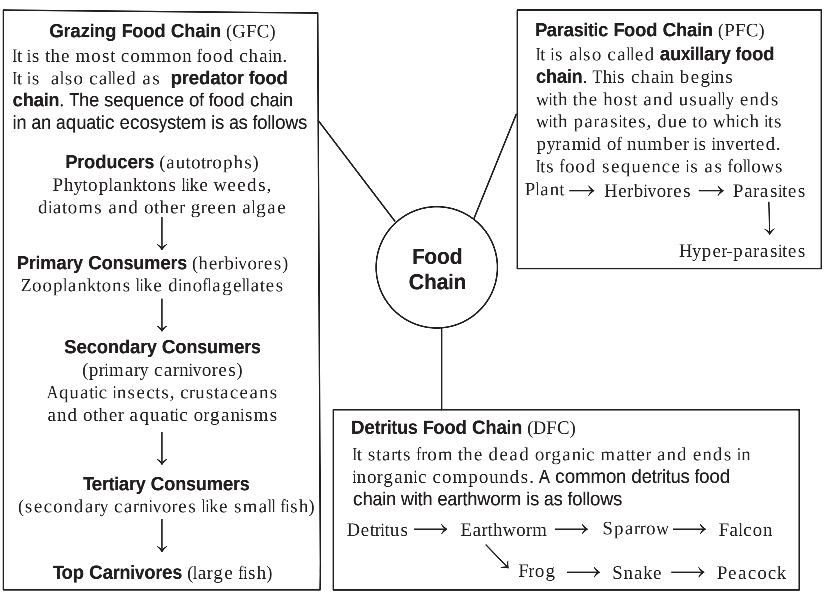
Food Chain

As the biotic factors of the ecosystem are linked together by food, a particular linking makes a chain called **food chain**. It is 'A group of organisms in which there is a transfer of food energy which takes place through a series of repeated process of eating and being eaten'.

It is always **straight** and usually contains 4-5 trophic levels.

Types of Food Chains

On the basis of habits of organisms involved, the food chain can be categorised as



Types of food chain

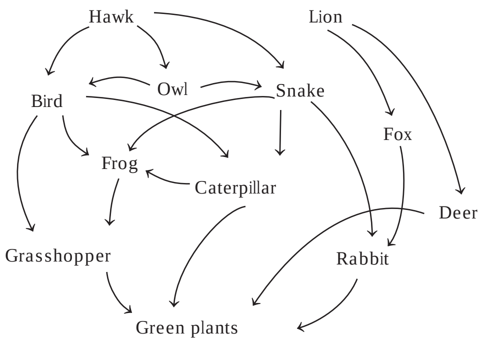
Food Web

It is the network of food chains which become interconnected at various trophic levels. In any complex food web, one can recognise several different trophic levels.

In a food web, a given species may occupy more than one trophic level. The complexity of food web varies greatly and this can be expressed by a measure called connectance of the food web.

$$\text{Connectance} = \frac{\text{Actual number of interspecific interaction}}{\text{Potential number of interspecific interaction}}$$

A typical food web can be represented as follows



Food web

1. Productivity

It refers to the rate of biomass production, **i.e.,** the rate at which the sunlight is captured by the producers for the synthesis of energy rich organic compounds.

It is the amount of organic matter accumulated per unit area per unit time.

Production Ecology is the branch of Ecology that deals with the rate of production of organic matter in ecosystem.

It is of following types

Productivity

- **Primary Productivity**
  The rate at which radiant energy is stored by the photosynthetic and chemosynthetic activities of producers. It is of following types
  - **Gross Primary Productivity** (GPP)
    It is the total rate of photosynthesis including the organic matter used up in respiration.
  - **Net Primary Productivity** (NPP)
    It is the rate of storage of organic matter in excess of respiratory utilisation.
- **Secondary Productivity**
  It is the rate of energy storage at consumer level, i.e., herbivore, carnivore and decomposers.
- **Net Productivity**
  It is the rate of storage of organic matter not used by the heterotrophs or consumers.

Measurement of Productivity

As a result of photosynthesis, there is an increase in dry mass. The **Relative Growth Rate** (**R**) is defined as the gain in mass per unit of plant mass in unit time.

$$\mathbf{R} = \frac{\text{Increase in dry mass in unit time}}{\text{Dry mass of plant}}$$

The increase in dry mass in unit time is equal to $\dfrac{\mathbf{w_t - w_0}}{\mathbf{t}}$

$\mathbf{w_t}$ = dry mass after time **t**,

$\mathbf{w_0}$ = dry mass at the start of time period.

The **Net Assimilation Rate** (NAR) relates increase in dry mass to leaf area.

$$\text{NAR} = \frac{\text{Increase in dry mass in unit time}}{\text{Leaf area}}$$

Biomass is the total dry mass of all organisms in an ecosystem.

Total biomass = Biomass of primary producers + Biomass of consumers + Biomass of decomposers + Biomass of dead organisms.

2. Energy Flow

'The movement of energy in ecosystem is termed as **energy flow**'.

It is unidirectional energy transformation. The flow of energy in ecosystem is controlled by two laws of thermodynamics.

(i) **First law** Energy can neither be created nor be destroyed, but can be transferred or transformed to another form.

(ii) **Second law** In every activity involving energy transformation, dissipation of some energy takes place.

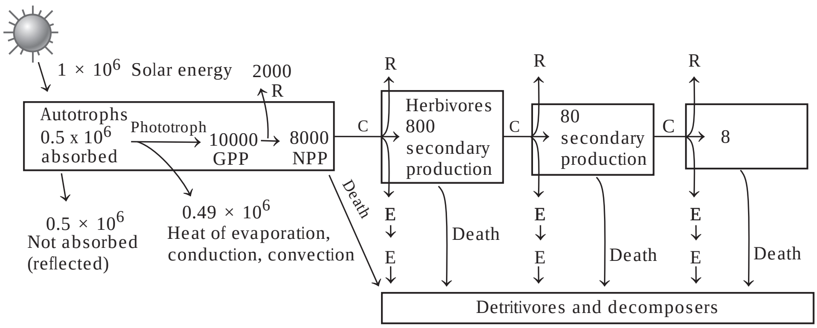
The **incident radiation** of plant is about 1×10^6 kJ/m^2/yr and of this, about 95-99% is immediately lost by plants through **reflection**, **radiation** or **heat of evaporation**.

The remaining 1-5% is used in the production of organic molecules. Organisms at each trophic level depend on those belonging to the lower trophic level for their energy requirements.

Each trophic level contains certain mass of living matter at a particular time called **standing crop**. The standing crop is measured as the mass of living organisms (biomass).

The number of trophic level in the food chain is restricted as the transfer of energy follows **10% law** given by **Raynold Lindemann**.

Following diagram clearly describes the flow of energy in a food chain applying 10% law



Energy flow through a grazing food chain

R = Energy loss through respiration, **E** = Energy loss from grazing food chain to detritivores and decomposers through excretion,

C = Consumption by organisms.

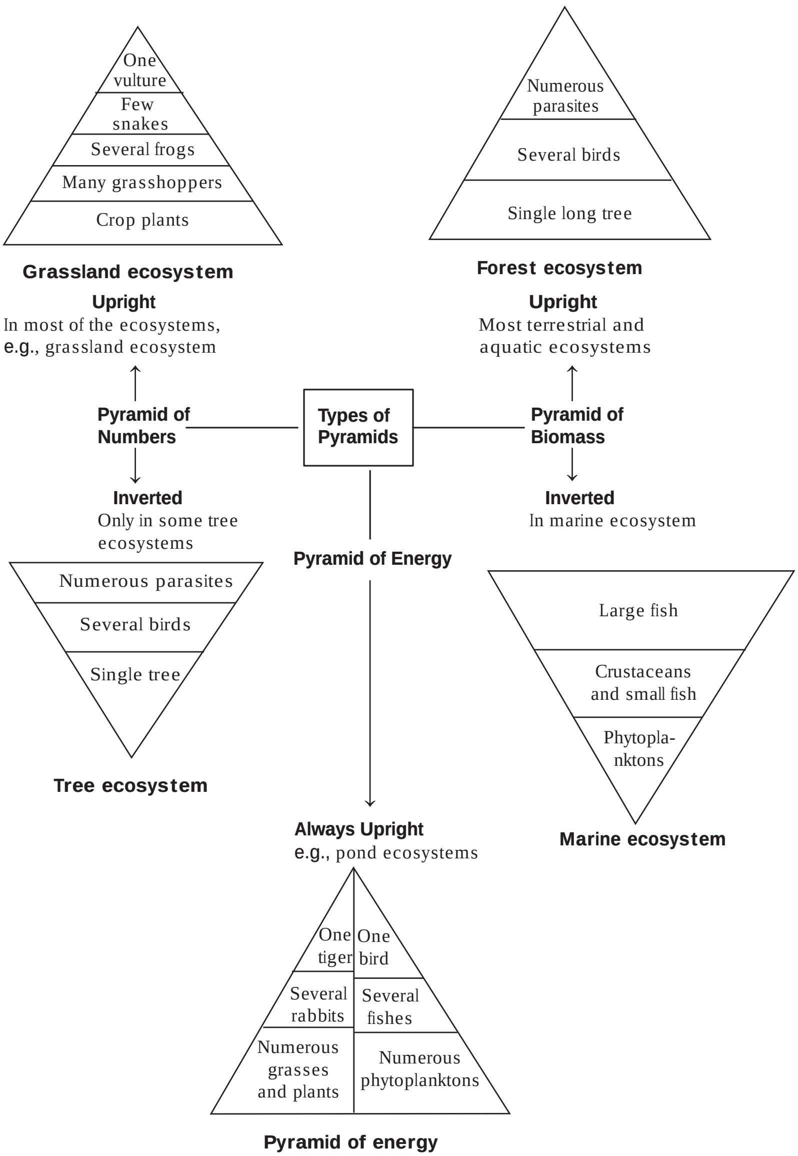
Here, biomass 800, 80 and 8 kJ/m^2/yr, NPP shows that only 10% energy is transferred to the next trophic level.

Ecological Pyramids

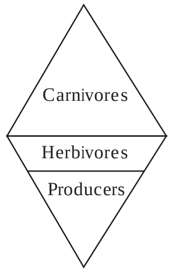
These are the diagrammatic representation of the relationships among numbers, biomass and energy content of the producers and consumers of an ecosystem. The concept was proposed by **Charles Elton** (1927). Hence, these are also known as **Eltonian pyramids**.

Types of Pyramids

Pyramids can be of different types including upright or inverted or spindle-shaped.



Spindle-shaped pyramid is seen in the forest ecosystem where the number of producers is lesser and they support a greater number of herbivores, which in turn support a fewer number of carnivores.



Partly upright pyramid of number

3. Development and Stabilisation

An ecosystem develops and stabilises through the process of **ecological succession**.

Ecological Succession

It is a sequence of **seres** (developmental stage of a community) from barren land to the climax.

The initial community of the area which is replaced in time by a sequence of succeeding communities until the climax is reached is called **pioneer stage** or **pioneer community**. The intermediate stages between pioneer and climax stages (**i.e.,** final stage) are called as **seral stages**.

Causes of Succession

The causes of ecological succession can be of three types which are as follows

Initial or Initiating Causes → These causes are both **climatic** and **biotic**. It includes factors such as erosion, wind, fire, etc. These heavily affect the population of that locality.

↓

Ecesis Causes → These are also called as **continuing causes** which modify the population to adapt several conditions of environment.

↓

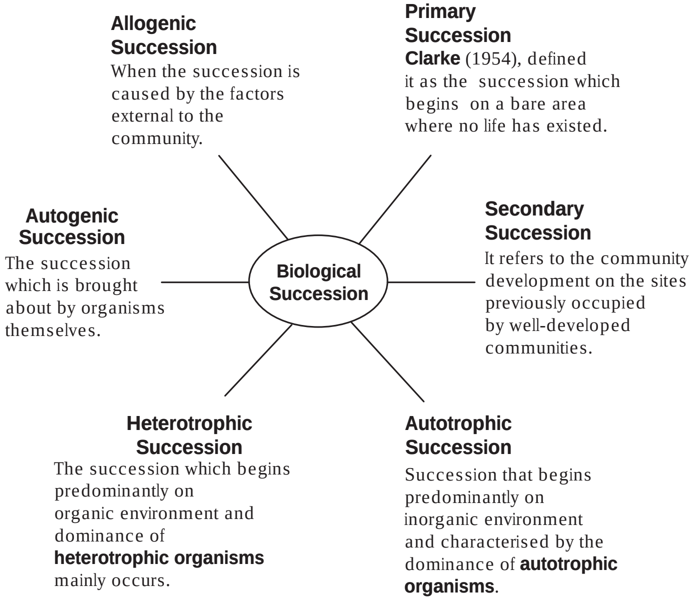
Stabilising Causes → The climatic causes determine the nature of climatic climax, i.e., the end point of succession.

Changes During Biotic Succession

The following changes may occur due to ecological succession

(i) Small short lived plants to large long lived plants.
(ii) Unstable biotic community to stable biotic community.
(iii) Little diversity to high diversity.
(iv) Greater niche specialisation.
(v) Increase in biomass.
(vi) Increase in soil differentiation.
(vii) Increase in humus content of the soil.
(viii) Aquatic or dry conditions to mesic conditions.
(ix) Simple food chains to complex food webs.

Types of Succession



Various types of succession

Process of Succession

The succession is a slow and complex phenomenon, **which is categorised into following stages and substages**

Nudation → This means the development of bare areas without any form of life.
It may be caused by following factors
Topographic, e.g., soil erosion by various factors.
Climatic, e.g., glaciers, dry period, hailstorm, fire, etc.
Biotic, e.g., human, fungi, viruses, etc.

↓

Invasion → It is the successful establishment of a species in a barren area. It is completed in following substages
Migration The seed, spores and propagules reach to barren area.
Ecesis Adjustment of establishing species with environment prevailing there.
Aggregation Multiplication of species in numbers.

↓

Competition and Co-action → After aggregation, the individuals of a species compete with other organisms for space, nutrition and other resources.

↓

Reaction → The modification of the environment through the influence of living organisms on it is called reaction.

↓

Stabilisation → The stage at which final or climax community becomes more or less stabilised for a longer period of time in that particular environment.

The processes involved in succession

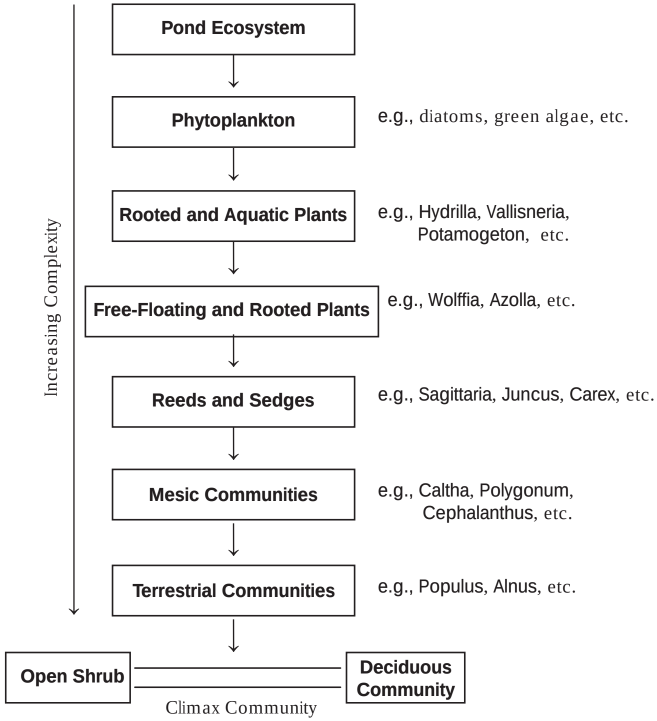
Examples of Biological Succession

Hydrosere and **xerosere** are the two main biological successions. **They are discussed below**

(I) Hydrosere/Hydrarch Succession

In this succession, a pond and its community are converted into a land community.

Developments in Hydrosere/Hydrarch succession can be represented as follows



Succession in aquatic ecosystem

(II) Xerosere/Xerarch Succession

Xerosere occurs on bare rock surface where the original substratum is deficient of water and lacks organic matter.

Developments in Xerosere / Xerarch succession occurs in following stages

Bare Rock

↓

Crustose Lichen Stage (pioneer community)

↓ e.g., Rhizocarpon, Rhinodina, etc.

Foliose Lichen Stage

↓ e.g., Parmelia, Dermatocarpon, etc.

Moss Stage

↓ e.g., Polytrichum, Grimmia, etc.

Herb Stage

↓ e.g., several herbs.

Shrub Stage

↓ e.g., Rhus, Phytocarpus, etc.

Forest Stage (climax community)

e.g., trees.

Seral Communities

Succession on bare rock

4. Decomposition

The process of decomposition completely takes place outside the body of decomposers.

They digest the organic substances outside their body and then absorb it. Hence, they are also known as **osmotrophs** (absorptive).

Process of Decomposition

There are three processes which occur simultaneously during decomposition.

Fragmentation of Detritus → The detrivore animals like **earthworms** and **termites** eat the detritus and convert it into simple inorganic substances. This is called fragmentation.

↓

Leaching → Soluble part of the detritus (i.e., sugar, inorganic nutrients) gets leached to the lower layers of soil by percolating water.

↓

Catabolism → It is carried out by saprotrophic bacteria and fungi. It is completed in following two substages.

Humification
It is the process of partial decomposition of detritus to form **humus**. It is a dark coloured, amorphous, organic matter rich in cellulose, lignin, etc. It is slightly acidic and acts as reservoir of nutrients.

Mineralisation
It is the release of inorganic substances i.e., CO_2, H_2O and minerals.

Factors Affecting Decomposition

(i) **Chemical nature of detritus** Slow decomposition (cellulose, lignin, tannin, resin), fast decomposition (protein, nucleic acid).

(ii) **Soil pH** Acidic (slow decomposition), alkaline soil (fast decomposition).

(iii) **Temperature** Temperature $\propto$ rate of decomposition.

(iv) **Moisture** Amount of moisture $\propto$ rate of decomposition.

(v) **Aeration** Amount of air $\propto$ rate of decomposition.

5. Nutrient Cycling

For the maintenance of ecosystem, the nutrients get recycled in ecosystem. The cycling of nutrients is also known as **biogeochemical cycling**. **This can be categorised as**

Nutrient Cycle/Biogeochemical Cycle

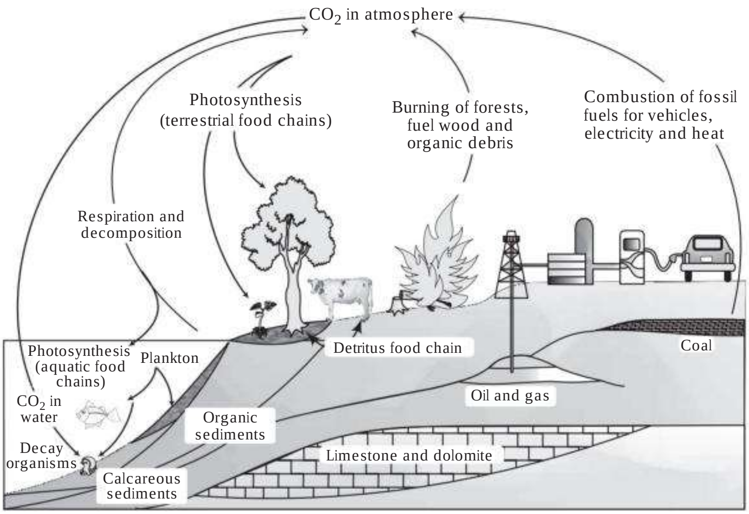
Gaseous Cycles
In these cycles, the main reservoirs of chemicals are atmosphere and ocean, e.g., carbon cycle, nitrogen cycle, etc.

Sedimentary Cycles
In these cycles, the main reservoirs are soil and rocks, e.g., phosphorus and sulphur cycle.

Hydrological Cycle
In this cycle, the reservoir may be in atmosphere or in soil, e.g., water cycle.

Carbon Cycle

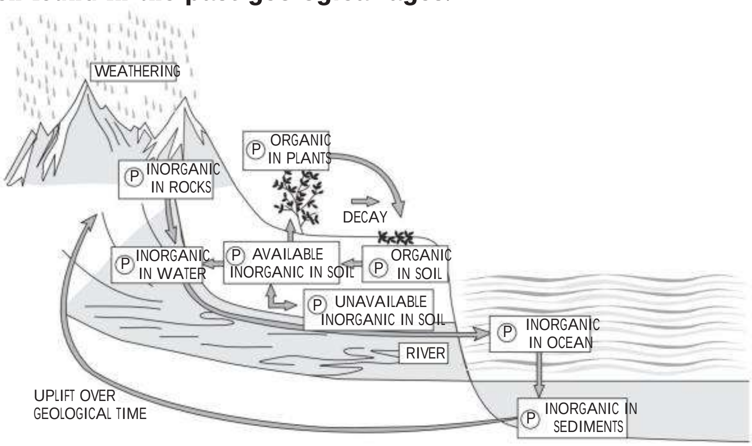
The atmospheric carbon dioxide is virtually the only source of carbon. This gas is used by all the plants in photosynthesis and the end products (organic substances) of this complex process are used in the construction of living matter. **The complete carbon cycle looks like**



The carbon cycle

Phosphorus Cycle

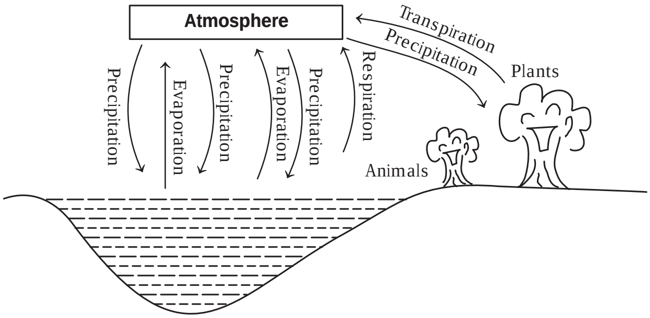
It lacks an atmospheric component. The basic source and the great reservoir of phosphorus are the **rocks** and other deposits, which have been found in the **past geological ages**.



Phosphorus cycle in nature

Hydrological (Water) Cycle

Water moves in ecosystem through various reservoirs, **i.e.,** ocean, atmosphere and living organisms. Following diagrammatic representation gives the idea of water cycle.



Water cycle in nature

Ecosystem Services

Healthy ecosystems are the base for a wide range of economic, environmental and aesthetic goods and services. The products of ecosystem processes are named as **ecological** or **ecosystem services**. Ecosystem services refer to a wide range of conditions and processes through which natural ecosystems and the species that are part of them, help to sustain and fulfil human life.

These services maintain biodiversity and the production of ecosystem goods, such as seafood, wild game, forage, timber, biomass fuels, natural fibres and many pharmaceuticals, industrial products and their precursors. It is also the transformation of a set of natural assets (soil, plants and animals, air and water) into things that we value.

Robert Constanza et. al., have tried to put price tags on nature's life-support services. Scientists have estimated this price to be 33 trillion US dollars a year, while our global gross production is only 18 trillion US dollar.

37

Biodiversity and Conservation

Biodiversity (Gk. **bios**–life; **divsersity**–forms) or Biological diversity can be defined as the vast array of species of living organisms present on the earth.

The term, 'Biodiversity, was coined by **WG Rosen** (1985), but later popularised by **EO Wilson**.

Due to difference in habitat and environment, the biodiversity can be studied at global as well as country level. In India, maximum species of arthropods are found (approx 68,389) among animals, while among plants, maximum species of angiosperms are found (17,500).

Levels of Biodiversity

For the convenience of study, **the biodiversity can be categorised in the following three levels of biological organisations**

1. Genetic Diversity (Within species diversity)

The diversity in number and types of genes as well as chromosomes present in different species and the variation in the genes and their alleles in same species.

It is useful as it involves the adaptation to change in the environmental conditions and is also essential for healthy breeding. It also helps in speciation.

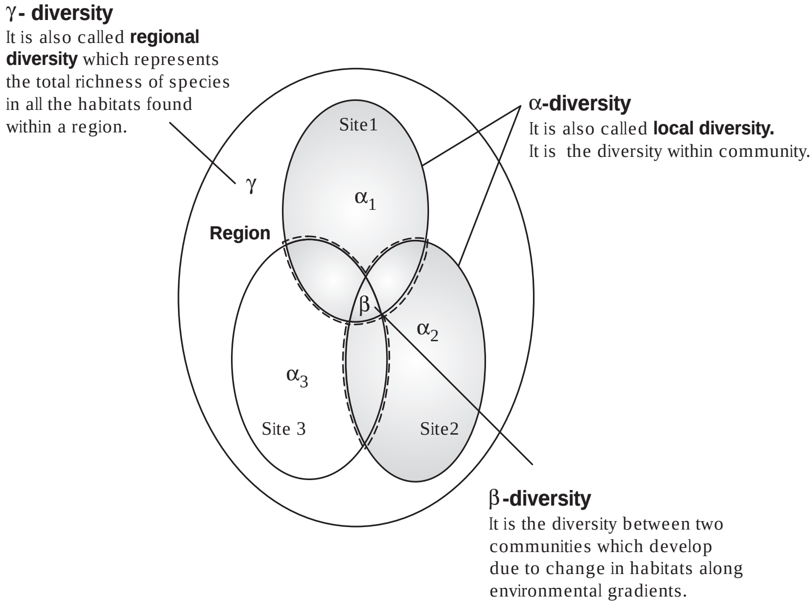
2. Species Diversity (Between species diversity)

It means the species richness in any habitat. Greater the species richness, greater will be their diversity. India is among the world's 15 nations that are exceptionally rich in species diversity. Number of individuals of different species represents the species evenness and species equitability.

3. Community and Ecosystem Diversity (Ecological diversity)

It is the diversity at ecosystem or community level. An ecosystem is referred to as natural when it is undisturbed by human activities.

- Diversity at the level of community or ecosystem has three perspectives, **i.e.,** α, β and γ (Whittaker; 1965).

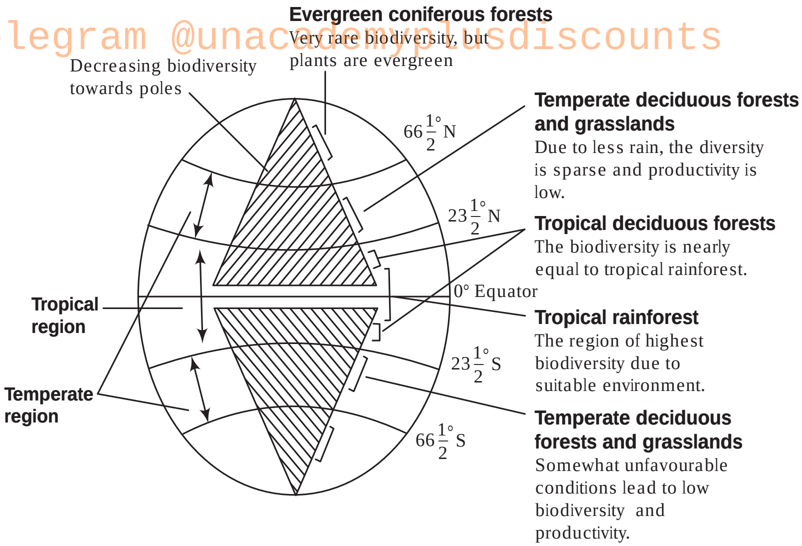


Schematic representation of various levels of diversity

Patterns of Biodiversity

1. Latitudinal Gradient

Generally, species diversity decreases as we move away from the equator towards poles.

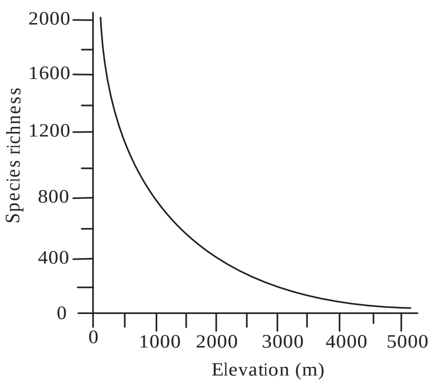


Biodiversity pattern on earth

2. Altitudinal Gradient

The impact of altitude is significant on the type of biodiversity. Mostly the increasing altitude leads to decrease in biodiversity as only some species can adapt the conditions prevailing at high altitude.

Following graph gives the clear idea of this relationship



Effect of altitude on biodiversity

3. Species-Area Relationship

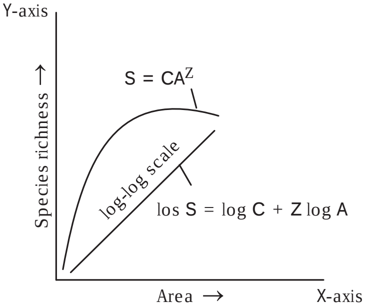
According to German naturalist and geographer **Alexander von Humboldt** "Species richness increases with increasing explored area, but only up to a certain limit".

The relationship between species richness and area gives a rectangular hyperbola curve for a wide variety of taxa like birds, bats, freshwater fishes and flowering plants.

On a logarithmic scale, the relationship is a straight line and is described by the following equation

$$\log \mathbf{S} = \log \mathbf{C} + \mathbf{Z} \log \mathbf{A}$$

Here, **S** is species richness, **Z** is slope of line or regression coefficient, **C** is **Y** intercept, while **A** is area.



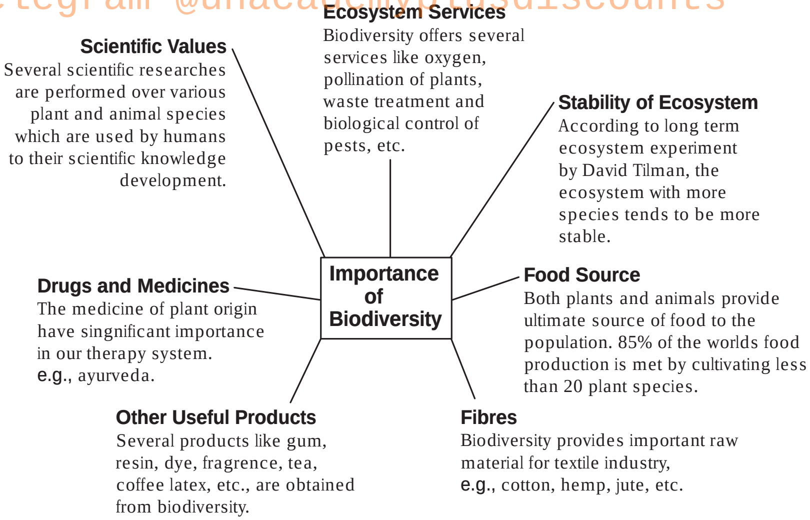
Species-area relationship

Ecologists have discovered that the value of **Z**-line is similar for a small region or area particular, regardless of taxonomic group or region (**i.e.,** 0.1–0.2). But, if we consider a large area (**i.e.,** whole continent), the value of **Z** deviates between 0.6-1.2.

Importance of Biodiversity

Biodiversity is essential not only for ecosystem, but also for the survival of human race. It maintains high productivity and human health.

The detailed description of importance of biodiversity is given below



Importance of biodiversity

The importance of biodiversity is described through an analogy (the 'rivet popper hypothesis') used by **Paul Ehrlich** in which he compared ecosystem with airplane and the species with rivets.

Loss of Biodiversity

The loss of biological diversity is a global crisis. Out of the 1.6 million species known to inhabit the earth, about 1/4 to 1/3 is likely to get extinct within the next few decades. Tropical forests are estimated to contain 50-90% of the world's total biodiversity.

The IUCN (International Union for Conservation of Nature and Natural Resources) Red List (2004) documents the extinction of 784 species (including 338 vertebrates, 359 invertebrates and 87 plants) in the last 500 years.

Some examples of recent extinctions include the **dodo** (Mauritius), **quagga** (Africa), **thylacine** (Australia), **Steller's sea cow** (Russia) and three subspecies of tiger (Bali, Java, Caspian).

The last twenty years alone have witnessed the disappearance of 27 species. Careful analysis of records shows that the extinctions across taxa are not random; some groups like amphibians appear to be more vulnerable to extinction.

Adding to the grim scenario of extinctions, the fact is that more than 15,500 species worldwide are facing the threat of extinction.

Presently, 12% of all bird species, 23% of all mammal species, 32% of all amphibian species and 31% of all gymnosperm species in the world are facing the threat of extinction.

In general, loss of biodiversity in a region may lead to

- Decline in the plant production.
- Lowered resistance to environmental perturbations such as drought.
- Increased variability in certain ecosystem processes, such as plant productivity, water use and pest and disease cycles.

IUCN and Red List Categories

International Union for Conservation of Nature and Natural Resources (IUCN) is now called World Conservation Union (WCU), headquartered at Morges, Switzerland.

The Red Data Book, catalogue the taxa who face the risk of extinction. It was initiated in 1963. The Red List contains 9 categories of individuals according to their threats. **These are**

- Extinct (Ex)
- Extinct in the Wild (EW)
- Regionally Extinct (RE)
- Critically endangered (CR)
- Endangered (EN)
- Vulnerable (VU)
- Near Threatened (NT)
- Least Concern (LC)
- Data Defecient (DD)

Out of these categories, 4, 5 and 6 are the threatened categories.

Causes of Biodiversity Loss

Unbalanced human activities lead to accelerated extinction of species from the world. The major causes of biodiversity reduction are termed as '**Evil Quartat**'.

Some important causes of biodiversity loss are given below

Causes of Biodiversity Loss

Coextinction In ecosystem, the species are related with each other in a trophic structure. Extinction of one species led to the extinction of others as well, it is called coextinction.

Habitat Loss This is the most important cause of of biodiversity loss, e.g., the tropical rainforest once covering 14% surface of earth, now covers not more than 6%. After removal of these habitats, the harbouring species also lost.

Alien Species Invasion When alien species invade in a system by any method, they do not have any environmental barrier which lead to overcrowding of the species and resulted into the replacement of inhabited species.

Overexploitation The human dependency on nature for food, shelter turns into "greed" "need" which in turn led to heavy loss of natural resources, i.e., biodiversity.

Factors causing biodiversity loss

Biodiversity Conservation

Conservation means **protection**, **upliftment** and **scientific management** of biodiversity so as to maintain it at its optimum level and derive sustainable benefits for the present as well as future strategies.

The following are the three major reasons to conserve biodiversity

Narrow utilitarian The useful human products like food, fibres, drugs and medicines are obtained from biodiversity.

Broadly utilitarian Biodiversity provides ecosystem services like providing oxygen, pollinating crops and controlling floods and erosions, etc.

Ethical utilitarian Every living species has an intrinsic value, though it may not have direct economic value and also every species has right to live.

Methods of Biodiversity Conservation

Some main strategies of conservation are as follows

(i) All the threatened species should be protected. Priority should be given to ones belonging to the monotypic genera, endangered over vulnerable, vulnerable over rare and rare over other species.

(ii) All the possible varieties (old or new) of food, forage and timber plants, medicinal plants, livestock, aquaculture animals, microbes should be conserved.

(iii) Wild relatives of economically important organisms should be identified and conserved in protected areas.

(iv) Critical habitats for feeding/breeding/resting/nursing of each species should be identified and safeguarded.

(v) Resting/feeding places of migratory/wide ranging animals should be protected, pollution controlled and exploitation regulated.

(vi) National Wildlife Protection Law should be enacted (in India, 1972), wildlife protection strategies should be formulated (1983) and protection programmes should be integrated with the international programmes.

(vii) Ecosystems should be prioritised.

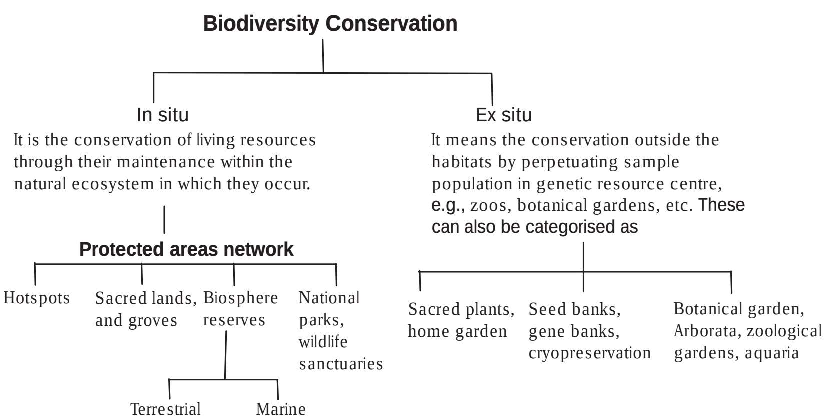
(viii) The reproductive capacity of the exploited species and productivity of the ecosystem should be determined.

(ix) International trade in wildlife should be highly regulated.

(x) Development of reserves or protected areas should be initiated.

(xi) Introduction of new species should be in strict control of regulatory laws.

(xii) Pollution reduction and public awareness should be promoted.



The detailed description of these protected areas is given below

1. Hotspot

The concept of hotspot was given by **Norman Myers** in 1988. Hotspots are the areas that are extremely rich in species diversity, have high endemism and are under constant threat.

Among the 34 hotspots (cover less than 2% of earth land area) of the world, two are found in India extending into neighbouring countries **The Western Ghats/Sri Lanka** and the **Indo–Burma Region** (covering the Eastern Himalayas also known as cradle of speciation).

The key criteria for determining a hotspot are as follows

(i) Number of endemic species, **i.e.,** the species which are found nowhere else.

(ii) Degree of threat which is measured in terms of habitat loss.

Hotspots in India

The two hotspots in India are as follows

(I) Eastern Himalaya

The Eastern Himalayan hotspot extends to the North-Eastern India and Bhutan. The temperate forests are found at altitudes of 1,780 to 3,500 metres. Many deep and semi-isolated valleys found in this region are exceptionally rich in endemic plant species.

Besides being an active centre of evolution and rich diversity of flowering plants, the numerous primitive angiosperm families (**e.g.,** Magnoliaceae and Winteraceae) and primitive genera of plants, like **Magnolia** and **Betula**, are found in Eastern Himalaya.

(II) Western Ghat

The Western Ghats region lies parallel to the Western coast of Indian Peninsula for almost, 1600 km, in Maharashtra, Karnataka, Tamil Nadu and Kerala.

The forests at low elevation (500 m above mean sea level) are mostly evergreen, while those found at 500-1,500 metres height are generally semi-evergreen forests. The Agasthyamalai hills, the Silent valley and the new Amambalam reserve are the main centres of biological diversity.

2. Wetlands

These are an integral part of the watersheds and generally lie at the interface between the land and water. On the basis of their function of filtering water before entering into the large water bodies, they are also known as 'kidneys of ecosystem'.

A convention for the protection of wetlands held in Ramsar on 2nd February 1972, since then 2nd February was celebrated as **World Wetland Day**.

In India, there are 26 Ramsar sites present.

3. National Parks of India

India's first national park (IUCN Category-II Protected area) was **Hailey National Park**, now known as **Jim Corbett National Park**, established in 1935. By 1970, India had only five national parks.

In 1972, India enacted the **Wildlife Protection Act** and **Project Tiger** to safeguard habitat. Further, Federal Legislation strengthening the protections for wildlife was introduced in the 1980s. As on April 2012, there are 102 national parks.

Some important national parks of India are mentioned in the following table with their belonging states

Some National Parks in India

Name	State
Bandipur National Park	Karnataka
Bannerghatta National Park	Karnataka
Bhitarkanika National Park	Odisha
Buxa Tiger Reserve	West Bangal
Corbett National Park	Uttarakhand
Dachigam National Park	Jammu and Kashmir
Dibru-Saikhowa National Park	Asom
Gir National Park	Gujarat
Great Himalayan National Park	Himachal Pradesh
Gugamal National Park	Maharashtra
Hemis National Park	Jammu and Kashmir
Indravati National Park	Chhattisgarh
Intanki National Park	Nagaland

Name	State
Kanha National Park	Madhya Pradesh
Kaziranga National Park	Asom
Kanchenjunga National Park	Sikkim
Kishtwar National Park	Jammu and Kashmir
Madhav National Park	Madhya Pradesh
Manas National Park	Asom
Mouling National Park	Arunachal Pradesh
Namdapha National Park	Arunachal Pradesh
Nameri National Park	Asom
Nanda Devi National Park	Uttarakhand
Palani Hills National Park	Tamil Nadu
Periyar National Park	Kerala
Pine Valley National Park	Himachal Pradesh
Rajaji National Park	Uttarakhand
Rani Jhansi Marine National Park	Andaman and Nicobar Islands
Sariska National Park	Rajasthan
Silent Valley National Park	Kerala
Simlipal National Park	Odisha
Sri Venkateshwara National Park	Andhra Pradesh
Sundarbans National Park	West Bangal
Tadoba National Park	Maharashtra
Valmiki National Park	Bihar

4. **Wildlife Sanctuary**

India has over 448 wildlife sanctuaries. Characteristically in wildlife sanctuaries, the protection is given to animal life only.

Some important sanctuaries of India are given in following table

Some Important Sanctuaries in India

Name and Location	Area (in sq km)	Key Vertebrate Species being Protected
Chilka Lake (Odisha)	990	Flamingoes, sandpipers, ducks, water fowls, cranes, golden plovers and ospreys.
Keoladeo Ghana Bird Sanctuary (Rajasthan)	29	Migratory birds Siberian crane, spoon bill, herons, egrets and variety of other local birds. Mammals Blue bull, wild boar, black buck and spotted deer. Reptiles Python.
Mudumalai Wildlife Sanctuary, Nilgiri (Tamil Nadu)	520	Mammals Flying squirrel, porcupine, elephant, sambhar, cheetal, barking deer, mouse, deer, four-horned antelope, giant squirrel, wild dog, cat and civet. Reptiles Rat snake, python, flying lizard and monitor lizard.
Manas Wildlife Sanctuary, Kamrup (Asom)	—	Tiger, wild boar, sambhar, golden langoor, one-horned rhino, panther, swamp deer, wild dog and wild buffalo.
Periyar Sanctuary (Kerala)	777	Mammals Elephants, leopard, black langoor, sambhar, gaur, bison. Birds Egret and horn bills.
Sultanpur Lake Bird Sanctuary (Uttar Pradesh)	12	Birds Cranes, duck, green pigeon, drake and spot bill. Reptiles Python and crocodile.

5. Biosphere Reserves

These are special protected areas of land and/or coastal environments, wherein people are an integral component of the system. These are the representative examples of natural biomes and contain unique biological communities within. They represent a specified area zonated for particular activities.

These consist of

- **Core zone** No human activity is allowed in this zone.
- **Buffer zone** Limited activity is permitted.
- **Manipulation zone** Several human activities are allowed.

There are 14 biosphere reserves established in India, which are mentioned here.

The main biosphere reserves of India include

(i) Nilgiri Biosphere Reserve
(ii) Pachmarhi Biosphere Reserve
(iii) Manas Biosphere Reserve
(iv) Great Nicobar Biosphere Reserve
(v) Nanda Devi Biosphere Reserve
(vi) Nokrek Biosphere Reserve
(vii) Agasthyamalai Biosphere Reserve
(viii) Kanchenjunga Biosphere Reserve
(ix) Dehang-Debang Biosphere Reserve
(x) Dibru-Saikhowa Biosphere Reserve
(xi) Simlipal Biosphere Reserve
(xii) Sundarbans Biosphere Reserve
(xiii) Gulf of Mannar Biosphere Reserve

6. Zoos

It is the place where wild animals are kept for public viewing. Many of them have various rare species of animals and have recorded success in captive breeding of animals.

The following table will give the information about important zoos in India.

Zoos in India

Name	City	State
Arignar Anna Zoological Park	Chennai	Tamil Nadu
Asom State Zoo	Guwahati	Asom
Aurangabad Zoo	Aurangabad	Maharashtra
Bannerghatta Biological Park	Bangaluru	Karnataka
Children's Corner Zoo	Chennai	Tamil Nadu
Guindy Snake Park	Chennai	Tamil Nadu
Indira Gandhi Zoological Park	Vishakhapatnam	Andhra Pradesh
Indore Zoo	Indore	Madhya Pradesh
Jawahar Lal Nehru Biological Park	Bokaro	Jharkhand
Kamla Nehru Zoological Park	Ahmedabad	Gujarat
Kanpur Zoological Park	Kanpur	Uttar Pradesh
Nehru Zoological Park	Hyderabad	Andhra Pradesh
Sanjay Gandhi Biological Park	Patna	Bihar
Sri Chamarajendra Zoological Park	Mysore	Karnataka
Veermata Jijabai Udyan Zoo	Mumbai	Maharashtra

7. **Botanical Gardens**

These play an important role in the conservation of plant species as that there are several instances when plants believed to be extinct, were found living only in a botanical garden. **Sophora toromiro** is the famous example.

Record of threatened plants that are in cultivation have been kept in Green Books. The **Indian Green Book** prepared by BSI which lists 100 such species which are rare, endangered or endemic, but all are growing in a living state in various botanical gardens.

With the help of above measure, we can easily protect the biodiversity present all around us. The protection of biodiversity cannot be only accomplished by government organisation, but it is the cumulative responsibility of every individual.

38 Environmental Issues

Humans have always inhabited **two worlds**. One is the **natural world** of plants, animals, soil, air and waters that preceded us by billion of years and of which, we are a part. The other is the **world of social institutions** and artifacts that we create for ourselves using science, technology and political organisation.

Where earlier people has limited ability to alter their surroundings, we now have power to extract and consume resources, produce wastes and modify our world in a way that threatened both our continued existence and that of many organisms with which we share the planet.

Environmental issues include the aspects which adversely affect our biophysical environment. Pollution, global warming, deforestation, etc., are the topics of major concern in current perspective.

Pollution

Pollution is the addition of the harmful agents to the ecosystem, which has detrimental effects on it. Environmental pollution is any discharge of materials or energy into air, water or land that may cause **acute** (short term) and **chronic** (long-term) effects on the earth's ecological balance or may lower the quality of life.

Pollution can be defined by different organisations differently.

Some of these are as follows

World Health Organisation (WHO) has defined that 'Pollution is the introduction of harmful materials into the environment'.

According to Central Pollution Control Board (CPCB), 'Pollution means contamination of water, air and land in such a way that alters the physical, chemical and biological property of that resource'.

Ministry of Environment and Forest (MOEF) defined pollution as 'Introduction of different harmful pollutants into certain environment that makes it unhealthy to live in'.

Pollutants

Pollutants are chemicals or biological substances that deteriorate our natural environment.

Types of Pollutants

- On the basis of their chemical nature
  - Organic pollutants e.g., DDT, oils, etc.
  - Inorganic pollutants e.g., nitrates, metals, etc.
  - Acid pollutants e.g., runoff from coal mining
  - Radiological pollutants e.g., radioactive chemicals found in soil, rocks, etc.
  - Biological pollutants e.g., bacteria, virus, etc.
  - Multiple pollutants e.g., xenobiotics
  - Physical pollutants e.g., soil carried in rainwater.
- On the basis of existence in nature
  - Quantitative pollutants e.g., CO_2, etc.
  - Qualitative pollutants e.g., pesticides, etc.
- On the basis of natural degradation
  - Biodegradable e.g., sewage
  - Non-biodegradable e.g., DDT, BHC, etc.
- On the basis of persistence
  - Primary pollutants e.g., DDT, CO_2, etc.
  - Secondary pollutants e.g., O_3, PAN, etc.

Types of Pollution

On varions basis pollution can be categorised as

Pollution

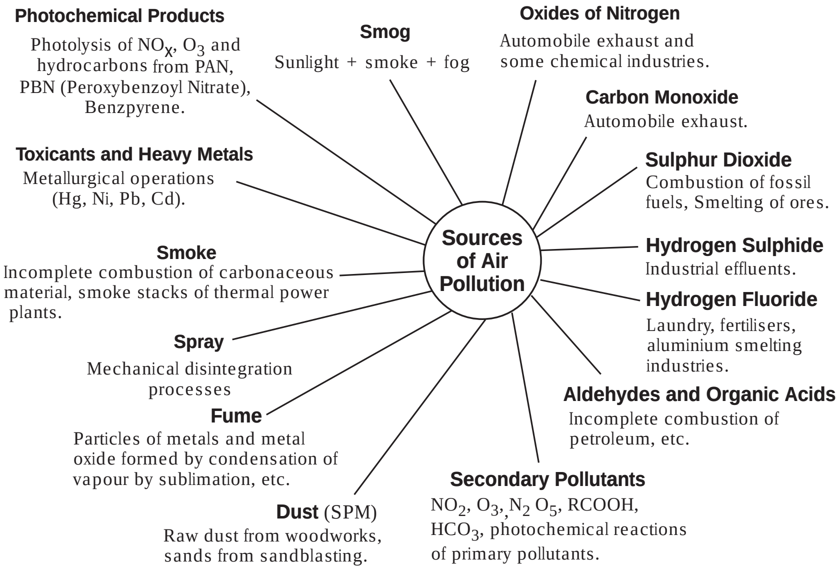
- **On the basis of part of environment where it occurs**
  - Air pollution
  - Water pollution
  - Land pollution
  - Genetic pollution, etc.
- **On the basis of its origin**
  - Natural e.g., volcanic eruptions, etc.
  - Anthropogenic e.g., fossil fuel burning, mining, etc.
- **On the basis of physical nature of pollutant**
  - Gaseous pollution
  - Dust pollution
  - Thermal pollution
  - Noise pollution
  - Radioactive pollution
- **On the basis of emission of pollutants**
  - Point source pollution
  - Line source pollution
  - Area source pollution
  - Diffuse source pollution
  - Fixed source pollution
  - Mobile source pollution

Air Pollution

It is an undesirable change in the natural characteristics of the atmosphere due to contamination of indoor and outdoor environment by any chemical, biological or physical agent.

Sources of Air Pollution

Various air pollutants and their originating causes are given in the following figure



Chief air pollutants and their sources

The six types of air pollutants that account for the most of the air pollution are called **criteria air pollutants**.

Effects of Air Pollution

The air pollution has following effects on various organisms

1. Effects on Humans

The following table provides the list of various air pollutants and their effects on human body

Common Air Pollutants and their Effects on Human Body

Pollutants	Effect on Human Body
Aldehydes	Irritate nasal and respiratory tract.
Ammonia	Inflames upper respiratory passage.
Arsenic	Breakdown of red cells in blood, damage to kidneys, causes jaundice, lung and skin cancer.
Carbon monoxide	Reduces O_2 carrying capacity of blood.
Chlorine	Attacks entire respiratory tract and mucous membrane of eyes, causes pulmonary oedema.
Cyanides	Interfere with nerve cells, resulting in dry throat, indistinct vision, headache.
Fluorides	Irritate and corrode all body passages, cause osteoporosis.
Sulphides	Cause nausea, irritate eyes and throat.
Nitrogen oxides	Inhibit ciliary action of nose, cause bronchitis.
Phosgenes (carbonyl chloride $COCl_2$)	Induce coughing, irritation and sometimes fatal pulmonary oedema.
Sulphur	Causes chest constriction, headache, vomiting and death from respiratory ailments.
Suspended particles (ash, soot, smoke)	Cause emphysema, eye irritation and possibly cancer.

2. Effects on Plants

Air pollution also causes several damages to plants.

These are listed below

Injury Thresholds and Effects of Air Pollutants on Plants

Pollutant	Effect on Plants	Concent ration (ppm)	Sustained Exposure Time
Ozone (O_3)	Flecks, bleaching, bleached spotting, growth suppression. Tips of conifer needles become brown and necrotic.	0.03	4h
Sulphur dioxide (SO_2)	Bleached spots, bleached areas between veins, chlorosis, growth suppression, reduction in yield, leaf curling.	0.03	8h
Peroxyacetyl Nitrate (PAN)	Glazing silvering or bronzing on the lower surface of leaves.	0.01	6h

Pollutant	Effect on Plants	Concentration (ppm)	Sustained Exposure Time
Hydrogen Fluoride (HF)	Chlorosis, dwarfing, leaf abscission, lower yield.	0.0001	5 weeks
Chloride (Cl_2)	Bleaching between veins, tips and leaf abscission.	0.01	2h
Ethylene (C_2H_4)	Withering, leaf abnormalities, flower drooping and failure of flower to open.	0.05	6h

3. Effects on Climate

Air pollution causes **acid rain**. The acid rain has various negative effects. **The effects of acid precipitation can be categorised as**

Effect on Climate

Effects on Aquatic Life
Acidic deposition adversely affects the aquatic life by making water acidic. The ponds in which the biodiversity reduces at significant level, are called 'Biologically dead'.

Effects on Forest
Acid deposition negatively affects the forests. The red spruce forest in tropical areas are killed severely.

Effects on Building and Monuments
The oldest building and monuments all over the world are destroyed by atmospheric acids at an alarming rate.

Effects of air pollution on climate

Control of Air Pollution

Several methods are used to control air pollution.

Some of them are as follows

1. Use of High Chimneys

For proper escaping of smoke, fumes and heated air, the industrial plants should have high chimneys.

2. Government's Norms for Emission

In the line of world standard, Government of India also has formulated new fuel policies.

These fuel policies with their applicable regions are given below

Standard	Reference	Date	Region
India 2000	Euro 1	2000 2001	Nationwide, NCR*, Mumbai, Kolkata, Chennai
Bharat stage II	Euro 2	2003. 04 2005. 04	NCR*, 10 cities Nationwide
Bharat stage III	Euro 3	2005.04 2010.04	NCR*, 10 cities Nationwide
Bharat stage IV	Euro 4	2010.04	NCR*, 10 cities

* National Capital Region (Delhi)

 Mumbai, Kolkata, Chennai, Bangaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur and Agra

3. Other Control Measures to Control Air Pollution

These methods are characterised on the basis of physical nature of pollutants.

(i) Methods to Control Particulate Pollutants

Different technological equipments are used to control particulate pollution. **These are**

(a) **Cyclonic separator** In this, centrifugal force causes the settling of particulate matters.

(b) **Trajectory separators** In this, heavier particles settle down, when dirty air is passed from a chamber as an oblique jet.

(c) **Electrostatic precipitator** Particulate matter present in dirty air are charged electrically and passed through a chamber where these particles loose their charges and settle down.

(d) **Filters** Particulate matter get filtered out by passing dry emissions under pressure through polyester, teflon and polyamide bags which are large sized and porous.

(ii) Methods to Control Gaseous Pollutants

The gaseous pollution can be inhibited by following set of methods

Adsorption Technique
The toxic gases from dirty air are removed by very fine solid particles (e.g., charcoal).

Combustion Technique
The emission are burnt at high temperature to remove gaseous pollutants.

Absorption Technique
The packing materials, fixed in scrubber are used to absorb the gaseous pollutants.

Scrubber
The exhaust is passed through a spray of water or lime to remove gases like SO_x.

Catalytic Converter
It contains expensive metals like Platinum, Palladium and Rhodium as the catalyst. After passing through it, unburnt hydrocarbons are converted into CO_2 and water.

Water Pollution

Water is said to be polluted when its quality gets degraded due to the addition of various inorganic, organic, biological and radiological substances, which make it unfit and a health hazard.

Impurities in the form of variables are as follows

Water Quality Variables

Chemical
It includes all possible inorganic and organic substances, such as chlorides, sulphates, nitrates nitrites, boron, heavy metals, pesticides, phenol, cyanide, oil, etc., ions concentrations, BOD and COD, etc., of water.

Physical
It includes **appearance, temperature**, **turbidity**, **colour**, **odour** and **taste**, etc.

Biological
The presence of all flora and fauna in water at a particular time.

Categories of water pollutants

The comparative account of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) is given as

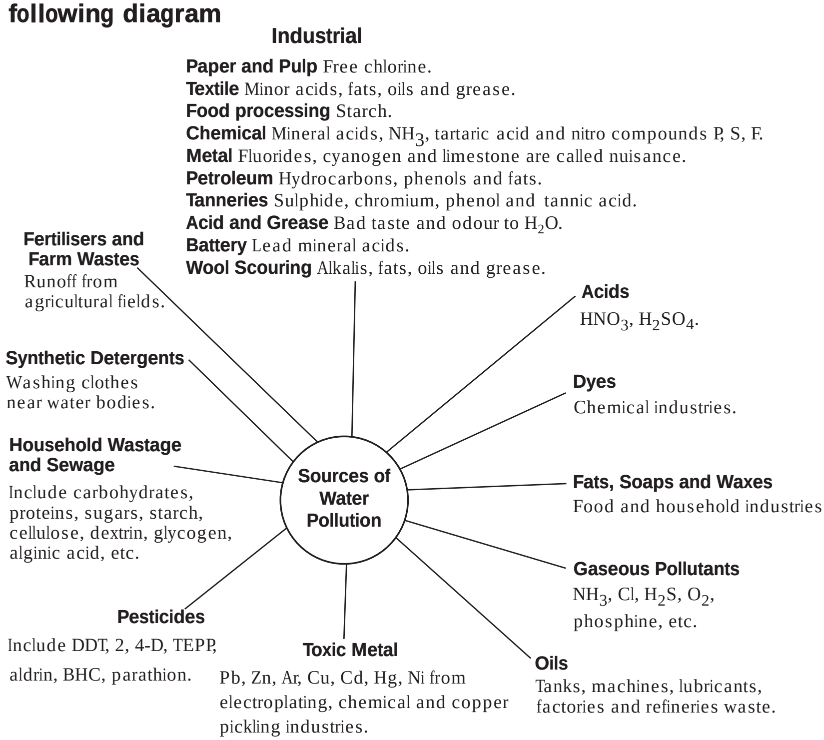
Comparison of BOD and COD

Biochemical Oxygen Demand (BOD)	Chemical Oxygen Demand (COD)
It is the amount of oxygen used for biochemical oxidation by microorganisms in a unit volume of water.	It is the amount of oxygen required by organic matter in a sample of water for its oxidation by a strong chemical oxidant and is expressed as ppm of oxygen taken from the solution of potassium dichromate in 2 hours.

Biochemical Oxygen Demand (BOD)	Chemical Oxygen Demand (COD)
BOD value approximates the amount of oxdisable organic matter and therefore, used as a measure of degree of water pollution and waste.	This value is a poor measure of strength of organic matter, as oxygen is also consumed in the oxidation of inorganic matter such as nitrates, sulphates, reduced metal ions and also that some organic molecules such as benzene, pyridine and few other cyclic organic compounds which are not oxidised by this test.
BOD test is influenced by many factors such as types of microorganisms, pH, presence of toxins, some reduced mineral matter and nitrification of microorganisms.	Presence of toxins and other such unfavourable conditions for the growth of microorganisms does not affect COD values.

Sources of Water Pollution

The various sources of water pollution can be explained through the following diagram



Water pollutants and their sources

Effects of Water Pollution

Water pollution affects individuals severely and causes various diseases, which depend upon the nature of pollutants.

Chief pollutants and their toxic effects are given in the following table

Some Elements and their Toxic Effects in Humans

Elements	Toxic effects
Aluminium	Interferes with phosphate metabolism, inhibits absorption of fluorides, Ca and iron compounds.
Arsenic	Loss of appetite, copious secretion of mucus in respiratory tract, black foot disease.
Cadmium	Itai-itai disease (Japan), kidney damage.
Fluorine	Fluorosis, about 5-12 ppm is toxic, enamel becomes brittle, bones lose their elasticity and are prone to fractures, impairs glycolysis, knock-knee disease.
Lead	Anaemia and mental retardation due to degenerative changes in motor nerves.
Mercury	Minamata disease, main site of injury is CNS leading to tremors inability to coordinate, impairment of vision and loss of hearing. Two major episodes of mercury poisoning have occurred in Japan, in Minamata bay and Niigata. Mercury was absorbed, bioaccumulated and biomagnified to high levels. Fish collected from this bay had 10-12 mg of Hg per kg of their flesh and bones. The largest mercury epidemic occurred in 1971-72 in Iraq, when 6000 people were affected and 500 died; infertility in human.

Control of Water Pollution

Water pollution can be controlled through various measures, **some of them are discussed here**

(i) Reduced use of pesticides and chemical fertilisers in agriculture.

(ii) Avoid the disposal of waste into water.

(iii) Proper sewage treatment before disposal into large water bodies.

(iv) Control of disposal of industrial waste into water.

(v) Proper maintenance of water bodies.

Special Cases of Water Pollution

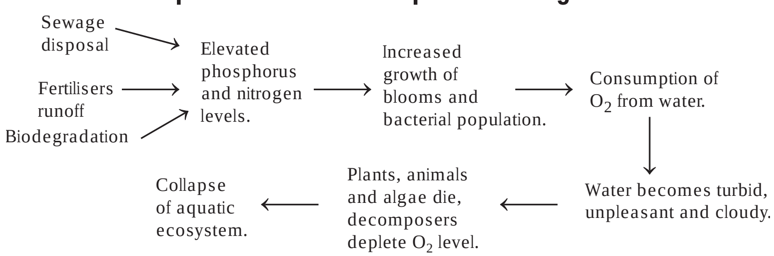
Eutrophication and biomagnification are two special cases of water pollution.

Eutrophication

Eutrophic (**eu** + **trophic** = truely nourished) waters are rich in organisms and organic materials. Eutrophication is an **increase in nutrient level and productivity**.

As with BOD, eutrophication often results from nutrients enrichment. Sewage, fertiliser runoff and other human activities cause increase in biological productivity which is called **cultural eutrophication**.

The schematic representation of eutrophication is given below.



Events of eutrophication

Algal Bloom

The presence of large amount of nutrients in water causes excessive growth of algae which is known as algal bloom. It imparts distinct colour to the water bodies and causes deterioration of water quality.

Biomagnification/Bioaccumulation

Many pesticides such as DDT, aldrin and dieldrin have a long life in the environment. These are fat soluble and generally non-biodegradable.

After incorporation into food chain, they get magnified and accumulated in higher trophic level. The process of **biological magnification** is also reported for certain other pollutants such as lead (Pb), mercury (Hg), copper (Cu) and strontium-90.

The diagrammatic representation of bioaccumulation is shown below.

	Water	Microscopic Aquatic Organisms	Small Fishes	Large Fishes	Fish Eating Birds
DDT levels	0.000003 ppm	0.04 ppm	0.5 ppm	2.0 ppm	25.0 ppm

Soil Pollution

It is defined as the build up in soils of **persistent toxic compounds**, **chemicals**, **salts**, **radioactive material** and **disease causing agents** which have adverse effects on health of inhabiting organisms.

It can be of following two types

(i) **Negative soil pollution** It is the reduction in soil productivity due to erosion and overuse.

(ii) **Positive soil pollution** It is the reduction in soil productivity, because of addition of undesirable substances like fertilisers into soil.

Sources and Effects of Soil Pollution

The chief agents of soil pollution and their effects on soil are presented diagrammatically below.

Sources of Soil Pollution

Biological Agents

Excreta of humans, animals and birds is the major one.
Pathogenic organisms are
(i) Bacteria, fungi and parasitic worms, etc.
(ii) Excreted by animals, cow, pig, sheep, etc.,
(iii) Naturally found in soil due to some edaphic cause.

Diseases caused by these agents are **dysentery**, **cholera**, **typhoid**,etc.

Industrial and Urban Waste

Examples of industrial and urban wastes are
(i) Coal and mineral mines, metal processing industries and engineering industries.
(ii) Domestic and community wastes, i.e., sludge.
(iii) Garbage, rubbish materials such as paper, residues from home, fuels, street sweepings, glasses, rubber and abandoned vehicles, etc.

Dumping of solid wastes not only creates aesthetic problems but also public health problems.

Radiological Agents

From nuclear explosion and radioactive wastes (nuclear testing and laboratories) like ruthenium 106, rhodium 106, iodine 131, barium 140, lanthanium 140, cerium 144, promethium 144, carbon 14, cesium 137, create several serious health hazards, e.g., cancer.

Agricultural Practices

Fertilisers, pesticides, soil condition, fumigant and other chemical agents. Farming phosphates, nitrates, DDT, BHC, endrin, aldrin, dieldrin, organosulphurous compounds, organic compounds with Pb, Hg, Ar are toxic to plants. Lindane has been reported to, taint carrots. Flies, insects and rodents multiply which in turn harm the crop.

Various factors causing soil pollution

Control of Soil Pollution

The control of soil pollution can be done through following steps

(i) It involves safer land use, planned urbanisation, controlled developmental activities, safe disposal and the management of solid wastes.

(ii) In recovering and recycling some waste items like plastics, tin cans, other metals, glass, polyethylenes, rags, papers, etc., are picked up by rag pickers for recycling. All these items are recycled in recycling units to make new items. This reduces soil pollution.

(iii) To reduce soil pollution solid waste is sometimes disposed off by burning. **The methods of burning are**

(a) **Incineration** Carried out at very high temperature, **i.e,** 900-1300°C.

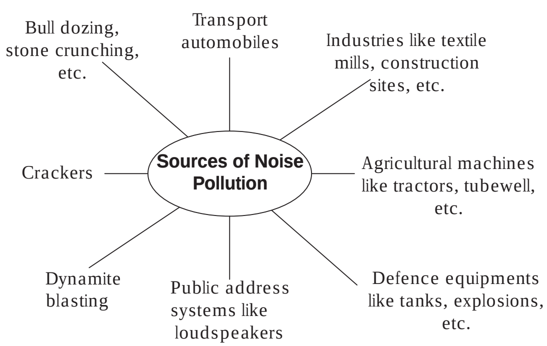
(b) **Pyrolysis** It is combustion at temperature 1650°C in the absence of oxygen.

Noise Pollution

Noise is defined as any loud disturbing sound released into the ambient atmosphere. It is measured by a sound meter and is expressed in a unit called decibel (dB). Any value more than 80 dB causes noise pollution.

Sources of Noise Pollution

There are as follows



Effects of Noise Pollution

- May cause a partial or permanent loss of hearing.
- Can impair the development of nervous system of unborn babies.
- Hatching of birds is disturbed.

Control of Noise Pollution

- Volume of loudspeakers should be kept low.
- Traffic police personnel and factory workers exposed to high noise pollution should be provided with the **ear plugs** or **ear muffs**.
- **Green belt vegetation** should be maintained to serve as noise absorbers.

Thermal Pollution

It is the degradation of water quality by any process that changes the whole water temperature.

It can also be defined as 'warming up of an aquatic ecosystem to the point where desirable organisms are adversely affected' (Owen, 1985).

Causes of Thermal Pollution

Major sources of thermal pollution are many industries, thermal power plants, oil refineries, etc. The use of coolants and boilers in thermal power plants is an important cause of thermal pollution.

Effects of Thermal Pollution

Harmful effects of thermal pollution on aquatic ecosystems are as follows

(i) Reduction in dissolved oxygen.
(ii) Interference with reproduction of aquatic animals.
(iii) Increased vulnerability to diseases.
(iv) Direct mortality.
(v) Invasion of destructive organisms.
(vi) Undesirable changes in algal population.
(vii) Elimination of flora and fauna of cold water.

Radioactive Pollution

The release of radioactive material into environment is called radioactive pollution. This is very dangerous as radiation can mutate the DNA which causes abnormal growth and sometimes cancer. The radiation remains in atmosphere for years, slowly diminishing over times.

Causes of Radioactive Pollution

There are many causes of radioactive pollution. The most important one is inappropriately disposed radioactive wastes.

Some of these causes are as follows

(i) Production of nuclear weapons
(ii) Decommissioning of nuclear weapons
(iii) Medical waste
(iv) Mining of radioactive ores
(v) Coal ash
(vi) Nuclear power plants
(vii) Nuclear tests

Effects of Radioactive Pollution

The nuclear radiations cause genetic variation (**i.e.,** mutation) and cancer in exposed organs or body parts. These radiations affect the future generations as it can alter the DNA composition permanently.

Solid Wastes

These wastes are left over that goes out in trash. The various sources of solid wastes are municipal waste, mining waste, hospital waste, defunct ships, electronic wastes (e-wastes), etc.

Different modern industries are releasing large amount of solid wastes which need to be managed in proper way to avoid environmental loss.

Control of Solid Wastes

There are various controlling measures of solid wastes, **some of them are discussed below**

(i) Dumping or landfilling is pilling of waste on selected low lying land. **Open landfilling** is dumping of waste material on uncovered low lying area. The waste is burnt periodically or compressed at intervals. In **sanitary landfilling**, wastes are dumped in a depression or trench after compactions and covered with dirt everyday.

Most importantly the solid wastes can be treated after separation into three types

(a) Biodegradable (b) Recyclable (c) Non-biodegradable

(ii) E-wastes are treated scientifically in an environment friendly manner and then either buried in landfills or incinerated.

(iii) Other methods of disposing wastes are source reduction, composting, recovery and recycling.

(iv) **Ahmed Khan** in 1998, developed polyblend, a fine powder of recycled modified plastic, which can be used for road carpeting when mixed with bitumen in Bengaluru.

Consequences of Pollution

Greenhouse Effect (GHE)

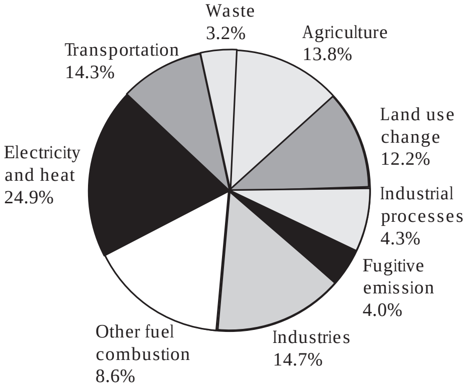
It was first described by **Fourier** in 1827.

It is defined as 'The trapping of solar radiation by a layer of Greenhouse Gases (GHGs), which is important for the maintenance of habitable temperature on earth'.

Greenhouse Effect (GHE) is a **positive concept** as it is needed for existence of life on earth and in the absence of it, the temperature of earth would be –18° C.

Causes of GHE

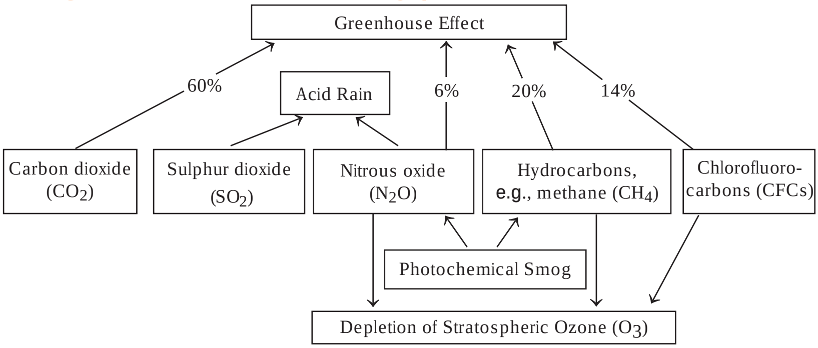
The greenhouse effect is caused by several gases. **The share of greenhouse effect by different sources are given in following figure**



Annual global greenhouse gas emission in 2010, by different sectors

Despite their differential concentrations, different gases cause varied level of greenhouse effects. This is called **differential greenhouse effect**.

Differential greenhouse effect caused by various substances is shown in the following figure



Differential greenhouse effect

The greenhouse effect is increasing day by day with increasing concentration of these substances into the environment. **Chief greenhouse substances and their brief descriptions are as follows**

Greenhouse Gases (GHGs)

Carbon Dioxide (CO_2)
Present level in atmosphere is 380 ppm (parts per million).
Atmospheric lifetime is 5-200 yr.
It is increasing due to fossil fuel's burning, deforestation and change in land use.
High concentration may cause fertilisation effect, i.e., increase in the rate of photosynthesis and growth of plants, decrease in stomatal conductance and transpiration rate.

Methane (CH_4)
Present level in atmosphere is 1750 ppb (parts per billion).
Methanogen bacteria increase greenhouse effect by producing methane.
The major sources are freshwater wetlands, enteric fermentation in cattle. Flooded rice fields along with biomass burning.

Nitrous Oxide (N_2O)
Present atmospheric concentration is 316 ppb (parts per billion).
Major sources are agriculture, biomass burning, nylon industries, nitrogen rich fertilisers and fuels.

Chlorofluorocarbons (CFCs)
Present atmospheric concentration is 282 ppt (parts per trillion).
Atmospheric life is 45-260 yr.
Major sources are leakage from air conditioners, refrigeration units, evaporation of industrial solvents, production of plastic foams and propellants in aerosol, spraycans.

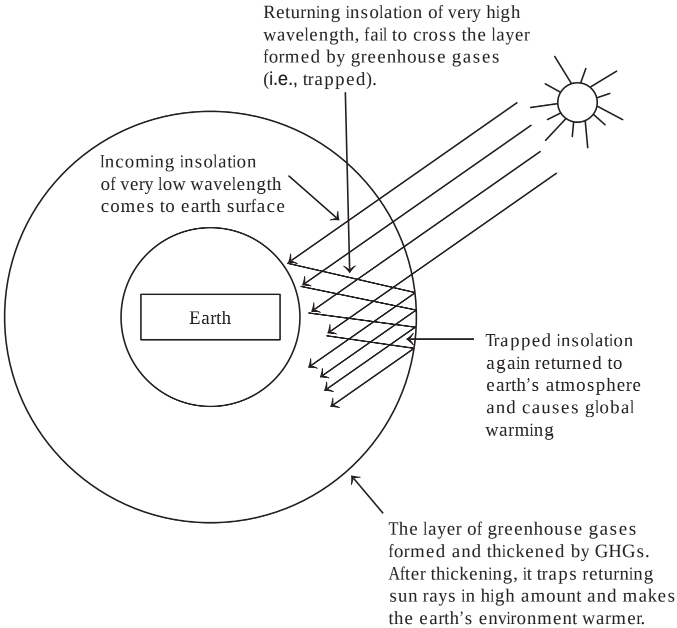
Chief greenhouse gases, their sources and effects

In most scenarios, emissions continue to rise over the century, while in a few, emissions are reduced. Over the last three decades of 20th century, GDP per capita and population growth were the main driving factors in greenhouse gas emissions.

Global Warming

The gradual continuous increase in average temperature of the surface of earth as a result of increase in the concentration of greenhouse gases is termed as **global warming**.

The global average surface temperature rose 0.6 - 0.9°C (1.1-1.6°F) between 1906 and 2005 and the rate of temperature increase has doubled in the last 50 years.



Schematic representation of global warming

Effects of Global Warming

Various effects of global warming are as follows

(i) The temperature of the earth has increased by 0.6°C in last three decades, which will lead to changes in precipitation patterns.

(ii) Rise in temperature leads to deleterious changes in environment resulting in odd climatic changes called **El Nino effect**.

(iii) The rise in temperature will lead to the increased melting of polar ice caps, which will cause the rise in sea level and many coastal areas will be submerged.

(iv) Increased temperature will lead to increased weed growth, eruption of diseases and pests. Thus, crop productivity will decrease.

Steps to Control Global Warming

(i) Kyoto (Japan) hosted an international conference from December 1-10, 1997 of G-77 (a group of 140 developing countries) to discuss **global warming**.

(ii) To assess the role of human activities in climate change, the **World Meterological Organisation** (WMO) and United Nations Environment Programme (UNEP) set-up an Intergovernment Panel on Climate Change (IPCC) in 1988. The IPCC and United Nations Framework on Climate Change (UNFCC) that had reviewed the situation in October 1997, submitted their report in Kyoto in **Kyoto Protocol**.

(iii) **Earth Day (22 April)** It was founded by **Gaylord Nelson** and organised by **Danis Hayes**. It marks the beginning of environment consciousness with clear focus on reducing pollution. The earth day network promotes environment awareness and year round progressive action.

Acid Rain

It is a broad term referring to a mixture of wet and dry deposition from the atmosphere containing higher than normal amount of **nitric** and **sulphuric acids**.

Acid rain occurs when these gases (SO_x and NO_x) react in the atmosphere with water, oxygen and other chemicals to form various acidic compounds.

Acidic deposition occurs in two ways, i.e., wet and dry.

Acid Deposition (acid rain)

Wet Deposition

It refers to **acidic rain**, **fog** and **snow.** They result when acidic chemicals in air are blown into wet areas. The strength of the effect depends upon the acidity of water, chemistry and buffering capacity of soil, etc.

Dry Deposition

When acidic chemicals are deposited in the form of dust or smoke and fall to the ground through dry deposition.

Causes of Acid Rain

It may cause due to natural sources like volcanoes or by the combustion of fossil fuel in which SO**x** and NO**x** get released.

Effects of Acid Rain

Acid rain have various adverse effects on several groups of organisms. The overall pH of water bodies and soil gets reduced by acidic rain. Acid deposition adversely affects both the floral and faunal biodiversity in various ecosystems.

Finally acid rain also causes the damage to several architecture and buildings. It causes the process of mineralisation, especially in limestone constructed buildings.

Ozone Layer Depletion

In the region of upper stratosphere (ozonosphere), 17-26 km above the earth's surface, exists a thin veil of renewable ozone (O_3). This ozone layer absorbs 99% of the harmful incoming UV radiations.

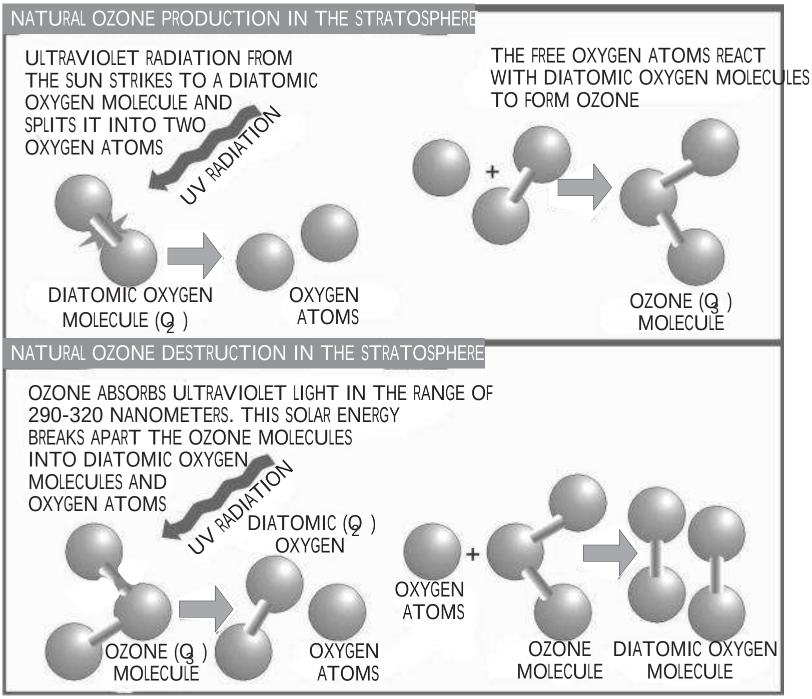
The energy of radiation gets dissipated in the following reaction

$$O_3 \rightarrow O_2 + [O]$$

Ozone is being depleted by several man-made chemicals called **Ozone Depleting Compounds** (ODCs) or **Ozone Depleting Substances** (ODSs)

It was first detected by **Farman** et al. in 1984.

The process of the formation and breakdown of ozone in stratosphere is diagrammatically represented below.



Ozone production and destruction in nature

Rather than a 'hole', ozone depletion is more a thinning, where ozone level has decreased by 50% to 100%. Ozone loss is projected to diminish gradually until around 2050, when polar ozone holes will return to 1975 levels.

Mechanism of ozone depletion is as follows

$$CFCl_3 \xrightarrow{\text{UV-C}} CFCl_2 + Cl$$

$$CFCl_2 \xrightarrow{\text{UV-C}} CFCl + Cl$$

$$Cl + O_3 \rightarrow ClO + O_2$$

$$ClO + O_3 \rightarrow Cl + 2O_2$$

Harmful Effects of Ozone Layer Depletion

Depletion of ozone leads to various direct and indirect effects, **some of them are discussed below**

(i) **Rain failure** Due to depletion of ozone layer in stratosphere, the temperature of earth increases and it will be responsible for the failure of rainfall.

(ii) **Increase in radiation** Reduction of O_3 in stratosphere would allow UV rays to reach the earth.

(iii) **Cancer** Due to thinning of ozone layer, threat of skin cancer (melanoma) may increase. A 5% decrease in stratospheric ozone appears likely to lead 10-20% increase in skin cancer globally.

(iv) **High dose of UV-B** causes inflammation of cornea (snow blindness), cataract, etc.

(v) **Other effects** include destruction of aquatic flora and fauna, loss of immunity and epidemic proportions of cataracts.

(vi) Increased UV radiation's entry to earth's atmosphere leads to increased **global warming**.

Note

(i) To protect ozone depletion, **Montreal Protocol** was signed in **Montreal** (Canada) in 1967 (effective since 1989).

(ii) **Dobson Unit** (DU) It is a measurement of column ozone level. In tropics, it is 250-300 DU year around.

Degradation by Improper Resource Utilisation and Maintenance

Degradation of natural resources can occur, not just by the action of pollutants but also by improper resource utilisation practices.

1. Soil Erosion and Desertification

Topsoil is the most fertilie soil and it takes centuries to build. Improper human activities can remove it, resulting in arid patches of land. Natural resources get degraded not only by pollutants, but also by improper practices of their utilisation and maintenance. Soil erosion is caused by human acitivities like overcultivation, unrestricted grazing, deforestation and poor irrigation. All these practices lead to the removal of topsoil. Desertification is also a major problem these days, that occurs mainly due to urbanisation.

2. Water-Lodging and Soil Salinity

Irrigation without proper drainage of water leads to water-lodging in the soil. It draws salt to the surface of the soil. Deposited salt starts collecting at the roots of the plants and affect the plant growth and productivity. It is extremely damaging to the agriculture.

Deforestation

It is the conversion of forest area to non-forested area.

The prime reason for deforestation is increased demand of humankind and its dependence on forest products. **Jhum cultivation** is such a technique in which mostly tribal population slash and burn forests to make it agricultural land. After some time, these populations move to different place and do the same practice again, hence this agriculture is also called **shifting agriculture**.

Effects of Deforestation

It causes loss of biodiversity, as it leads to habitat destruction, soil erosion and sometimes desertification as well. Deforestation is also responsible for increased concentration of CO_2 in the atmosphere, because trees use CO_2 during photosynthesis.

Reforestation

It is the process of restoring forest that once existed, but was removed at some point of time in the past.

Case Studies of Forest Conservation

(i) Amrita Devi Bishnoi in 1731 had shown exemplary courage by hugging a tree and daring kings people to cut her first. Government of India recently instituted **Amrita Devi Bishnoi Wildlife Protection Award** for individuals or communities, which protect and save forests.

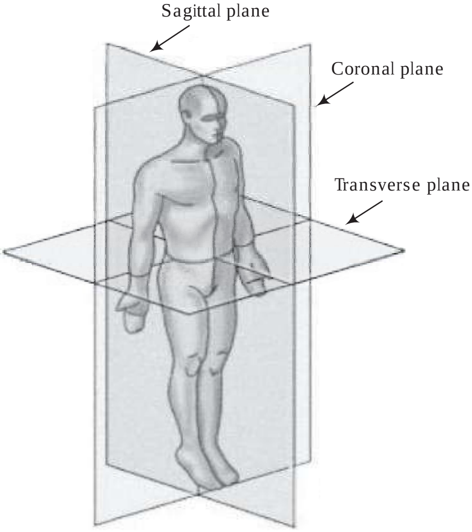
(ii) **Chipko movement** was launched by **Chandi Prasad Bhatt** and **Sundar Lal Bahuguna** against large scale falling of trees by timber contractor in Uttarakhand hills.

These all protection movements led to introduction of **Joint Forest Management** (JFM) concept in 1980s for protecting and managing forests.

Appendix

1. Planes of the Body

Different sections of the body are termed as anatomical planes (flat surfaces) by the medical professionals. These planes are imaginary lines vertical or horizontal, which are drawn through an upright body. The terms are used to describe a specific body part.



Body Planes

Coronal (Frontal) Plane

It is a vertical plane running from side to side. It divides the whole body or any of its parts into anterior and posterior portions.

Sagittal (Lateral) Plane

It is a vertical plane running from front to back. It divides the body or any of its parts into right and left sides. Median plane is a sagittal plane that runs through the midline of the body.

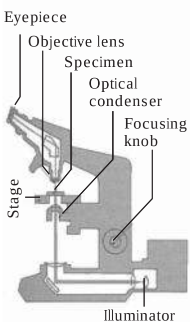
Transverse Plane

It is a horizontal plane. It divides the body or any of its parts into upper and lower parts.

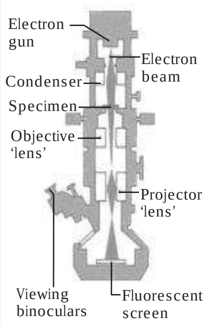
2. Comparison of Compound Microscope, Transmission Electron and Scanning Electron Microscope

Characteristics	Compound Microscope	Transmission E. Microscope	Scanning E. Microscope
Resolution (Average)	500 nm	10 nm	2 nm
Resolution (Special)	200 nm	0.5 nm	0.2 nm
Magnifying Power	Up to 1,500X	Up to 5,000,000X	~ 100,000X
Depth of Field	Poor	Moderate	High
Type of Object	Living or non-living	Non-living	Non-living
Preparation Technique	Usually simple	Skilled	Easy
Preparation Thickness	Rather thick	Very thin	Variable
Specimen Mounting	Glass slides	Thin films on copper grids	Aluminium stubs
Field of View	Large enough	Limited	Large
Source of Radiation	Visible light	Electrons	Electrons
Medium	Air	High vacuum	High vacuum
Nature of Lenses	Glass	1 electrostatic + a few em. lenses	1 electrostatic + a few em. lenses
Focusing	Mechanical	Current in the objective lens coil	Current in the objective lens coil
Magnification Adjustments	Changing objectives	Current in the projector lens coil	Current in the projector lens coil
Specimen Contrast	By light absorption	By electron scattering	By electron absorption

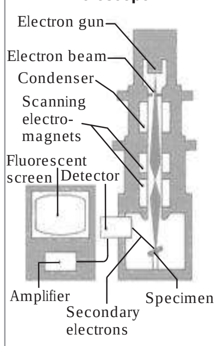
Light Microscope



Transmission Electron Microscope



Scanning Electron Microscope



3. Important Plant Products

Common Name	Botanical Name	Important Plant Part	Uses
A. Food yielding plants			
(a) Cereals			
1. Wheat	**Triticum aestivum**	Caryopsis, a one seeded fruit	Flour for bread and chapatis, suji, maida.
2. Rice	**Oryza sativa**	" "	Rice is staple food for 70% of population of world, straw- paper, mats.
3. Maize	**Zea mays**	" "	Food for man and also fodder, zeatin, a cytokinin is obtained from grains in milk stage.
(b) Millets			
1. Bajra (Pearl millet)	**Pennisetum typhoides**	Small sized grain	Food for poor.
2. Jawar (Great millet)	**Sorghum vulgare**	" "	Food for poor and also for cattle.
3. Ragi (Finger millet)	**Eleusine coracana**	" "	Flour used for preparing cakes and pudding.
(c) Legumes			
1. Matar (Garden pea)	**Pisum sativum**	Ovule or seed	Eaten green or as vegetable.
2. Chana (Bengal gram = Chick pea)	**Cicer arietinum**	Seed	Used as besan, bread and also cattle feed.
3. Arhar (Red gram = Pigeon pea)	**Cajanus cajan**	Seed	Dal and as cattle feed.
4. Mung (Green gram)	**Phaseolus aureus**	Seed	"
5. Urd (Black gram)	**Phaseolus mungo**	Seed	"
6. Soya bean	**Glycine max**	Seed	Eaten roasted or as milk.
7. Mungphali (Ground nut = Peanut)	**Arachis hypogea**	Seed (lomentum, underground)	Rich in proteins, eaten roasted or as vegetable ghee.
8.Lobia (Cowpea)	**Vigna sinensis**	Young pods and seeds	Used as vegetable.
9. Masur (Lentil)	**Lens culinaris**	Seeds	Used as dal.
(d) Nuts			
1. Almonds (Badam)	**Prunus amygdalus**	Seeds	Used in the preparation of various dishes.
2. Green Almond (Pista)	**Pistacia vera**	Seeds	As flavouring material in ice creams, candy and sweets.
3. Cashew nut (Kaju)	**Anacardium occidentale**	Kernels	Sugared or salted kernels are consumed as table nuts, also used in confectionary.
4. English walnut (Akhrot)	**Juglans regia**	Kernels	Eaten raw, preparation of candy and ice creams.

Common Name	Botanical Name	Important Plant Part	Uses
B. Spices and condiments			
1. Red pepper (Chillies)	**Capsicum** sp.	Dried fruit	Dried pepper is used as powder with most of the Indian foods, fresh also eaten.
2. Black pepper (Kali mirch = Black pearl)	**Piper nigrum**	Seeds	Dried mature seeds used in cooking.
3. Turmeric (Haldi)	**Curcuma domestica**	Rhizome	Dried rhizome is very aromatic and used to colour pickles, food stuffs and also to prepare kumkum.
4. Cumin (Zira)	**Cuminum cyminum**	Fruits	Aromatic fruits are used in soup, curries, cakes, pickles, oil is used for flavouring beverages and other food stuffs.
5. Coriander (Dhania)	**Coriandrum sativum**	Fruits and leaves	Fruits and leaves are aromatic, used in making soup, pickles, etc.
6. Clove (Laung)	**Syzygium aromaticum**	Flower bud	Dried unopened flower buds are very aromatic, fine flavoured and imparts warming qualities.
7. Saffron (Kesar)	**Crocus sativus**	Stigma and style	The dried stigma and tops of the style make the saffron of commercial use. It possesses pleasant aroma, used as spice and dye stuff.
8. Cardamom (Chhoti Ilaichi)	**Elettaria cardamomum**	Fruits and seeds	Fruits and seeds are used for flavouring sweet dishes, beverages, etc.
9. Bengal cardamom (Badi Ilaichi)	**Amomum aromaticum**	Fruits and seeds	Fruits and seeds are chief ingredient of 'garam masala'.
10. Asafetida (Hing)	**Ferula assafoetida**	Roots	Resin obtained from the roots is used for flavouring food products.
C. Edible oil			
1. Mungphali (Ground nut=Peanut)	**Arachis hypogea**	Seeds	Seeds yield edible oil, roasted seeds eaten, oil cake used as cattle feed and manure.
2.(a) Rape (b) Mustard	**Brassica napus** **B. campestris**	Seeds	Seed oil used for cooking, oil cake a good manure and cattle feed.
3. Til (Sesame)	**Sesamum indicum**	Seeds	Seeds yield cooking oil, oil used for hairs as medicine.
4. Coconut	**Cocos nucifera**	Seeds	Seeds yield cooking oil, also used as hair oil, for soaps; fruit husk yields coir.
5. Cotton	**Gossypium** sp.	Seed	Oil is used as ghee and cake as fodder of animals.

Common Name	Botanical Name	Important Plant Part	Uses
D. Timber yielding plants			
1. Sisham	**Dalbergia sissoo**	Wood	For carved door pans, wooden statue.
2. Rosewood	**D. latifolia**	"	For furniture, houses.
3. Teak (Sagaun)	**Tectona grandis**	"	Furniture.
4. Sal	**Shorea robusta**	"	Door frame, beams, railway sleepers.
5. Mulberry	**Morus alba**	"	Sports goods, mainly hockey sticks, tennis rackets, cricket stumps.
6. Walnut (Akhrot)	**Juglans regia**	"	Musical instruments, rifle butts.
7. White willow	**Salix alba**	"	Cricket bats.
E. Medicinal plants			
1. Sarpgandha	**Roauwolfia serpentina**	Root	For blood pressure, snake bite, mental disorders.
2. Opium (Afeem)	**Papaver somniferum**	Latex from unripe fruit (capsule)	Narcotic, sedative, in relieving pain.
3. Quinine	**Cinchona officinalis**	Bark	For malaria.
4. Belladonna	**Atropa belladonna**	Dried leaves and roots	Narcotic, diuretic, antispasmodic, leaves stimulant of CNS, relieving pain.
5. Datura	**Datura stramonium**	Fruit juice	For removing dandruff, for bronchial ailments.
6. Amla	**Emblica officinalis**	Fruit	Diuretic, laxative for haemorrhage, diarrhea, dysentery.
7. Kuchla	**Strychnos nux-vomica**	Seed	In paralysis and mental disorders.
8. Isabgol	**Plantago ovata**	Seed husk	For constipation and peptic ulcers.
9. Liquorice (Mulhati)	**Glycyrrhiza glabra**	Roots	For cough and bronchitis.
10. Santonin	**Artemesia cina**	Flowers	Antihelminthic and antimalarial, contains a variety of steroidal.
11. Yam	**Dioscorea** species	Tubers	Drugs, some of which are used to make birth control pills.
12. Foxglove	**Digitalis purpurea**	Leaves	Used as cardiac stimulant and toxic.
13. Madagascar periwinkle (Sadabahar)	**Catharanthus roseus**	Leaves	Treatment of leukemia and other cancers.
F. Sugar yielding plants			
1. Sugarcane	**Saccharum officinarum**	Stem	Sugar, molasses, card board, paper.
2. Chukander (Beet sugar)	**Beta vulgaris**	Root	Paper, sugar, salad.